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Eco-friendly Extreme Pressure Lubricants for Water based Drilling Fluids

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Abstract. Water based drilling fluids possess very high coefficient of friction as compared to oil based drilling fluids (mud). High coefficient of friction can be reduced by adding lubricating additives to the mud. Lubricating agents reduces the torque and drag produced during the drilling process. Our study involves the analysis of various eco- friendly Extreme Pressure lubricating additives which are derivatives of fatty acids, seed oil. Non-dispersed conventional mud, Non-dispersed salt water mud and Inhibitive Polymer mud systems were used as Base mud for the study. Different oil additives are added in proportion ranging from 1.75 ppb to 7.0 ppb and also in combination by formulating Extreme Pressure Lubricants. Extreme Pressure Film strength and Lubricity coefficients were carried out using OFITE Lubricity/ Extreme pressure Tester. Detailed study on rheology, cheesing/ greasing effect, Mud weight, foaming tendency, pH and performance in brine phase were also analyzed. Pure seed oil is found to be best lubricant from the set of oil samples. It showed excellent lubricity coefficient and extreme pressure film strength in all three types of mud systems. This was followed by the fatty acid derivative of the same seed oil.

Keywords: Extreme pressure, lubricant, Non-dispersed, conventional mud, inhibitive, polymer mud, lubricity coefficient, film strength, rheology, cheesing, greasing, foam tendency.

1. Introduction

One of the significant functions of the drilling fluids is to lubricate the bit and the stem. It is a critical function, particularly while drilling directional wells, since the frictional forces between the drill string and wellbore or casing are so significant that they can lead to several problems such as high torque and drag, which can lead to premature damage to the drilling tools, as a consequence of excessive wear and heat [1]. Lubricating additives, lubricants in drilling fluids, give typical savings in terms of: i) Increased drilling performance to Oil and Gas depth by reducing friction, less bit/pipe trips, cooler running mud motors allows for deeper wells, longer laterals and more efficient drilling options. ii) Bit Cost Savings - Reducing friction saves heat and wear on drill bits, increases the shelf life of the bit. iii) Reduced Drag- Drilling horizontal wells can cause up to 40% more drag on the top drive and mud motors. A good lubricant possesses the following characteristics: a)High boiling point, b)Low freezing point, c)High viscosity index, d)Thermal stability, e)Hydraulic Stability, g)Corrosion prevention, h)High resistance to oxidation [2].

Lubricating additives are - fatty acid derivatives, seed oil based, triglyceride based, petroleum based, poly-propylene glycol based etc [3]. Lubricating property of the oil depends upon the functional moieties present in the oil. Oxygen carrying moieties enhances the lubricity and film strength of the additive. The order of the oxygen atom carrying functional moieties -COOH > -CHO > -OH > -COOCH3 > -C=O > -C-O-C [4]. Lubricants which remain adhered to the moving parts even during high pressure and torque are

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extreme pressure lubricants. In deep wells liquid lubricants show higher performance compare to solid lubricants. Plugging problems observed in solid lubricants [5].

Water based drilling fluids are most extensively used drilling fluids, due to their cost effectiveness and compatibility with the environment, in comparison to oil based drilling fluid. Conventional water based drilling fluids are bentonite based.

In the present work fatty acid derivatives and seed oil based oils have been used as lubricating additives. Lubricants used in the experiment are naturally available and easily biodegradable, hence are eco-friendly. Lubricity coefficient and Extreme Pressure tests were carried out using OFITE EP/Lubricity Tester. Lubricity coefficient measurements help in assessing friction reduction, whereas Extreme Pressure tests are find out stability of the thin film formed between the two metal surface of Lubricity Tester. Effect on Rheology, Mud weight, Thermal stability, foaming tendency, cheesing/ greasing, pH and stability in brine phase were also analysed.

