SPE 149555

Drilling Fluid: State of The Art and Future Trend

Adeleye Sanmi Apaleke, SPE, Abdulaziz Al-Majed, SPE, and M. Enamul Hossain, SPE, King Fahd University of Petroleum & Minerals

This paper was prepared for presentation at the North Africa Technical Conference and Exhibition held in Cairo, Egypt, 20–22 February 2012.

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 while it tries to make forward steps to improve the petroleum industry's position as an environment friendly industry. 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. 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.

Introduction

Generally, drilling fluid may be defined as all of the compositions used to assist the generation and removal of cuttings from a borehole in the ground. Drilling fluid is more or less the single most important part of any earth excavation exercise, especially when drilling for oil and gas. The drilling fluid can be compared with the blood of the human body, so also drilling fluid to drilling (Table 1). Principal components of drilling fluids are: water, oil/gas, and chemical additives. These components

Corresponding author: Dr. M. Enamul Hossain, Department of Petroleum Engineering, P.O. Box 2020, King Fahd University of Petroleum & Minerals (KFUPM), Dhahran 31261, Saudi Arabia. Tel: 0096638602305, Fax: 0096638604447, Email: menamul@kfupm.edu.sa; dr.mehossain@gmail.com

form the basis of the classification of drilling fluids. Mud, which are suspension of solids in either water or oil, and a mixture of other substances called additives (Table 2) make a complete drilling fluid.

Many requirements are placed on the drilling fluid. However, 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 drilling cuttings, cores, and electrical logs (Hossain and Al-Majeed, 2012).

General Types of Drilling Fluid

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). OBDF will be pointed out later in this study includes a number of oil based formulations that are modifications of the OBDF. In discussing each fluid type, early developmental efforts and the current trends in their formulations especially as it pertains to additives modification (overtime the continuous phases are not changing) will be emphasized.

Water Based Drilling Fluid (WBDF)

Early Development of the WBDF

Water was the first drilling fluid ever used in any drilling operation (Brantly, 1961). The Egyptians, far back in the third millennium used water to remove cuttings from holes drilled using hand-driven rotary bits (Brantly, 1971). Around the 600 B.C, wells were drilled in China for brine, gas, and water where water was poured into these wells to soften the rock and to help removing cuttings (Pennington, 1949). Through a patent in 1844, Robert Beart proposed that cuttings from holes being drilled may be removed by water (Beart, 1845). To bring cuttings from a borehole to the surface, Fauvelle (1846) pumped water through a hollow boring rod. In 1887, it was proposed in a U.S. patent that a mixture of water and a quantity of plastic material can be used to remove cuttings and also to form an impervious layer along the wall of the borehole (Chapman, 1890). The addition of mud to water as a means of hole stabilization in weak formations commenced in Texas and Louisiana around 1901. According to Hayes et al. (1903), the first mud used was sufficient clay (gumbo). However, in California, other types of clays from surface deposit were mixed with water using hand shovels by mud crew with little attention paid to the mud properties (Knapp, 1916). Increased drilling activities and hence demand for mud and also the need to increase mud density for pressure control triggered the commercial sale of heavy mud made by adding heavy minerals to surface clays. In 1922, the sale of paint-grade barite for oil well usages started in California under the brand name Baroid^R by the National Pigments and Chemical Company (Stroud, 1925). The George F. Mepham Corporations of St. Louis, Missouri sold iron minerals as mud weighting agent while the California Talc Company, a producer and marketers of clays sold Aquagel^R brand of bentonite as an admixture for cement in 1928.

However, the problem of the settling of the heavy minerals in some mud reinstated the need for a suspending agent (thinner) that will prevent the heavy minerals from settling. The first thinning agent for mud, Stabilite^R, was introduced by T.B. Wayne in 1938 (Parsons, 1932). This product, a mixture of chestnut bark extract and Sodium Aluminate thinned mud without decreasing the density, released entrapped gas, and allowed further increase in mud weight. One of the other earliest mud thinners was the Quebracho extract proposed by Fischer in an U.S. patent (Fischer, 1951). It is extracted in the form of tannin by hot water from the wood of certain dense hardwood trees which grows in northern Argentina and western Paraguay. In 1947, leonardite, mined lignin, brown coal, and slack were introduced as partial substitute for quebracho extract as limitations were placed on it due to the World

War II.

