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REDUCING FRICTION DURING DRILLING IN WATER-BASED MUD USING GLASS BEADS

ISSHAM ISMAIL[1], AZMI KAMIS[2] & NUR SURIANI MAMAT[3]

Abstract. This paper discusses the use of glass beads as a lubricating agent, which was considered as it is chemically inert, non-abrasive, and non-toxic. The glass beads size used were in the range of 22 to 163 μm. The experimental results showed that water-based mud with glass beads experiencing 41% reduction of coefficient of friction (CoF) compared to water-based mud without glass beads The presence of 4 ppb of glass beads in water-based mud was found to have given the optimum rheological properties and lowest fluid loss than mud without glass beads and with 2 ppb and 6 ppb of glass beads. The experimental results also revealed that carbolite has the potential to be used as a lubricating agent in water-based mud.

Keywords: coefficient of friction; carbolite; glass beads; lubricating agent; water-based mud

Abstrak. Artikel ini mengetengahkan perbincangan tentang penggunaan butiran kaca sebagai agen pelincir berikutan sifatnya yang lengai, tidak menghakis, dan bebas toksik. Saiz butiran kaca yang digunakan adalah dalam julat 22 hingga 163 μm. Hasil kajian menunjukkan bahawa lumpur dasar air yang mengandungi butiran kaca berjaya mengurangkan pekali geseran sebanyak 41% berbanding lumpur dasar air tanpa butiran kaca. Penggunaan 4 ppb butiran kaca dalam lumpur dasar air didapati telah menghasilkan sifat-sifat reologi yang optimum dan kehilangan bendalir yang paling rendah jika dibandingkan dengan lumpur tanpa butiran kaca dan lumpur dengan 2 ppb dan 6 ppb butiran kaca. Keputusan uji kaji juga menunjukkan bahawa karbolit mempunyai potensi untuk digunakan sebagai agen pelincir dalam lumpur dasar air.

Kata kunci: pekali geseran; karbolit; butiran kaca; agen pelincir; lumpur dasar air

1.0 INTRODUCTION

Directional drilling and extended-reach drilling have been used widely to bring hydrocarbon up to the surface. Generally, directional drilling is a process of directing the wellbore along some trajectory to a predetermined target, while extended-reach drilling has evolved from simple directional drilling to horizontal, lateral, and multi-lateral step-outs. The extended-reach drilling has become the

[1&2] Department of Petroleum Engineering, Faculty of Petroleum and Renewable Energy Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai.
[*] Corresponding author : issham@petroleum.utm.my

focused of oil operators due to its ability in achieving horizontal well departures and also total vertical depth-to-deviation ratios beyond the conventional hole.

But, it is found that the torque and drag has become a major issue in accomplishing an extended reach drilling [1, 2]. The torque and drag arises from the frictional forces which occur between casing or the rotating drill string and the wellbore. Generally, analysis of torque and drag from drilling operations revealed that friction factors can be simplistically grouped based on type of surfaces in contact, such as cased hole or open hole and the types of mud, namely mineral oil, synthetic oil, or water based [3].

The use of oil-based mud as drilling fluids has been proved that it can improve the mud lubricity, but it becomes environmentally unacceptable due to its immiscibility problem with water. Thus, water-based mud is still reconsidered as a major drilling fluid but with addition of additives in order to have the same effectiveness as oil-based mud. Finding the best technique to mitigate the effect of torque and drag in water-based mud becomes more critical as more new and matured fields require extended reach drilling. It was found that many different techniques have been used to reduce torque and drag, such as using either chemical liquid or solid particles [4].

Chemical liquid lubricants need to form a strong and continuous film on a metal surface in order to mitigate the effect of torque and drag [5]. Nevertheless, the use of chemical liquid lubricants may cause a concern to environment. Thus an effort has been taken to use inert and environmental-friendly solid particles, such as glass beads. These solids move to produce a planar ball or roller bearing effect in the mud to keep the metal-to-metal or metal-to-rock interface from occurring [4]. Besides, the solids movement minimizes the frictional forces between them. Therefore, in this research work, an effort was initiated to examine the effect of glass beads as lubricating agent in water-based mud.

2.0 MATERIALS AND EXPERIMENTAL SYSTEM

The discussion of this segment comprises the materials and experimental system.

