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Polymer Drilling Fluids Emulsions (PDFE): A Review

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Abstract: Polymeric drilling fluids emulsions (PDFE) are very important because they are used as drilling fluid systems used in modern drilling operations. For low pressure and exhausted gas and oil reservoirs Oil-in-water (o/w) emulsion polymeric drilling fluids are used however for drilling completion and work over high pressure gauge wells Water-in-oil (w/o) invert emulsion polymeric drilling fluids are preferable. The stability of polymeric drilling fluids emulsions systems are possible as a result suitable chemical components called surfactants which creates good emulsion stability. The rheological and filtration properties are controlled by polymeric materials and bridging agents. This paper is a review on the recent developments and trends as new technologies emerge in polymeric drilling fluids emulsion and their level of efficiencies in drilling gas and oil wells. At times the mud components serve as soil supplement or agricultural aid. A lot of work needs to be done to popularise both drilling and waste problems. Some programmes have already been adopted to bring together economic and environmental considerations in drilling practices. A lot has been done in exploring waste reducing technologies. Pre-treatment of emulsion muds before disposal is easier and lower in cost than oil based muds. Oils can be removed from the cuttings with the help of mechanical cuttings dryers and thermal desorption units. As per a recent developed technique, oil from drilled cuttings can be recovered by liquefied gas extraction technique. This paper touches not only on the progress made in drilling fluid technology but also on the environmental impact of the drilling fluids at the drilling sites.

Keywords: Polymeric Drilling Fluids, Emulsions, Rheology, Filtration, Invert Emulsions, Oil and Gas Reservoirs

1. Introduction

PDFE are primary used for drilling oil and gas wells, completion and the successful for production of hydrocarbons to take place. The selection of the right kind of drilling fluids and maintenance of its properties has an important role to play in the efficiency of the drilling operations. The following are some of the essential functions of drilling fluids are hole cleaning, cutting suspension, reduction in frictional force at drill bits maintain well stability, reduce fluid formation loses, eliminates and reduces stuck pipe problems.

2. Current Trends and Developments in Pdfe in the Oil and Gas Industry for Drilling of Oil Wells

2.1. LWD and MWD Operations [2, 3]

PDFE are colloidal systems containing droplets of one liquid dispersed in another liquid, the two liquids are usually immiscible.

Water –in-oil (w/o) emulsion are produced e.g pasteurized milk, w/o are applied in various industries such as pharmaceutical, food, paints, agricultural and oil and petrochemical industries. PDFE are usually referred to as o/w emulsion drilling fluids systems however the water-in water emulsions are referred to as invert emulsion polymer drilling fluid systems [2]. Thus we can clearly define PDFE as water based drilling fluids in which oil have been introduced, where water is the continuous phase and oil is the dispersed phase. On the other hand polymer drilling fluids invert emulsions are oil based drilling fluids where water is added and in this case oil becomes the continuous phase and water the discontinuous phase. The type of oil selected to be used as drilling fluids depends on many factors including environmental considerations, diesel and mineral oils are usually utilized [5-8]. High gravity crude oil are easier to emulsify than lower gravity crude oil, however the later produces drilling fluids with higher viscosity and gel strength [5]. API recommends Oils with 25-50 API gravity (9). The type of oil selected to be used in the production of the PDFE determines to a large extent the properties inherent in the drilling fluids such as: ease of emulsion, emulsion stabilization odour, effect of the drilling fluids on materials such as plastics, rubber and metals [8].

The nature of the PDFE produced also depends to a large extent on the following formulation requirements: nature of hole to be drilled, temperature of formation, type and nature of the cutting to be transported.

Emulsions are usually two immiscible phases usually oil and water brought together with the help of surface active agent called emulsifiers or emulsifying agents [11]. Examples of emulsifiers include fatty acids and alcohols, egg albumin [12]. The structures of emulsifier include a polar (hydrophilic) head and a non polar (hydrophobic) tail. The surfactants or emulsifiers are found in the oil-water interface bringing the water and oil together in as a single phase. The emulsification acts in such a way that it reduces free energy involved with the surface area interface resulting in the reduction of interfacial surface tension (IFT), due to its bipolar interaction in the drilling fluids emulsion [3, 13-15], which results in a more stable emulsion system.

