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Emulsion Based Drilling Fluids: An Overview

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Abstract: Emulsion based drilling fluids have emerged as an important class of drilling fluid systems, which have gained a significant interest in modern drilling operations. Oil- in-water (O/W) emulsion mud is widely used for low pressure and depleted oil and gas reservoirs. On the other side water-in-oil (W/O) invert emulsion mud can be useful in the drilling, completion and work over of subterranean and gauge wells. The stabilization of the emulsion systems is achieved with the help of suitable surfactants. The polymers and bridging agents are used to control the rheological and filtration properties of the drilling fluid systems. This research paper reviews the emerging developments in emulsion based drilling fluids and their effectiveness for oil and gas well drilling. It also discusses the environmental and waste disposal considerations of these drilling fluids at the drill site.
Keywords: emulsion mud, depleted reservoir, invert emulsion mud, bridging agents, rheology, filtration loss.

1.Introduction

Drilling fluids are the complex fluids used for the drilling of oil and gas wells. The successful completion of an oil and gas well and production of hydrocarbons from the oil and gas reservoir depends to a considerable extent on the properties of drilling fluids selected during drilling operations. The selection of a right fluid and the maintenance of the properties primarily influence the production rate while drilling (1). The complex fluids play several functions simultaneously. They are supposed to clean the well, hold the cuttings in suspension, reduce friction between the drill string and sides of the well, maintain the stability of the well bore, prevent the fluid loss to the formation to avoid formation damage and differential pipe sticking by making thin impermeable filter cakes, cool and lubricate the drilling tools and most importantly helps in the evaluation of formation by raising the cuttings from the well bore bottom to the surface (2, 3).

Emulsions are the colloidal systems in which fine droplets of one liquid are dispersed in another liquid where the two liquids are otherwise immiscible. If water droplets are dispersed in oil, W/O emulsion system is formed such as oil based skin creams and if oil droplets are dispersed in water, an O/W emulsion system is formed such as milk dairy emulsions. Emulsions are heavily used in the food industry, pharmaceutical industry, paints, cosmetics, agriculture products and petroleum industry (4). The term *emulsion mud* applies specifically to O/W emulsion drilling fluid systems and W/O emulsion drilling fluids are called '*invert emulsion muds'* (2). So, emulsion mud can be defined as that category of water based drilling fluids to which oil is added. The oil becomes the dispersed phase and water becomes the continuous phase and invert emulsion mud can be defined as oil based drilling fluids to which water is added. In these types of drilling fluid systems, oil becomes the continuous phase. Ordinarily, oil is added to the base drilling fluid is diesel oil, mineral oil or sometimes crude oil (5-8). The selection of type of oil depends on several factors. A low gravity crude oil causes higher viscosity and gel strength than a high gravity crude oil. On the other hand, high gravity crude oils are easily emulsified but not recommended primarily because of fire hazards involved and high maintenance costs required as a result of losses by evaporation and to the formation (5). Usually, oils with 25°-50° API gravity are recommended (9). API gravity is a measure of density and variation from the specified range which controls the final viscosity of the fluid system (2). The type of oil can influence the ease of emulsification, stabilization of emulsion, odour of the drilling fluids and effect on the rubber in contact with the emulsion drilling fluid systems (8). However, it should be noted that oil concentration and requirements vary according the nature formation drilled, the gravity, temperature at the surface and the hole and the type of oil used for the formulation of emulsion drilling fluids(5). The concentration of oil also depends upon several other factors such as the volume of fluid in the circulation, the diameter of the open hole, the amount of cuttings transported to the surface and the number of round trips. A considerable decrease in the demand of oil content is observed after some time. This is due to the reason that a certain amount of oil penetrates into the filter cake (essentially concentrated drilling fluid) on the walls of the wellbore before an equilibrium condition is achieved. This equilibrium condition corresponds to reduction in the permeability of the oil bearing filter cake (1, 10).