2.1 Materials

The water-based mud was prepared with the addition of glass beads as lubricating agent. Glass beads (is also known as microbeads) was considered in this research work due to its ability to produce a planar ball or roller bearing effect when moving in the mud which can keep the metal-to-metal or metal-to-rock interface from occurring. This solid movement is believed to have the ability to minimize the frictional forces between them. Generally, glass beads are spherical and made of oxide. It is noncombustible and compatible with all extinguishing media.

Carbolite which is widely used as proppant in hydraulic fracturing was also considered in this research work in order to reduce the coefficient of friction (CoF). It has a specific gravity of 2.71. The bulk density and specific gravity is similar to sand.

The water-based mud was prepared as per the field formulation, as shown in the Table 1. Table 2 shows the function of respective mud additives used in the mud system.

Table 1 Water-based mud formulation

Additives	Concentration
Water	0.85 bbl/bbl
Barite	As required
Potassium chloride (KCl)	30 lb/bbl
Caustic soda (NaOH)	Up to pH 9.0
Bentonite	0.75 – 1.0 lb/bbl
Hydro-PAC	1 – 3 lb/bbl
Hydro-STAR	4 – 8 lb/bbl
Glass beads/Carbolite	4 ppb

Table 2 Functions of the mud additives

Additives	Function
Water	Base fluid
Barite	Weighting material
Potassium chloride (KCl)	Water activity or cation exchange
Caustic soda (NaOH)	Alkalinity control
Bentonite	Viscosifier
Hydro-PAC	Filtration loss control
Hydro-STAR	Filtration loss control
Glass beads/Carbolite	Lubricant

2.2 Experimental System

This research study comprised two processes:

(1) Mud preparation.
(2) Lubricity analysis via LEM-4100 and Fann Lubricity Tester

2.2.1 Mud Preparation

The base mud was prepared as per the formulation highlighted in Table 1. Glass beads were then added into the base mud as lubricating agent in order to reduce the CoF. Five groups of different sizes of glass beads were used, namely 99-163 µm, 74-120 µm, 48-83 µm, 35-58 µm, and 22-35 µm. The intention of using these ranges was to complement the roller bearing effect produced by each of the size [6]. Carbolite of size 600 µm, which is widely used as proppant in hydraulic fracturing, was also considered in this research work.

All the water-based mud samples were prepared in the Drilling Laboratory of Universiti Teknologi Malaysia, and their mud rheological properties were measured and tested according to the American Petroleum Institute (API) standards [7]. The standard equipment used for the measurement of mud rheological properties was mud balance, rheometer, and low pressure filter press.

2.2.2 Lubricity analysis via LEM 4100 and Fann Lubricity Tester

The CoF of each mud was measure using two equipment: LEM (Lubricity Evaluation Monitor)–4100 and Fann Lubricity Tester. The LEM (Lubricity Evaluation Monitor)–4100, which comprised a rotating bob, housed in a small pressure vessel, used for lubricity testing of oil well drilling and completion fluids at surface and downhole temperature and pressure conditions. In the system, a sample of steel casing, rock, or quartz was forced against the rotating bob at a controlled contact force, and the torque required to rotate the bob at the set rpm was measured. The objective of the test was to compare the relative lubricities by comparing the corrected torque and calculated friction coefficient at similar conditions of different fluids and additives.

