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Research Article

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Comparative Investigation of the Effects of Barite Sag at Elevated Temperature on High Density Drilling Fluids for Wellbore Stability Management

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Abstract A major challenge that could lead to wellbore instability during drilling operation is the settling of barite particles (Barite Sag), particularly in low rheology and high density drilling fluids. The settling particles of barite would form a bed on the lower side of a wellbore which alters the mud density and ultimately leads to pressure imbalance and down-hole equivalent circulation density (ECD) fluctuations. This study investigated the effects of barite sag in low rheology and high density drilling fluids. The behaviour of the barite particles in both static and dynamic mud conditions with time for different drilling fluid systems under elevated temperature were also studied. Simulated barite sag tests were carried out on oil and water based drilling fluids. The Oil Based Mud (OBM) and Water Based Mud (WBM) were tested at different aging periods of 8, 16 and 24 hours at a baseline elevated temperature of 175°F. Two samples were prepared for each mud system under dynamic and static conditions using hot roll ovens. The experimental results indicated significant barite sag which was more prevalent under static conditions at elevated temperatures. The gel strength of the mud was observed to have reduced. Temperature was seen to have the greatest impact on sagging behaviours from the experiment. The barite sagging effects also increased with time. It was concluded that this study could be very useful in wellbore management during well planning and drilling optimisation.

Keywords Barite Sag, Elevated Temperature, High Density, Drilling Fluids, Stability Management

Introduction

Barite sag is the separation of barite particles from the liquid phase of the drilling fluids which leaves the particles settling at the bottom leading to an imbalance in mud weight in and out while drilling with high density mud or in low rheology drilling fluids. Sagging is seen in significant variations in mud density particularly during bottoms up, logging runs and other activities that may need the drilling fluids to be static over a long period of time. However, it also occurs in dynamic conditions on mud with low annular velocity. Hole instability is seen to increase in high-angle wells as a result of an increase in the rate of Barite particle settling. Barite sag also occurs both in static and dynamic condition as a result of slumping of the weighted material due to insufficient yield point and gel strength of the drilling fluids.

Barite static sag is seen more when circulation is stopped with barite particles settling under gravity, thereby causing a difference in top and bottom mud weights and leading to wellbore instability. Also, weighting materials used in formulating drilling fluids usually settles or sag in the wellbore particularly in drilling fluids that has low viscosity, low gel strength and heavily weighted mud (> 12.5ppg). This affects the mud performance and the entire drilling program.

Methodology

Experimental investigations were carried out to study the settling behaviour of barite particles in static and dynamic mud conditions, and also to determine the effects of barite sag in high density drilling fluids (WBM and OBM). These experiments were carried out using two sets of 5-HOT ROLL equipment which consisted of a temperature computing devices and 5- Rolling Pistons. One of the equipment was set 'NOT TO ROLL', which was used for the static mud test, while the other was set 'TO ROLL' and used for dynamic test.

Four barite sag tests were carried out, two on oil-based mud (OBM) and two on water based mud (WBM) for different aging periods of 8 hours, 16 hours and 24 hours at a baseline temperature of 175^{o}F. Four cups of 350 ml each were formulated, two cups were OBM and the other two were WBM used for Dynamic and Static conditions respectively.

The mud weights of the top and bottom parts were separately measured with pressurised mud balance to know the variations in mud densities under static and dynamic conditions for OBM and WBM. The rheological properties of the drilling fluids were measured using a rotational 8-speed viscometer. The rheology tests were done on the mud samples to evaluate their initial plastic viscosities (PV), yield points (YP) and gel strengths. These were done before and after the barite sag tests. After each ageing period, the mud samples were analysed to determine the sag effects. After which, the rheology was checked all over again to determine the changes that may have occurred. This was to examine changes in densities and rheology of the mud samples due to the sagging effects. The dial reading values of the viscometer at 600 rpm, 300 rpm, 200 rpm, 100 rpm, low ends of 6 rpm and 3 rpm shear stress, 10 seconds and 10 minutes gel strength were all recorded. The Plastic Viscosity (PV), Apparent Viscosity and Yield Point were calculated from the 600 rpm and 300 rpm dial readings.

Results and Discussion

The results are split into two sections, with the first covering for the oil based mud experiment while the second section covers for the water based mud experiment.