Emulsions are also unstable thermodynamic systems formed by two immiscible phases, oil and water. To help stabilize emulsions of pure components, an additional third component is required which can work as emulsifying agent. Emulsifying agents or emulsifiers are typically molecular surfactants such as fatty acids or alcohols (11), polymers or may be large protein type agents such as egg albumin (12). Molecular surfactants usually contain a polar (hydrophilic) head group and a non polar (hydrophobic) chain tail. Surfactants preferentially absorb to the oil-water interface forming a skin around the interface. The skin acts as a physical barrier, preventing the droplets from coalescing when they collide (1). This reduces the free energy involved with producing a high surface area interface and a result of this there is a reduction in interfacial surface tension (IFT). Lowering the IFT between two immiscible liquids requires the presence of a bipolar material that has partial solubility in both the phases (3, 13, 14). Lower the interfacial tension and smaller the droplet size, typically results in more stable emulsion system (15). Polymers and proteins stabilize emulsions mainly through steric and electric repulsion controlled by the degree of unfolding (denaturing) and conformational layer structure on droplets (16, 17). Some polymers which are 'semi-dilute' and larger 'globular' proteins, do not usually denature to the same extent can further cause stabilization through changes in the rheological properties of the dispersion medium (specifically through increase in viscosity). The stabilization of emulsion systems also depends upon the concentration, the particle shape and size, particle wettability and inter particle interactions of the particles which can work as stabilizers (emulsifiers) (4, 8). Surfactants also work as foamers, defoamers, wetting agents, lubricants and corrosion inhibitors in almost all kinds of drilling fluids depending upon their specific requirements for a particular type of drilling fluid (5). Surfactants may be anionic, cationic or non-ionic. The suitability of a particular surfactant is based on two important parameters, the hydrophilic-lipophilic balance (called as HLB number) and the chemical identity of the two chains. The former was introduced by Griffin in 1949 and is defined as the ratio of the hydrophilic part of to the lipophilic part of the molecule which describes the relative affinity of a surfactant for water and oil (18, 19). Lower the HLB number, the more oil soluble is the molecule (1). On the basis of emulsion theory, the surfactants with a HLB value of 8-18 will stabilize an O/W emulsion and surfactants with HLB number around 4 will form W/O emulsion (20, 21). For emulsion mud systems, preferentially, a water soluble surfactant will be more effective because it lowers down the surface tension on the water side of the oil-water interface and the interface curves towards the side with the greater surface tension, thus forming oil droplets enclosed by water. The stability of an emulsion also increases with increase in viscosity of continuous phase. The stability of emulsion systems are measured using a number of techniques. Apart from conventional method, the degree of stability of an emulsion drilling fluid can be obtained by measuring the resistance offered by that fluid to conduct electric current or the breakdown voltage. In addition, mud viscosity and filtration loss tests are considered to be the best parameters for the drilling fluid stability measurements (1).

The development of emulsion based drilling fluids has counter balanced some of the undesirable characteristics of water-based drilling fluids. These characteristics are mainly due to the properties of water; specifically its abilities to dissolve salts, to intervene with the flow of oil and gas through porous media, to promote the disintegration of clays and to affect corrosion of metal tools (22). These kinds of drilling fluids provide the highest probability of drilling gauge holes. Experiments conducted for the suitability of these fluids in high-temperature high-pressure (HTHP) conditions has shown that emulsion based drilling fluids provide greater degree of well bore stability as compared to water-based drilling fluids (23).

The oil based drilling fluids have a number of well known disadvantages like more detrimental effects on the environment due to higher percentage of aromatic compounds, thickening of the fluids when contaminated with strata waters and large amount of hydrophilic solids, thickening upon the loss of disperse medium during filtration, dependency of rheological properties on the temperature. Moreover, higher soap content in such kinds of fluids can have unwanted effects on the formation fluid characteristics sometimes and above all the cost of oil based drilling fluids is much higher than that of emulsion based drilling fluids. On the other side, emulsion based drilling fluids have many advantages like softer rheological flow profile, better lubricating characteristics and lesser ecological load on environment than the conventional oil based drilling fluids. The main significance of these kinds of drilling fluids is that they may be used at varying temperature and pressure conditions. They remain electrically conductive, as a result of which normal electric logs can be obtained with conventional equipment (24, 25).

