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Review of biodegradable synthetic-based drilling fluid: Progression, performance and future prospect

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ABSTRACT

This paper provides a comprehensive review on ester based drilling fluid (EBDF). It is no secret that esters with biodegradability and bioaccumulation attributes are among the promising alternatives to synthetic base oil in drilling fluids. The findings from the literature explained the critical parameters for drilling fluid base which are i) kinematic viscosity, ii) pour point and iii) flash point iv) thermal stability and v) hydrolytic stability and vi) elastomer compatibility. In an ideal case, an EBDF requires base oil with low viscosity, low pour, high flash point, high thermal and hydrolytic stability and compatibility with existing elastomer. However in the real application, these requirements may not be the same as the bottom hole condition which is always subjected to high pressure and high temperature environment. At the moment, the performance of EBDF is considered outstanding for normal borehole depth and complexity. Nevertheless the constraints such as low temperature at the seabed while high temperature and high pressure at the bottom hole may be slightly different when dealing with an EBDF. This is due to its unique molecular structure of ester. Affected parameters include i) high kinematic viscosity, ii) hydrolytic degradation and iii) thermal stability. Failure in managing these parameters may lead to detrimental impacts on the drilling fluid performances and the fluid's stabilities. The application of low viscosity, high thermal and hydrolytic properties of esters and combination with unique carbon based nanomaterials into formulation might be able to close the gap of current EBDF performances.

1. Introduction

EBDF is still gaining their popularity despite the attention given to hydrocarbon derived synthetic-based drilling fluid (SBDF). Ester is the first type of base oil used in SBDF followed by hydrocarbon poly alpha olefins (PAO), synthetic paraffin (n-paraffin), linear alpha olefin (LAO), and isomerized olefin (IO) [1–7]. Esters and other base oils have been developed due to the stringent cuttings discharge requirements in the marine ecosystem whereby diesel failed to comply. Diesel has been strictly banned in the Gulf of Mexico, the North Sea and many other places in the world since 1984 due to its toxicology issue to marine life [8]. Water-based drilling fluid (WBDF) although non-toxic, biodegradable and has lower cost of drilling fluid is unsuitable for drilling complicated wells particularly in shale formation. Shale formation complicates drilling process. It can be observed in shallow vertical onshore wells to deeper and deviated holes, higher temperature, higher pressure or deeper water, where SBDF can be the only option available in these wells [9,10]. About 75% of the footage drills worldwide contain shale formation and 90% of the wellbore stability problems originate from the shale since it contains a significant amount of clays such as smectite and montmorillonite [11–16]. SBDF is preferred in shale formation drilling due to its ability in clay stabilization, high lubricity, less corrosion, fewer formation damage, minimal temperature effect and low-cost factor [17].

It has been reported that SBDF is less toxic. SBDF degrades faster than diesel and mineral oils, without compromising the performance of

Abbreviations: ANN, artificial neural network; AV, apparent viscosity; ES, electrical stability; EBDF, ester based drilling fluid; SBDF, synthetic based drilling fluid; PAO, poly alpha olefins; LAO, linear alpha olefin; IO, isomerized olefin; WBDF, water based drilling fluid; OBDF, oil based drilling fluid; POME, palm oil methyl ester; HPHT, high pressure high temperature; LTMO, low toxicity mineral oil; ECD, equivalent circulation density; LTOBDF, low toxic oil based drilling fluid; DOBDF, diesel oil based drilling fluid; CCI, carrying capacity index; ECETOC, European Centre for Ecotoxicology and Toxicology of Chemicals; MWCNT, multiwall carbon nanotubes; CNT, carbon nanotube; HBPA, hyperbranched polyamine; GO, graphene oxide; OTMOS, octadecyltrimethoxysilane

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Nomenclature

°C	centigrade	m	meter
°F	fahrenheit	ml	milliliter
cSt	centistoke	ppg	pound per gallon
cp	centipoise	gm	gram
lb	pound	rpm	revolution per minute
ft^2	feet square	psi	pound per square
ft	feet	kPa	kilo pascal
		%	percentage

oil based drilling fluid (OBDF) [18–20]. SBDF is also designed to fulfill certain requirements guided by [21] such as it should be less volatile than OBDF (higher flash point) and its vapors must be free of aromatic compound. Such base oil properties are very important for health and safety aspects. Nonetheless, issue related to the biodegradability of hydrocarbon derived SBDF still exist [22,23]. The degradation of hydrocarbon derived SBDF is fast in aerobic condition [19,24]. However, it degrades slowly and sometimes is not fully biodegradable under anaerobic [24–26].

