# Drilling Fluids; Types, Formation Choice and Environmental Impact

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***Abstract*—For the successful drilling of oil and gas drilling, the drilling fluids are essential materials. In the drilling applications, the most commonly used drilling fluids are water based fluids. Water-based fluids are the first fluids of choice for drilling applications because of their cost effective, environmental friendly and non-hazardous nature. However, these fluids are ineffective when dealing with water-sensitive shale that can lead to shale hydration, consequently wellbore instability is compromised. The geological occurrences which is water-sensitive may require oil-based and synthetic-based fluids. A proper formulation of oil-based drilling fluid can prevent water movement from the fluid into the shale occurrence. Despite its effectiveness, oil-based drilling fluid can give negative impact to environment when the pollutant is discharged and subsequently dispersed to the sea. The ester-based drilling fluids take attention as alternative fluids in the drilling applications of water-sensitive geological occurrences such as shale formations. They are a new class of materials used to provide safe and cost-effective technology for drilling oil and gas wells. Their enhanced drilling performance decreases drilling time and provides advantaged safety, human health, and, in some cases, environmental performance above diesel oil fluids.**

***Keywords*— Drilling, drilling fluids, water-based fluids, oil-based fluids, geological occurrence**

## I. INTRODUCTION

The methods and devices for drilling of stones, glasses, metals, jewels and bones were developed by ancient people (20-10 thousand years ago) in different regions of the world such as Europe, Asia, Egypt, America. Modern engineers may use great experience received from ancient ages. At the point reached in drilling applications, achievements in modern drilling techniques may be applied not only to reach deeper wells or drill larger holes, but could help to drill wells for different purposes in other planets of the solar system (Moloney, 1995; Kpoey, 2017).

Petroleum drillingis the primordial step in the success of oilfield exploration. This success is based, on the one hand, on the important details derived from geological drilled formations and, on the other hand, on the good drill-in reservoir conditions. Thus, paramount drilling objectives are to reach the target safely in the shortest possible time and at the lowest possible cost, with required additional sampling and evaluation constraints dictated by particular application.

Drilling fluids went through major technological evolution, since the first operations performed in the US, using a simple mixture of water and clays, to complex mixtures of various specific organic and inorganic products used nowadays. These products improve fluid rheological properties and filtration capability, allowing to penetrate heterogeneous geological formations under the best conditions (Khodja et al., 2010).

Drilling of oil wells occurs by using drilling fluids to remove rock fragments as the drilling progresses (Amorim et al., 2005). Traditionally drilling muds are classified according to the base used to prepare them, which are air, water or oil. Most drilling operations in the world use water-based fluids, due to their low toxicity. Nevertheless, these have some disadvantages that can be overcome by the use of oil-based fluids (Lucas et al., 2009; Cardoso et al., 2010).

It is commonly understood that drilling is a process of creating a borehole, and one of the main technological elements of drilling, including access holes in subglacial environments, is the removal of borehole products when cutting or melting the ice. The removal of material is critically important to all drilling systems, as the presence of excessive material at the bottom of the borehole leads to decreasing penetration rates and even loss of the drill. For intermediate and deep drilling, it is also necessary to prevent borehole closure through visco-plastic deformation by filling the borehole with a fluid (Talalay and Hooke, 2007; Talalay et al., 2014).

Drilling fluids are any fluids which are circulated through a well in order to remove cuttings from a wellbore. The fluid is pumped down the drill string, through the nozzles of the bit, and returns back up the annulus between the drill string and the wellbore walls, carrying the cuttings produced by the bit action to the surface. The main function is to clean the hole while drilling but the drilling fluid also serves to cool the bit, provide power to the mud motor and measuring-while-drilling tool, support the walls of the hole and control the well pressure (prevent the well from flowing). An alternative method is called reverse circulation, where the flow of the fluid is reversed from the previously mentioned one (Finger and Blankenship, 2010; Chemwotei, 2011).

