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STATE OF THE ART AND FUTURE TREND OF DRILLING FLUID: AN EXPERIMENTAL STUDY

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Abstract

In its endeavor to provide a sustainable flow of hydrocarbon energy, the Petroleum industry has been recognized by the general public as an industry that has negatively impacted the environment as a result of using either harmful materials or risky practices. This leads the industry to continuously invest in R&D to develop environmentally friendly technologies and products. For any new technology or product, the current R&D trend is toward the development of sustainable practices and expertise. Drilling fluids are necessary for drilling oil and gas wells. Unfortunately drilling fluids have become increasingly more complex in order to satisfy the various operational demands and challenges. The materials used in the process to improve the quality and functions of the drilling fluids, contaminates the subsurface and underground systems, landfills, and surrounding environment. Due to the increasing environmental awareness and pressure from environmental agencies throughout the world it is very important to look back to the drilling fluid technology to reassess its progress. To sustain its position as an environment friendly industry, the petroleum industry should make forward steps to improve its practices. This article outlines the state-of-the-art of drilling fluids. The major types of drilling fluids, their strengths, limitations, and remedies to limitations are discussed. It also presents the current trend and the future challenges of this technology. An experiment was conducted to develop an environment friendly drilling fluid which is found more convenient and user friendly based on sustainability analysis. The results of the experiment are discussed in this article. In addition, future research guidelines are presented focusing on the development of environmentally friendly drilling fluids with zero impact on the environment. The paper concludes that future trend leads toward the development of sustainable drilling fluids.

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Introduction

Generally, drilling fluid may be defined as a composite fluid which is used to assist the generation and removal of cuttings from a borehole in the ground. In rotary drilling, the principal functions of the drilling fluid are to: (1) carry cuttings from beneath the bit, transport them up the annulus, and permit their separation at the surface; (2) cool and clean the bit; (3) reduce friction between the drilling string and the side of the hole; (4) maintain the stability of uncase sections of the borehole; (5) prevent inflow of fluids from permeable rocks penetrated; (6) form a thin, low-permeability filter cake which seals pores and other openings in formation penetrated by the bit, and (7) assist in the collection and interpretation of information available from drill cuttings, cores, and electrical logs (Hossain and Al-Majeed, 2012). Broadly, drilling fluids for oil and gas well drilling can be classified into three major categories: Water-Based Drilling Fluid (WBDF); Oil-Based Drilling Fluid (OBDF); and Gas-Based Drilling Fluid (GBDF). Recently, Apaleke et al., (2012) discussed elaborately the strengths, weaknesses, the remedies to the weaknesses of each of the main category of drilling fluid, current trends and the future challenges associated with the development of drilling fluids. This study is based on that reference and conducted sets of experiment toward the development of a sustainbable drilling fluid.

The research area of the development of environment-friendly mud systems is relatively new. Researchers in this field have been using non-toxic, edible vegetable grade oils, and plant seed oil as the external or the continuous fluid phase in the development of non-toxic, sustainable, and biodegradable oil-based mud systems. Dosunmu et al. (2010) developed an oil-based drilling fluid based on vegetable oil derived from palm oil and ground nut oil. The fluid did not only satisfy environmental standards, it also improved crop growth when discharged into farm lands. Generally, all these formulation do not have zero environmental impact. Amanullah et al. (2010) proposed the use of waste vegetable oil as an alternative to the use of mineral and diesel oil as the continuous phase in the formulation of high performance drilling fluids for high temperature-high pressure (HTHP) applications. This formulation is not only eco-friendly, it is also cheap, and will be vastly available because large volumes of waste vegetable oil are generated annually worldwide. Amin et al. (2010) developed an environmentally friendly drilling fluid system based on esters sourced from the Malaysian palm oil bio-diesel production plant which include methyl ester and ethylexyl ester. The short coming of this formulation is that the palm oil bio-diesel market determines the availability of the identified esters (the esters are by-product from the bio-diesel plant which means that increase in demand for bio-diesel, means increase in availability of esters, and vice-versa).