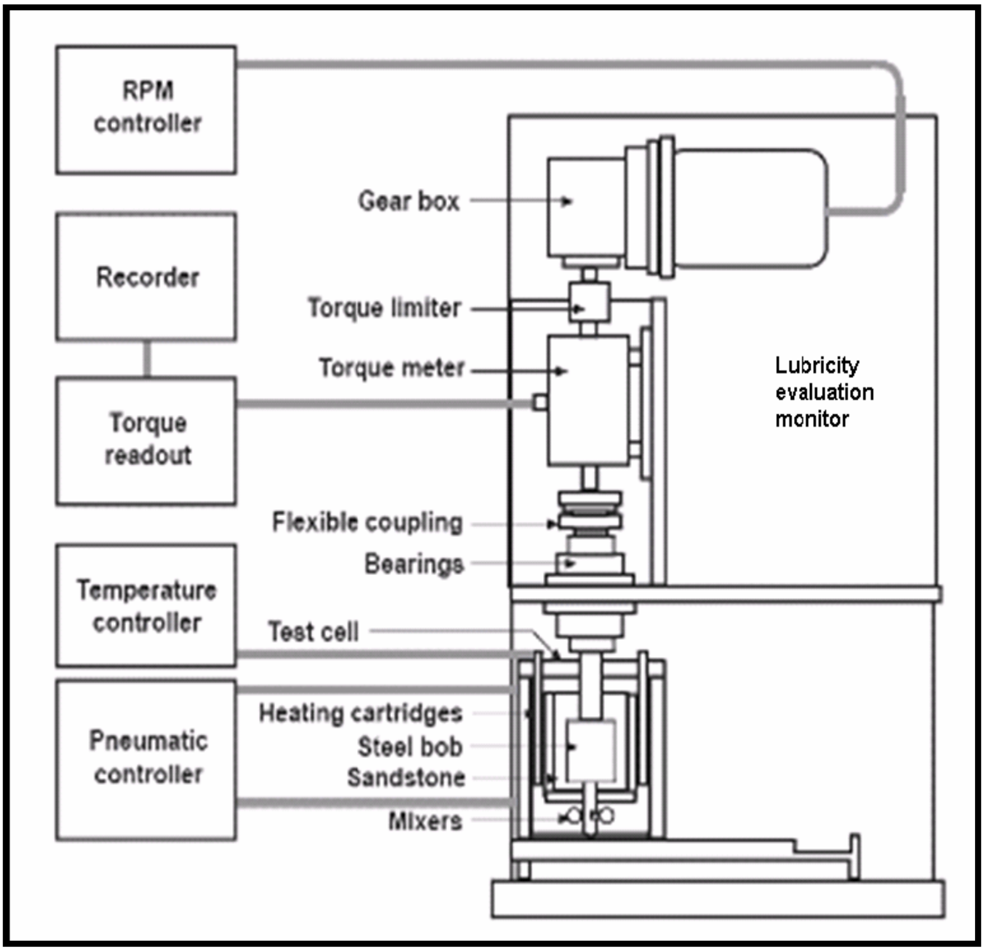

Figure 1 LEM-4100

The equation [8] used to calculate the friction coefficient measured by this equipment was:

$$\mu = \frac{T}{r.F} = \frac{T_{corr}}{\left(\frac{D_{BOB}}{2}\right)F_{corr}}$$

where,

μ	=	Friction coefficient, dimensionless
T	=	Applied torque
r	=	Radius of round rotating tool
F	=	Applied force between two surfaces
$Tcorr$	=	Corrected torque, in. lbsf.
D_{BOB}	=	Diameter of bob, inches
$Fcorr$	=	Corrected external contact force, lb.f, or
	=	Corrected internal contact force, lb.f.

The second equipment used to measure lubricity was the Fann Lubricity Tester, Model 212 EP/Lubricity Tester. The unit approximates the speed of rotation of the drill pipe and the pressure with which the pipe bears against the wall of the hole where the friction is generated [9]. The lubricity can be calculated using the following equation:

$$\text{Coefficient of friction} = \frac{\textit{Torque Reading}}{100}$$

with the instrument set at 60 RPM and a pressure of 100 lbs.

The lubricity effect of each of the mud with different glass beads size, and also with carbolite, was then evaluated by comparing with base mud.

3.0 RESULTS AND DISCUSSION

The experimental results were discussed as follows:

(1) Rheological properties
(2) Coefficient of friction (CoF)

3.1 Rheological Properties

The selected mud weight used was 9.7 ppg. Even though glass beads and carbolite were used with different concentrations, the mud weights of these samples were kept constant at 9.7 ppg (Figure 2). Discussion was focused on the glass beads of

48-83 μm because it gave the best lubricity performance, which was highlighted in Section 3.2.

Figure 3 shows the plastic viscosity of various concentrations of glass beads in water-based mud. The plastic viscosity for mud without glass beads was found to be comparable to mud with 2 ppb glass beads. This was due to the small quantity of glass beads present in mud which was insufficient to affect the plastic viscosity. As glass beads concentrations increased, plastic viscosity of the mud increased but was still in the recommended value used by industry (i.e., 20 cp) in order to prevent excessive friction [10]. These results were in good agreement with Skalle *et al.* [11] which mentioned that the presence of glass beads would increase plastic viscosity.

