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Laboratory Study of the Heavy Weight Reversible Invert Emulsion Drilling Fluid

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Abstract

A novel reversible invert emulsion drilling fluid which is useful in resolving the contradiction between drilling efficiency, cementing and environmental effect has been invented based on the protonation reversibility of amine. The new drilling fluid has reversible emulsion-phase behavior. The formulation of the reversible invert emulsion drilling fluid was: white oil (5)+25% $CaCl_2$ brine+50% weight agent ZFU-3+1.5% organoclay+0.5% lime +4.5% reversible emulsifier UPSG-1+1% wetting agent DYSL-3+an appropriate amount barite, oleaginous fluid to non-oleaginous fluid-ratio was 50/50, drilling fluid density was 1.9 kg/L, weight agent ZFU is sodium formate. Comprehensive performance evaluation with laboratory test showed that the new drilling fluid could be readily and reversibly converted from a water-in-oil emulsion to an oil-in water emulsion and back to a water-in-oil emulsion using an acid-based chemical switch. And before and after converting the emulsion mud maintains good performance, with emulsion-breaking voltage of 900-1,100 V, resistance to temperature of 150℃, HEHP filter loss of less than 6 ml. Additionally, the filter cake and oily cuttings could be treated easily. This suggests that the reversible invert emulsion drilling fluid has both merits of oil-based fluid and water –based fluids, and all properties are excellent. The reversible invert emulsion drilling fluid is capable of resolving the problems with the application of conventional oil-based drilling fluid. The density of the reversible invert emulsion is 1.9 kg/L, which is also better than the traditional reversible invert emulsion drilling fluid.

Key words: Drilling fluid; Heavy weight drilling fluid; Reversible invert emulsion drilling fluid

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INTRODUCTION

Since their inception, many types of drilling fluids have been developed. For example, the most common drilling fluids are water based muds, the oil based muds also been extensive used recently[1-2]. The oil-based muds (OBM) offer definite advantages over water-based muds (OBM) in many situations. The primary benefits of selecting an OBM over WBM include excellent shale inhibition, lubricity, corrosion inhibition, thermal stability, tolerance to contaminants, and ease of maintenance. But the use of the OBM also would result in some problems in cementing period. Residual OBM mud and filtercake in the wellbore is relatively difficult to remove and requires in some completions a multi-step procedure as oil-wet solids are often incompatible with common acids and chemicals. This can result in emulsions and sludge which may have an impact on the completion and subsequent production[3-4].

The advantage of the reversible invert emulsion drilling fluid is can change from OBM to WBM and vice versa[5]. The reversible invert emulsion drilling fluid can exist as OBM in drilling period.

In cementing period, the style of the drilling fluid would become WBM after acid treatment[6]. So the reversible invert emulsion drilling fluid do not have the problems that general OBM have like filtercake treating, oiliness cuttings treating and cementing strength[7].

The reversible invert emulsion drilling fluid was studied since 1999. Many reversible invert emulsion drilling fluid system was researched. Some researchers

like M. A. DickSyed Ali[8], Arvind D Patel[9], M. R. Lyyster[10], all have done many research about reversible invert emulsion drilling fluid, but most research have done is about the reversible phase inversion properties of the reversible invert drilling fluid, not any research about property of the weight of the reversible invert emulsion drilling fluid. The weight of the drilling fluid is a very important property for the drilling fluid. The weight of the drilling fluid used to balance the formation pressure and stratigraphic tectonic stress to avoid the blowout and borehole collapse. The weight agent used in reversible agent is barite because it would not affect the other properties of the reversible invert emulsion drilling fluid. But the weighting effect of the barite is limited in low weight. Another weighting agent is found by us which can be used together with barite to weight the drilling fluid to a high number. Using this weighting agent system also would not effect the other properties of the reversible invert emulsion drilling fluid.

1. EXPERIMENTAL SECTION

1.1 Meterials

The water is deionized water purified by ion exchange. The SKALN 5# white oil is purchased from Songxing Trade Company and was used as received. The reversible emulsifier UPSG-1, wetting agent DYSL-3, weight agent ZFU-3, organoclay and barite is purchased from Jianglai Biological Technology Company and is used as received. The hydrochloric acid, $CaCl_2$, lime and sodium hydroxide are purchased from SinopharmChemical Reagent Company and is used as received.