WBDF may contain several additives. These include alkalis, salts, surfactants, organic polymers in colloidal solution, and various insoluble weighting materials such as barite, and clay. The selection of additives is based on the type of formation to be drilled, dispersive materials in the formation, and cost.

Current Trends in the Formulation of WBDF

The water based drilling fluids, which simulate the performance of the oil-based drilling fluid are commonly referred to as high performance water based fluids (HPWBF) (Morton, 2005; West and Morales, 2006; Dye, 2006; Patel, 2007; Marin et al, 2009). The main benefits of HPWBF include the reduction of environmental impacts, and lower down costs associated with cuttings and fluids disposal. Reid et al. (1992) evaluated a novel inhibitive water-based fluid for tertiary shale that was formulated primarily from tetra-potassium pyrophosphate (TKPP or K4P207). They observed that the formulation was considerably more inhibitive than other mud systems (even approached the level of that observed with oil based mud). Kjosnes et al. (2003) designed a water-based drilling fluid from a mixture of potassium chloride and polymers such as polyanionic celluoses/xathan gum. When this mud is applied, they observed that the formulation resulted in improved hole cleaning optimization, and hole stability.

Al-Ansari et al. (2005) formulated a HPWBM comprising of partially hydrolyzed polyacrylamide (PHPA, for cutting encapsulation) and polyamide derivatives (for suppressing the hydration and dispersion tendency of reactive clays). In their conclusions, they stressed the fact that the formulation which had been used successfully to drill several wells in the Arabian Gulf is an environmentally friendly and performance driven alternative to OBM. Young and Ramses (2006) developed a unique water-based fluid by blending a hydration suppressant, a dispersion suppressant, a rheology controller (xathan gum), a filtration controller, and an accretion suppressant. The formulation according to them delivered an invert emulsion-like drilling performance. Ramirez et al. (2007) developed an aluminum-based HPWBM that was used successfully to drill an exploratory well in the Magellan Strait, Argentina. They claimed that not only did the HPWBM replace the oil-based mud, it is also environmentally friendly. Marin et al. (2009) formulated a HPWBF from a blend of salt and polymers at different mud weights. They recommended the inclusion of sized calcium carbonate if drilling through high permeability sands.

Limitations of WBDF

Major limitations of WBDF include (Mellot, 2008), include:

1) The ability of WBDF to dissolve salts which may result in unwanted increase in density.
2) The ability of WBDF to interfere with the flow of oil and gas through porous medium.
3) The ability of WBDF to promote the disintegration and dispersion of clays.
4) The inability of WBDF to drill through water sensitive shale or "heaving shale".
5) The ability of WBDF to corrode iron such as drill pipes, drill collars and drill bits.

Strenghts of WBDF

1) It is cheap and hence cost effective.
2) It is environmentally friendly at some extent.
3) It is easily accessible and abundantly available.
4) Faster ROP.

Remedies to Limitations of WBDF

The most important remedy to make-up for the limitations of WBDF is to use OBDF.

According to Dye et al., (2006), unlike WBDFs, OBDFs do not dissolve salts because they are non polar. They do not interfere with the contents of the reservoir and the porous media because the base oil (no.2 diesel) is native to the reservoir. They do not promote clay disintegration and hence can be used to drill through heaving shale because they are unreactive. They are lubricants hence do not not corrode pipes, collars and drill bits.

Oil Based Drilling Fluid (OBDF)

Early Development of the OBDF

OBDF contain oil as the major part and water as second. The common base oils are diesel, mineral oil, and some crude oils at some extent. As some percentage of water exists, the OBDF must contain water-emulsifying agents. When water is intentionally added, the OBDF becomes an Invert Emulsion Drilling Fluid (IEDF). A number of thickening and suspending agents may also be added to the OBDF. Organic-Phase Drilling Fluid (OPDF) is the newly-coined collective term (and euphemism) for oil-based, synthetic-based, and emulsion-based drilling fluids (Oslo-Paris Commission and UK Department of Trade and Industry, 2000).