The values of yield point for 2 ppb, 4 ppb, and 6 ppb muds with glass beads were 20 lb/100 ft^2, 29 lb/100 ft^2, and 31 lb/100 ft^2 respectively as shown in Figure 4. These values increased with the concentration of glass beads. However, these yield point values were found to have exceeded the recommended minimum yield point, which is more than 20 lb/100 ft^2. Higher yield strength is needed with respect to the gel strength so that the mud becomes very thin in flow shear.

It is interesting to note that the presence of glass beads in the mud increases the solids content in the mud and consequently moves the particles closer together, and thus increases the attraction between particles. This phenomenon results in higher yield point value. It is crucial to have yield point around 30 lb/100 ft^2 in the deviated hole in order to maximize hole cleaning. Generally, deviated holes are the most difficult to clean due to the tendency of drill cuttings to form beds and slide back down to the hole due to the gravity effect [12].

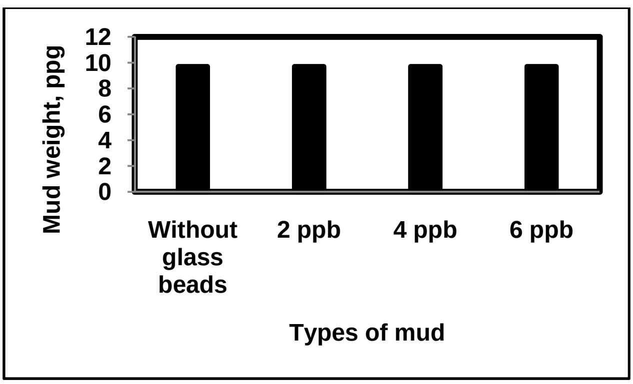

Figure 2 Mud weight for different 48-83 μm glass bead concentrations

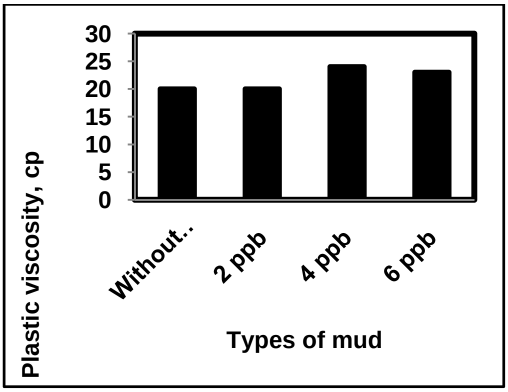

Figure 3 Plastic viscosity for different 48-83 μm glass bead concentrations

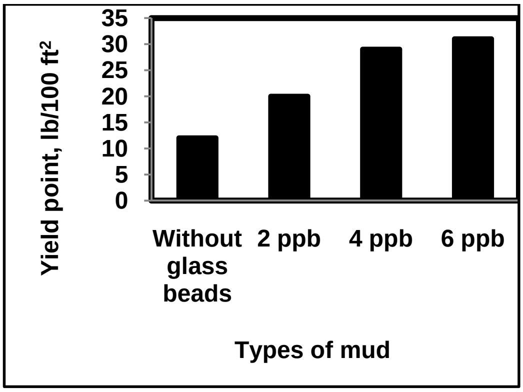

Figure 4 Yield point for different 48-83 μm glass bead concentrations

Figure 5 shows the gel strengths for both 10 seconds and 10 minutes. The 10 seconds gel strengths for 2 ppb, 4 ppb, and 6 ppb mud samples were 2 lb/100 ft^2 respectively. While for 10 minutes, the gel strengths for 2 ppb, 4 ppb, and 6 ppb were 2 lb/100 ft^2 respectively. The experimental results revealed that there was no much effect when adding the glass beads even though the concentration is increasing.