However, in this research, the base oil used to develop an environment-friendly mud system is Canola oil. The term "canola" is used as the name for rapeseed with substantially reduced quantities of erucic acid and glucosinolates. "Canola" is used mainly in American continent and Australia, and rapeseed is used commonly is Europe and other countries, (Bailey's Industrial Oil and Fat Products). Oilseed rape species from which canola oil is produced are from the Brassica genus in the Cruciferae family. They were first cultivated in India about 4000 years ago. In Europe, large-scale cultivation was first reported in the thirteenth century. The Brassica species probably evolved from the same common ancestor as wild mustard (Sinapsis), radish (Raphanus), and arrugula (Eruca), (Przybyliski et al, 2005). Early rapeseed cultivars had high levels of erucic acid in the oil and glucosinolates in the meal. The presence of erucic and glucosinolates in high levels in canola caused fatty deposition in the heart, skeletal muscles, and adrenals of experimental rodents. Cases of growth impairment were also recorded. Due to this, initiated plant breeding programs resulted in the identification in 1959 of Liho, a rapeseed line having low levels of erucic acid. A program of backcrossing and selection was conducted to transfer the low erucic acid trait into agronomically adapted cultivars. This led to the first low erucic acid cultivar of B. napus, Oro, in 1968. In 1950, Dr. Krzymanski, identified a Polish line with low-glucosinolate trait. Dr. Baldur Stefansson at the University of Manitoba introduced the Polish line trait into the low erucic cultivars to produce the first low-glucosinolate, low-erucic acid cultivar of B. rapa in 1977. The name canola was registered by the Western Canadian Oilseed Crushers in 1978 and subsequently transferred to the Canola Council of Canada in 1980, (Przybyliski et al, 2005). In 1986, the definition of canola was amended to B. napus and B. rapa lines with less than 2% erucic acid in the oil and less than 30μmol/g glucosinolates in the air-dried, oil-free meal. The oil was added to the Generally Recognized as Safe (GRAS) list of food products in the United States.

Composition of Canola Oil

The compositional analysis is one of the important issues during the formulation of a sustainable drilling fluid. Table 1 shows the typical composition of canola oil based on the experimental study done by (Ying et al, (1989) and T. Mag et al, (1990)). According to them, triacylglycerols (TAGs) constitute 94.4% to 99.1% of the total lipid in canola oil. Edible oils and fats are composed primarily of TAGs, ester of one molecule of glycerol, and three molecules of fatty acids.

Research Methodology

Base Oil Specification

The oil which would be used as base oil for the development of an OBM system must be analyzed in order to determine its physical properties. The data values must fall within the range of the particular standard values for maximum safety and reliability of mud properties. The properties of canola oil were measured using standard ASTM methods. Measured properties meet the set standards, thus confirming its suitability for use as the base oil. Table 2 shows the results of the tests and the specification carried out on canola oil based on the experiment conducted for this research. The Flash Point is the temperature at which vapour above an oil sample will catch fire, the Fire Point is the temperature at which the ignited fire will continue for burn, and the Aniline Point is the minimum temperature at which an oil sample will dissolve Aniline (an organic compound) completely. This property is a measure of wether the oil under test will be damaging to rubber component on the rig or not. Yassin et al, (1991) recommended that to avoid rubber degradation and possibly equipment failure due to low base-oil Aniline Point, rubber components should be substituted by neoprene or similar components Generally, an oil to be used for mud formulation should have Flash, Fire and Aniline Points higher than the standard values.

Selection of Additives

The uses of additives for the development of the canola oil-based mud system were carefully and cautiously evaluated and selected. It is very important because additives that will function in base oil coming from hydrocarbon or synthetic source may not be functioning in vegetable grade base oil medium. Considering the factors such as toxicity, compartibility, and sustainability, the following additives were selected: (1) primary emulsifier, (2) secondary emulsifier, (3) filtration control additive, (4) viscosifier, (5) lime, (6) calcium chloride, (78%) pure.

Laboratory Equipment used for Experimentation

This study is an applied research that involved the conduction of a series of experiments. Laboratory equipment used include: (1) mud balance, (2) weighing balance, (3) viscometer, (4) mixers, (5) HTHP single cell filtration loss tester, (6) hot-rolling oven with cells, (7) electrical stability tester.

Selection Criteria for Canola OBM Composition

According to Omland, (2009), finding a real composition (in field it is called as "recipe") of any mud system is a very challenging task. Beause the development of a novel mud system is very difficult, unpredictable and time consuming exercise due to the following reasons: (1) drilling fluids are ternary systems, that is they are solids, dispersed, and continuous phase, (2) they exhibit complex viscoelastic properties, (3) nature of emulsions and how they interact with particles of solid suspended in them, (4) the colloidal nature of drilling fluids, (5) composition of the internal brine phase, (6) added shear energy during preparation, and, (7) particle morphology. The method which used in this research is called Guided Empiricism. This method leads to arrive at the final compositions on which the development of the canola OBM system is based. This involved the development of several trial formulations based on trial recipes guided by compositions available in literatures. Table 3 shows the composition of the canola OBM system formulated using this standard procedure.

