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The Experimental Investigation of Viscosity of Water Base Drilling Fluid

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Abstract

The application of nano particles to measure the slurry viscosity of drilling fluid is the novelty of this paper. The primary objective of drilling slurry is to improve rheological properties and displacement efficiency of the drilling fluid system. Oil well slurries depend on its homogeneity of additive concentrations, quality and quantity contribute the placement and success of a well drilling cementing operation. This experimental research investigated the High Performance Drilling Fluid System (HPDFS). Results show the increase in the amount of shear stress (0 to 30 Pa) decreases the amount of viscosity in both types of with and without nano particles. However, the values of viscosity increase from 100 cp to 200 cp when shear stress increases from 30 to 45 for drilling fluid contains nano particles.

Keywords

Drilling Fluid Additives, High Performance Drilling Fluid System, Dynamics Properties, Viscosity, Shear Stress

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1. Introduction

During a well cementing operation purpose should be achieve zonal isolation (American Petroleum Institute, 2005 and Nediljka *et al*., 1994). That belongs to the slurry design, to ensure the best quality of cementing especially at high temperature environment such a HPDFS Silica Fume (SF) use as a cement slurry additive to reduce the density of cement (Siddique and Khan, 2011). SF increase slurry performance and control hydrostatic pressure during drilling cementing. This mixture used as a primary source for a hydraulic seal in the well bore as secondary application is used for remedial operations, including depleted zone closing, splits and leak repair (Nediljka *et al*., 1994). The function of SF allows a well to reach full production potential besides producing a blocking effect in the oil well. It is also responsible to prevent gas migration and highly effective for proper placement and decrease permeability for better control of weak zones (Siddique and Khan, 2011). Compressive strength of concrete containing SF is proved higher strength; as increase the concentration of silica fume it improves stress resistance in the early development and reduces the free water (Mehta and Gjorve, 1982). The mixing of silica fume into cement several optimum conditions are noticed (Shadizadeh *et al*., 2010):

• It is natural to consume more water to prove as a function of extender and substitute for lightweight cements.

• High water adsorption to increased pozzolanic reactivity promotes enhanced compressive strengths.

• The purity and solubility of the material make it suitable for combating strength retrogression in cements at temperatures above 230°F (110°C).

1.1. History

Rheological properties of cement slurry play important role to determine the workability of slurry, fineness (Shahriar and Nehdi, 2012). The mixing process is very important

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parameters for rheological behavior of cement slurry, the criteria of designing slurry depend on formulation, density, plastic viscosity, shears tress, yield point and gel strength for enhance durability and toughness for cement slurry (Shahriar and Nehdi, 2011). Cement grout is used for sealing geothermal wells for olatezones during drilling cementing operation. Rheological behavior of cement slurry is important for the drilling process; it will be optimized to predict correctly about slurry placement (Bannister, 1980). Cement slurry is concentrated suspensions of small and heavy particles so rheological measurements are suffering to the disruption of cement operation (Miranda *et al*., 2010). Rheology of Oil Well Cement (OWC) should be considered when it applied to the originally and primarily casing cementing. Therefore, fundamental knowledge of OWC slurry rheology is necessary to evaluate the ability to mix and pump grout, remove mud and slurry placement optimization and to predict the effect of temperature on the slurry pit (Shahriar and Nehd, 2011). Incomplete mud removal can result in poor cement bonding, zone communication and ineffective stimulation treatment (Bannister, 1980). A rheology is study related to the flow of fluids and deformation of solids under stress and strain. In shear flows, fictitious parallel layers of liquid past each other in response to a shear stress to produce a velocity gradient, in the term of to shear rate, which is equivalent to the rate of increase of shear strain (Guillot, 2006). Rheology of cement slurry is complex which has the appearance and interactions between the additives (Banfill and Kitching, 1991). The chemical composition of cement, particle distribution, testing methods, size shape, W/C ratio, mixing time and temperature (Grinrod et al., 1988 and Frittella *et al*., 2009). Cement slurry is viscous plastic materials that exhibit yield stress and tension below the yield stress ultimately slurry behaves as a rigid and solid (Mirza *et al*., 2002). Bingham plastic and power-law model is widely used to describe the rheological properties of cement slurry measurements. Frittella *et al*. (2009) that can be determined the properties of cement flow i.e., plastic viscosity, yield point, friction characteristics and gel strength (Harris and Service,1991). Concentration and form of so lid particles has a significant impact on the rheological properties of the OWC slurry to yield stress and plastic viscosity of cement paste usually increase as the cement becomes finer and increases the stability of slurry (Boukhelifa *et al*., 2005). Equivalent Circulating Density (ECD) is important factor to understand the flow behavior, flow rate, annular velocity and differential pressure; for that purpose number of computer simulation software is available to predict the ECD. The displacement efficiency is achieving the maximum mud displacement. A standoff value of the percentage of casing centralization in the wellbore, job operation time for proper thickening and Reynolds numbers base on laboratory methods is measuring rheological properties to understand flow behaviors (Labibzadeh *et al*., 2010). These parameters will be evaluating the cement pump-ability and cement grout with strength correspond to behind the casing to increase efficiency and displacement. High flow rate may cause fracture the formation there should be investigated the current effective equivalent cement density (Hodne, 2007).

