Performance of Conventional Drilling Fluids and Nano Based Drilling Fluids

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Abstract

The world's energy demand is about to increase over 60% in next 30 years. Several mature fields are nearly in depleting conditions. The oil and gas industry is striving to seek advance methods for the recovery of the remaining hydrocarbons which are difficult to produce using conventional recovery methods. Drilling is the only way which provides a path to produce the hydrocarbons from subsurface. During drilling operations, oil and gas industry faces several problems including borehole instability, torque and drag, sticking, bit balling and issues due to high pressure high temperature (HPHT) environment etc. These challenges can only be minimized using a suitable drilling fluid system, composed of Nano-scale particles for turning the behavior of the rheological properties of drilling fluid to ensure safe drilling and production operations. Nano-scale particles are usually very ultra-fine materials, whose size ranges between the size of atom and ordinary micro-scale particles having high specific surface area of interaction. The nano-scale particles used as an additive which exhibit strong potential inhibition both internally and externally. Due to the high specific surface area of nano sized particles, these fluids need very low concentration of the additives used.

This paper depicts the potential challenging problems encountered during drilling activity. It is also compared that how nano based smart fluids can overcome the drilling problems by improving drilling fluids properties like viscosity, density, and filtration properties etc.

Key Words: Smart Drilling Fluids; Drilling Fluids Properties; Nano-Technology; Nano-Scale Particles.

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INTRODUCTION

Drilling is a road to reach the hydrocarbons located at subsurface locations. The successful drilling job is totally dependent on the proper designing of the drilling mud. In oil and gas industry, drilling fluid is termed as "The life blood of drilling company". The success and failure shows the effective use of drilling fluids technology and an understanding of such fluids behavior. In drilling operations, fluids have an important impact on non-productive time (NPT), rate of penetration (ROP), cementing job success, health, safety, environment issues, time to drill, complete a well and the ultimate reservoir performance for many wells (Scott, 2007). It is treated as an integral part of drilling operations. Drilling fluids are used for several purposes including removal of cuttings from subsurface, control of uncontrolled formation pressure, keep the borehole in a regular shape by preventing the caving, lubricates the bit and keeps the complete assembly cool etc. (Rogers, 1948). Different types of drilling fluids are used in drilling and production operations depending on the nature of operation such as drilling, completion, stimulation and work-over etc. It is a very complex system of solids, liquids and other chemical additives. Chemical and polymer additives in the drilling fluids plays a vital role to maintain the specific properties and behaviors of the fluid used in oil and gas drilling, production and workover operations. The determination and analysis of the factors which guide towards the selection of the base fluid and additives used in the drilling fluids leads to complex system (George, 1998).

The greater environmental and technical challenges are most likely to face during drilling and production operations in the current scenario as well as in future is because of the changing operational depth, subsurface geo-hazards with depth, shape of wellbore trajectory, lateral wells, horizontal departure length, drilling operations complexity etc. (James and Helland, 1992).The challenges that are usually handled during

drilling and production operations depends on geographical field location, geological basin history, environmental sensitivity, subsurface pressure profile field and subsurface formation characteristics. Some technical challenges such as unconsolidated formations, torque and drag, borehole instability, shallow water flow problem, loss of circulation, bit balling, acid air environment, pipe sticking problem, stimulation and fracturing fluid formulation, HPHT environment etc. also encountered during oil and gas industry at various stages from drilling to production operations (Bjorkevoll et al., 2008; Meister et al., 2003; Rocha et al., 2003). Several macro and micro sized additives have been used since decades. Some of these are still used in oil and gas industry. The researchers are struggling for drilling fluids additives which are efficient, economical, trouble free, and environmentally safe (Apaleke et al., 2012). Nano sized particles are used as an additive in the drilling fluids to perform numerous functions due to their special characteristics. The selection if these particles are based on environmental and technical challenges about the specific area Nano particles are tailored made materials having size in the range of 1 to 100 Nano meters (Whitesides, 2005). These particles have some specific characteristics which plays a leading role in overcoming the technical and environmental challenges faced during drilling and production (Jimenez et al., 2003).The Nano based drilling fluid with its excellent applications is the suitable substitute to solve the problems occurred during drilling as well as in production operations.

Problems Occurred During Drilling Operations

The oil and gas and the broader energy industry is facing major future challenges from upstream to midstream and to downstream applications in terms of materials, techniques and safe environmental operations. In order to overcome these challenges, the industry is looking for revolutionary solutions. In recent year's micro and Nano technologies have received significant attention as potential candidates to offer solutions to some of these challenges (Kong and Ohadi, 2010).