2. Experimental Approach

2.1. Extreme pressure lubricants

Four different types of industrial grade oil samples were collected, which includes fatty acid derivatives and seed oils. Physical and chemical properties of the lubricants are as follows:

Table 1: Physical and chemical properties of lubricants

S.No	Sample name	Description	Appearance	pH	Density (Kg/m^3 at 25 ^{0}C)
1	EP - 1	Seed oil derivative - 1	Dark brown liquid	7.5-8.0	0.96-0.98
2	EP - 2	Seed oil derivative - 2	Dark brown liquid	7.5-8.0	0.95-0.97
3	EP - 3	Biodiesel based oil	Light brown liquid	6.0-6.5	0.92-0.94
4	EP - 4	Pure Seed oil	Light brown liquid	7.5-8.0	0.92-0.94

2.2. Preparation of water base mud

2.2.1. Water Base Mud – 1: Inhibitive polymer mud: Inhibitive polymer mud was formulated using the following additives

Table 2: Additives for inhibitive polymer mud

Additive	Functions	Concentration
Caustic soda	pH modifier	0.25 ppb
Soda Ash	Hardness controller	0.25 ppb
KCl	Shale stabilizer	17.50 ppb
PAC-LV	Fluid loss controller	2.0 ppb
X C Polymer	Viscosifier	1.25 ppb
Calcium Carbonate (Micronized)	Weighting / Bridging agent	21.0 ppb

2.2.2. Water Base Mud – 2: Non-dispersed conventional mud

Mud was prepared by adding 35.0 ppb bentonite into technical water. For proper dispersion of the Bentonite 0.1 ppb Soda ash was added. The pH of the sample maintained is 9.5. Prepared bentonite gel is kept for 24 hours hydration. After 24 hours Rheology has been measured and by dilution with water the apparent viscosity reduced to 15 ± 1 cp using a Fann VG Meter at 600 rpm by dilution with de-ionized water for the analysis.

2.2.3. Water Base Mud – 3: Non-dispersed salt water mud

Mud was prepared by adding 35.0 ppb bentonite into technical water. For proper dispersion of the Bentonite 0.1 ppb Soda ash was added. The pH of the sample maintained is 9.5. Prepared bentonite gel is kept for 24 hours hydration. After 24 hours, add 14.0 ppb sodium chloride (LR) and age for 24 hrs at 24 ± 2 ^{0}C. Adjust the apparent viscosity of this suspension to 15 ± 1 cp using a Fann VG Meter at 600 rpm by dilution with 4% (w/v) sodium chloride solution.

2.3. Sample preparation

`Prepared water base mud was treated with different lubricants with concentrations 1.75 ppb, 3.50 ppb, 5.25 ppb and 7.0 ppb in a Hamilton beach mixer at 6000 rpm for 20 minutes. Thus prepared samples were analyzed using OFITE Extreme pressure and lubricity tester to determine lubricity coefficient, Extreme Pressure film strength. Also other properties of mud such as rheology, gel strength, pH, cheesing/ greasing effect and foam tendency in terms of mud weight were determined.

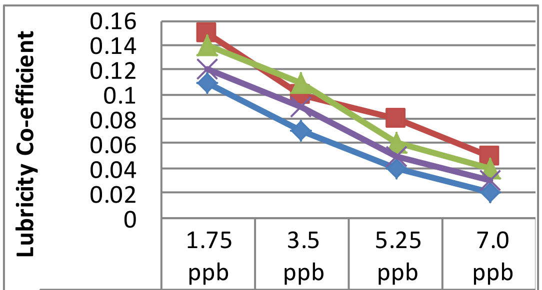
3. Results and Discussion

3.1. Lubricity test by surface to surface drag method

Lubricity coefficient was studied using OFITE Lubricity/ Extreme pressure Tester. The more common lubricity test measures fluid resistance of various lubricating additives. For the standard lubricity coefficient test, 150 inch-pounds of force the equivalent of 5,000 to 10,000 psi (34,500 - 69,000 kPa) pressure on the intermediate fluid) are applied between two hardened steel surfaces, a block, and a ring rotating at 60 RPM[6].