Maximum drilling fluid or colloids or emulsions as a non-Newtonian liquids in plastic or behave in such circumstances is that the gel analysis function of the intermolecular forces. The initial 10-sec and 10-min gel strength measurements gelatin indications of the gel that will occur after the flow is stopped and the drilling fluid remain static (Teodoriu *et al*., 2008). When circulating drilling mud and fluids during cementing operations abnormal results in the bottom hole, which may cause challenge to the integrity and safety (Soliman *et al*., 2008). To maintain hydrostatic pressure of the fluid column below the fracture gradient, but above the pore pressure and designing drilling slurry to improve efficiency and displacement without causing any form of collapse to the formation for this condition to focusing on ECD and rheological properties (Stephen and Samuel, 2008).

1.2. Design of Cemetery Slurry

Oil well cement compositions are typically used for sealing subterranean zone at High Temperature and High Pressure (HTHP) such as the annular space in oil well between the surrounding formation and casing (Shahriar and Nehdi, 2011). Slurry blend consists of cement class G with additives and water. The productivity of an oil well is significantly affected by the quality of cementing between the well casing and the surrounding strata (Teodoriu *et al*., 2008). Cement slurry flow ability and stability are major requirements for successful oil well cementing (Kulakofsky and Vargo, 2005) because the cement is the most active component of the slurry and usually has the greatest unit cost. Its selection and proper use are important in obtaining an effective, for the long term integrity of the well (Williams *et al*., 1999). Portland cements can be used for cementing around the casing of oil and gas wells having deeper depth wells usually require special oil well cements (Mueller et al., 1991 and Teodoriu *et al*., 2008). There are currently eight classes of API Portland cement designated A through H that are arranged according to the depths to which they are placed at pressure and temperature to which they are exposed (Harris and Service, 1991). In the oil well drilling industry class G and H type well cement are well known for deep wells; because initiation other than calcium sulfate and water both shall be inter-ground or blended to the clinker during the manufacturing of these oil well cement. Therefore, with the addition of ample quantities of additives such as retarders and dispersants can change their setting time to the cover wide range of well depths, pressure and temperature (Kulakofsky and Vargo, 2005). In this study silica fume used as an extender, as it is function to reduce slurry density also light slurry is used to control hydrostatic pressure during cementing operation. This slurry has greater strength to use in weak and unconsolidated formation.

Mixing energy: The cement slurry is a mixture of cement, water and additives (Stephen and Samuel, 2008). The mixing process is exothermic and the energy required is called as mixing energy.

The mixing energy equation is given as Williams *et al.* (1999):

$$E/M = k\omega^2 t/V \tag{1}$$

Where,

E	Mixing energy (KJ)
M	Mass of slurry (kg)
K	$6.1*10^{-8} m^5/s$ (constant found experimentally)
ω	Rotational speed (radians/s) t
t	Mixing time (sec)
V	Slurry volume (m^3)

The prepared cement slurry is dispatched to Viscometer for measuring rheological properties.

Standard of well drilling fluid test: American Petroleum Institute (API) has presented "Recommended practice for testing well drilling fluids (American Petroleum Institute, 2005). The standard has been followed, which is used worldwide. These tests are advise and very helpful to drilling personnel for determining a given drilling fluid composition will be feasible for well conditions according to API-10B (American Petroleum Institute, 2005) Experimental procedure: Drilling fluid slurry is prepared according to API-10B (American Petroleum Institute, 2005). The mixing method strongly influences on slurry and set cement properties. Cement additives can be wet blended in cement slurry. When additives are mixed in water prior into cement, it is called wet blending.