Results and Discussion

This article reports only the two formulated mud systems: (1) canola oil-based mud 1, (COBM-1), and (2) canola oil-based mud 2, (COBM-2) based on the recipe as described in Table 3. COBM-1 was formulated using an Oil/water ratio of 90/10, while COBM-2 was formulated using an Oil/water ratio of 80/20. The amount of all other additives remained same in the two mud system except for the filtration control additive. Table 4 shows a detailed comparison of the composition of COBM-1 and COBM-2. In the COBM-1, a 90/10 Oil/water ratio means that it contains 290 ml of canola oil and 35 ml of brine water, while in the COBM-2, an 80/20 Oil/water ratio corresponds to 240 ml of canola oil and 62 ml of brine water. Since the higher the amount of water in any emulsion system means a higher level of instability, it is expected that COBM-2 will be less stable compared to the COBM-1. Complete mud check was conducted on COBM-1 and COBM-2 before hot-rolling (BHR) at 120 ^{0}F, and after hot rolling (AHR) at 300 ^{0}F and 300 psi. In addition, HTHP and electrical stability test were also conducted on these mud systems. Table 5 shows the results of complete mud check and other tests carried out on COBM-1 and COBM-2.

Rheological Behaviour of Mud Systems BHR

COBM-1 shows a dial reading of 125 lb/ft^2 at 600 rpm, while the COBM-2 shows 135 lb/ft^2 which is 10 lb/ft^2 higher than COBM-1. This is because COBM-2 contains more brine water (the internal or the discontinuous fluid phase) which has added to the viscosity of the mud system thus increasing the shear stress. In practical terms, this means that the drill bit will have a low rate of penetration (ROP) if COBM-2 is the drilling fluid. This is a challenge for the COBM-2. The 6 rpm dial reading of COBM-1 is 7 lb/ft^2 and COBM-2 is 14 lb/ft^2 which may also be higher for a potentially good mud. COBM-1 shows a plastic viscosity (PV) of 59 cp compared to 53 cp shown by COBM-2. In practical terms, this variation may be considered as intangible. The higher viscosity of COBM-1 is basically due to the added viscosity of canola oil alone which stands at 23 cp. Interestingly, COBM-2 shows a higher yield point (YP) compared with COBM-1 which shows a lower YP. Table 5 summarises all the rheological behavior of mud system BHR.

Rheological Behaviour of Mud Systems AHR

COBM-1 and COBM-2 were aged for 16 hrs at 300 ^{0}F and 300 psi. The 600 rpm dial reading of COBM-2 increased further from 135 lb/ft^2 to 145 lb/ft^2. This means that COBM-2 is sensitive to elevated temperature and pressure and hence it will be unstable under simulated down-hole conditions. If COBM-2 is weighted, dial readings may become abnormal. However, COBM-1 shows a reduction in 600 rpm dial reading from 125 lb/ft^2 to 95 lb/ft^2. This means that elevated temperature and pressure has a thinning effect on it. This is good for the mud because the thinning effect will be normalized when barite is added to the mud. The higher PV development of COBM-2 from 53 cp to 67 cp is another indication of its instability. A very strong indication of the instability of COBM-2 and the stability of COBM-1 is that while COBM-2 looses yield, COBM-1 gains yield. Table 5 summarises all the rheological behavior of mud system AHR. In practical terms, an increasing YP means a good and stable mud which helps in removing cuttings from the hole, while a reducing YP means a bad and unstable mud which results in loosing viscosity, not removing cuttings, experience sagging. These problems may lead to stuck pipe and or loss circulation.

Ageing under Gravity BHR and AHR

COBM-2 would have its liquid phase completely separated from the sagged added materials when it is allowed to age at room temperature for a few hours. This observation gives the understanding that both the colloidal and emulsion systems in COBM-2 are unstable. However, if aged for 72 hours, COBM-1 remained stable. Figure 1 shows an unstable COBM-2, while Figure 2 shows a stable COBM-1 developed in the laboratory.

Electrical Stability Test

The higher the value measured by the electrical stability tester in Volts when dipped into a mud system at 120^0F, the more stable the mud system and vice-versa. While measuring the electrical stability tests, COBM-1 shows 900 Volts, and COBM-2 shows 302 Volts which indicates that COBM-1 is more stable than COBM-2.