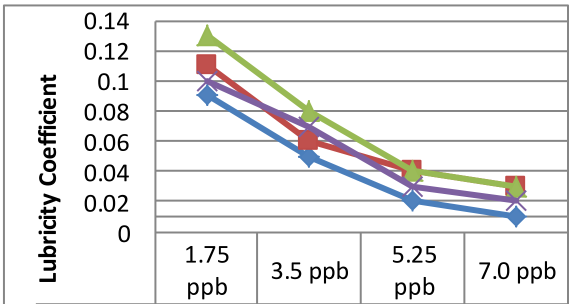
$$\text{Lubricity coefficient} = \frac{\text{Torque reading X Correction Factor}}{100} \quad (1)$$

A good extreme pressure lubricant will have lubricity coefficient of less than 0.15 in fresh water mud and less than 0.20 in salt water mud at a minimum dosage of 1.75 ppb. The lubricity coefficient of treated samples is shown in the figures.



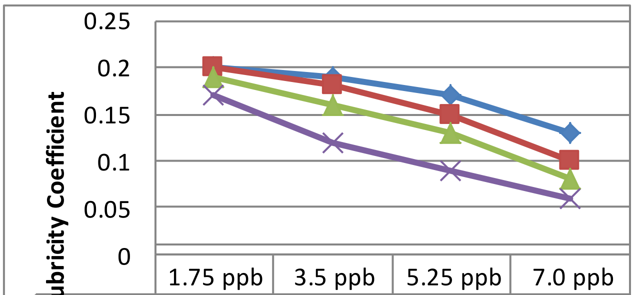
	1.75 ppb	3.5 ppb	5.25 ppb	7.0 ppb
EP-1	0.11	0.07	0.04	0.02
EP-2	0.15	0.1	0.08	0.05
EP-3	0.14	0.11	0.06	0.04
EP-4	0.12	0.09	0.05	0.03

Fig. 1: Lubricity study of WBM -1



	1.75 ppb	3.5 ppb	5.25 ppb	7.0 ppb
EP-1	0.09	0.05	0.02	0.01
EP-2	0.11	0.06	0.04	0.03
EP-3	0.13	0.08	0.04	0.03
EP-4	0.1	0.07	0.03	0.02

Fig. 2: Lubricity study of WBM -2



	1.75 ppb	3.5 ppb	5.25 ppb	7.0 ppb
EP-1	0.2	0.19	0.17	0.13
EP-2	0.2	0.18	0.15	0.1
EP-3	0.19	0.16	0.13	0.08
EP-4	0.17	0.12	0.09	0.06

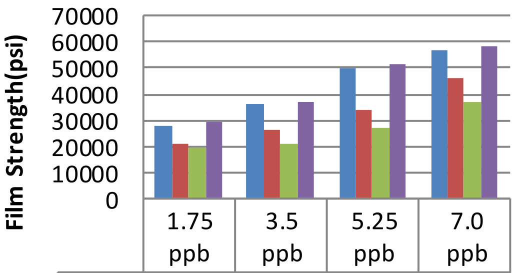
Fig. 3: Lubricity study of WBM -3

3.2. Extreme pressure test

Extreme pressure film strength was analyzed using OFITE Lubricity/ Extreme pressure Tester. This test indicates the film strength of the fluid being tested by applying a measured force to a torque-sensitive bearing cup with the torque arm. The Extreme Pressure test is typically run at a high shear rate, 1,000 RPM, with fluid with torque 300 inch-pounds of force equivalent to pressures ranging from 5,000 to 10,000 psi (34,500 - 69,000 kPa) between the steel surfaces and a ring [6].

