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Separation and Reuse of Invert Emulsion Fluids

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Abstract

Invert drilling fluids are macro emulsions consisting of a hydrocarbon continuous phase with an emulsified internal aqueous “brine” phase in addition to organophillic clays, weighting agents, and other additives. These fluids perform multiple functions during the drilling process, one of which is to remove excavated rock (i.e., drilled cuttings) from the borehole. The unearthed solids are continuously incorporated into the drilling fluid; therefore, solids-control equipment such as centrifuges and shale shakers are employed at the rig site to remove the drilled solids and return the fluid to its optimum performance condition. Traditional solids control equipment can remove solids greater than 5 -7 microns at best, but colloidal fines (i.e., particles less than 2 microns in spherical diameter) are typically difficult to remove *via* mechanical processes relying on screening or gravity alone. As a result, these colloidal fines accumulate in the fluid over multiple wells ultimately resulting in reduced fluid performance. The contaminated fluid has to be diluted and reformulated to lower the concentration of these colloidal solids to restore acceptable fluid properties. Such processes tend to be costly, both economically and environmentally.

Traditional technology with an innovative approach has provided a new pathway to enhanced solids control. The combination of chemical and mechanical treatment to drilling fluids allows for the removal of colloidal solids and water, thus allowing the recycling of the hydrocarbon continuous medium. The utilization of emulsion destabilization components, flocculating polymers, and traditional solids control equipment permits the recovery of the low density base fluid for reuse in drilling fluid production thereby eliminating the need for large scale dilution and reformulation. Such a development significantly benefits the process of fluids recycling and inventory control, reduces waste disposal volumes, and improves drilling performance.

Introduction

The utilization of drilling fluids within the petroleum industry dates back to the late 1800’s. Initially, fluid formulations consisted of an aqueous continuous phase with various amounts of phyllosilicates (i.e., clays), weighting materials, and other stabilization additives. However, in the 1950’s the technology shifted to the application of commercial oil-based muds.[1] Traditional oil-based muds (OBMs) contained small amounts of water (< 5 %) that were either formed by the neutralization of organic acids or were inadvertently introduced. In such fluids, water was considered to be a contaminant that led to drastic alterations of the fluid properties and performance. The need for better emulsifiers evolved from this concern and directed technology to utilize emulsified water in oil to our advantage. The term “inverted” or “invert emulsions” was applied to such formulations since “oil emulsion mud” had been applied to emulsions of oil in water. The invert fluids generally contain > 10 % water (as high as 60 %) in the liquid phase and utilize the water as a suspending agent.

The current technology of invert drilling fluids has evolved with experience and usage. Improved and more efficient emulsifiers have been discovered as has the application of organophillic clays. Both developments have lead to the increased performance of inverts in a broad spectrum of conditions that include extended reach drilling (ERD), high temperature high pressure drilling (HTHP), and extreme environment drilling (EE). However, the functions that the fluids serve remain the same. Solids control equipment is employed on location in order to remove up to 90% of the drilled cuttings that report to the surface while the fluid is performing its desired function.[2] The removal efficiency of such processes typically range from 50% to 85%, with the balance of the drilled solids being incorporated into the drilling fluid. A combination of traditional solids control and dilution are used to maintain the fluid in a usable condition. Conventional solids control equipment such as screening machines and centrifuges are, at best, able to remove particles 5 to 7 microns or greater, but colloidal solids (i.e., particles with sizes less than 2-5 microns) cannot be separated exclusively by such mechanical means.

Currently, invert drilling fluids are utilized to drill multiple holes during their service lifetime. In doing so, the concentration of colloidal particles tends to increase over time resulting in dramatic alterations in fluid properties, frequently rendering the fluid inadequate. In most cases, the drilling fluid is diluted and reformulated to minimize the concentration of the non-commercial, colloidal solids and restore the desired rheological and performance properties to the invert system. Dilution, as a method of solids control, can be very costly due to large additions of base oil with additional commercial additives required to maintain desired properties (i.e., emulsifiers, organophilic clays, polymers, weighting agents, etc). These enlarged fluid volumes lead to storage, transport, and disposal issues. As a worst case scenario, the invert fluid can become so highly contaminated that dilution is no longer a viable option resulting in emulsified mixtures being entirely disposed of as waste. New, clean fluids have to be blended.

New methods have been applied to enhance the removal of colloidal fines from invert fluids.[3-4] Chemical processes that result in less dispersion aid the mechanical separation processes.[5] More recently, polymeric invert emulsions have been employed to reduce the amount solids and water by flocculation and separation using conventional oilfield centrifuges. Such methods have had limited success but lend themselves to improvement.