Electronic balance: This is used for weighting dry cement, distilled water and additives, to use in preparation of drilling fluid slurry.

Electronic standard 7000 constant speed mixer: Measure cement and additive prepared in the lab using the standard 7000 Constant Speed Mixers provide all the necessary functions to mix drilling slurries according to API and ISO specifications and recommended practices. Normally 600 ml of slurry is prepared. Slurry is mixed for 70 sec the mixer is operated at 4000 RPM during first 15 sec which the dry cement is added to water this is followed by 35 sec at that condition set mixer at 12000 RPM followed at 70 sec.

Rheology measurement: The prepared drilling slurry is placed into sample cup i.e., Bob1 having a capacity of drilling fluid is 42 ml slurry different Bob having different capacity for drilling slurry's high performance advance pressurized viscometer model 1100 with ORCADA software is used for measuring rheological properties of drilling slurry's. According to API recommended practice 10B viscometer is used for oil well drilling fluid testing materials having a wide range of temperatures. Where the viscosity is determined, the dial readings at various rotational speeds are given the slurry behavior at different condition. In this study the temperature is set at above 120°C the viscometer heat bath help to simulate down whole condition. After heat conditioning, the viscometer starts to take the dial reading at different RPMs to measure the rheological parameter at down whole condition. Omole et al. in 2013 stated the apparent viscosity of different types of drilling fluid is changed between 0.0 to 30cp at 600 rpm. They stated the apparent viscosity of drilling fluid is decreased with the increasing the shear stress. (Omole O. et al., 2013).

The some of physical properties of water based drilling fluid is evaluated in this paper. The injected dosage of nano particles, plastic viscosity, slurry viscosity and shear stress are evaluated in this paper.

2. Materials and Method

2.1. Properties of Aluminum Oxide

The aluminum oxide nanoparticles as a common ingredient has a huge variety of applications. This topic is proven that, the application of Al_2O_3 nano particles in low dosage is not toxic (Sadiq et al., 2011). So, this type of metal oxide is chosen as additive.

2.2. Method of Preparation of Aluminum Oxide Nanoparticle

Nano fluids that are used in this experimental work are prepared in two steps. At the first, the amount of 1.16 g of Aluminum oxide in powder form is dissolved in de-ionized water contains 0.38 g of citric acid crystals. Then Ammonium hydroxide is added gradually (till obtaining pH=7) into the mixture and is homogenized effectively in magnetic stirrer simultaneously. To produce the powder form of aluminum oxide, the mixture is heated for 1h at 250 °C and then to 500 °C for 90 min to change the color of the powder into bright yellow. Nano particle diameter is in the range of 40-60 nm and morphology of particles are characterized by SEM and TEM images. Table 1 shows the specifications of the used nano aluminum oxide. Then 0.01 wt% nano particles are added in the drilling fluid, alkyl-aryl sulfonate as a surfactant in the fraction of 0.3:1 to the amount of nano particles is used to improve the interaction between nano particles and the molecule of drilling fluid. Stabilization step is done with the ultrasonic technique through 2 hours. The individual effect of surfactant on the properties of drilling fluid could be neglected, considering the less amount of surfactant compared with the amount of drilling fluid. Produced spherical particles with the average diameter of 40 -60 nm in size are observed approximately. Figure 1 shows TEM and SEM photos of producing nano particles a and b) in the scale of 5 micrometer and c) in the scale of 500 nm.

Table 1. Physical properties of aluminum nano-catalyst.

Aluminum nano-catalyst properties	
Assay	≥95% Trace metal basis
Form	Nano powder
Resistivity	>10'4 μΩ-Cm at 20C
Average Particle Size	75 - 89nm
Thermal conductivity	20W/m.K
Density	gr/ml at25C

3. Results and Discussion

The pysical properties of water based drilling fluid is investigated in this paper. The plastic viscosity, dosage of nano particles, slurry viscosity and shear stress is evaluated in this study.