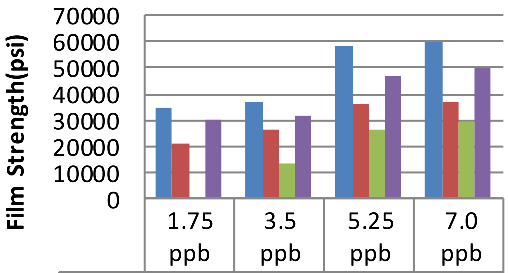
$$\text{Film strength (psi)} = 533 \times \frac{\text{Torque (pounds)}}{\text{Scar width (inch)}} \qquad (2)$$

For a good extreme pressure lubricant its film strength should be more than 25,000 psi in fresh water mud and more than 20000 in salt water mud at a minimum concentration of 1.75 ppb. The extreme pressure film strength of treated samples is shown in the figures.



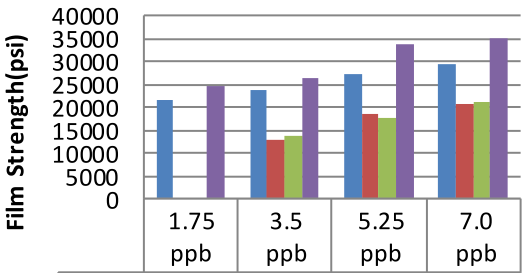
	1.75 ppb	3.5 ppb	5.25 ppb	7.0 ppb
EP-1	27716	36244	50102	57031
EP-2	20609	26294	33685	45838
EP-3	19188	21320	26863	36777
EP-4	29492	37096	51701	58097

Fig. 4: E.P study of WBM -1



	1.75 ppb	3.5 ppb	5.25 ppb	7.0 ppb
EP-1	34620	36928	58277	60008
EP-2	20772	26157	36005	37390
EP-3	0	13156	26518	29081
EP-4	30292	32023	46737	50199

Fig. 5: E.P study of WBM -2



	1.75 ppb	3.5 ppb	5.25 ppb	7.0 ppb
EP-1	21586	23985	27183	29315
EP-2	0	13058	18655	20520
EP-3	0	13592	17589	21053
EP-4	24518	26383	33846	35158

Fig. 6: E.P study of WBM – 3

3.3. Study of rheology, pH, mud weight and cheesing/greasing effect of the mud

Rheology studies were carried out using Fann VG meter. The effect on apparent viscosity, interaction of particles by measuring plastic viscosity and cutting carrying capacity yield point were analyzed. Thixotropic properties of the mud were determined by measuring gel strength Gel_0 and Gel_{10} at the intervals of 10 second and 10 minutes respectively.

Mud weight was determined using OFITE mud balance. Foaming tendency can be directly related to the mud weight as the foam increases mud weight decreases. Cheesing / greasing effect were determined. As Cheesing / greasing effect increases mud performance decreases. Hydrogen ion concentration was determined by using pH meter. Variation of pH affects the rheological properties of the mud.

3.4. FTIR study of the lubricants

FTIR spectra of lubricants were recorded on PerkinElmer Spectrum 2 (Software: Version 10.4.2) in the ATR mode. Peak table of the four samples are given in Table. 15.

Table 3: EP-1 treated with WBM-1

Concentration	AV (cP)	PV (cP)	YP (Lbs/100 sq.ft)	Gel_0 (Lbs/100 sq.ft)	Gel_{10} (Lbs/100 sq.ft)	Mud Weight (ppg)	Cheesing/ Greasing	pH
Base Mud -1	15	6	18	6	9	8.90+	No	10.0
1.75 ppb	16	7	18	6	10	8.90+	No	9.9
3.50 ppb	16	7	18	6	10	8.90	No	9.8
5.25 ppb	17	7	20	7	10	8.90	No	9.6
7.0 ppb	17	7	20	7	10	8.90	No	9.5