1.2 Method

1.2.1 Preparation of Reversible Invert Emulsion Drilling Fluid

Firstly, reversible invert emusifier (using Electronic Balance FA1004, Shanghai Fang Rui Instrument Company) was added to SKALN 5# white oil. The mixture dispersion was stirred for 5 min in 12,000 r/min using FLUKO variable speed laboratory blender (FLUKO Equipment Shanghai Company) to obtain solution A. Secondly, deionized water (25% $CaCl_2$ solution) was added to the solution A. The mixture dispersion was stirred for 40 min in 12,000 r/min using FLUKO variable speed laboratory blender to obtain emulsion B. Thirdly, stirring for 10 min in 12,000 r/min after the adding of every kind of additive. After the last additive adding and 10min stirring time, the reversible invert emulsion drilling fluid attained.

1.2.2 Characterization of Emulsion

(a) Conductivity Measurements. The conductivity of the emulsions was measured using a digital conductivity meter (Leici digital conductivity meter DDS-307, Shanghai Jingke Industry Company) immediately after preparation. A high conductivity indicated an O/W emulsion or W/O/W emulsion, and a low (immeasurable) conductivity (<1 $\mu S \cdot cm^{-1}$) indicated a w/o emulsion or O/W/O emulsion.

(b) Electrical Stability. Electrical stability was measured by Model DWY-2 Electrical Stability Tester which is a kind of instrument used mainly to measure the relative stability of W/O emulsion. Water is not continuous in a W/O emulsion and the voltage would keep rising until emulsion is broken and that current could be measured. On the contrary, the water is continuous in the O/W emulsion and current could be measured at a very low voltage. High electrical stability measured number means high stability of the w/o emulsion.

(c) Viscosity. The viscosity is measured by the six-speed rotational viscometer and calculated by the following formula: $AV = \theta_{600}/2$, $PV = \theta_{600}-\theta_{300}$, $YP = 0.511(\theta_{300}-PV)$.

(d) API and FL_{HTHP}. API is measured by Filtration tester. FL_{HTHP} is measured by high pressure and high temperature filter tester, is measured in the condition that the pressure is 3.5 MPa and the temperature demanded by us.

2. RESULTS AND DISCUSSIONS

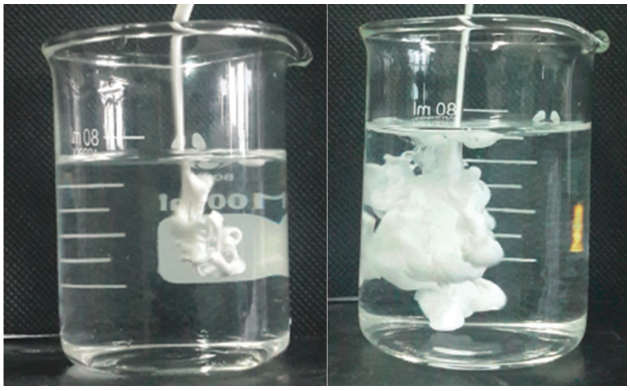
2.1 Reversible Phase Inversion Properties of the Reversible Invert Emulsion

The key point of the reversible invert drilling fluid is reversible invert emulsion. The typical formulation of the emulsion studied is white oil (5)+25% $CaCl_2$ brine+1.5% organoclay+0.5% lime +4.5% reversible emulsifier UPSG-1+1% wetting agent DYSL-3. The properties of the initial emulsion, after heat aged, after acid treated, after base treated was studied and the result is given in Table 1. The phenomenon of the emulsion dilute into water is given in the Figure 1.