2. Emerrging Developments in Emulsion based Drilling Fluids for Oil and Gas well Drilling

The emulsion based drilling systems have been developed with different types of oils such as diesel oil and mineral oil and different polymers and bridging agents whereby the fluid systems have played an integral part in providing enhance rheological properties and fluid loss characteristics. Down the time with advancement in technology and refinement in formulation has brought about some emerging developments in emulsion based drilling fluid systems

2.1. Diesel oil-based emulsion drilling fluids

Various grades of petroleum based oils are used to meet the variety of needs in drilling technology but diesel oil is the most widely used oil component in both O/W emulsion muds and W/O invert emulsion muds. The use of diesel oil is mainly done to improve the rheological properties and control filtration losses (26, 27), promote lubrication while drilling and minimize the problems associated with stick pipes (5-8).

One of the major problems related to almost all kinds of drilling fluids containing an oleic phase is their stability at higher temperature and high pressure conditions because the stability decreases with increase in temperature as the number of collisions between the droplets increases(1). So the stabilization factor is associated with is emulsion based drilling fluids also. The filtrate from properly stabilized emulsion drilling fluids is substantially 100 % water with all the oil retained in the filter cake. They also promote hole stability in poorly cemented formations, and finally avoid or overcome the loss of circulation. The stabilization of emulsion drilling fluids containing diesel oil can be achieved by a suitable emulsifier such as starch, carboxymethyl cellulose (CMC), lignosulfonates, lignitic compounds. The use of starch and CMC is also done to control the filtration losses to the formation (5, 28). Some of the soap based emulsifiers which promotes emulsification are sodium, potassium or ammonium salts of higher fatty acids and various synthetic detergents (29).

The other colloidal particles that stabilize the emulsion based drilling fluids (containing diesel as oleic phase) both by providing steric hindrance to the coalescence of oil and water droplets and by modifying the rheological properties of interfacial region are calcium carbonate ($CaCO_3$), barium sulphate ($BaSO_4$) and carbon graphite (1). As per some recent development it has been investigated that Xanthan gum works as an emulsifier for emulsion drilling fluids containing diesel as internal phase in the presence of $CaCO_3$. Xanthan gum not only works as emulsifier but viscosity modifier for such drilling fluid systems (27). Clays used as drilling fluid additive in almost all kinds of drilling fluids; mainly a *montomorillonite* species is added to increase the rheological properties such as apparent viscosity, plastic viscosity and gel strength (1, 2). Most of the material of this type is generally known as *bentonite* (30-32). The drilling fluids containing clays have other numerous advantages such as improved hole cleaning properties, decreased water seepage or filtration into permeable formation by providing a thin impermeable filter cake. The colloidal clays, particularly *bentonite* act as emulsifier for emulsion based drilling fluid systems. Use of some organic emulsifiers in clay water drilling fluids can provide a greater degree of stabilization to the emulsions (33).

Polymers are added in the development of both O/W and W/O emulsion based drilling fluids containing diesel oil to maintain rheological properties and control the filtration losses. Some organic polymers such as guar gum, partially hydrolyzed polyacrylamide (PHPA) are added to enhance the rheological properties of the fluid systems (34-36).

2.2. Mineral oil-based emulsion drilling fluids

The use of paraffinic based mineral in the place of diesel oil in the drilling fluids has gained paramount interest in the petroleum industry. Mineral oil based drilling fluid systems possess the same properties but have some advantages over diesel oil based drilling fluids. The characteristics and advantages have been cited in laboratory evaluations and field case histories. Regardless, the results of laboratory toxicity tests have shown that mineral oil based drilling fluids are less toxic than diesel oil based drilling fluids. Tests have also indicated that oil retention properties of mineral oil based drilling fluids are lesser than diesel oil based drilling fluids (37).