Emulsifiers bring about stability in PDFE through steric and electric repulsion influenced by the degree of conformational layer structure on the droplets and degree of denaturing (unfolding) [16, 17].

Stabilization of the emulsions could also be affected by the following properties of the surfactants/ emulsifiers:- rheological properties concentration of the emulsifiers, particle size and shape, particle wettability, interparticle particle interaction.

Surfactants also play other important roles such as defoamers, wetting agents, lubricants and corrosion inhibitors. Surfactants can also be anionic, cationic or nonionic [5]. The suitability of a surfactant can be based on two parameters which include the hydrophilic-lipophilic balance (HLB number) and the chemical identity of the two chains. The ratio of the hydrophilic part to the lipophilic part of the molecule which defines the affinity of the surfactant for water and oil [18, 19]. The lower the HLB number, the more oil soluble is the molecule [1]. The surfactants with a HLB value of 8-18 stabilizes and are better suited for an o/w emulsion and surfactants with HLB number around 4 will produce w/o emulsion [20, 21]. PDFE systems, preferably a water soluble surfactant will be more effective due to the fact that it reduces the surface tension on the water side of the oil-water interface and the interface curves towards the side with greater surface tension, this helps to form oil droplets enclosed by the after. The stability of the emulsion also increasing viscosity of the continuous phase.

The following techniques can be used to measure the stability of emulsion systems: measurement of the resistance offered by the fluid to conduct electric current, break down of voltage, viscosity and filtration loss tests.

PDFE have tremendous advantages over the water based drilling fluids. This is as a result of ability of water in the PDFE which are capable of dissolving salts, the ability of the PDFE to form good wall cakes for good filtration control, to eliminate or reduce the possibility of clay hydration [22-23]. These kind of drilling fluids are excellent in the drilling of gauge holes.

PDFE may be detrimental to the environment due to compounds inherent in them such as aromatic compounds and polar compounds. The environmental degradation of this kind of fluid may be enhanced by the higher soap content in the fluid which may have detrimental effects on the formation drilled in addition to higher costs [24-25].

Many types of PDFE have been developed with different types of oils such as mineral oils and diesel oils using different kinds of additives including polymers and bridging materials, the PDFE produced have resounding rheological and fluid loss properties; however, recent developments in PDFE technologies in their formulation have brought about some innovations in emulsion based drilling fluid systems.

2.2. Mineral Oil- Based Emulsion

The use of mineral oils such as paraffin based in place of diesel from drilling fluids have gained tremendous popularity in the drilling industry, These type of oils perform well as diesel oils and have added advantages over the diesel oil such as lower toxicity compared to the diesel oils [37], PDFE made from mineral oils usually composed of paraffin based oil phase emulsifiers, dispersants, calcium oxide, organo-clays, stabilizers and water. They are low viscosity drilling fluids and the solids in the PDFE are maintained as low as possible (ALAP). Other important factors of mineral oils that should be pour point, and aromatic contents. Some of the emulsifiers and dispersants used in the mineral oil used for PDFE are fatty acids amides calcium sulfonate and modified imidazoline. These have relatively low toxicity content and are relatively cheap and available [37].

2.3. Reversible Invert Emulsion Drilling Fluids

These are PDFE that can be reversibly converted from w/o emulsion to o/w emulsion and back to w/o emulsion with the aid of an acid base chemical switch, this is a most innovative method to use emulsion based drilling fluid for optimum performance for drilling operations [24]. The acid base chemical switch creates an alternating ionic strength of the hydrophilic end of the surfactant compound. In this process o/ w emulsions or w/o emulsions can be readily created. This allows an oil external fluid to be converted to water external fluid by adding a trigger compound such as an acid and eternal fluid to be converted to a water external fluid by adding a trigger chemical compound such as acid and then changed back by adding a base compound [38]. The reversible emulsion properties allow the surfactants used in the PDFE system to converted from an invert emulsion to a regular emulsion drilling fluid at different stages of drilling and completion operations. The reversible invert emulsion systems are simple and easy to run. The additives used in the fluid systems are common additives used in the PDFE. The chemical nature and property of the surfactants used in the reversible invert PDFE play an important role in the performance of the fluid systems. The emulsifiers used in the reversible systems form a very stable invert emulsion in the presence of alkalinity (lime). The surfactants being non-ionic and non-protonated remain stable and unaffected by brines. The absence of hydrolysable functionality in the surfactants makes them stable at high alkaline temperature conditions. The non-ionic nature of the surfactants makes it compatible with additives used in oil based drilling fluids [39-42].