In this body of work, a new approach to the treatment and recovery of invert fluids will be discussed. Traditional technology with an innovative approach has provided a new pathway to chemically enhanced solids control that will result in the complete recycling of the drilling fluid with focus on the recovery of the base hydrocarbon continuous media and the hydrocarbon soluble components. The utilization of emulsion destabilization components, flocculating polymers, and traditional solids control equipment permits the recovery of the low density base fluid for reuse in drilling fluid production thereby eliminating or greatly reducing the need for dilution and reformulation steps. Such a development significantly benefits the process of fluids recycling and inventory control, reduces waste disposal volume, and improves drilling performance.

Experimental

Materials

Field Invert Drilling Fluid:

- 62% Oil (diesel)
- 16% Water
- 22% Solids
- Density 12.5ppg (1500 kg/m^3)
- Electrical Stability: 430V

(Compositions determined *via* retort analysis)

Methods

Phase One Testing. Fifty (50) ml OBM samples were added to glass jars. Various compositions of acid and/or water-acid mixtures were then added to neutralize the fluid (i.e., typically 15-45 % dilution of original volume). As much as 1-4 % of de-emulsifier was then added. The bottle was shaken approximately 500 times until solution began to break. The resultant mixture was then transferred to a 100 ml centrifuge tube and centrifuged for 5 minutes at 1200 rpm. The fractionated samples were observed and recorded.

Phase Two Testing. OBM samples of 150, 500, and 1500 ml were added to various glass beakers. Compositions of acid and/or water-acid mixtures were then added to neutralize the fluid (i.e., typically 15-45 % dilution of original volume). As much as 1-4 % of de-emulsifier was then added. The mixture was agitated with a paddle mixer (500 rpm) for 30 minutes. Samples of 100 ml were centrifuged for 5 minutes at 1200 rpm.

Large Capacity Field Trial Thirty (30) bbls of field invert fluid were placed in a 50 bbl mixing tank equipped with paddle stirrers and recirculation pumps. A predetermined acid/water mixture was then applied to lower the pH of the fluid. After the pH was adjusted, addition of demulsifying additives followed, and the mixture was allowed to react with gentle agitation for 1.5 hours. Once the chemical treatment was completed, the fluid was transferred from the mixing tank by means of a progressive cavity feed pump to a decanting centrifuge where the solids were separated from the liquid phase. The liquid phase was recovered in a storage tank, allowed to stratify, and analyzed.

Results and Discussion

Laboratory Testing. Phase One examination of the optimization process began with small scale samples *via* bottle testing. Table 1 provides the summarized record of the most successful candidates from the bottle tests. These small scale assessments allowed for the inspection of an extensive list of the various concentrations of each additive before the final components (e.g., acid and combinations of demulsifiers) were chosen for scale up testing at 150, 500, and 1500 ml.

During Phase One, the choice of acidizing agent proved to be an intricate step in the success of the OBM breaker package. The intended effect of the acid was to neutralize the high pH of the mud thus lowering it into the acidic regime. As the pH of the OBM falls, the stabilization characteristics of the emulsifiers within invert fluid became less active at the oil-water interface. This interfacial disruption allowed for deterioration of the emulsion. Once the emulsion properties of the fluid were rendered inoperative, the fluid could be separated into the appropriate fractionated layers due to their polarity and density differences. The choice and strength of acid can vary depending on the chemical composition of the drilling fluid and base oil. It was concluded that hydrochloric was the most viable option to test on the larger scale with the field invert that was chosen.

Phase Two included testing at 150, 500, and 1500 ml. In this process, a paddle mixer was added as well as burettes for the addition of the various components. The experimental setup allowed for the examination of the actual visual changes in the fluid as the components were added. As the OBM was stirred at 500 rpm, a slight vortex can be seen in the fluid (as expected). As the drop-wise addition of the acidic solution began, an increase in viscosity was observed as the stirred fluid's vortex became shallow and practically disappeared. Effervescence within the fluid occurred as CO_2 was released due to the reaction of the acidic component with carbonate species within the mixture. Once all species are neutralized, the viscosity of the fluid achieved a maximum as the emulsion properties of the fluid were almost completely destroyed. The presence of the excess water and demulsifier combated this issue. Soon after, the solids "flipped" and became water wet as the fluid fell apart. At this point, the viscosity dramatically decreased, and the breaking of the fluid was visually obvious (Figure 1). The optimum formulation from Phase Two is shown in Table 2. This formulation was successful at separating and fractionating all OBMs tested while providing the most efficient recovery of base oil at the lowest cost. It should be noted that ‘field’ muds tend to be over-treated and contain widely varying concentrations of emulsifiers, formation solids, and property modifiers. Thus, each mud will be different and will require bottle testing for the determination of the most efficient combination of OBM breaker components.