Invert type of mineral oil based drilling fluids typically consist of refined paraffinic based oil phase, emulsifiers, dispersants, organophilic clays, calcium oxide or hydroxide, high temperature stabilizer and water. They can be considered to be low viscosity drilling fluids. The concentration of colloidal solid content is maintained as low as possible. The viscosity, pour point and aromatic content of the mineral oil are the important factors that have to be considered for the formulation of drilling fluids. The emulsifiers and dispersants are selected on the basis of toxicity. The emulsifiers and dispersants used in the conventional diesel oil based drilling fluids are compatible with the mineral oil based drilling fluids. Some of the emulsifiers and dispersants used in the mineral oil based drilling fluids are fatty acid amide, tall oil fatty acid, calcium sulfonate and modified imidazoline. All have low toxicity content and are relatively inexpensive(37).

2.3. Reversible invert emulsion drilling fluids

The reversible invert emulsion drilling fluids are type of emulsion based drilling fluids that can be readily and reversibly converted from water-in-oil emulsion to oil-in-water emulsion and back to a water-in-oil emulsion with the help of an acid-base chemical switch. It is an innovative approach to use the emulsion based drilling fluids for their optimum performance in drilling operations (24). The addition of acid or base compounds to the drilling fluid systems has the effect of altering the ionic strength of the hydrophilic end of the surfactant compound. In this process O/W emulsions or W/O emulsions are created. This finally allows an oil external fluid to be converted to a water external fluid by adding a trigger compound such as an acid and then changed back by adding a base compound (38). The reversible emulsion property of the surfactants used in drilling fluid systems allows the systems to be changed from an *invert emulsion mud* to a regular *emulsion mud* at different stages of drilling and completion operations. During the stage of drilling operation, the drilling fluids can be invert emulsion muds achieving all the properties associated with conventional oil based muds and during the completion stage, the emulsion systems can be reversed by adding water soluble acid which can provide excellent filter cake cleanups, better cementing, improved production in an openhole completion, efficient cutting clean ups and finally waste management. The reversible invert emulsion systems are simple and easy to run. The additives used in these fluid systems are common additives used in oil based muds. The invert emulsion systems are formulated as an emulsion in which the oil forms the continuous phase and brine water serves as dispersed phase. Any amount of oil can be used as a continuous phase in the reversible invert emulsion mud. The solids and brine used in the drilling fluid systems are suspended in the oleic phase thus maintaining the integrity of shale formations and drilled cuttings. As a result of which well bore remains stable during the drilling operation. The chemical nature and property of the surfactants (emulsifiers) used in the reversible invert emulsion muds play an important role in the performance of these fluid systems. The surfactants 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 and high 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 oil-in-water emulsifiers which are in their protonated form and thus form oil-in-water 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 water-in-oil emulsion or oil-in-water emulsion without destroying the properties of emulsifier. The reversible nature of the emulsion systems allows the muds to achieve optimum production, minimal environmental impact and cost control (43).

3. Effectiviness of Emulsion based Drilling Fluids in Drilling Operations

Emulsion based drilling fluids offer many advantages over conventional water based drilling fluids in oil and gas well drilling. Some of them have been elaborated as follows:

***3.1. Rheological and filtration properties*:** Rheology of drilling fluids is a key property which influences different important aspects of the drilling operation. It influences the ability of the fluid to carry drill cuttings to the surface and to keep solids suspended form when flow stops, thus affecting hole cleaning in the annulus. It directly affects the pressure differential in the drill-pipe and the annulus which is ultimately associated with the pumping requirements. It determines the degree of turbulence achieved when fluid passes through bit nozzles, thus affecting rate of penetration. It can also affect fluid flow in the porous media thus controlling fluid loss high-permeability formations or through the natural or induced fractures in the rock(44).