OBDFs were developed to solve some of the unwanted characteristics of water-base muds. OBDFs originated with the usage of crude oil in well completions; however the date of first usage is unknown. Historians believe that a patent application filed by J.C. Swan in 1919 and granted in 1923 (Swan, 1923). He observed the beginning of the use of oil to drill the productive zone in shallow, low-pressure wells in many early fields. In 1935, Humble Oil & Refining Company (now Exxon) used an oil mud made from gas oil and spent clay to drill through heaving shale interval in Creek Field, Texas (Moore, 1936). During the next two years, studies were carried out on cores taken with oil mud in Texas Fields on the connate water content of reservoir sands so as to be able to improve on the formulation of oil-base muds (Schilthuis, 1938). In 1942, when George L. Miller founded the OBDFs Company in Los Angeles, California, commercial oil muds became available. This Company (now Oil Base, Inc.) supplied blown asphalt in the form of Black Magic^{R}, a powder which was mixed with suitable oil at the well site (Miller, 1942). Properties of the blown asphalt and of the preferred diesel oil were specified (Miller, 1943). Naphthenic acid and calcium oxide were other components of the oil mud (Miller, 1949).

Use of oil mud for drilling had its drawbacks: water was a severe contaminant; high risk of fires; low rate of penetration (ROP); very costly; and most importantly, it is not environmentally friendly. Future research efforts as indicated by current trends in oil well drilling fluids research will be directed mainly towards the development of an environmentally friendly drilling fluid that will be a substitute to the oil-base drilling fluids.

Current Trends in the Formulation of OBDF

OBDF is the most effective drilling fluid when drilling or exploring for oil in frontier areas where extremely high geothermal gradient is a major challenge. However, in recent years, concerns about the restrictions of its use globally due to stiffer government regulations, very high cost of disposal and treatment of cuttings from the use of OBDF, and cost of formulation have received more attentions from researchers than improved formulation (Oakley et al., 1991). In this section, some current formulations and hazardous effects of OBDF are outlined.

Miller (1950) reported that muds containing air blown asphalt were the most effective due in part to their superior plastering properties and flexibility of temperature range. Oakley et al. (1991) designed an oil based mud based on oil-soluble polymers (amidoamines and imidazolines) that would reduce the oil on drill cuttings. Based on results from their laboratory tests, they concluded that oli on cuttings can be reduced by up to 30% on current 50:50 oil: ratio fluids. Herzhaft et al. (2003) studied the influence of temperature and clays/emulsion microstructure on oil-based mud low shear rate rheology. They concluded that organophilic clays, in interaction with the emulsion droplets are responsible for the low shear rate. Chen et al. (2004) formulated an oil based mud system using VERSA, LLD, BOO, and NOVA (emulsifying and oil-wetting agents) to study the effects of OBDF invasion on irreducible water saturation. From the experiments they conducted, they observed that originally strong water-wet Berea and limestone cores were altered to become intermediate-wet or oil wet by OBM surfactants thus faulting the assumption of water-wetness by the NMR T_2 cut-off model which generally underestimates the value of S_{wir} it measures. They proposed that the magnitude of underestimation depends on: the type of OBM surfactants, their concentration in the flushing fluid, and the flushing time. In their conclusion, they suggest that in the real drilling process, the effects of OBM invation on the NMR misinterpretation when wettabilty alteration coccurs can be minimized by controlling the invasion volume and the concentration of OBM surfactants in the invasion fluid.

Limitations of OBDF

1) It is very expensive.
2) Disposal of cuttings resulting from the use of OBDF is very expensive.
3) Treatment of cuttings prior to disposal is also very expensive.
4) OBDF are not environmentally friendly because their disposal may result in the pollution of lands, contamination of water bearing aquifers, and the decimation of the coral reefs.
5) Lower ROP compared with WBDF.
6) They may cause changes in wettability, (Chen et al., 2004).
7) Unsuitable for use in dry gas reservoirs.

Strenghts of OBDF

1) It provides a means for avoiding all the limitations of the WBDF.
2) It provides better lubrication.
3) It has higher boiling points.
4) It has also a lower freezing point.

Remedies to Limitations of OBDF

No doubt, the OBDF is the better comparing with WBDF in terms of performance and OBDF is the most widely used drilling fluid. However, it has a major limitation, not environmentally friendly. Hence, the solution to this shortcoming is the development of environmentally friendly drilling fluids that will be cheaper and hence cost effective.

Gas Based Drilling Fuid (GBDF)

GBDF is also known as Reduced- Pressure Drilling Fluid. Gas based drilling fluid can be classified into: (1) dry gas, (2) mist (in which droplets of water or mud are carried in the air stream, (3) foam (in which air bubbles are surrounded by a film of water containing a foam stabilizing-agent, and (4) gel foam (in which the foam contains film-strengthening agents, such as organic polymer or bentonite). The most common gas drilling fluid is air, although, natural gas (methane) exhaust, or combustion gases are sometimes used.