Field Trial Testing. The first large scale field trial of the OBM breaker system was performed at the field service facility that was the source of the fluids examined in the lab. The optimized formulation shown in Table 2 was employed to achieve the field trial results. Upon the initial mixing of the acidic solution, a slight increase in viscosity was observed (as expected). However, on complete addition, the viscosity decreased; and the fluid began to break from the emulsion state. From there, the demulsifying components were added to propel the destabilization process further and aid in water-wetting the remainder of the originally oil-wet solids. This reaction took place over 1.5 hours with slight agitation being applied in the mixing tank.

After the reaction was finalized, the fluid was transferred through a decanting centrifuge operating at 20000 m/s^2 (2000 g′s). Thus, the solids were removed; and the fluid was transferred to a storage tank. In severe contamination scenarios, a flocculating polymer may be added during this stage to increase the efficiency of the centrifugation process. However, none were needed during this trial. The separated solids and liquid phases are shown on Figure 2 and Figure 3, respectively. The retained fluid was taken from the discharge line and immediately analyzed onsite by conventional retort. Due to utilization of the two-stage centrifuge, the oil and water were placed into the same tank; but, after settling, the water phase migrates to the bottom and the base hydrocarbon can be decanted from the top. Once the top oil was removed, traditional laboratory experiments were employed to determine its composition. The complete results are given in Table 3. Gas chromatography/mass spectrometry (GC/MS) chromatograms of the base oil (i.e., diesel) and standard diesel were compared (Figure 4). The organics extracted from the submitted sample were slightly depleted in the lighter compounds, possibly due to evaporation. The composition of diesel varies depending on the source of the original crude, the season (winter and summer), and usage (marine and land) adjustments.

It can be seen that the OBM breaker system effectively separated the component phases of the invert fluid. The solids content was drastically reduced from 22 % to 4 %, and the base oil was recovered at 96 % purity. Therefore, the retained base oil can be utilized to rebuild invert fluids, eliminating the dilution process, the need for added base oil, the extra storage facilities, and the increased disposal costs.

Since the original field trials, the overall procedure has been modified to streamline the process and is provided in the diagram shown as Scheme 1 in Figure 5. The OBM breaker components can be sequentially added to the mixing tanks. After the chemical treatment, the demulsified fluid undergoes centrifugation as the solid and liquid phases are separated. The retained liquid phase enters a clarifier and disc stack. The application of these tools allows for the removal of the base-oil as the acidic water phase is recycled back to the mixing tank for another batch chemical treatment.

Conclusions

Through a unique blend of multi-disciplinary technologies coupled with an innovative approach to traditional methods, a new pathway to solids control and recycling of base oils from invert emulsion drilling fluids has been demonstrated. The combination of chemical and mechanical treatment to invert drilling fluids allows for the removal of colloidal solids and water thereby allowing recovery of the hydrocarbon continuous medium. The utilization of emulsion destabilization components, flocculating polymers, and traditional solids control equipment permits the recovery of the low density base fluid for reuse in drilling fluid production. Thus, the need for frequent dilution and reformulation steps is eliminated. Such a development significantly benefits the process of fluids recycling and inventory control, reduces waste disposal volumes, and improves drilling performance.

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Nomenclature

OBM: Oil Based Mud
RPM: Revolution per Minute

References

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Tables

Table 1. Phase One components of OBM breaker.

Component, % vol	1	2	3	4	5	6	7	8
Acid 1	15	15	15	15	---	---	---	---
Acid 2	---	---	---	---	40	40	40	40
H2O	20	20	20	20	---	---	---	---
Part A	3	1	2	1	2	1	1	1
Part B	1	3	---	1	1	2	---	---
Part C	---	---	3	---	---	---	3	
Part D	---	---	---	4	---	---	---	3
Separation	Y	Y	N	N	Y	Y	N	N

Table 2. Optimized components for the OBM breaker.

Component	% vol
Acid 2	40
Part A	1.5 - 2.0
Part B	0.5

Table 3. Results of field trial.

Sample	Original Fluid[a]	Treated Fluid[a] (prior to settling)	Recovered Base Fluid[b]
Base Oil, %	62	73	96
Water, %	16	20	< 1
Solids, %	22	7	4

[a] Compositions determined via retort analysis onsite

[b] Compositions determined via extraction and gas chromatography/mass spectrometry (GC/MS)

Figures

Figure 1. Invert fluid after emulsion “break.”

Figure 2. Separated solids from field trial.

Figure 3. Recovered fluid (before separation) from the field trial.