Results of the barite sag analysis of the oil base mud (OBM) at 175^{o}f for ageing periods of 8 hrs, 16 hrs and 24 hrs

Table 1 below shows the top and bottom mud weights of the oil based mud at 175^{o}F over different time intervals under dynamic conditions. The bottom mud weights were higher at all time intervals, confirming barite sagging at this temperature.

Table 1: Barite Sag Ageing Analysis for DYNAMIC OBM after Hot Rolling at Temperature of 175 °F

Measurement	Before ageing	8 hrs ageing	16 hrs ageing	24 hrs ageing
Mud Weight (ppg)	14.0	Top = 13.4 Bottom = 13.8 Sag Factor = 0.507	Top = 13.0 Bottom = 13.9 Sag Factor = 0.517	Top = 11.3 Bottom = 14 Sag Factor = 0.553
ϴ600	66	85	70	66
ϴ300	37	49	40	37
PV (cP)	29	36	30	29
YP (lb/100ft^2)	8	13	10	8
Gels (lb/100ft^2)	2/4	13/17	8/14	7/14
ϴ200	25	37	29	21
ϴ100	14	24	19	17
ϴ6	2	8	7	5
ϴ3	1	7	6	4

Figure 1 is the graphical representation of the top and bottom weights for the results displayed in Table 1. Table 2 below shows the top and bottom mud weights of the oil based mud at 175^{o}F over different time intervals under static conditions. The bottom mud weights were higher at all time intervals, confirming barite sagging at this temperature under static conditions. Figure 2 is the graphical representation of the top and bottom weights for the results displayed in Table 2. Figure 3 shows the comparison between the static and dynamic conditions plastic viscosity of the oil based mud. The plastic viscosity was observed to remain almost constant over time under static conditions but the plastic viscosity reduced with time under the dynamic conditions. Figure 4 shows how the yield point for the oil based mud varied over time for static and dynamic conditions. The yield point reduced over time in both the static and dynamic conditions, although the yield point at static condition was higher. Table 3 is a summary of the sag factors for the oil based mud under both static and dynamic conditions. Figure 5 is a plot to show the relationship b between the sag factor and time for oil based mud under static and dynamic conditions.

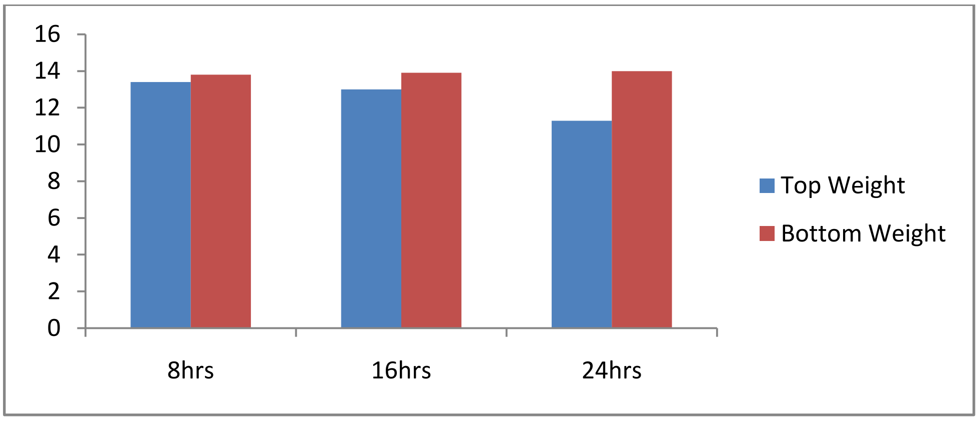

Figure 1: Comparison of Density Variations of the Dynamic OBM for the three ageing periods at Temperature of 175 ºF

Table 2: Barite Sag Ageing Analysis for STATIC OBM after Hot Rolling at Temperature of 175 ºF

Measurement	Before ageing	8 hrs ageing	16 hrs ageing	24 hrs ageing
Mud Weight (ppg)	14.0	Top = 12.9 Bottom= 13.3 Sag Factor = 0.507	Top = 12.3 Bottom = 13.7 Sag Factor = 0.527	Top =12 Bottom = 13.9 Sag Factor = 0.537
Ɵ600	66	80	79	71
Ɵ300	37	47	46	39
PV (cP)	29	33	33	32
YP (lb/100ft^2)	8	14	13	7
Gels (lb/100ft^2)	2/4	14/33	13/33	7/32
Ɵ200	25	34	32	27
Ɵ100	14	22	20	16
Ɵ6	2	7	5	4
Ɵ3	1	6	4	3