Table 1
Emulsion Properties of the Reversible Invert Emulsion

Period	The type of the emulsion	AV /mPa·s	PV /mPa·s	YP /Pa	API /mL	Electrical stability/V	Electrical conductivity/$S \cdot m^{-1}$	pH
Initial	W/O	32	25	7	0.4	720	0	8
Heat Aged@120 ℃ × 6 h	W/O	35	28	7	0.4	693	0	8
Acid treated	O/W	27	21	6	2.0	0	6,000	6.5
Base treated	W/O	38	30	8	0.7	655	0	8.5

We can know that the electrical stability of the emulsion is bigger than 600 V, the electrical conductivity is 0 $S \cdot m^{-1}$, the rheological properties and the filter loss also do not change in the initial station and after heat aged means the emulsion have preferable stability in 120 ℃. The particularity of the reversible invert emulsion is achieving reversible phase inversion. The pH of the emulsion change from 8 to 6.5, the electrical stability of the emulsion change from 693 V to 0 V, the electrical conductivity change from 0 $S \cdot m^{-1}$ to 6,000 $S \cdot m^{-1}$, the performance of the emulsion change from oil soluble to water soluble following the acid treating means the style of the emulsion change from w/o emulsion to o/w emulsion in this process. The pH of the emulsion change from 6.5 to 8.5, the electrical stability of the emulsion change from 0 V to 655 V, the electrical conductivity change from 6,000 $S \cdot m^{-1}$ to 0 $S \cdot m^{-1}$, the performance of the emulsion change from water soluble to oil soluble following the base treating means the style of the emulsion change from W/O emulsion to O/W emulsion in this process.



w/o o/w

Figure 1
Phenomenon of the Emulsion Dilute Into Water

We also can know the type of the emulsion through the water solubility experiment. The phenomenon of the water soluble of the different style emulsion is given in the Figure 1. The emulsion can not disperse in the water when the style of the emulsion is W/O emulsion. The emulsion can disperse in the water when the style of the emulsion is O/W emulsion.

2.2 The Performance of the Reversible Invert Drilling Fluid With Different Density

The settle would happen when the amount of the barite is too much. The weight agent ZFU is sodium formate which used to weighting up the drilling fluid together with the barite. We can know the maximum added amount of the sodium formate is 50% through the previous studies with which the performance of the reversible invert drilling fluid would not be affected. A fixed amount of the sodium formate is 50%. Change the density of the reversible invert drilling fluid through change the amount of the barite. Different styles of the emulsion with different density which achieve through change the amount of the barite are tested. The properties of the initial emulsion, after heat aged, after acid treated, after base treated was studied and the result is given in Table 2.

We can know the rheological properties and the reversible phase inversion performance is preferable, the API and FL_{HTHP} also performance well when the density is less than 1.9 kg/L. The viscosity of the reversible invert drilling fluid also very high when the density is 1.9 means the capacity of bringing debris is well which can meet bringing cutting requirements of long horizontal-section drilling. The electrical stability of the emulsion is bigger than 900 V and the FL_{HTHP} is also less than 5 ml after heat aged means the emulsion performance well in the high temperature condition. Barite falling appears after the heat aged when the density of the emulsion is 2.1 kg/L. The reversible invert emulsion performance well when the density of the emulsion is 1.9 kg/L. So the highest density that the reversible invert drilling fluid can reach is 1.9 kg/L.

Table 2
Emulsion Properties of the Reversible Invert Emulsion With Different Density

Density/ kg/L	Period	The type of the emulsion	AV/ mPa·s	PV/ mPa·s	YP/ Pa	API/ mL	FL_{HTHP}/ ml	Electrical Stability/V	Electrical Conductivity/$S \cdot m^{-1}$	pH
1.5	Initial	W/O	43	33	10	0.2	—	862	0	8
	heat Aged@120℃	W/O	45	35	10	0.3	3.2	812	0	8
	Acid treated	O/W	39	28	9	1.8	5.1	0	4,213	7.5
	Base treated	W/O	47	36	11	0.6	3.7	761	0	8.5
1.7	Initial	W/O	55	42	13	0.2	—	1,021	0	8
	Heat Aged@120℃	W/O	56	44	12	0.4	2.6	974	0	8
	Acid treated	O/W	51	40	11	1.5	4.5	0	3,764	7.5
	Base treated	W/O	59	46	13	0.6	3.1	946	0	8.5