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 upto 10^5 s^{-1} during its flow through bit nozzles. Again when the same drilling fluid flows through the wider cross sectional area of the annulus, shear rates are of order 10^2 s^{-1}. Thus the drilling fluid has to be compatible with rheological requirements which are required with varying shear fields. The rheological properties of significance are apparent viscosity, plastic viscosity and gelling properties of the fluid. These rheological parameters are well achieved in emulsion based drilling fluids. As a general rule, viscosity at the bit effects penetration rate, this will be better when viscosity is low. The viscosity in the annulus affects hole cleaning efficiency and the viscosity in the pits influences the effectiveness of solids separation technique. Other rheological parameters like plastic viscosity and yield point also play a significant role in the performance of a drilling fluid. Usually a drilling fluid with 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 accordingly. The emulsion droplets behave as fine solid particles which finally attributes to enhanced rheological properties. As a result drilling fluids containing brine content as external phase and oleic phase as internal phase have improved rheology as compared to water based drilling fluids. The improved rheological properties are also due to the fact that the drops are coated with solid particles and the continuous phase can be made viscous due the aggregation of excess particles (45, 46).

Apart from these above mentioned advantages, emulsions have ability to reduce the filtrate loss to the formation. The reason behind lower filtrate volume is the ability of emulsion droplets to provide thin filter cake while drilling. The filter cake (essentially concentrated drilling fluid) 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 (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 practiced to enhance the level of fluid loss control and improve the properties of filter cakes in invert emulsion based drilling fluids(15).

3.2. Drilling rate: The enhanced drilling rate upon the addition of oil has been reported in two ways. Firstly with the increase in the rate of penetration immediately after the addition of oil and secondly decrease in the rotating time or rotating hours (8). The reason for the greater rate of penetration is possibly that more weight is on the bit than in the case. One of the reasons of more indicator weight being on the bit is due to the reason that emulsion muds cause smaller amount of wall friction (5). Emulsion based drilling fluids usually allow faster rate of penetration and decreased bit balling than water based drilling fluids. There has been a general agreement among the users of emulsion drilling fluids that the bit life increased from 5-50% and bore hole conditions encountered during the drilling operation minimized to a great extent. As a result of improved bore hole conditions and reduction of torque, the use of emulsion muds has been successful in directional drilling and crooked holes (5, 48). In some cases reduction in torque as high as 40% have been reported after addition of oil in the drilling fluids. Some evidences have revealed that by the application of emulsion muds the hole diameters remain nearer to gauge(49).

3.3. Lubricity: Wellbore lubrication is exceptionally important especially shallow, horizontal wells (50) and emulsion based drilling fluids show superior lubricating qualities. These fluids usually form a thin filter cake and thus minimize the friction between drill pipe and the wall of wellbore thus enhances the lubricating properties and reduces the risk of differential sticking(1). Differential sticking 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. For years it has been a common practice to use oil in freeing a fish stuck in a bore hole. This use of oil is attributed to its lubricating properties. This advantage is specifically noticeable in the case of a crooked hole or a whip stocked hole (5). Emulsion muds containing mineral oil have proved to be excellent lubricant additives for water based drilling fluids. The affect of torque and drag can be reduced with the addition of from 2-4 % (by Vol.) of the oleic phase. The superior lubricating properties of the emulsion muds provide a very important safety margin in the drilling and make them ideal fluids for deep and difficult drilling operations. The emulsion muds are usually recommended for the running of long strings of casing with very small clearances between the pipe and the hole (51).

3.4. High temperature and high pressure conditions: Emulsion muds are suited to drill formations where bottom hole temperature and pressure exceeds the tolerance level of conventional water based muds, especially in the presence of contaminants such as cements, salts and gases. Moreover, emulsion muds are suitable for drilling water sensitive shale. The fluid systems are non reactive towards shale (7, 8). The 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 using an invert emulsion muds. They also provide excellent wellbore stability in high temperature high pressure (HTHP) conditions as compared to water based drilling fluids (23).