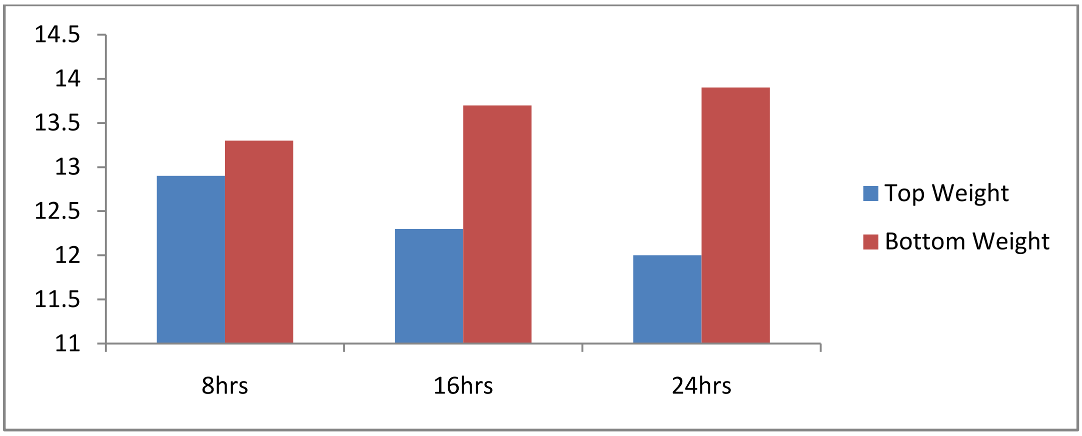

Figure 2: Comparison of Density Variations of the Static OBM for the three ageing periods at Temperature of 175 ºF

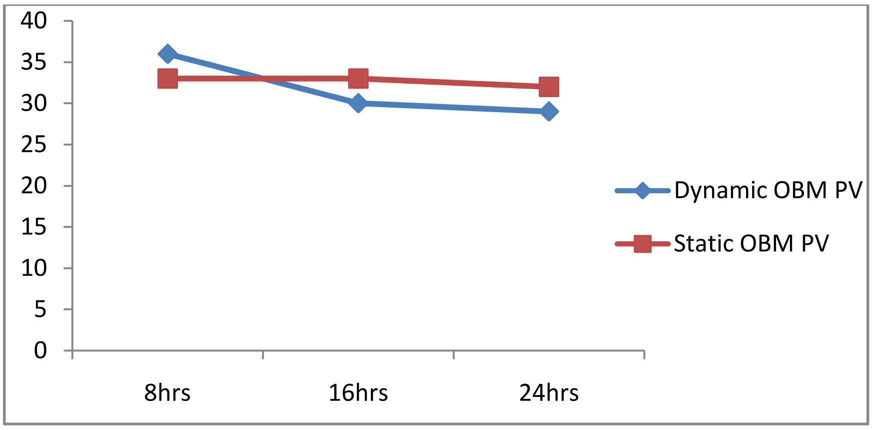

Figure 3: Comparison for Dynamic and Static condition of OBM Plastic Viscosity and Aging Periods at Temperature of 175 °F

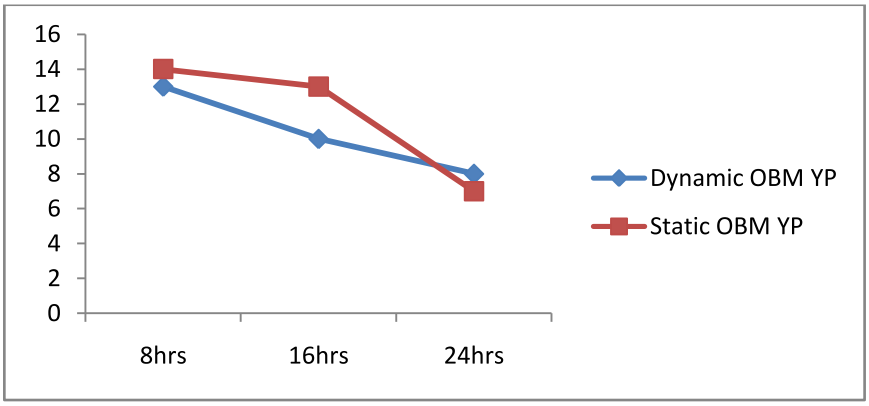

Figure 4: Comparison of Dynamic and Static condition of OBM Yield Point and Aging Periods at Temperature of 175 °F