Water is also used as a circulation medium in hot-water drilling systems. In this case, water has two main functions: (1) to convey heat to the bottom of the hole to melt the ice and (2) to remove melted water by mixing with pumped hot water. The main advantages of exploration of the subglacial environment with hot-water drilling systems are that the equipment can provide cleaner samples of subglacial water and sediments and that access to the ice-sheet base is rapid (Talalay et al., 2014).

## II. DRILLING FLUIDS

There are many papers on the subject of drilling fluids, but they are primarily oriented towards petroleum drilling. There are some papers on geothermal drilling fluids, but biased towards drilling mud and the modifications and treatments done to it for use in drilling high temperature reservoirs. The drilling fluids commonly used for the drilling of geothermal wells, and the advantages and disadvantages of each was highlighted. The use of water for geothermal drilling was described for the first time (Janson, 1975; Hole, 2008; Chemwotei, 2011). The flow of drilling fluid on the drilling system is shown in Fig. 1.

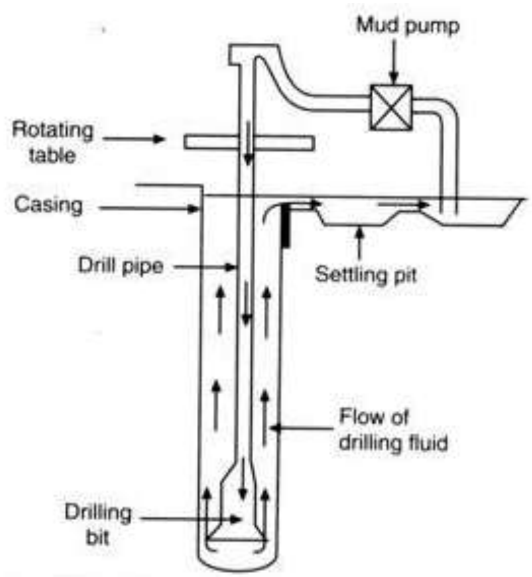


Fig. 1. Schematic diagram of drilling system (Sen, 2019)

The drilling fluids are complex mixtures formed from solids, liquids, chemicals, and sometimes even gases. From the chemical point of view, they can assume aspects of suspension, colloidal dispersion or emulsion, depending on the physical state of the components. The drilling fluids called drilling muds, can often be defined as liquid compositions to help the process of drilling petroleum wells and they depend on the particular requirements of each perforation (Tomas, 2001; Barbosa, 2006; Oliveira et al., 2016).

Drilling fluid technology is in constant evolution due to (1) rapidly expanding needs due to more severe conditions, such as high temperature and pressure, tight gas and shale-gas reservoir, (2) increasing technical demands, such as increased lubricity requirements in air drilling and (3) growing restrictions on oil-based systems, such as environmental remediation.

The drilling fluids with specific physical and chemical properties are multi-component and dispersion-colloidal systems and serve several important tasks in borehole drilling. These tasks depend on the kind of drilled rock, the formation thickness, the existence of formation water and its salinity, the existence of producing formations, the formation pressure, and the temperature depending on borehole depth. The success of borehole penetration rates depends to a great extent on the drilling mud quality circulating in the well, and on the proper control of its properties (Uliasz et al. 2006; Steliga and Uliasz, 2014).

Generally, two or three kinds of water-based drilling muds are used bentonite drilling mud, polymer drilling mud without clays that diminish shale formation hydration, and a drill-in fluid that prevents permeability damage as well as possesses inhibitory properties depending on the borehole's depth and the formations drilled at the time of borehole drilling. The main ingredient of bentonite drilling mud is the bentonite, which acts as a structural building component (Lewicka et al. 2008). However, in clay-free mud the structure and viscosity is built by biopolymer-XCD, high viscosity, plant-derived organic polymers or their mixtures (Steliga and Uliasz 2012; Steliga and Uliasz, 2014).

One of the main drilling fluid additives used to achieve the required density to overbalance formation pressure during drilling operations and prevent any loss of well control is weighting material (Caenn et al., 2011; Hossain and Al-Majed, 2015; Mohamed et al., 2019). Also, the drilling fluids have many functions, such as circulating the drilled cuttings to the surface and suspending the cuttings while drilling operation is stopped and cooling and lubricating the drill bit to ease the drilling operation (Gordon et al., 2008; Fink, 2012). A special drilling fluid formulation is required to meet the critical downhole conditions in high-pressure high-temperature applications. In such cases, drilling fluids should have a high density to suppress the high formation pressure with good stability at that elevated temperatures (Mohamed et al., 2017; Mohamed et al., 2019).