Table 4: EP-1 treated with WBM-2

Concentration	AV (cP)	PV (cP)	YP (Lbs/100 sq.ft)	Gel_0 (Lbs/100 sq.ft)	Gel_{10} (Lbs/100 sq.ft)	Mud Weight (ppg)	Cheesing/ Greasing	pH
Base Mud -2	15	5	20	7	10	8.6+	No	9.5
1.75 ppb	15	5	20	7	10	8.6	No	9.5
3.50 ppb	16	4	24	9	11	8.5+	No	9.4
5.25 ppb	17	5	24	9	11	8.5	No	9.4
7.0 ppb	17.5	6	23	9	10	8.5	No	9.2

Table 5: EP-1 treated with WBM -3

Concentration	AV (cP)	PV (cP)	YP (Lbs/100 sq.ft)	Gel_0 (Lbs/100 sq.ft)	Gel_{10} (Lbs/100 sq.ft)	Mud Weight (ppg)	Cheesing/ Greasing	pH
Base Mud -3	15	5	20	5	8	8.7	No	9.5
1.75 ppb	15	5	20	7	9	8.6+	No	9.5
3.50 ppb	16	5	22	8	11	8.6+	No	9.4
5.25 ppb	17	5	24	9	11	8.5+	No	9.4
7.0 ppb	17.5	5	25	9	11	8.5+	No	9.2

Table 6: EP-2 treated with WBM -1

Concentration	AV (cP)	PV (cP)	YP (Lbs/100 sq.ft)	Gel_0 (Lbs/100 sq.ft)	Gel_{10} (Lbs/100 sq.ft)	Mud Weight (ppg)	Cheesing/ Greasing	pH
Base Mud -1	15	6	18	6	9	8.90+	No	10.0
1.75 ppb	15	6	18	6	9	8.90	No	9.9
3.50 ppb	17	7	20	6	9	8.80+	No	9.7
5.25 ppb	17	7	20	6	9	8.80+	No	9.6
7.0 ppb	17.5	7	21	6	10	8.80	No	9.5

Table 7: EP-2 treated with WBM -2

Concentration	AV (cP)	PV (cP)	YP (Lbs/100 sq.ft)	Gel_0 (Lbs/100 sq.ft)	Gel_{10} (Lbs/100 sq.ft)	Mud Weight (ppg)	Cheesing/ Greasing	pH
Base Mud -2	15	5	20	7	10	8.6+	No	9.5
1.75 ppb	15	5	20	7	10	8.6+	No	9.5
3.50 ppb	15.5	5	21	7	11	8.6	No	9.5
5.25 ppb	16	5	22	8	11	8.6	No	9.4
7.0 ppb	17	6	22	8	11	8.5+	No	9.4

FTIR spectra of EP-1 and EP-4 are similar to each other, indicating similar nature of functional groups. Absence peak around 3009 cm^{-1} in EP-2 and EP-3 indicates absence of alkenes, however, EP-3 and EP-4 showed characteristic peaks of C=O groups, which was not so prominent in EP-1. Spectrum EP-3 indicated presence of ethereal group due to peak appearing at 1117.13 cm^{-1}.

Table 8: EP-2 treated with WBM -3

Concentration	AV (cP)	PV (cP)	YP (Lbs/100 sq.ft)	Gel_0 (Lbs/100 sq.ft)	Gel_{10} (Lbs/100 sq.ft)	Mud Weight (ppg)	Cheesing/ Greasing	pH
Base Mud -3	15	5	20	5	8	8.7	No	9.5
1.75 ppb	15	5	20	5	8	8.7	No	9.5
3.50 ppb	15.5	5	21	6	9	8.6+	No	9.5
5.25 ppb	16.5	5	23	6	10	8.6+	No	9.4
7.0 ppb	17	6	22	7	10	8.6+	No	9.4