Table 3: Comparison of Sag Factors of Dynamic and Static OBM for the three Aging Periods at Temperature of 175 °F

Ageing Period	Dynamic OBM Sag Factor	Static OBM Sag Factor
8 hrs	0.507	0.507
16 hrs	0.517	0.527
24 hrs	0.553	0.537

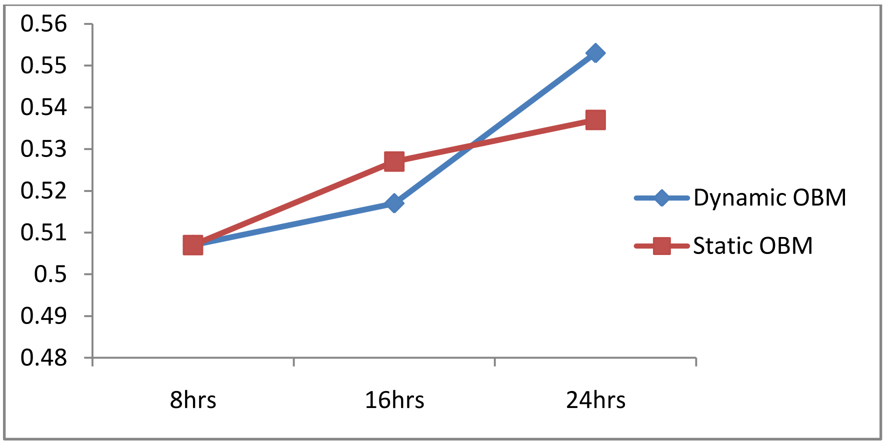

Figure 5: Comparison of Sag Factors between Dynamic and Static OBM and Aging periods at Temperature of 175 °F

Results of the barite sag analysis of the water base mud (WBM) at 175 °F for ageing periods of 8 hrs, 16 hrs and 24 hrs

Similarly, Table 4 below shows the top and bottom mud weights of the water based mud at 175 °F over different time intervals under dynamic conditions. The bottom mud weights were higher at all time intervals, confirming barite sagging at this temperature for the water based mud. Figure 6 is the graphical representation of the top and bottom weights for the results displayed in Table 4. Table 5 below shows the top and bottom mud weights of the water based mud at 175°F over different time intervals under static conditions. The bottom mud weights were higher at all time intervals, confirming barite sagging at this temperature under static conditions. Figure 7 is the graphical representation of the top and bottom weights for the results displayed in Table 5. Figure 8 shows the comparison between the static and dynamic conditions plastic viscosities of the water based mud over time. The plastic viscosity was observed to reduce over time under both the static conditions and dynamic conditions. Figure 9 shows how the yield point for the water based mud varied over time for static and dynamic conditions. The yield point reduced over time in both the static and dynamic conditions, although the yield point was higher under static condition. Table 6 is a summary of the sag factors for the water based mud under both static and dynamic conditions. Figure 10 is a plot to show the relationship b between the sag factor and time for water based mud under static and dynamic conditions.

Table 4: Barite Sag Ageing Analysis for dynamic WBM after Hot Rolling at Temperature of 175 ºF

Measurement	Before ageing	8hrs ageing	16hrs ageing	24hrs ageing
Mud Weight (ppg)	14.0	Top = 13.5 Bottom= 13.6 Sag Factor = 0.502	Top = 13.3 Bottom = 13.8 Sag Factor = 0.509	Top = 11.9 Bottom = 13.9 Sag Factor = 0.538
ϴ600	136	110	100	95
ϴ300	82	60	54	51
PV (cP)	54	50	46	44
YP (lb/100ft^2)	28	10	8	7
Gels (lb/100ft^2)	15/32	16/38	14/34	12/34
ϴ200	65	56	50	48
ϴ100	43	51	42	43
ϴ6	15	16	13	12
ϴ3	9	15	11	9