The world's oil and gas industry facing different problems that are usually faced during drilling and production operations depending on many parameters including geographical field location, geological basin history, environmental sensitivity, sub-surface pressure profile field and sub-surface formation characteristics. The technical and mostly occurring problems encountered during oil and gas drilling are discussed below and the application of the Nano-scale particle as a remedy to overcome these problems is also been highlighted (Amanullah and Al-Tahini, 2009).

- Borehole Instability
- Pipe Sticking
- Unconsolidated Formation
- Shallow Water Flow Zone problem
- Balling up of Bit
- HPHT Environment
- Torque and Drag During Drilling
- Economics
- Time consumption
- Hazardous gases
- Lost circulation
- Corrosion

A drilling fluid is a complete system typically containing water, colloidal material, both gel forming and non-gel forming materials, as well as large particles which are suspended in the water (Milton, 1942).Various drilling fluids have been used since decades to overcome these annoying conditions. With the advancement in technology, anew fluid has been recently introduced in oil and gas industry called Nano Fluids, which is composed of Nano materials. These fluids have at least an additive with particle size ranges between 1 to 100 nanometers (Buzea et al., 2007). Figure 1 shows a Ladder's scale, which explains different scales and categories starting from atom size to macro scale. Nano-scale particles are usually very ultra-fine materials, whose size exist between the size of an atom and ordinary micro-scale particles having high specific surface area of interaction (Mcelfresh et al., 2012) (Mcelfresh, 2012)

Drilling Fluid Properties

The important physical properties of drilling fluids such as density (specific gravity), gel strength, viscosity and percentage of sand content present in the mud fulfills the numerous physical requirements for safe and efficient drilling processes if utilized properly.

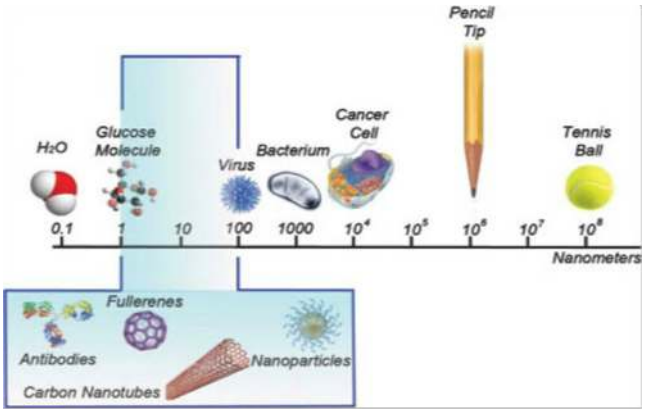

Figure 1: Ladder's Scale for materials size distribution (Ma, 2007)

Density (Specific Gravity)

To keep formation fluids in their original place, mud is equipped with weighting materials. Most commonly used weighting materials includes calcium carbonates, hematite, galena and barite depends on the density required. Density is "The weight per unit volume ". In industry density is stated in pound per cubic feet (lb. /ft^3), pounds per gallons, ppg (lbs. /gallons) and kilogram per cubic meter (kg/m^3 or gm. /cm^3) or it is compared to the weight of an equal volume of water as specific gravity. It is measured with mud balance. Density changes of a specific type of a drilling fluid can be treated as a function of temperature and pressure (McMordie et al., 1982).

Viscosity

Viscosity of drilling fluid is an important parameter to hold the cuttings for the entire stay of mud in the wellbore. It is defined as "The internal resistance to flow". In field, viscosity is normally measured using marsh funnel in seconds per quartz. A rotational viscometer is also used in laboratories to determine the actual viscosity of a mud. Different viscosifiers are used to maintain the viscosity during drilling including, Bentonite, Asbestos, Attapulgite and Carboxymethyl cellulose, etc. (Lee and Patel, 1997).

Plastic Viscosity (PV)

A resistance in flow due to mechanical friction is termed as Plastic Viscosity. The friction may be occurred between solids and liquids, solids present in the mud and/or with the liquid shearing itself (Hiller, 1963).