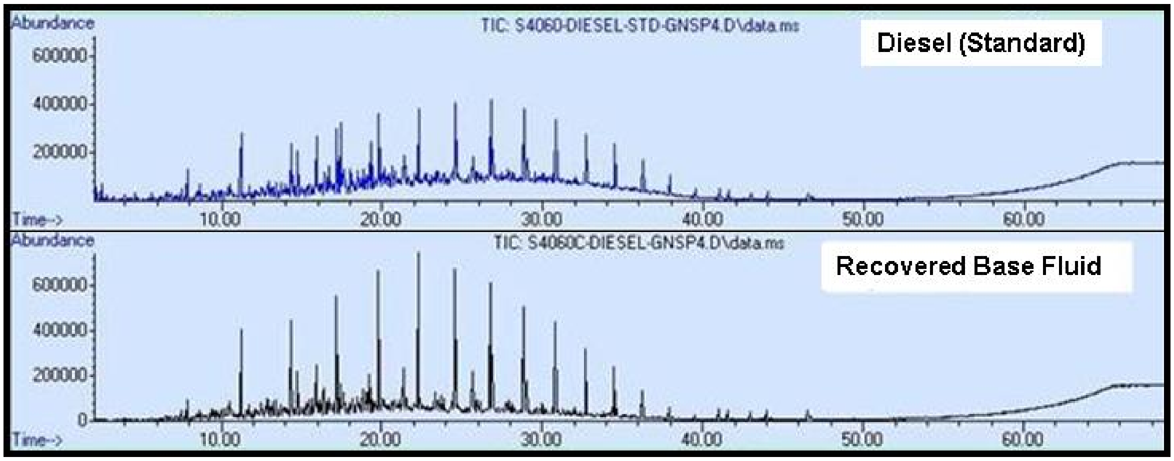

Figure 4. The gas chromatograms of the organics extracted from the recovered base fluid (diesel) and from a laboratory diesel standard.

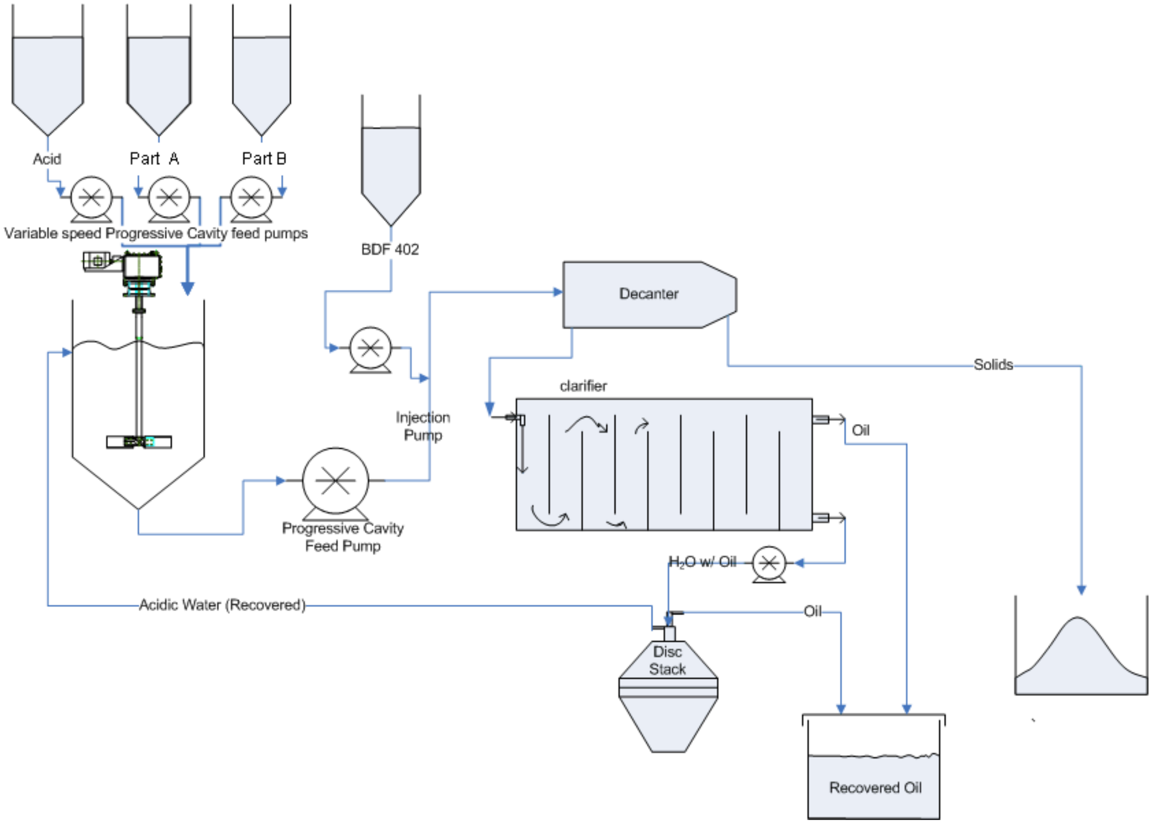

Figure 5. Scheme 1, the proposed model for field applications of the OBM breaker.