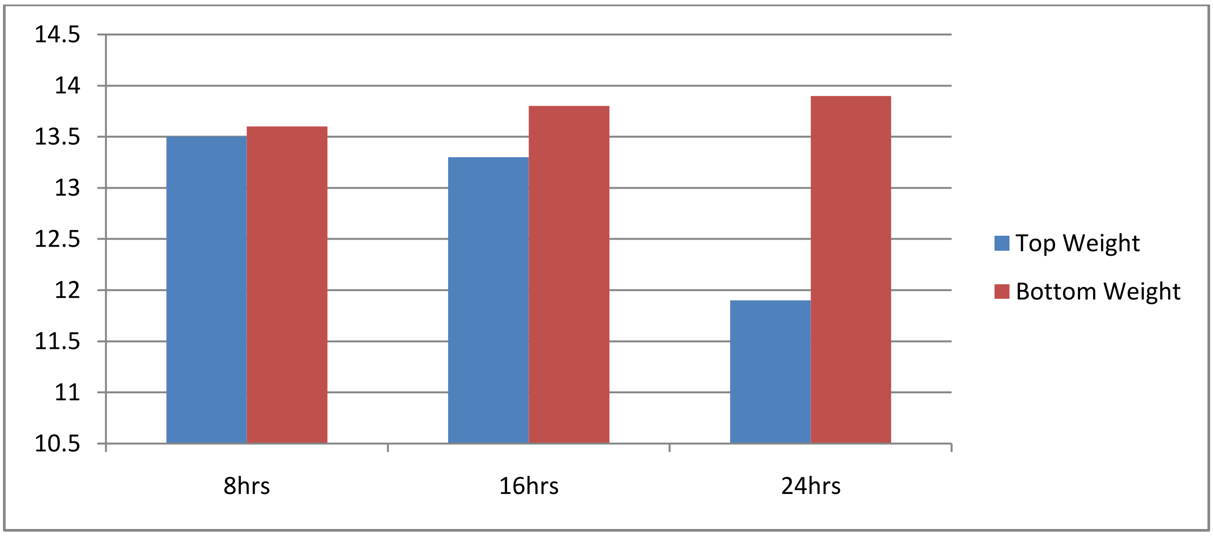

Figure 6: Comparison of Density Variations of the Dynamic WBM for the three ageing periods at Temperature of 175 ºF

Table 5: Barite Sag Ageing Analysis for STATIC WBM after Hot Rolling at Temperature of 175 °F

Measurement	Before ageing	8 hrs ageing	16 hrs ageing	24 hrs ageing
Mud Weight (ppg)	14.0	Top = 12.8 Bottom= 13.2 Sag Factor = 0.508	Top = 12.5 Bottom = 13.8 Sag Factor = 0.525	Top = 12.0 Bottom = 14.0 Sag Factor = 0.538
ϴ600	136	106	100	96
ϴ300	82	59	55	52
PV (cP)	54	47	45	44
YP (lb/100ft^2)	28	12	10	8
Gels (lb/100ft^2)	15/32	19/25	16/27	13/30
ϴ200	65	42	36	34
ϴ100	43	29	25	23
ϴ6	15	10	9	9
ϴ3	9	9	8	7