Early development of GBDF

Gas was first injected in September 1932 (Foran, 1934) in the Big Lake Field, Texas to flush formation water out of the productive zone. Earlier in the 1920s, pressure drilling with a control head, which allows control of gas and oil flow while drilling the productive zone had been used in Mexico. Around this time in Oklahoma, gas at a volume ratio of 143:1 metered into the circulating water was used for drilling and it was observed that productivity was greatly improved compared to that of oil wells drilled with mud. Similarly, in Carlifornia, gas-injection practices were used to drill subnormal –pressure sands (Grinsfelder and Law, 1938). Around the 1950s, rigs carrying out seismic exploration in parts of Canada shot-holes using compressed air due to water scarcity of extremely low temperatures (Shallenberger, 1953). In 1951, El Pao Natural Gas Co. began drilling with gas to avoid loss circulation. They also observed that ROP and Footage per bit increased greatly, productivity was much higher, and well clean-up was facilitated (Hollis, 1953). As the method was continuously tried in different areas, both practical limitations and advantages were recorgnized.

Current trend in the Formulation of GBDF

Most of the technological improvements seen in the drilling of well with air have come from the mining industry which is primarily associated with shallow large bore wells. The oil and gas industry has failed to make the same technological advancement in air drilling as compared to wells drilled with liquid or mud systems (Mellot, 2008). However, the followings are some of the current trends in the use of air for drilling:

Foam

This involves the injection of a dilute solution of a suitable foaming into the air stream. Foam effectively removed cuttings at lower annular velocities that was possible with air alone (Mellot, 2008).

Aerate Mud

This involves the direct injection of compressed air from a 3-stage compressor through the stand pipe into the mud system. A special check valve is placed in the drill string one joint below the Kelly to prevent the problem of mud spray when making connections (Kenneth et al., 2007).

Gel Foam and Stiff Foam

Basically, this is the use of a slurry prepared consisting of (by weight) 98% water; 0.3%soda ash; 3.5%bentonite; 0.17% guar gum; and 1% volume of a suitable commercially available foaming agent. In recent formulations, guar gum has been substituted by other polymers and bentonite by other clays (Crews, 1964).

Limitations of GBDF

1) It cannot be used to drill through water bearing zones. When water-bearing formations are drilled using air, the wetted cuttings will stick together and will not be carried from the hole by the air stream.
2) Gas may be corrosive.
3) High risk of explosion.

Strenghts of GBDF

1) Reduction of the pressure gradient of the drilling fluid to less than that exerted by a column of water.
2) Risk of formation damage is minimized when using GBDF.
3) Faster drilling rate in hard rock areas.
4) It is abundantly available and cheap.
5) Minimization of loss circulation.
6) Improved bit performance.
7) Ready detection of hydrocarbon.

Remedies to Limitations of GBDF

Wetting and balling of cuttings can be reduced by introducing zinc or calcium stearate into the air stream. Having gas detectors on the rig floor will reduce the risk of explosion due to leakage.

Current Development in Drilling Fuids

Development of environment-friendly mud system

The current trend in drilling fluid development is to come up with novel environmentally friendly drilling fluids that will rival the OBDF in terms of low toxicity level, performance, efficiency, and cost. Several researchers have come up with formulations of drilling fluid with minimal but not zero environmental impact. E Van Dort et al. (1996) formulated an improved water based drilling fluid based on soluble silicates capable of drilling through heaving shale which is environmentally friendly. But this is not recommended because silicate has the potential to damage the formation. Shake et al. (1999) suggested the use of microsized spherical monosized polymer beads as a blend to WBDF to improve lubrication. Thaemlitz et al. (1999) formulated a new environmentally friendly and chromium-free drilling fluid for HPHT drilling based on only two polymeric components. Brady et al. (1998) came up with a polyglycol enriched water based drilling fluid that will provide high level of shale inhibition in fresh water and low salinity water based drilling fluid. However, this formulation has a defect in that for it to perform optimally, electrolytes must be present. Nicora et al. (1998) developed a new generation dispersant for environmentally friendly drilling fluids based on zirconium citrate. The zirconium citrate functions to improve the rheological stability of conventional water based fluids at high temperature. However, this formulation has a limitation in that the concentration of zirconium citrate may be depleted in the drilling fluid due to solids absorption.