On the other hand, EBDF derived from plant oils have been recognized in providing the best environmental performance of any SBDF [27]. Apart from that, it is also fully biodegradable; aerobically and anaerobically [19,23,28–30]. Ester emits the lowest organic vapour compared to LAO and IO [19,31]. EBDF has been proven as superior in the aspects of biodegradation, bioaccumulation, eco-toxicity and lubricity, in comparison to other synthetic base fluids. However, it possess a high kinematic viscosity, has a poor thermal stability and prone to hydrolysis either in acidic or base condition [32]. Hence, research and development of EBDF to overcome these issues are still continued. Enhancement of the EBDF performance in order to fulfill the requirements of complex holes and deepwater drilling process is crucial especially in sensitive marine areas [33,34]. In spite of the rules that limit the discharge of SBDFs into the sea, EBDF remains as the best option, when environmental aspects are concerned.

The main objective of this paper is to provide a comprehensive review on EBDF. The subjects discussed in this paper include the progress in EBDF, the qualities of esters as the base oil for drilling fluid, the performances and issues related to EBDF and applications of nanomaterials in drilling fluid. Finally, this paper also suggests a future direction study and development of EBDF.

2. The progress of EBDF

Numbers of research on alternative biodegradable based drilling fluids have been conducted since 1980s. The drilling fluids formulated from pure vegetable oils failed to fulfill the technical requirements of a drilling fluid due to its excessive viscosity and poor thermal stability [1,27,35]. These vegetable oils were peanut, rapeseed and soybean oil.

Table 1
Summary of ester based drilling fluids studied by Mueller et. al.

Carboxylic Acid	Alcohol	Lime (g)	PV (cp) after aging	YP (lb/bbl) after aging	References
Rapseed oil (oleic, linoleic, linolenic acids)	Isobutanol	2	62	24	[1]
		4	Cannot be measured	Cannot be measured	
Oleic acid	Isobutanol	1	41	32	
		2	46	45	
Lauric acid	n-hexanol	1	28	24	[39]
		3	72	59	
Palm kernel oil (lauric, palmitic acids)	2-Ethyl hexanol	1.5	30	14	
		*increased water content	32	56	
Rapeseed oil	Methanol	2	25	6	[2]
Soybean oil	Methanol	2	23	6	
Technical grade oleic acid	Methanol	2	23	6	
Mixture of 80% isobutyl Rapseed oil ester and 20% capric/caprilic methyl esters	-	1	23	6	
Mixture of 80% isobutyl rapseed oil ester and 20% capric/caprilic methyl esters	-	2	24	6	
Isononanic acid	isoheptanol	1	31	8	[40]
		2	31	14	
Mixtures of hexanoic acid to decanoic acid	2-Ethylhexanol	1	23	12	
		2	33	12	
Caprylic acid	2-Ethylhexanol	1	22	11	
Capric acid	2-Ethylhexanol	1	31	14	
Capric acid	n-octanol	1	28	16	
Isononanic acid	n-octanol	1	29	13	
Caprylic/capric acid	Isotridecyl alcohol	2	55	24	
Caprylic/capric acid	2-Ethylhexanol	2	35	15	
Acetic acid	Isotridecyl alcohol	0	30	9	Rolled for 16 hours [41]
		1	25	12	
		2	29	17	
		2 + 1 g oleophilic amine	25	8	
		1	37	16	Rolled for 72 hours [41]
		2	34	13	
		2+1 g oleophilic amine	36	14	