To be continued

Continued

Density/ kg/L	Period	The type of the emulsion	AV/ mPa·s	PV/ mPa·s	YP/ Pa	API/ mL	FL_{HTHP}/ ml	Electrical Stability/V	Electrical Conductivity/$S \cdot m^{-1}$	pH
1.9	Initial	W/O	69	54	15	0.1	---	1,017	0	8
	Heat Aged@120℃	W/O	70	56	14	0.2	2.7	970	0	8
	Acid treated	O/W	65	52	13	1.5	4.8	0	3,156	7.5
	Base treated	W/O	73	58	15	0.4	3.1	934	0	8.5
2.1	Initial	W/O	115	96	19	0.1	---	698	0	8
	Heat Aged@120℃	Barite falling								

2.3 The Performance of the Reversible Invert Drilling Fluid With Different Temperature

The reversible drilling fluid whose density is 1.9 $g \cdot cm^{-3}$ is chosen and used to test the high temperature stability. The properties of the initial emulsion drilling fluid, after heat aged with different temperature was studied and the result is given in Table 3.

We can know the rheological properties performance well, the electrical stability, the gel intensity and the FL_{HTHP} change little between the initial station and after heat aged when the temperature is less than the 150 ℃ means the emulsion have preferable stability in 150 ℃.We also can know that the electrical stability would become very little and the FL_{HTHP} also would become very high after the heat aged when the temperature is 160 ℃ means the reversible invert drilling fluid that we prepare can not afford the requirement of 160 ℃. As have discussed above that the reversible invert drilling fluid can afford the requirement of 150 ℃.

Table 3
Heat-Resisting Properties of the Reversible Invert Emulsion

Temperature/ ℃	PV/ mPa·s	YP/ Pa	Gel/ Pa/Pa	φ6/φ3	YP/PV/ Pa/mPa·s	ES/ V	FL_{HTHP}/ mL
Intial	54	15	3.5/4.5	8/6	0.28	610	—
120	56	14	3.5/5.5	10/7	0.25	635	8
130	53	15	4.0/6.0	10/6	0.28	605	7
140	55	15	5.0/6.5	11/9	0.27	565	8
150	56	17	6.5/8.5	12/8	0.30	507	10
160	67	26	10.5/12.0	15/13	0.39	20	31
170	84	30	14.5/16.5	19/16	0.36	0	41

2.4 Reversible Phase Inversion Properties of the Reversible Invert Drilling Fluid

The critical nature of the reversible invert drilling fluid is the ability of reversible phase inversion. The reversible drilling fluid whose density is 1.9 $g \cdot cm^{-3}$ is chosen to be tested. The temperature of the heat aged chosen is 150 ℃ which is the highest temperature can be chosen known from the studies above. The properties of the initial emulsion drilling fluid, after heat aged, after acid treated, after base treated was studied and the result is given in Table 4.

We can know the rheological properties performance well, the electrical stability very high and the API is very little in the initial station and after heat aged. The FL_{HTHP} would less than 6 mL, the electrical stability would become 0 V and the electrical conductivity would become 3,227 $S \cdot m^{-1}$ after acid treating means the drilling fluid become O/W emulsion drilling fluid. The FL_{HTHP} would less than 6 mL, the electrical stability would become 911 V and the electrical conductivity would become 0 $S \cdot m^{-1}$ after base treating means the drilling fluid become W/O emulsion drilling fluid. The result of the experiment on one hand shows that the reversible invert emulsion drilling fluid can achieve reversible phase inversion through change the pH of the reversible invert emulsion drilling fluid, on the other hand that rheological properties performance well, the electrical stability very high and the API is very little in the initial emulsion drilling fluid, after heat aged, after acid treated, after base treated. We can take a conclusionthat control the style of the drilling fluid through change the pH of the reversible invert emulsion drilling fluid is feasible.