To avoid some of the above mentioned problems, Sharm et al. (2001) developed an environmentally friendly drilling fluid which can effectively replace oil based drilling fluid by using eco-friendly polymers derived from tamarind gum and tragacanth gum. Tamarind gum is derived from tamarin seed while tragacanth gum is from astragalus gummifier. This formulation is also cheaper and has less damaging effect on the formation. Hector et al. (2002) developed a formulation with a void toxicity based on a potassium-silicate system. The advantage of this formulation apart from being environmentally friendly is that cuttings from the use of this drilling fluid can be used as fertilizers. Warren et al. (2003) developed a formulation based on water-soluble polymer amphoteric cellulose ether (ACE) which is cheaper, low in solids content, environmentally friendly but with some potential to damage the formation. Davidson et al. (2004) developed a drilling fluid system that is environmentally friendly. It also removes free hydrogen sulphide which may be encountered while drilling based on ferrous iron complex with a carbohydrate derivative (ferrous gluconate). Ramirez et al. (2005) formulated a biodegradable drilling fluid. It maintains hole stability and also enable drilling through sensitive shale possible based on aluminum hydroxide complex (AHC). This formulation contains some blown asphalt and hence posses some environmental problems. 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.

All these efforts of the researchers brought the drilling fluid technology in a responsible position which is environmentally friendly and cost effective up to some extent. However, these formulations do not have zero environmental impact yet. Therefore, the question – is the development of a zero impact environmentally friendly drilling fluid possible?

Application of Nanotechnology to Mud Additive Formulation and Development

Nano-Silica, nano-graphene, and other nano-based materials have been proposed for use as alternative mud additives. A nano-material based mud system is defined as that mud containing at least one additive with particle size in the range of 1-100 nanometers (Amanullah et al., 2009). It is based on the number of nano-sized additives in the mud system; mud systems can be classified as simple nano-mud system or advanced nano-mud system. Nano-materials in mud systems are expected to reduce the total solids and/or chemical content of such mud systems and hence reducing the overall cost of mud system development.

Application of Biomass

Cellulose is the main component on the cell walls of trees and other plants. Its purest form is called nano crystalline cellulose (NCC) which is treated as strengthens and stiffens materials. Currently, a number of oil companies in Canada have teamed up to conduct research into the possibility of using NCC as an alternative drilling fluid additive toward the development of a sustainable mud system (Website 3).

Future Direction of Research and Challenges in Mud Engineering

Cost of developing environment-friendly OBM for Field Application

The future of research in drilling fluid development should be directed towards the formulation of an environmentally friendly drilling fluid with zero impact on the environment. This is pertinent because incidents of environmental pollution due to the discharge of oil based drilling wastes into the environment keep increasing, while the regulations set by the government agencies and NGOs of different countries are restricting the use of oil based drilling fluids. Therefore, the use of OBM is becoming stricter. To solve the stringent pollutant contents from mud system, Ammnullah (2010) proposed the use of waste vegetable oil in the formulation of environment friendly OBM. Ogunrinde and Dosunmu (2010) suggested the use of palm-oil. A major multinational oil company for off-shore drilling operations had used highly de-aromatized aliphatic solvents to formulate low toxicity mud system. These formulations though have zero environmental impact, are very expensive. Bringing their cost of formulation down so that over all cost of drilling becomes cheaper is definitely a challenge.

Development of environment friendly mud additives

Hazardous effects of additives such as defoamers, descalers, thinners, viscosifiers, lubricants, stabilizers, surfactants and corrosion inhibitors on marine and human life had been reported. Effect ranges from minor physiological changes to reduced fertility and higher mortality rates. For example, Jonathan et al. (2002) reported that ferro-chrome lignosulfonate (a thinner and deflocculant) affected the survival and physiological responses of fish eggs and fry (Website 1). The filtration control additive CMC (carboxymethylcellulose) causes the death of fish fry at high concentrations (1000-2000 mg/ml) and physiological changes start the level of at 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. Another example of the use of toxic additive in OBM formulation is the dumping of 896 tonnes of drilling mud containing SOLTEX damage the coast of Great Britain. When questioned, both the company and the government body overseeing the industry provided only the trade name of the active additive in the dumped drilling mud as SOLTEX with no reference to the fact that SOLTEX contained potentially toxic heavy metals as revealed by Greenpeace in a publication in 1995 (Table 3). Information provided in the product data sheet of some additives has revealed that these additives can cause cancer in an individual if he/she is exposed to these additives. 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 researchers will have to contend with.