3.1. Effect of Nano Particles on the Plastic Viscosity

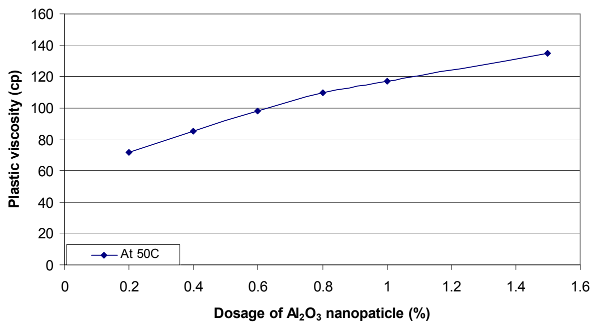

Figure 1. Plastic viscosity versus amounts of nano aluminum oxide.

Figure 1 shows the effect of nano aluminum oxide added on the amounts of plastic viscosity, in the constant temperature 50 C. Experiments show the increase in the amount of plastic viscosity due to the increase in the amount of nano aluminum oxide.

Dhiman in his thesis stated, the concentration of mud additives is vital to control the rheological properties of drilling mud. Significant changes in drilling fluid plastic viscosity were noted to correspond to changes in the concentration of mud additives. Dhiman results show the plastic viscosity of drilling fluid is increased from 18 to 35 cp when the additives increase from 0.0 to 20wt%. (Dhiman Annudeep Singh, 2012, Rheological properties and corrosion characteristics of drilling mud additives, thesis, Master of Engineering).

3.2. Effect of Nano Particles on the Slurry Viscosity

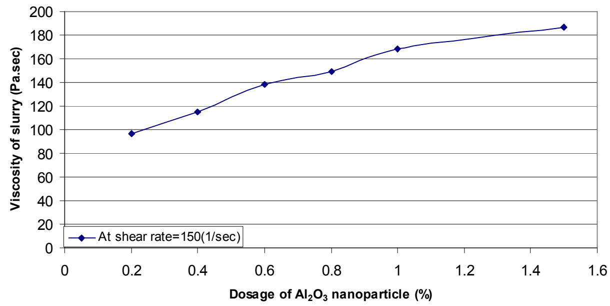

Figure 2. The effect of amount of aluminum oxide on the values of viscosity.

The effect of amounts of nano aluminum oxide on the amount of viscosity of slurry at the constant amount of shear rate (150 sec^{-1}) is shown in Figure 2. The increase in the amount of nano particle increases the amount of viscosity of slurry. It seems each extra 0.2% nano oxide increases the viscosity about 0.2 pa.s from 0.2% to 0.6%. The slope of the curve in Figure 2 decreases with the increase in the amount of nano aluminum oxide (0.6% to 1.5%). So, a value of the nano aluminum oxide seems to be which at higher than that value, the amounts of viscosity will be constant.

Dearing et al., 2004 studied the formulation of drilling fluid of Shale. They showed the viscosity if drilling fluid is increased versus increasing the liquid Shale treatment. They stated the viscosity of slurries can be increased to 35cp. They results show the trend of increasing of slurry viscosity is a function of added dosage and. (Dearing Harry et al., 2004).

3.3. The Relation Between Slurry Viscosity and Shear Stress

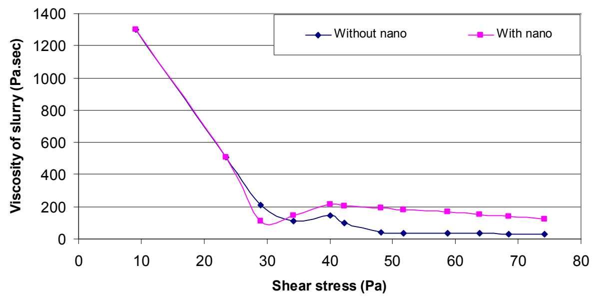

Figure 3. Viscosity versus shear stress.

The effect of shear stress on the amounts of viscosity is shown in the Figure 3. The increase in the amount of shear stress (0 to 30 Pa) decreases the amount of viscosity in both types of with and without nano particles. However, the values of viscosity increase from 100 cp to 200 cp when shear stress increases from 30 to 45 for drilling fluid contains nano particles.

4. Conclusions

In fact, the application of nano particles to measure the slurry viscosity of drilling fluid is the novelty of this paper. Nano particles in drilling fluid, prevents variations in yield stress in various temperatures in the range of 20 C to 80 C. Results show the increasing in the amount of shear stress (0 to 30 Pa) decreases the amount of viscosity in both types of with and without nano particles. The experimental results show the increase in the amount of nano particle increases the amount of viscosity of slurry.

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