In the drilling operations, drilling fluids have many key functions, and almost all problems encountered are directly or indirectly related to drilling fluid properties (Adams 1985; Chilingarian and Vorabutr 1983; Plank and Gossen 1991). In the minimizing drilling time and cost , optimum selection of drilling fluid is a key factor (Mokhtari and Ozbayoglu 2010; Salih et al. 2016). The water-based drilling fluids are more preferable and attractive option than oil and synthetic fluids for drilling oil and gas wells in sensitive areas where oil base fluids are not desired, due to cost and environmental effects.

Therefore, water base fluids are desirable due to the development of high performance and more environmental friendly (Salih et al. 2016; Saboor et al., 2018).

## III. CLASSIFICATION OF DRILLING FLUIDS

In geotechnical engineering, drilling fluid is a fluid used to drill boreholes into the earth. In drilling rigs, drilling fluids help to do drill for exploration of oil and natural gas. Liquid drilling fluid is often called drilling mud (Mukherjee, 2013).The drilling fluids are generally classified under three distinct classes such as water-based drilling fluids, oil-based drilling fluids and synthetic-based drilling fluids.

Water-based drilling fluids account for 80% of the total drilling operation carried out due to their environment friendly nature and they are highly cost-effective as compared to the synthetic or oil-based drilling fluids. The choice of the drilling fluid depends on the factors (Medhi et al., 2019). These factors are (1) the location and the type of formation which is to be drilled, (2) the variation in the pressure and temperature of the wellbore, (3) the nature of the formation fluids i.e. strength, porosity and permeability and (4) the other important factors considered while making the selection of the drilling fluids are production factors, environmental factors and safety.

The water-based fluids are used to drill approximately 80 % of all wells. These fluids may be fresh water, seawater, brine, saturated brine, or a formate brine. The type of fluid selected depends on anticipated well conditions or on the specific interval of the well being drilled. Some commercial bentonite or attapulgite also may be added to aid in fluid-loss control and to enhance hole-cleaning effectiveness. The water-based fluids fall into two broad categories such as no-dispersed and dispersed.

The oil-based drilling fluids were developed and introduced in the 1960s to help the drilling problems. They are formulated with diesel, mineral oil, or low-toxicity linear olefins and paraffins. Barite is used to increase system density, and specially treated organophilic bentonite is the primary viscosifier in most oil-based systems. The emulsified water phase also contributes to fluid viscosity. Organophiliclignitic, asphaltic and polymeric materials are added to help control HP/HT (High pressure/High temperature).

The surfactants used for oil-wetting also can work as thinners. Oil-based systems usually contain lime to maintain an elevated pH, resist adverse effects of hydrogen sulfide and carbon dioxide gases, and enhance emulsion stability. Shale inhibition is one of the key benefits of using an oil-based system. The high-salinity water phase helps to prevent shales from hydrating, swelling, and sloughing into the wellbore.

The synthetic-based drilling fluids were developed out of an increasing desire to reduce the environmental impact of offshore drilling operations, but without sacrificing the cost-effectiveness of oil-based systems. Field data gathered since the early 1990s confirm that the synthetic-based drilling fluids provide exceptional drilling performance, easily equaling that of diesel and mineral oil-based fluids.

In many offshore areas, regulations that prohibit the discharge of cuttings drilled with oil-based drilling fluids do not apply to some of the synthetic-based systems. The synthetic-based drilling fluids are formulated with linear alpha olefins and isomerized olefins exhibit the lower kinematic viscosities that are required in response to the increasing importance of viscosity issues as operators move into deeper waters.