Yield Point (YP)

Yield Point (YP) represents the stress required to move the fluid. It is the resistance of initial flow of fluids. YP is due to the attractive force among solid particles in drilling fluids. A mud have electro-chemical forces due to which the yield point exists. These forces are in the form of charges (negative and positive) located near the particles surfaces. Yield point is a measure of these forces under flow conditions and depends upon;

- Electrical environment of these collides (Hemphill et al., 1993)
- Concentration of solids(Mahto and Sharma, 2004)
- Surface physical properties of the mud collides (Foerster et al., 1994)

Gel Strength

Cuttings produced during drilling are required to remain suspended while pumps are off. Gel strength is the mud thixotropic property. If a drilling mud is kept un-agitated for some time it will thicken up. In drilling fluids the presence of some colloids forming gels when combined with water (Parsons, 1931). Different additives are used to maintain the gel strength of mud while the pumps are in off position because if the mud is left un-agitated for some time, the cuttings will move to the bottom of the well bore and will cause borehole problems like sticking etc. (Maglione et al., 2000). This case is very serious in directional drilling (Figure 2).

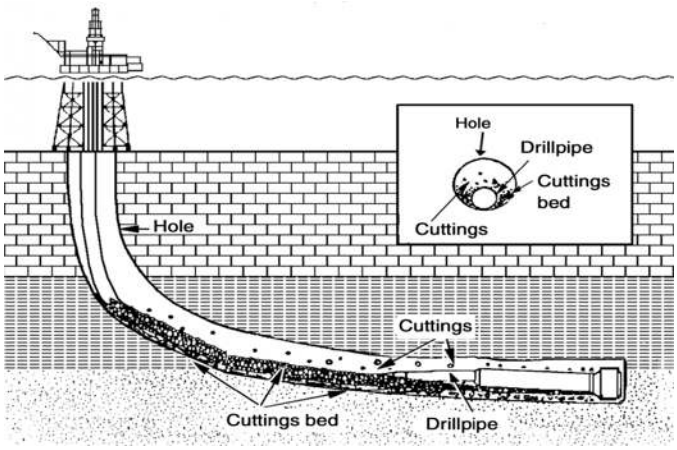

Figure 2: Cuttings buildup in directional drilling (Sanchez, et al., 1997)

Filtration Loss

A mud cake is formed against the wall of the borehole when the mud filtrate enters into the permeable zone leaving the solid particles. The formation of mud cake is mainly dependent upon permeability of the formation, the solids size and concentration of the solids. The lower the permeability, the thinner is the filter (Zhong-Hua, 1995). A thick filter cake is unattractive as it tightens the walls of the borehole and permits unnecessary amount of mud filtrate to move into the formation resulting problems such as tight pulls, caving, held ups, sticking etc.

Literature studies shows that different additives/chemicals which are used since decades to improve the above mentioned properties of drilling

mud. Some of these are;

- Bentonite, Asbestos, Attapulgite (Marshall et al., 1942)
- Barite, Calcium carbonates, Hematite. Galena (Zhang, 2008)
- Synthetic polymers, X-C Polymer (Molyneux, 1983)
- Pre-gelatinized starch (Dobson et al., 1998)
- Carboxymethyl cellulose (CMC), Poly anionic cellulose (Dolz et al., 2007; Steiger, 1982)
- HT-Stable resin lignite (Nahm and Rowe, 1976).

With the advancement in the technology, it has beennoticed that there are some additives which can contribute more than the available additives if utilized properly. These additives were termed as “Nano-Based Additives”. The fluid containing these Nano based additives were known as Smart Fluids.

Smart Drilling Fluids

Nano technology has been introduced in oil and gas industry since last fifty years. The first focus of the Nano technology was to overcome the problems occurred during oil and gas well drilling operations. Due to the opportunity of developing some tailored nanoparticles with customized functions, physical shapes and sizes, ionic in natures, densities and unit volumes etc. Nanotechnology has introduced a new generation of fluids named as “Smart fluids” for various purposes including drilling, production as well as well stimulation applications. Nano fluids are a new category of fluids formed by dispersing Nano meter (nm) sized particles (Nanoparticles, Nano fibers, Nano rods, nanotubes, nanowires, Nano sheet, or droplets) in base fluids. In other words, Nano fluids are Nano scale colloidal suspensions containing Nano sized materials. They are two-phase systems i.e. solid phase and liquid phase (Yu and Xie, 2012).

Advanced drag reduction, wettability alteration and binders for sand consolidation can be optimized by utilizing such smart fluids (Wasan and Nikolov, 2003). One specialized petroleum laboratory has established an advanced fluid composed of Nano sized particles and superfine powder that significantly improves drilling speed. Such Nano fluids can eliminate damage to the reservoir rocks in the well, making it possible to produce more oil (Suleimanov et al., 2011).The main objective of the Nano sized particles is the increase of surface area and ultimately the reactive exposed area. The increasing surface area of additive particles improves

the rheological properties of drilling fluids which directly prevent the well from challenging situations (Figure 3).