This phenomenon was due to lower specific gravity of glass beads, i.e. 2.5g/cc, as compared to barite. But Brister *et al.* [13] highlighted that additional bentonite was needed in order to increase gel strength to ensure the glass beads were held in suspension under static conditions. Thus, the amount of bentonite added was sufficient to suspend all glass beads which were supporting the result, where there were no changes in gel strength as the concentration of glass beads increased. It is interesting to note that these values were in good agreement with Lummus *et al.* [14], which stated that initial gel strengths between 2-8 lb/100 ft^2 were sufficient

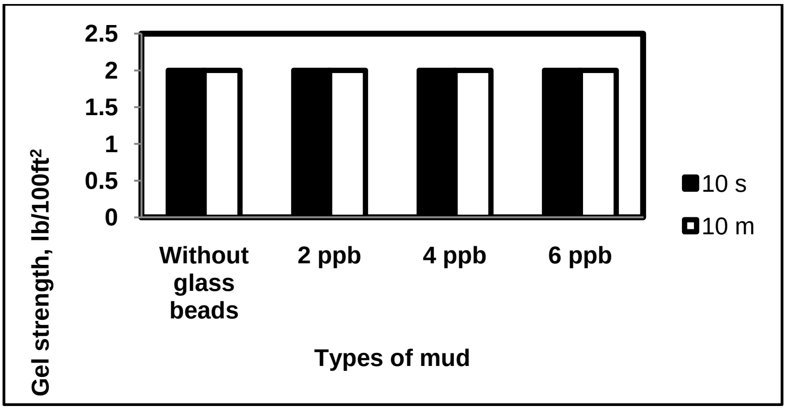

Figure 5 Gel strength for different 48-83 μm glass bead concentrations

Figure 6 shows that mud with 2 ppb, 4 ppb, and 6 ppb produced filtrate loss of 10.2 ml, 8.0 ml, and 12.4 ml respectively. The experimental results revealed that the amount of solids presence in the mud influenced the filtration volume. The 48-83 μm glass beads, especially 4 ppb, was found to have resulted in lower filtrate volume as compared to the mud without glass beads. It showed that the glass beads succeeded in forming an initial seal on the largest pore openings and in filling the spaces between larger particles deposited on a *permeable formation*.

The volume of filtrate for 2 ppb glass beads mud was found to be higher due to the insufficient quantity of glass beads used. But, 6 ppb glass beads showed the highest volume filtrate loss because the glass beads inclined to concentrate and pack in the mud. This phenomenon created spaces between the glass beads, thus producing a permeable and porous mud cake. Generally, filtrate loss should be low enough, if possible less than 5 ml/30 min, to prevent excessive cake thickness and consequently reducing the chances of differential pressure sticking [5].

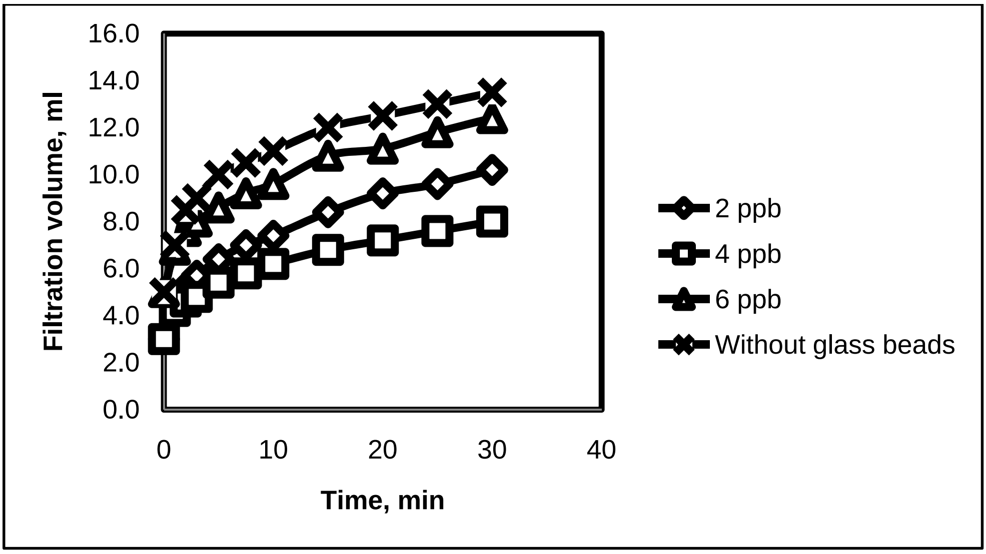

Figure 6 Filtration volume for different 48-83 μm glass bead concentrations

3.2 Coefficient of Friction (CoF)

The value of coefficient of friction (CoF) for every experiment was evaluated based on the trend of the value for an elapsed time of 2.5 minutes. This experiment was conducted using 4 ppb of glass beads mud and steel to rock surface as a stationary sample. Figure 7 shows the overall values of CoF for all prepared muds. All of the values were obtained after tested for the suggested time. Based on Figure 7, overall curves showed inconsistent curve due to high rotation speed used, i.e 250 rpm. Moreover, different sizes of glass beads in the given range of size added in the mud also influenced the results. Next, mud without glass bead showed a decreasing trend in the range 8.8 until 6.5. This is because the presence of barite as a weighting material. Apparently, this barite forms a dynamic bearing between tool joint and wellbore, and contributes to the reduction of CoF but does not produce a dramatic effect. This statement was supported by Aston *et al.* [3].