Table 9: EP-3 treated with WBM -1

Concentration	AV (cP)	PV (cP)	YP (Lbs/100 sq.ft)	Gel_0 (Lbs/100 sq.ft)	Gel_{10} (Lbs/100 sq.ft)	Mud Weight (ppg)	Cheesing/ Greasing	pH
Base Mud -1	15	6	18	6	9	8.90+	No	10.0
1.75 ppb	15	6	18	6	9	8.90	No	9.9
3.50 ppb	15.5	7	17	6	9	8.90	No	9.7
5.25 ppb	15.5	7	17	6	9	8.80+	No	9.6
7.0 ppb	16.5	8	16	6	9	8.80	No	9.5

Table 10: EP-3 treated with WBM -2

Concentration	AV (cP)	PV (cP)	YP (Lbs/100 sq.ft)	Gel_0 (Lbs/100 sq.ft)	Gel_{10} (Lbs/100 sq.ft)	Mud Weight (ppg)	Cheesing/ Greasing	pH
Base Mud -2	15	5	20	7	10	8.6+	No	9.5
1.75 ppb	18.5	6	25	10	16	8.6+	No	9.5
3.50 ppb	20	6	28	10	16	8.6	No	9.4
5.25 ppb	21	6	30	12	16	8.5	No	9.4
7.0 ppb	22	6	32	13	16	8.5	No	9.3

Table 11: EP-3 treated with WBM -3

Concentration	AV (cP)	PV (cP)	YP (Lbs/100 sq.ft)	Gel_0 (Lbs/100 sq.ft)	Gel_{10} (Lbs/100 sq.ft)	Mud Weight (ppg)	Cheesing/ Greasing	pH
Base Mud -3	15	5	20	5	8	8.7	No	9.5
1.75 ppb	17.5	6	23	7	10	8.7	No	9.5
3.50 ppb	19.5	6	27	10	13	8.6+	No	9.4
5.25 ppb	21	6	30	10	16	8.6	No	9.4
7.0 ppb	21.5	6	31	10	16	8.6	No	9.3

Table 12: EP-4 treated with WBM -1

Concentration	AV (cP)	PV (cP)	YP (Lbs/100 sq.ft)	Gel_0 (Lbs/100 sq.ft)	Gel_{10} (Lbs/100 sq.ft)	Mud Weight (ppg)	Cheesing/ Greasing	pH
Base Mud -1	15	6	18	6	9	8.90+	No	10.0
1.75 ppb	15	6	18	6	10	8.90+	No	10.0
3.50 ppb	16	6	20	6	10	8.90	No	9.9
5.25 ppb	16	6	20	6	10	8.90	No	9.9
7.0 ppb	16.5	6	21	7	10	8.90	No	9.8

4. Conclusion

EP-1 performs better in WBM by giving the lubricity value ranging from 0.02 to 0.11 and film strength above 20000 psi. Slight change is observed in mud rheology and pH is observed. There is no cheesing/ greasing effect due to EP-1. Overall it acts good extreme pressure lubricant.

Table 13: EP-4 treated with WBM -2

Concentration	AV (cP)	PV (cP)	YP (Lbs/100 sq.ft)	Gel_0 (Lbs/100 sq.ft)	Gel_{10} (Lbs/100 sq.ft)	Mud Weight (ppg)	Cheesing/ Greasing	pH
Base Mud -2	15	5	20	7	10	8.6+	No	9.5
1.75 ppb	15	5	20	7	9	8.6	No	9.5
3.50 ppb	15.5	5	21	8	11	8.6	No	9.4
5.25 ppb	16.0	5	22	9	12	8.50+	No	9.4
7.0 ppb	16.5	5	23	9	12	8.50+	No	9.3

Table 14: EP-4 treated with WBM -3

Concentration	AV (cP)	PV (cP)	YP (Lbs/100 sq.ft)	Gel_0 (Lbs/100 sq.ft)	Gel_{10} (Lbs/100 sq.ft)	Mud Weight (ppg)	Cheesing/ Greasing	pH
Base Mud -3	15	5	20	5	8	8.7	No	9.5
1.75 ppb	15	5	20	6	9	8.6+	No	9.5
3.50 ppb	15.5	5	21	7	11	8.6+	No	9.4
5.25 ppb	16.0	5	22	9	11	8.6	No	9.4
7.0 ppb	16.0	5	22	9	11	8.6	No	9.3