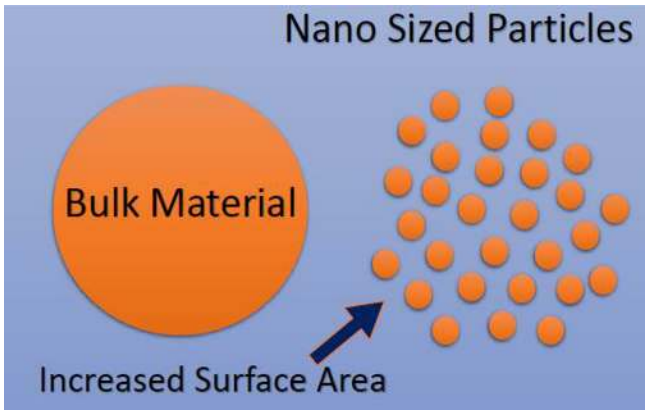

Figure 3: Surface Area Comparison between bulk material and Nano-Scale Particle

According to the number of Nano sized particles additives, Nano fluids are categorized with respect to size as;

- Simple Nano Fluids and
- Advanced Nano Fluids

If the fluid is composed of only one-sized Nano particles called as a simple Nano fluids and the fluid composed of more than one sized particles is called advanced Nano fluids. Based on functions performed by using Nano particles, these fluids are categorized as;

- Single Functional Nano Based Fluids and
- Multifunctional Nano Based Fluids

Only one function is achieved by the single functional Nano-fluids and more than one functions are achieved by the multi-functional Nano fluids.

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Requirements for Nanoparticles and Base Fluids

Nano based fluids are prepared Nano particles and base fluids.

Solids Phase include:

- Oxide ceramics
- Metal carbides
- Nitrides
- Metals
- Functionalized nanoparticles

Liquid Phase Base fluids include:

- Water
- Ethylene
- Oil and other lubricants
- Bio-fluids
- Polymer solutions

- Other common fluids

Preparation of Nano fluids

There are two fundamental methods to obtain Nano fluids (Sridhara & Satapathy, 2011)

- Direct evaporation method/Single-step: To produce stable Nano fluids, the direct evaporation and condensation of the Nano particulate materials in the base liquid are obtained.
- Two-step method: In this technique, first the nanoparticles are acquired by different methods and then are dispersed into the base liquid.

Comparison of Nano Based Fluids and Conventional Drilling Fluids

Literature depicts that when conventional drilling fluids have been compared with the Nano based drilling fluids, it has been found that Nano based drilling fluids are more beneficial to be used in different challenging situations during drilling, production and even in enhanced oil recovery stages. Due to the higher reactive surface area, it can be used as the suitable additive for different operations in oil and gas industry. It was also noticed that these particles are very economical and environmentally friendly. The summary of the Nano based fluids and conventional fluids is given in Table 1.

Table 1: Comparison of Nano Based Fluids and Conventional Drilling Fluids

Conventional Fluids	Nano Based Fluids
Cannot withstand high pressure differential	Withstand the large differential pressures encountered
No susceptibility at high temperature and pressure	Highly susceptible at high temperature and pressure
High density due to solids presence in the mud	Optimum density due to solids-free mud
Mixing equipment at surface required	No mixing at surface required
Penetration problems due to viscosity	No penetration problems due to low initial viscosity
Formation of thick mud cake	Formation of very thin mud cake
Chances of pipe sticking problem	No pipe sticking problem
No control on formation damage	Control formation damage
Acceptable sealing capacity	Excellent sealing capacity when added with LCM
Additives required at high concentration	Less additives requirement

MATERIALS AND METHODS

First the fluid to be used was mixed well and the rheological properties were measured carefully, as discussed below. By running a mud sample in the Fann viscometer before and after a test, it was calculated on average power-law parameters. Density of different fluids were determined using mud balance (Figure 4). Five different samples were used for determination of density (g/cm^3).

For determination of Viscosity, Plastic viscosity and Yield strength, Fann Rheometer (Model, 286) was used (Figure 5). This model has different rotational speeds starting from 100 to 600 rpm.

Figure 4: Density measurements by Mud Balance

Figure 5: Determination of PV and YP by Fann Rheometer

RESULTS AND DISCUSSION

Different parameters were determined by utilizing laboratory equipment. The details are given below.

Plastic Viscosity (PV) = Reading at 600 rpm – Reading at 300 rpm

Yield Point (YP) = Reading at 600 rpm – PV

Figure 6 and 7 shows the experimentally obtained density and shear thinning effect of the Nano based drilling fluids.