Table 4
Emulsion Properties of the Reversible Invert Drilling Fluid

Period	The type of the emulsion	AV/ mPa·s	PV/ mPa·s	YP/ Pa	API/ mL	Electrical stability/V	Electrical conductivity/S·m^{-1}	FL_{HTHP}/ mL	pH
Initial	W/O	69	54	15	0.1	1,017	0	---	8
Heat aged@150℃	W/O	73	56	17	0.3	945	0	2.9	8
Acid treated	O/W	53	45	8	2.0	0	3,227	5.3	6.5
Base treated	W/O	65	51	14	0.5	911	0	3.2	8.5

2.5 The Filtercake Treating Performance of the Reversible Invert Drilling Fluid

Residual oil based drilling fluid and filtercake in the wellbore is relatively difficult to remove and requires in some completions a multi-step procedure as oil-wet solids are often incompatible with common chemicals which used in the completion[8]. Some kinds of filtercake treating fluids used to clear the filtercake are surfactants. But on one hand using filtercake treating fluid would increase the cost, on the other hand the main filtercake treating fluid is surfactant which would pollute the environment. The use of the reversible invert emulsion drilling fluid can solve the problem mentioned above. The result of the filtercake treating experiment is given in the Figure 2.

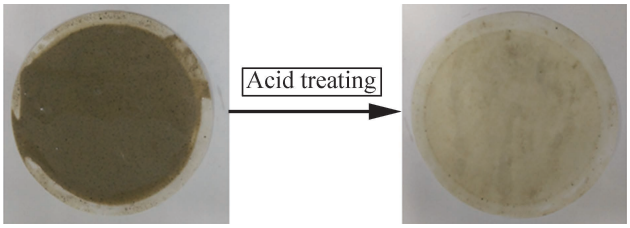


Figure 2
Phenomenon of the Filtercake Treating Performance

The filtercake is attained after FL_{HTHP} (150 ℃, 3.5 MPa) at the first step. In the second step the filtercake is put in the acid for 30 min and lightly stirring meantime. The filtercake would gradually depart in this process. The filtercake of the reversible invert emulsion drilling fluid clear more simple. Injecting acid in the completion well period to change the oil based drilling fluid into water based drilling fluid when the drilling fluid is reversible invert emulsion drilling fluid can lead to the completion method which is used in water drilling fluid is useful for this well. This method on one hand can increase the completion intensity, on the other hand can decrease the cost and convenient construction.

2.6 The Oiliness Drilling Cuttings Treating Performance of the Reversible Invert Drilling Fluid

The treating of the oiliness drilling cuttings is a hot point and a difficult point. The methods used to treat oiliness drilling cuttings also include pyrolysis, extraction separation method and biodegradation. But these methods also have shortcomings of high cost and poor effect. A new method presented to solve the problem of oiliness drilling cuttings treating which is through reversible invert emulsion drilling fluid. In our experiment, firstly, oiliness drilling cuttings is added into reversible invert emulsion drilling fluid and undergo heat aged (150 ℃ × 2 h), secondly, drilling cuttings departed and immersed in acid (30%) for 2 hours, thirdly, put the drilling cuttings in the second step into the water and record the depart time. The result of this experiment is given in the Table 5.

Table 5
Oiliness Drilling Cuttings Treating Performance

Oil drilling cuttings	Oil drilling cuttings dispersed time	
Type	Oil based drilling fluid	Reversible invert drilling fluid
Initial	No disperse	No disperse
Acid treating	No disperse	Disperse perfect after 4 h

We can know the drilling cuttings can depart from water after 4 h. The surface of the oilinessdrilling cuttings which formed by reversible invert emulsion drilling fluid would become from hydrophobic to hydrophilic after acid touch. The drilling cuttings would depart from oil in this process and become disperse in water more simple.

CONCLUSION

The character of the reversible invert emulsion was evaluated. The reversible phase inversion properties of the reversible invert drilling Fluid. The reversible invert emulsion drilling fluid whose density can reach 1.9 g/cm^3 can keep stabilization when temperature is 150 ℃. The rheological properties, the electrical stability, the gel intensity and the FL_{HTHP} of the initial emulsion drilling fluid, after heat aged, after acid treated, after base treated performance well. The filtercake treating performance of the reversible invert drilling fluid is well means the reversible invert emulsion drilling fluid can solve the problem of the filtercake treating when using oil based drilling fluid. The oiliness drilling cuttings treating performance of the reversible invert drilling fluid is well means the reversible invert emulsion drilling fluid can solve the problem of the treating of the oiliness drilling cuttings which occurred when using oil based drilling fluid.

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