Table 15: Peak table of the FTIR spectra of lubricants

Sample EP-1								
PeakNo.	X (cm^{-1})	Y (%T)	Peak No.	X (cm^{-1})	Y (%T)	Peak No.	X (cm^{-1})	Y (%T)
1	3009.16	90.5	2	2923.3	61.69	3	2853.97	71.64
4	1708.81	58.82	5	1457.42	85.31	6	1282.75	85.57
7	937.06	90.24	8	722.21	85.37	9	478.83	96.03
Sample EP-2								
PeakNo.	X (cm^{-1})	Y (%T)	Peak No.	X (cm^{-1})	Y (%T)	Peak No.	X (cm^{-1})	Y (%T)
1	2923.22	63.31	2	2853.77	73.72	3	1742.33	78.79
4	1711.32	79.85	5	1463.73	85.05	6	1377.58	90.46
7	1166.68	82.56	8	722.25	87.3			
Sample EP-3								
PeakNo.	X (cm^{-1})	Y (%T)	Peak No.	X (cm^{-1})	Y (%T)	Peak No.	X (cm^{-1})	Y (%T)
1	2922.85	62.36	2	2853.4	72.65	3	1743.45	64.54
4	1645.8	94.65	5	1464.31	84.73	6	1376.8	90.57
7	1163.73	71.39	8	1117.13	83.1	9	722.19	86.49
Sample EP-4								
PeakNo.	X (cm^{-1})	Y (%T)	Peak No.	X (cm^{-1})	Y (%T)	Peak No.	X (cm^{-1})	Y (%T)
1	3009.27	94.38	2	2923.13	63.46	3	2853.76	73.68
4	1743.88	61.89	5	1464.41	86.6	6	1377.73	91.86
7	1160.84	72.23	8	1099.05	83.81	9	721.91	85.29

EP-2 shows better performance above 3.5 ppb concentration. At lower concentrations its film strength is less and in salt water muds its zero. Yield point of the system increases with increase in dosage but decrease mud weight and pH is observed. There is no cheesing/ greasing effect due to EP-2. This makes it a moderate performance lubricant.

EP-3 shows better performance above 3.5 ppb concentration. At lower concentrations its film strength is zero in fresh and salt water mud. Increase in the Yield point is high as the concentration of lubricant increases and decrease mud weight and pH is observed. There is no cheesing/ greasing effect due to EP-3. This makes it a moderate performance lubricant.

EP-4 lubricant proves to be the best lubricating agent as its enhanced performance in all the mud systems compare to other lubricants. Addition of EP-4 is improving the rheology of the mud and at the same time foam forming tendency is negligible. There is no cheesing/ greasing effect due to EP-4. From the above results it can be concluded that EP-4 is the best lubricant among four different oil samples.

Seed oil is found to be a better extreme pressure lubricant than its fatty acid derivative and biodiesel based oil. Higher fatty acid esters present in pure seed oil and its derivative processes polarity imparting oxygen atoms compared to biodiesel based oil, which is responsible for the enhanced lubrication and film strength. Since all the oils used in the experiment are naturally occurring oils and its derivatives. These are non-hazardous and biodegradable. Utilization of eco-friendly lubricants in water base drilling fluids makes it more attractive and versatile for drilling operations.

5. Nomenclature

- WBM = Water Base Mud
- Lbs/ 100 sq.ft = pounds per 100 square feet
- ppg = pounds per gallon
- ppb = pounds per barrel
- AV = Apparent Viscosity
- PV = Plastic Viscosity
- YP = Yield point
- cP = centipoise
- Kg/m^3 = Kilograms per cubic meter

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