However, in the presence of water soluble acids, these surfactants play a role of regular o/w emulsifiers which are in their protonated form and thus form o/w emulsions. The surfactants can be protonated using a water soluble organic or inorganic acid or deprotonated by a water soluble base. Thus the same surfactant is capable of forming either a w/o emulsion or o/w emulsion without eliminating the properties of the emulsifier. The reversible nature of the emulsion systems allows the PDFE to achieve efficient production, minimal environmental impact and relatively cheaper [43].

2.4. Diesel Oil-based Emulsion Drilling Fluids

Diesel oil is the most widely used oil component in both o/w emulsion and w/o invert emulsion muds. Diesel oil has excellent rheological properties, filtration loss control [26, 27], and excellent lubricity. It reduces problems associated with stuck pipe [5-8].

The stabilization of emulsion drilling fluids containing diesel oil can be achieved by a suitable emulsifier such as starch, carboxymethyl cellulose (CMC), lignosulfonates and lignites. Starch and CMC control the filtration losses to the formation [5, 28]. Soap based emulsifiers promotes are sodium, potassium or ammonium salts of higher fatty acids and other synthetic detergents [29]. Some colloidal particles such as calcium carbonate [CaCO3], barium sulphate (BaSO4) and carbon graphite [1] help to modify the rheological properties of interfacial region of the PDFE. Montomorillonite (bentonite) [30-32] clays are species added to modify the rheological properties such as apparent viscosity, plastic viscosity and gel strength [1, 2], the most commonly used is bentonite. The drilling fluids containing clays have other numerous advantages such as: improved hole cleaning properties, decreased water seepage to formation and good filtration control.

Use of some organic emulsifiers in clay water drilling fluids can provide a higher degree of stabilization to the emulsions (33). Polymers are added in the formulation of both o/w and w/o emulsion based drilling fluids containing diesel oil to maintain excellent rheological properties and good filtration loss control. Some organic polymers such as partially hydrolyzed polyacrylamide (PHPA) and guar gum are added to improve the rheological properties of the fluid systems [34-48].

3. Efficiency of PDFE for Drilling Operations

PDFE offer various advantages over conventional water based drilling fluids in oil and gas well drilling, they include.

3.1. Enhanced Drilling Rate

Enhanced drilling rate has been reported when oil is added, firstly there is increased rate of penetration (ROP) immediately after the addition of oil and secondly decrease in the time of rotation or rotation hours [8]. The reason for the greater rate of penetration is because there is more weight on the bit than in the case due to lower friction encountered at the wall of the well bore as a result of The PDFE [5].

Emulsion based drilling fluids usually allow faster rate of penetration and decreased bit balling than water based drilling fluids. Generally PDFE increases bit life from 5-50% and bore hole problems encountered during the drilling operations are reduced drastically. Due to the reasons mentioned above the use of PDFE are successfully deployed in directional drilling and crooked holes [5, 48]. In many cases reduction in torque as high as 40% have been reported after addition of oil in the drilling fluids. It has also been reported that the application of PDFE makes the wellbore remain close to targeted gauge [49].

3.2. Lubrication

Lubrication of well bore is important especially for shallow and horizontal wells [50]. PDFE have shown superior lubricating qualities. These fluids usually form a thin filter cake and minimize the friction between drill pipe and the wall of wellbore; this reduces the risk of differential stick pipe [1]. Differential stuck pipe is a condition whereby the drill string cannot be rotated or reciprocated along the axis of the well bore. It typically occurs when high contact forces are caused by low pressure reservoirs and/or high well pressures are exerted over a sufficiently large area of drill string. Oil is used as a result of its lubricating properties. This advantage is specifically noticeable in the case of horizontal and crooked holes (5). PDFE are usually recommended for the running of long strings of casing with very small gauge clearances between the drill pipe and the hole (51).