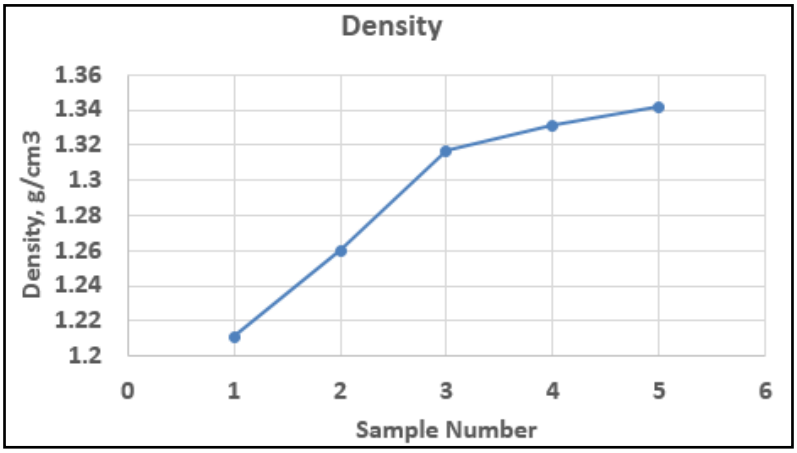

Figure 6: Density of Nano based drilling fluids

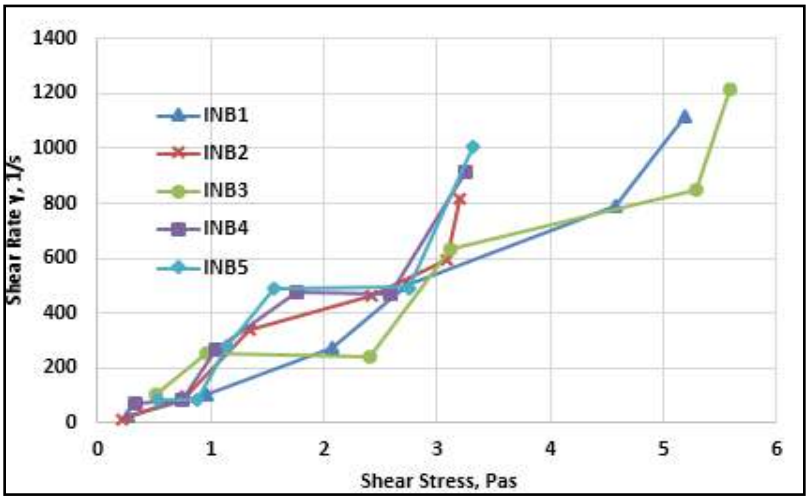

Figure 7: Shear thinning effect of drilling fluids

Table 2 and 3 summarizes the size, density, plastic viscosity and yield point of different samples

Table 2: Density of tested samples

Sample	Size, µm	Density, g/cm3
INB1	80	1.211
INB2	60	1.26
INB3	50	1.317
INB4	30	1.331
INB5	20	1.342

Table 3: Summary of some rheological properties

Sample	Reading at 600	Reading at 300	Plastic Viscosity (PV) cp	Yield Point (YP)
INB1	42	35	7	5
INB2	36	32	4	8
INB3	38	28	7	4
INB4	35	29	6	4.83
INB5	34	27	5	5.4

CONCLUSION

The nature is full of Nanoparticles and Nano fluids, like blood, which is a complex biological Nano fluid where different nanoparticles (at molecular level) accomplish different functions. Several manufacturing processes and industries leave waste products which consist of mixtures of Nano scale particles and that waste can be utilized in drilling fluids. It has been observed that Nano fluids can be considered as a potential candidate for many applications. The Nano sized particles have an excellent physical, chemical, thermal, and mechanical properties and possess superior surface to volume ratio as compared to macro material, which plays a vital role to overcome the problems occurred in oil and gas drilling and production operations.

The Nano-scale particles having some how different characteristics than the micro and macro material with respect to their parent materials. Nano sized particles were found more stable and efficient than macro and micro particles under HTHP environment. Borehole instability can be minimized using Nano based drilling fluids by forming a very thin mud cake on the wall of the borehole ensuring a very less filtrate loss into the formation. Nano fluids are very suitable as these fluids keeps the borehole clean while the pumps are off.

The pipe sticking problems are minimized by keeping a thin mud cake. Torque and drag problems can also be reduced using Nano based drilling fluids. Mechanical properties like compressive strength is improved using Nano particles in drilling fluids.

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