## IV. FORMATION CHOICE

In the proper selection of the drilling fluid, there are some governing agents such as the type of formation encountered, temperature and pressure of the formation, ecological and environmental considerations and cost need to be put into consideration when a proper selection of the drilling fluid (Bourgoyne et al., 1985; Khodja et al., 2010). The basically three types of drilling fluid can be used in any mud system. Water base mud comprises water as the continuous phase and is the most commonly used drilling fluid. Oil base mud consists of oil as the continuous phase and diesel oil is the one used largely. Gas is composed of either air or natural gas and foaming agents are sometimes used (Darley and Gray, 1988; Annis and Smith, 1996; Rabia, 2002). Drilling operations can be greatly improved by choosing an appropriate type of drilling fluid. An appropriate selection of the drilling mud has always been a big challenge to the crew working on the rig site (Dhiman, 2012; Hamoodia et al., 2018).

The rheology of drilling fluid determines its effectiveness in drilling a well (El Fakharany et al., 2017a). The effectiveness or the performance of the drilling fluid is measured by the capability of the fluid to accomplish its job. The prime use of the drilling fluid is to remove the formation cuttings within the well. The designed fluid should carry and suspend the cuttings while in circulation and transmitted securely through the annulus incurring minimum losses and environmental impact (Walker et al., 2016).

The selection and formulation of the fluid is done by the mud engineer, who determines the required viscosity, density, fluid loss control, chemical composition and many other properties of the fluid (Bland et al., 2006). The selection of the type of the drilling fluid is based on three important factors; the cost, technical performance and the environmental impact of the fluid on the formation. The selection of the best suiting type is important as it defines the success of the drilling operation. In recent years, researchers have focused on formulating a biodegradable oil base-mud that would save on cost of disposal, and simultaneously have less of a negative impact on the environment (Hussein and Amin, 2010; El Fakharany et al., 2017b).

The drilling fluid, also called drilling mud, is a heavy, viscous fluid mixture used in oil and gas drilling operations to carry rock cuttings to the surface and also to lubricate and cool the drill bit. The drilling mud, by hydrostatic pressure, also helps prevent the collapse of unstable strata into the borehole and the intrusion of water from water-bearing strata that may be encountered (Anon, 2014a). Three key factors usually determine the type of fluid selected for a specific formation such as cost, technical performance and environmental impact (Anon, 2014b).

Some researchers have gone as far as comparing the role played by drilling fluid in oil exploration and exploitation activities to that of the blood circulation in the human body. In this analogy, the fluid pump functions as the heart; the cuttings that are transferred from the borehole by drilling fluid represent the waste products excreted out of the body through the blood vessels, and the kidney and lungs function as the system for cleaning the mud (Al-Yasiri and Al-Sallami, 2015). It has been estimated that in oil exploratory and extraction activities, the cost of drilling operations is responsible for 50 to 80% of exploration finding costs, and about 30 to 70% of other field development costs (Khodja et al., 2010; Orji et al., 2016).

Drilling fluids are suspension of solids in either water or oil, which can be mixed with other substances, called additives (Apaleke et al., (2012).The principal functions of the drilling fluids 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 drilling bits; (3) reduce friction between the drilling string and the side of the hole; (4) maintain the stability of uncased sections of the borehole; (5) prevent inflow of fluids from permeable rocks penetrated; (6) form a thin, low permeable filter cake which seals pores and other openings in formations that penetrated by the bit, and (7) assist in the collection and interpretation of information available from drilling cuttings, cores and electrical logs (Apaleke et al., 2012, Hossain and Al-Majeed, 2015; Behnamanhar et al., 2014).

## V. ENVIRONMENTAL IMPACT

Drillers use specialized drilling fluids referred to as muds when drilling exploration and production oil and gas wells to help maintain well control and to remove drill cuttings from the drill hole (Burke and Veil, 1995). Recently, in response to the current global environmental challenges in addition to strict international and local regulations on drilling waste discharge requirements, the drilling industry has developed several types of synthetic-based fluids or synthetic-based fluids that combine the desirable operating qualities of oil-based drilling fluids with the lower toxicity and environmental impact qualities of water-based fluids (Burke and Veil, 1995, Cobby and Craddock, 1999; Chuma, 2011).