3.5. Low pore pressure formations: The ability to drill low pore pressure formations is well accomplished with emulsion muds since the mud weight can be maintained at a weight lesser than that of water. The formations where weight making shales are present in the same hole with possible lost circulation zones, the lighter weight of muds plays a very important role. This lighter weight of the muds results primarily due to lower specific gravity of the oil and also from the fact that shales do not disperse and make weight in oil. Formation damage is another important factor which determines the drilling fluid performance. Like most oil based muds, the emulsion mud systems are generally non-damaging to producing formations (5).

3.6. Effectiveness in horizontal and deviated wells: The newly developed oil-in-water 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 is implemented in tight carbonate deposits (24). In addition to its improvement on emulsion stability, the solid emulsifiers and biopolymers have proven to enhance wellbore lubrication and to be of benefit to the control of rheological parameters and filtration loss (48).

3.7. Corrosion control: The corrosion of drill pipe can be controlled 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. The non conductive nature of oil makes the emulsion muds resistant towards the attack of microorganisms. So, emulsion muds can also be stored for longer periods of time since the bacterial growth is suppressed.

3.8. Contaminants: For any drilling fluid, tolerance to contaminants is an important factor for its use in actual field conditions. 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: Once a well is drilled with an emulsion mud, the advantages of emulsions are better suited to the completion, production, cleanup and disposal of the cuttings. Many cases have been reported where enhanced productivity has been obtained from wells drilled with an emulsion mud when compared to offset wells drilled with a conventional mud. This advantage is attributed to the fact that less amount of water enters the formation. Other factors of increased productivity may be the surface tension of the filtrate and its effect on materials in the sand which are prone to hydration. In many cases the complete evaluation of the completion operation indicates that completion of a low permeability formation can be improved to a greater extent (8).

Likewise, if a well is drilled with reversible invert emulsion drilling fluid, the oil-wet pipe and 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: Drilling a wellbore is first and most expensive step in oil and gas industry. 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. So this way over all cost increases dramatically. Drilling fluids, which solely represent one fifth (15-20%) of the total cost of well drilling, must not be specifically too expensive. The cost of emulsion based drilling fluids particularly oil-in-water 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

Since the early 1990's, regulations have restricted the losses of hydrocarbon and closure of the site after drilling without treatment. Presently drilling fluid companies are developing fluid systems that are environmentally benign and more amenable to bio treatment of the drilling wastes (52, 53). To minimize the pollution caused by oil based muds, numerous programmes have evolved to reduce oil content according to regional and/or regional standards. Some of the remediation technologies primarily include dewatering, distillation, solvent extraction, cuttings reinjection, fixation, land farming and bioremediation (54). In some cases the mud components serve as soil supplement or horticultural aid. The holistic approach which has gained immense support mainly solves both drilling and waste problems (51, 55). Some concepts have already been introduced to integrate economic and environmental considerations in drilling practices, such as Environmental Performance Indicators (*EPI*) and Total Fluid Management (*TFM*). Thus much effort has been invested in exploring waste minimization 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. Therefore, 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 consider that the waste disposal method functions according to the base fluid used in the continuous phase of the drilling fluid systems. Under right environmental conditions, microorganisms are very efficient at degrading many types of hydrocarbons. In oil-in-water emulsion muds water is in continuous phase so degradation of such fluids is much easier and faster as 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. The idea behind the development of such emulsion muds is not to design a system that merely pose a neutral or negligible impact on the environment, but rather one that could prove to be beneficial (52).

5. Conclusion

The addition of oil can improve the performance of water based drilling fluids as evidenced by improvement in rheological and lubricating properties. Reduction in filtration loss, less torque and drag, less bit balling, less sticking of pipe and less hole enlargement have been cited as major advantages of emulsion based drilling muds. Some of the emerging developments such as reversible invert emulsion drilling fluids have proved to be an innovative approach to magnify the performance of emulsion based drilling fluid systems. The development of this new generation emulsion based drilling fluids typically represent a mid way solution among performance during drilling operations, economic and environmental considerations. Hence, emulsion based drilling fluids can be a pioneer in drilling fluid technology in case of highly water sensitive formations such as shales and fractured oil and gas reservoirs.

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