HTHP Filtration Test

This test should be conducted at the bottom-hole temperature if it is known. If not, the test should be run at 250 ^{0}F. Since we don’t know the bottom-hole temperature, we run this test at 250 ^{0}F. After 30 minutes of experimental run, filtrate volume from COBM-1 was found 10 ml of oil, and filtrate volume from COBM-2 was 15 ml of oil+water. This filtration test indicates a very strong sign of a bad and unstable mud system of COBM-2 or COBM-1.

Challenges and Future Trend toward the Development of Sustainable Drilling Fluid

It is always a challenge to reduce the oil/water ratio during the formulation of mud system. So far the industry was not able to reduce the oil/water ratio in their formulation beyond 85/15. This is a major gap in their previous works in the subject area toward the development of sustainable OBM systems using no-toxic, edible vegetable oils. Therrefore this research was attempting to consider a reduced oil/water ratio to formulate the target mud system. COBM-2 was an effort by this research which resulted in a reduced oil/water ratio. This reduction will ultimately minimize the cost of formulation because the more the water you have in the mud system, the cheaper it becomes in terms of cost of formulation. However, this is very challenging and difficult to achive as shown clearly by the instability of COBM-2 despite its showing of good rheology. Brine has a high density and contains a mixture of salts. Hence, the more the amount of brine internal phase added to a viscous vegetable oil such as canola oil, the more complex the entire nature of the mud system becomes.

Basically, drilling mud systems are colloidal systems in which insoluble materials such as additives and weighting materials (dispersed phase) are dispersed in a liquid medium (dipersion medium). The addition of more brine into a single phase OBM, or an invert system such as COBM-1 makes the liquid phase an emulsion where a liquid is dispersed in another liquid (Freundlich, 1926). Additives that are used in the mud system may either be solvent loving (lyophilic) or solvent hating (lyophobic). This causes an interplay of several forces that helps to forming a stable emulsion. Finally, it becomes very difficult and challenging to control. In addition, the chemistry of the brine phase containing a cocktail of salts affecting mud stability is not stable. Therefore, research efforts in the future should be tailored towards the formulation of a stable emulsion.

It is well recognized that toxic additives are the high performers. So, how will they be replaced? Answering this question obviously is one of the future challenges for the researchers who will have to contend with. For instance, hazardous effects on marine and human life have been reported in the literature due to the uses of additives such as defoamers, descalers, thinners, viscosifiers, lubricants, stabilizers, surfactants and corrosion inhibitors (Hossain and Apaleke, (2011)). This negative effects ranges from minor physiological changes to reduced fertility and higher mortality rates. In addition, Jonathan et al. (2002) reported that ferro-chrome lignosulfonate (a thinner and deflocculant) affected the survival and physiological responses of fish eggs and fry. The filtration control additive carboxymethyl cellulose (CMC) causes the death of fish fry at high concentrations (1000-2000 mg/ml). Physiological changes start at the level of 12-50 mg/ml. On the other hand, corrosion inhibitors such as phosphoxit-7, EKB-2-2, and EKB-6-2 cause genetic and teratogenic damages in humans (Apaleke et al., 2012). Information provided in the product data sheet of some additives, especially silica based ones has revealed that these additives can cause cancer in an individual if he/she is exposed to these additives. Therefore, replacing the toxic chemical additives from the conventional mud system is the timely research ideas and accordingly it is the challenges for the future research and innovation.

Conclusions

Based on results from this research work, the followings conclusions are drawn:

1) Canola oil can be used as a base-oil for the formulation of an oil-based mud system.
2) The reduction of the concentration of certain additives will help to reduce the cost of formulation on a large scale for field applications.
3) The developed canola oil-based mud system is formulated without a wetting agent. This will also help to reduce the cost of formulation.
4) The developed COBM-1 is stable at room temperature (BHR) and under simulated down-hole conditions (AHR)

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TABLE 1: COMPOSITION OF CANOLA

Component	**Canola**
Triacylglycerols (%)	94.4-99.1
Crude Oil (%)	up to 2.5
Water-degummed (%)	up to 0.6
Acid-degummed (%)	Up to 0.1
Free Fatty Acids (%)	0.4-1.2
Unsaponifiables (%)	0.5-1.2
Tocopherols (mg/Kg)	700-1200
Chlorophylls (mg/Kg)	5-50
Sulfur (mg/Kg)	3-25
Iron (mg/Kg)	Less than 2

TABLE 2: SPECIFICATION OF BASE OIL

Properties	**Standard**	**Diesel**	**Canola Oil**
API Gravity	$25\text{-}37^0$	$26\text{-}30^0$	24.4^0
Flash Point	180^0F	$126\text{-}204^0$F	442^0F
Fire Point	200^0F	410^0F	514^0F
Aniline Point	140^0f	201.2^0F	250^0F