3.3. High Temperature and High Pressure (Hthp) Conditions

PDFE are used to drill formations where bottom hole temperature and pressure that exceeds the tolerance level of conventional water based muds, especially in the presence of contaminants such as cements, salts and gases. PDFE also perform well when drilling water sensitive shale. PDFE are non-reactive towards shale (7, 8). Reports have shown that the problem of sloughing shales and hole enlargement because of the chemical interaction of the mud with the formations can substantially be eliminated by using PDFE. They also provide excellent wellbore stability in HTHP conditions as compared to water based drilling fluids (23).

3.4. Rheological and Filtration Properties

Rheology of drilling fluids is a key property which influences different important aspects of the drilling operation. These include cutting carrying capacity of mud, suspension of cuttings hole cleaning capacity of mud and pressure differential in the well bore, pumping pressure rate of penetration (ROP), fluid loss control and filter cake properties.

A drilling fluid experiences a wide range of shear rates during its cycle of flow through the well. During its flow through drill pipe, shear rates are prevalent in the order of 10^2–$10^3 s^{-1}$. This shear rate may develop up to $10^5 s^{-1}$ during its flow through bit nozzles. The important rheological properties are: apparent viscosity, plastic viscosity, yield Point viscosity, low shear rate Viscosity (LSRV) and gelling properties of the fluid.

These rheological properties are of primary importance in PDFE. Usually a drilling fluids having lower plastic viscosity and higher yield point is recommended as the lower plastic viscosity provides turbulence at the drill bit for better hole cleaning and higher yield point ensures enhanced carrying capacity and strong shear thinning behaviour [1]. The most appreciable characteristics of these types of fluids is that the rheological properties can be maintained with the ratio and type of oil used according to recommended mud programmes.

PDFE have ability to reduce the filtrate loss to the formation. PDFE (s) should have low permeability so that loss of filtrate in to the rock formation can be controlled but it should also allow the hydrocarbons to flow back during the production [45- 47]. It has been reported in many cases that addition of solid particles to the emulsion based drilling fluids reduces the filtrate volume dramatically with improved stability [27]. Likewise, fluid loss control in invert emulsion fluid systems can be achieved by a number of chemical methods. It can be attained by a combination of solid particles such as drilled solids and weighing agents and emulsion droplets. Several fluid loss additives have been used to enhance the level of fluid loss control and improve the properties of filter cakes in invert emulsion based drilling fluids [15].

3.5. Low Pore Pressure Formations

The ability to drill low pore pressure formations can be accomplished with emulsion muds since the mud weight can easily be maintained. During drilling operations the weight of the PDFE plays a very important role. This lighter weight of the muds is as a result of lower specific gravity of the oil and because shales do not disperse and add weight in oil. Formation damage is another important factor which determines the drilling fluid performance. Like most oil based muds, the emulsion mud systems generally do little or no damage to the well bore formations [5].

3.6. Effectiveness in Horizontal and Deviated Wells

The newly developed o/w emulsion mud stabilized by some solid emulsifiers has become one of the major mud systems used in directional and horizontal oilfields. O/w emulsions are applied for drilling weak argillaceous deposits in the lower part of the drilling interval under production string upto the deviation angle of 70^o. Clay less biopolymer emulsion muds are usually used in horizontal drilling under shank adaptor and implemented in tight carbonate deposits (24). In addition to improvement in emulsion stability, the solid emulsifiers and biopolymers have proven to enhance wellbore lubrication in addition to improved rheological properties and filtration loss control (48).

3.7. Corrosion Control

The corrosion of drill pipe can be minimized by using emulsion muds since the oil present as the internal phase coats the surface of the drill pipe. The most appreciable property regarding corrosion is the presence of oil which makes the additives non-reactive. As a result they become thermally stable. Oils are also reasonably resistant to biodegradability by microorganisms, this makes it possible for emulsion to be stored for long periods of time since the bacterial growth is suppressed.

3.8. Contaminants

PDFE (s) have tolerance to contaminations. The effects of contaminants are usually evaluated by measuring high temperature high pressure (HTHP) fluid losses and other parameters like emulsion stability and rheological properties of contaminated muds before and after the heat-aging cycle. The test have shown that in the presence of drilled solids and seawater make the emulsion system stable with smaller changes in rheological properties and fluid loss control.