The formation which is water-sensitive may require oil-based fluid and synthetic-based fluid. A proper formulation of oil-based fluid can prevent water movement from the fluid into the shale occurrence. However, in the formulation of the oil-base drilling fluids, the recognized the American Petroleum Institute (API) specifications must not be compromised. Table 1 shows the API standard for drilling fluids rheology requirements. API was formed in 1919 as a standards-setting organization and is the global leader in convening subject matter experts across segments to establish, maintain, and distribute consensus standards for the oil and gas industry.

Table 1. API (13B) specificationsforoil-basedrillingfluids (DarleyandGray, 1988; Mohammed, 2012)

| **Parameter** | **Numerical Value Requirement** |
|---|---|
| ***Basic OilCharacteristicsRequirements*** | |
| Flash Point | 150 °F (66 °C) |
| Fire Point | 200 °F (93 °C) |
| Aniline Point | 140 °F (60 °C) |
| ***FluidProperties*** | |
| Density | 7.5 toover 22.0 (lb/gal) |
| PlasticViscosity | < 65 (cP) or ALAP |
| Yield Point | 15-45 (lb/100 $ft^2$)) |
| PV/YP Ratio | 0.8-1.5 |
| Gel Strength 10 seconds | 3-20 (lb/100 $ft^2$) |
| Gel Strength 10 minutes | 8-30 (lb/100 $ft^2$) |
| CalciumChloride | 20-25 % byweight |
| Excess Lime | 1-3 ppg |
| ElectricalStability | > 400 (volts) |
| HPHT Filtratebeforerolling | 10-25 Millilitres (ml) |
| HPHT Filtrateafterrolling (350 $^o$F -500 $^o$F) | < 10 (ml/30 min) |
| API Fluidloss | 15.0 ml (maximum) |
| Oil/WaterRatio | 65/35 to 95/5 |
| EPA MysidShrimp Test | 30 000 ppm $LC_{50}$ (minimum) |
| pH | 8.5-10 |

In as much as oil based fluids are efficient in areas prone to shale swelling they tend to pose adverse impact to environment when the pollutant is discharged and subsequently dispersed to the sea. This becomes highly unfourable for aquatic bodies, both plants and fishes. In a long run damaging the ecosystem. Moreover, the fishes tend to be toxic and harmful when consumed by man. Also, these pollutants during onshore drilling may have drastic impact on soil quality; thus has serious effects on the chemical properties of the soil and hence affects people's habitat and wildlife significantly. The cuttings from oil-based fluid do not disperse as much as water-based fluid when it is discharged under water. It will form piles of cuttings that blanket parts of seabed. This condition may affect the bottom-dwelling organisms close to the rig (Seang et al., 2001; Yassin et a., 1991; Sauki et al., 2015).

The synthetic-based drilling fluids are a relatively new class of drilling muds that are particularly useful for deep water and deviated hole drilling. They are a new class of materials used to provide safe and cost-effective technology for drilling oil and gas wells. Their enhanced drilling performance decreases drilling time and provides advantaged safety, human health, and, in some cases, environmental performance above diesel oil fluids. They were developed to provide an environmentally superior alternative to oil-based drilling fluids (Neff et al., 2000; American Chemistry Council (ACC), 2006).

## VI. CONCLUSION

For the successful drilling of oil and gas drilling, the drilling fluids are essential materials. The drilling fluids are complex mixtures formed from solids, liquids, chemicals, and sometimes even gases. From the chemical point of view, they can assume aspects of suspension, colloidal dispersion or emulsion, depending on the physical state of the components. The drilling fluids are generally classified under three distinct classes such as water-based drilling fluids, oil-based drilling fluids and synthetic-based drilling fluids. In the proper selection of the drilling fluid, there are some governing agents such as the type of formation encountered, temperature and pressure of the formation, ecological and environmental considerations and cost need to be put into consideration when a proper selection of the drilling fluid. Notwithstanding the efficacy of oil-based fluids, they can give negative impact to environment when the pollutant is discharged and subsequently dispersed to the sea. Their enhanced drilling performance decreases drilling time and provides advantaged safety, human health, and, in some cases, environmental performance above diesel oil fluids. They were developed to provide an environmentally superior alternative to oil-based drilling fluids.

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