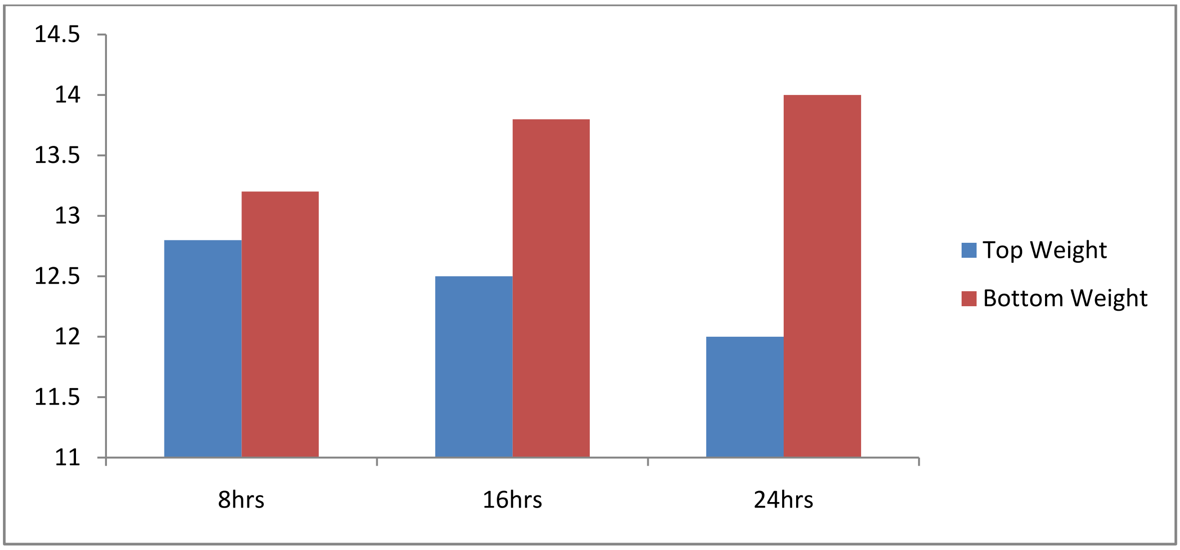

Figure 7: Comparison of Density Variations of the Static WBM for the three ageing periods at 175 °F

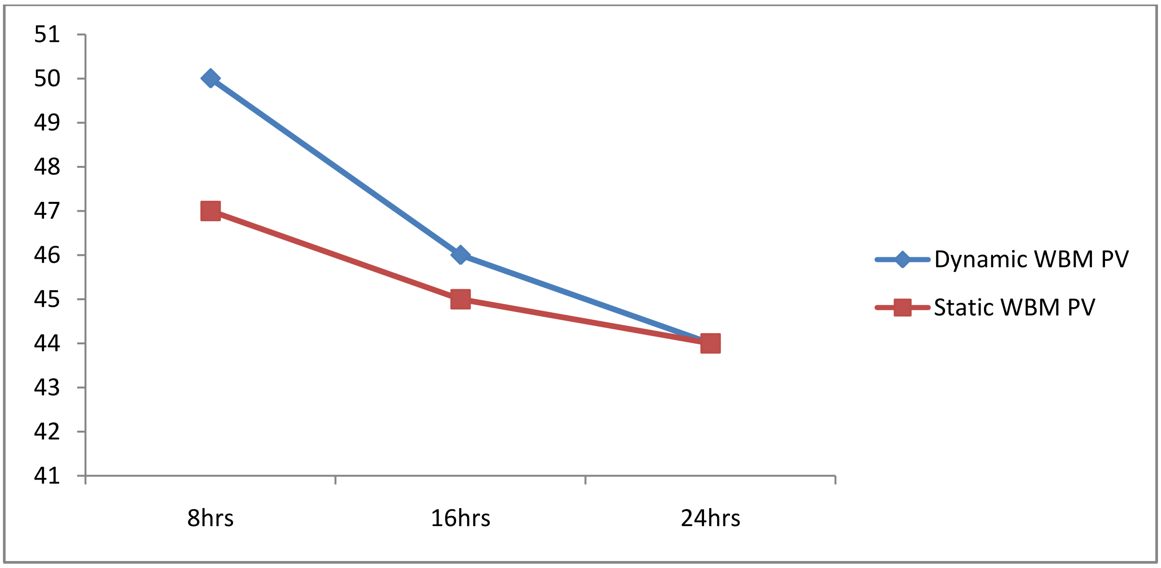

Figure 8: Comparison for Dynamic and Static condition of WBM Plastic Viscosity and Aging Periods at Temperature of 175 °F

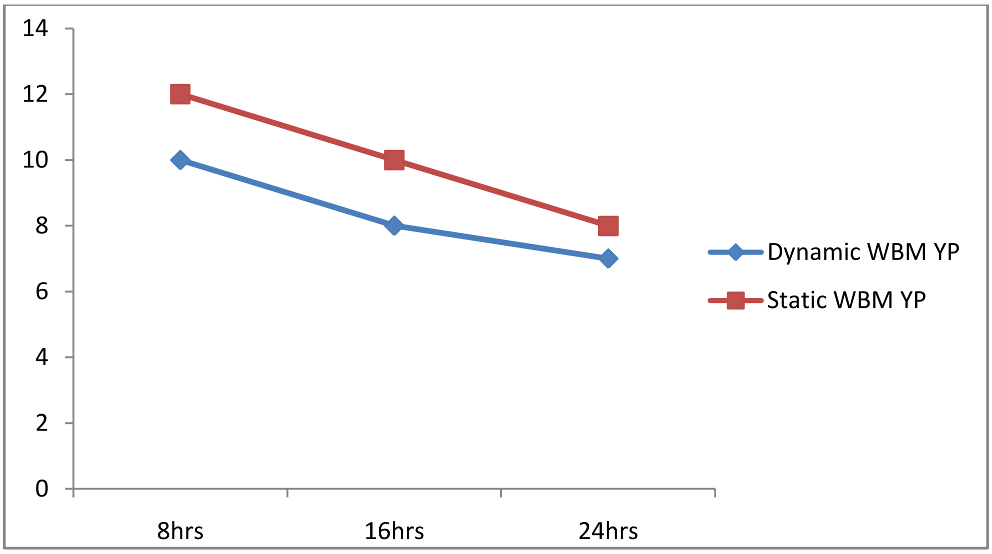

Figure 9: Comparison of Dynamic and Static condition of WBM Yield Point and Aging Periods at Temperature of 175 ºF