TABLE 3: COMPOSITION OF CANOLA OIL-BASED MUD SYSTEM

Material	**Amount**
Base-oil	90%
Primary emulsifier	12ml
Lime	Varied
Filtration control additive	10ppb
Water	10%
Gelant(Viscosifier)	6ppb
Secondary Emulsifier	8ml
$Cacl_2$ (78%)	17ppb
Barite	#
Density	8ppg

TABLE 4: COMPOSITION OF COBM-1 and COBM-2

Material	**Amount**	
	COBM-1	COBM-2
Base-oil	90%	80%
Primary emulsifier	12ml	12ml
Lime	5ppb	5ppb
Filtration control additive	6ppb	10ppb
Water	10%	20%
Gelant(Viscosifier)	2ppb	2ppb
Secondary Emulsifier	8ml	8ml
$Cacl_2$ (78%)	17ppb	17ppb
Barite	#	#
Density	8ppg	8ppg

TABLE 5: RHEOLOGICAL BEHAVIOR OF COBM-1 and COBM-2 BHR & AHR.

PARAMETERS	COBM-1		COBM-2	
	BHR	AHR	BHR	AHR
600 rpm	125	95	135	145
300 rpm	66	59	82	78
200 rpm	56	42	61	66
100 rpm	28	24	37	34
6 rpm	7	6	14	11
3 rpm	5	4	11	8
10 sec,lb/f^2	2	2	4	3
10min,lb/f^2	3	4	5	4
PV, cp	59	36	53	67
YP,lb/ft^2	7	23	29	11
HTHP filt.,ml	10	10	15	15
Elect. Stab., Vol	900	900		

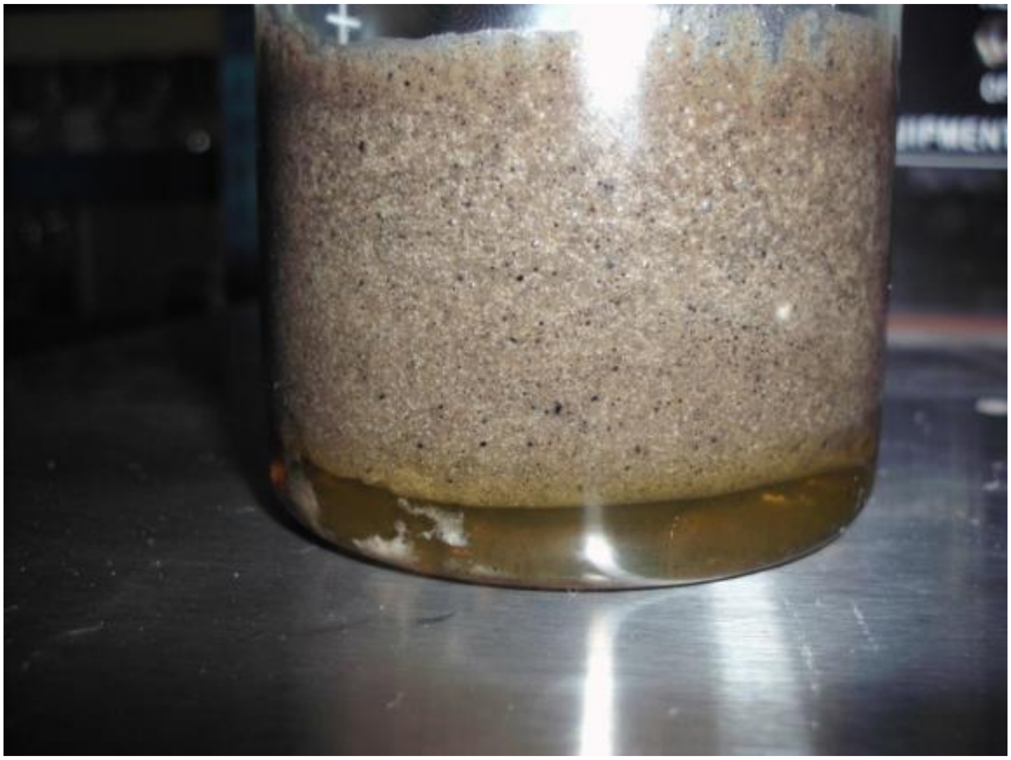

Figure 1: COBM-2 after ageing BHR and AHR.

Fgure 2: COBM-1 after Ageing BHR and AHR.