The emulsion stability also showed a moderate change. These tests conducted on reversible invert emulsion drilling fluids have shown a significant degree of tolerance towards contaminants which suits their applicability in actual well conditions [43]. On the other side, emulsion based drilling fluids containing mineral oil are not affected by carbonates, hydrogen sulfide and salt so they can be used in the areas where contaminants cause severe problems associated with water based drilling fluids [37].

3.9. Completion Operations

PDFE are better suited to the completion, production, cleanup and disposal operations in the drilling sites. It has been reported that enhanced productivity is obtained from wells drilled with an emulsion mud when compared to offset wells drilled with a conventional mud. These advantages are attributed to the fact that lower quantities of water enter the formation because of inhibition properties of PDFE. Completion operations are also greatly enhanced [8].

In reversible invert emulsion drilling fluid, the oil-wet the drill pipe and the formation drilled can readily and rapidly be reversed to water wet-state by treating with small amount of water soluble acid. Weak acids such as citric acid and acetic acid can reverse the nature of residual fluid left in the column and oil-wet surface of the formation drilled with the same fluid [43].

3.10. Cost

The average cost of drilling a well is related to the type, depth and location of the well and also includes the costs of drilling-related services. The expenditures for drilling represent 25% of the total oilfield exploration cost and are mainly focused in exploration and development of well drilling. Moreover, the search for new hydrocarbon sources is leading the industries to drill deeper wells. As the depth increases, not only the temperature and pressure increases but the formations to be drilled also become stronger. The induced plasticity makes it difficult to carry the cutting debris to the surface. As a result drilling rate decreases significantly. Other activities like tripping, running and cementing casing, logging and coring become more complex and time consuming. This increases overall costs dramatically. The cost of emulsion based drilling fluids mainly o/w emulsion mud is always lower than the cost of oil based muds. Many cases have been reported where the maintenance cost of emulsion muds decreased significantly [51].

4. Environmental Considerations and Waste Management

Waste management is a very important aspect of drilling operation. Presently drilling fluid companies are developing fluid systems that are environmentally friendly and more acceptable to bio treatment of the drilling wastes [52, 53]. To minimize the pollution caused by oil based muds, numerous programmes have been developed to reduce oil content according state regulations and laws. Some of the remediation technologies include:- dewatering, distillation, solvent extraction, cuttings reinjection, fixation, land farming and bioremediation (54).

Sometimes the mud components serve as soil supplement or horticultural aid. The holistic approach which has gained popularity solves both drilling and waste problems [51, 55]. Some concepts have already been developed to bring together economic and environmental considerations in drilling practices.

A lot of effort has been put in exploring waste reducing technologies [56, 57]. The pre-treatment of emulsion muds before its disposal is considered to be easier and less costly than oil based muds. Oils can be removed from the cuttings with the help of mechanical cuttings dryers and thermal desorption units. As per a recent developed technique, oil from drilled cuttings can be recovered by liquefied gas extraction technique. This way oil recovered can again be used in the emulsion muds. Thus, emulsion mud cuttings are less likely to cause adverse sea floor impacts than traditional oil-based cuttings to which oil ratio is higher [51].

It is important to note that e waste disposal methods are dependent on the type of base fluid used in the drilling fluid systems. Microorganism degradation of PDFE is much easier compared to typical conventional oil based muds. Alternatively, if the fluid systems are developed using a base fluid that does not contain any aromatic, branched or cyclic components, the degree of treatment can be optimized to a great extent. Some of the waste treatment technologies that oil and gas industries practice are physical/chemical processes, biological processes, solidification and recycle or reuse. Companies are looking at developing better emulsion systems that would bring about environmental benefits rather than destruction to the environment [52].

5. Conclusion

Oil improves the performability of water based drilling fluids by: improvement in rheological properties, better lubricating properties, good filtration and fluid loss control, lower torque and drag, reduction in bit balling, reduction in stick pipe problems and reduction in well bore enlargement.

These are numerous benefits of emulsion based drilling muds. Some emerging developments such as reversible invert emulsion drilling fluids have also proved to be an innovative approach to magnifying the performability of emulsion based drilling fluid systems. The development of this new generation emulsion based drilling fluids typically represent a futuristic plan to solving the numerous operational, economical and environmental considerations. Thus there is need to improve on the technology and use of PDFE in the industry.

Conflict of Interest

The authors declared no conflict of interest in this work.

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