Table 6: Comparison of Sag Factors of Dynamic and Static WBM for the three Aging Periods at Temperature of 175 ºF

Ageing Period	Dynamic WBM Sag Factor	Static WBM Sag Factor
8hrs	0.502	0.508
16hrs	0.509	0.525
24hrs	0.538	0.538

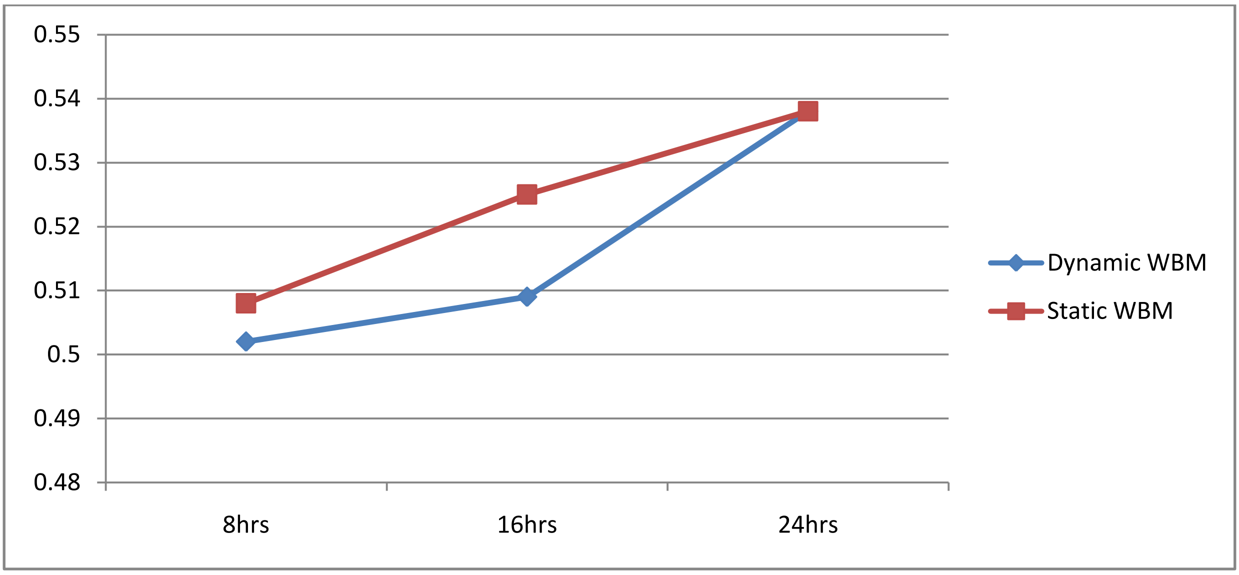

Figure 10: Comparison of Barite Sag Factors between Dynamic and Static WBM and Aging periods at Temperature of 175 ºF

The results showed that for both dynamic and static conditions in OBM and WBM, the lighter the top mud density the heavier the bottom density of the mud. This indicated that barite sagged in the mud column (cell) over time. Hence, time was an important factor in barite sagging, and it implies that the longer the drilling mud stays in the drilling column the heavier it becomes because of particles settling down. The reduction of the mud viscosity implies a reduction in the potency for the mud to suspend its solid particles which resulted in the settling of solids in the bottom. Under dynamic state, the turbulence created by the dynamic environment dominated the viscosity reduction due to shearing.

Barite sagging could be minimized under dynamic conditions through constant agitations such as extremely high shear rate.

Conclusion

In conclusion, the longer the mud stays in the drilling column, the more likely it will have depreciated rheological properties. Temperature had strong influence on the settling of barite particles. Increase in temperature facilitated the sagging process by reducing the rheology and the suspension ability of the fluids. An experimental guide to aid in preventing barite sagging was developed.

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