Sustainability

Drilling fluid’s position is still in a challenging environment if its status is analyzed based on sustainability though there is a tremendous advancement in this technology. It is due to the complex formulation of the mud system which is needed to meet the different desired properties for smooth functioning while drilling. In addition, mud system’s sustainability has to do with two issues: 1) Ensuring the continuous availability of the base oils used in the formulation of environment-friendly mud systems, 2) Executing a complete drilling program in a safe and environment friendly manner. These two issues put forward a challenging environment to the researchers. Recently, Hossain (2011) proposed a sustainable drilling pathway. He also proposed a diagnostic test procedure toward greening of the drilling fluid system. Follow up of his proposed protocol is a real challenge for the petroleum industry because of cost, need for technological advancement, and availability of the innovative sustainable chemical additives. The initialization should come considering the environment-friendly base oils with zero toxicity instead of conventional base oil. The sources are from plants where there is no use of toxic or unhealthy materials during the complete process. These objectives provide researchers in a challenging situation for achieving their goals. Ensuring resources availability in a timely manner is also a big challenge.

Development of mud and/or additives for HTHP Applications

At extreme high temperature and high pressure (HTHP) conditions, mud systems formulated with macro and micro based materials (chemicals and polymers) become drastically altered (Ammanullah et al., 2009). This is due to the breakage or association of polymer chains and branches by vibration, Brownian motion and thermal stress causing drastic reduction in gelling and viscous properties. To solve this problem, nanos with execellent thermal stability and with extreme pressure consistency should be developed.

Conclusions

A state-of-the-art literature survey has been completed in this article. It is identified that WBDF, OBDF, and other types of drilling fluids are not environmentally friendly so far. The OBDF is the best but unsustainable. As stricter environmental laws are put in place world wide and as far as oil exploration and production is concerned, their usage is becoming difficult. Efforts should be intensified towards developing alternatives that will transform the mud technology to a sustainable one.

Acknowledgement

The authors would like to acknowledge the support provided by the Deanship of Scientific Research (DSR) at King Fahd University of Petroleum & Minerals (KFUPM) for funding this work through project No. IN111020. The authors are also grateful for the support and guidance received from Saudi Aramco during the completion of the work.

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Table1. Similarities in the functions of the human blood and oil well drilling fluid.

Eliminates waste products of metabolism from the human body.	Removes drilling wastes, i.e. drilled cuttings from the hole.
Helps to cool or warm the human body	Helps to cool the drill bit and soften the rock.
Circulates round the human body via an artery-vein system of connection.	Circulates down hole and back to the surface via a drill-string-annulus connection system.
Pumped by the heart round the body.	Pumped by pumps, e.g. triplex pump.
The human blood is re-useable.	Drilling fluid is also re-useable.
Contains white blood cells and lymphocytes that defend the human body against diseases.	Contains additives that strengthen the hole wall, prevents formation damage and lengthen the life span of the drilling fluid.

Table 2. Common additives used in the preparation of oil well drilling fluid systems from World Oil, June, 1978.

Weighting materials	Thickening materials (viscosifiers)	Filtration control materials	Thinners(conditioning material)	Loss circulation materials
Galena	Bentonite	Starch	Tannins	Cellophane
Hematite	Attapulgite	Modified starch	Quebracho	Cotton seed hulls
Magnetite	Sepiolite	Guar gum	Modified tannins	Vermiculite
Iron Oxide	Organophilic clays	Xanthan gum	Polyphosphates	Mica
Illmenite	Palygorskite	Sodium Carboxymethlycellulo-se	Organic phosphates	Surfactants
Barite	Asbestos	Hydroxyethylcellulos-e	Phosphonates	Diatomaceous earth
Siderite		Acrylic polymer	Lignite	Olive pits
Celestite		Alkylene Oxide polymer	Lignosulfonates	Gilsonite
Dolomite				Bagasse
Calcite				Perlite

Table 3.Components of SOLTEX from www.earthworkscation.org

Components of SOLTEX	Concentration (mg/kg)
Antimony	6.0
Arsenic	0.4
Barium	16.0
Cadium	0.6
Cobalt	2.0
Copper	1.3
Fluoride	200.0
Lead	3.0
Mercury	0.2
Nickel	11.0
Vanadium	16.0
Zinc	2.1