Generally, all the mud samples with glass beads experienced a reduction in CoF. These experimental results revealed the effectiveness of glass beads as lubricating agent in water-based mud. But, the best glass bead size that gave the optimum performance consistently in reducing CoF was 48-83 μm with the reduction 41%. This was due to the creation of optimum standoff distance for pressure communication and flow. Furthermore, this standoff could reduce the overall frictional surface area by forming a slippery layer between the borehole and the drill string.

The 74-120 μm glass beads could reduce friction (i.e., with up to 68%) initially but would get crushed easily as 600 μm carbolite at later stage. The 99-163 did give a consistent result but could not reduce CoF significantly and was found to have performed quite comparable to mud without the glass beads. In that mud, most of the glass beads had been crushed during the initial stage of lubricity analysis and this process continued till the end of the experiment. The smaller glass beads, i.e 22-35 μm and 35-58 μm, were found to decrease in CoF for about 33% and 9% respectively, but tend to get buried easily in the filter cake at later stage.

An effort was taken to compare the lubricity effects using the Fann lubricity tester. The experimental results (Figure 8) from Fann lubricity tester showed that the lubricity values were comparable for all the mud samples. It proved that the Fann lubricity tester was not suitable for measuring the lubricity of solids lubricant but might be effectively in measuring liquid lubricants. The latter equipment does not allow particles to enter between the block and rotating ring which a serious limitation is considering that drilling mud comprises particles like barite [13].

Figure 9 shows the comparison between glass beads and carbolite with steel to rock surfaces. It showed that there was a significant reduction of CoF (i.e. 67%) when adding carbolite into water-based mud while the glass bead measured 41% reduction compared to the mud without glass beads. The size carbolite and glass beads used in this experiment were mostly 600 μm and 48-83 μm (i.e. the best size) respectively. The findings showed that the carbolite [16] has the potential to be used as a lubricating agent in water-based mud due to its tougher physical characteristics. It is interesting to note that there was no research supports the use of the proppant as a lubricating agent in drilling mud and this might be due to its price.

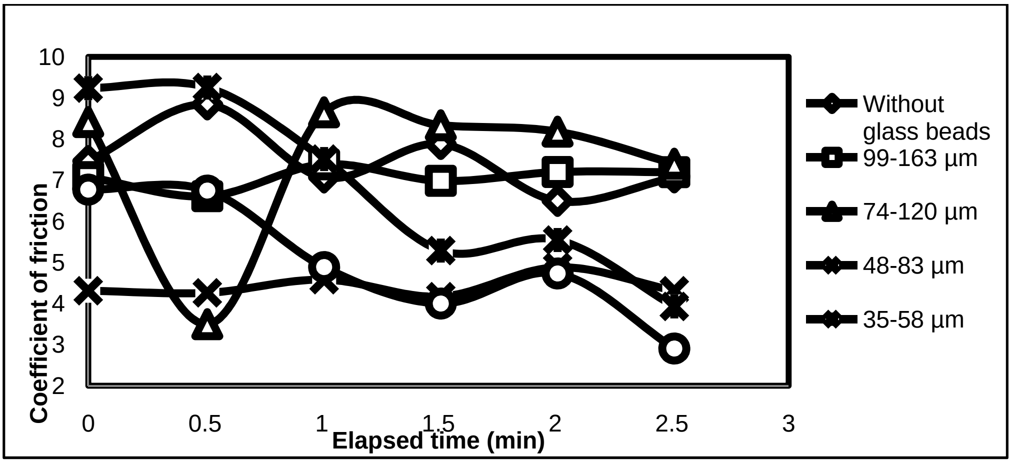

Figure 7 Coefficient of friction vs elapsed time

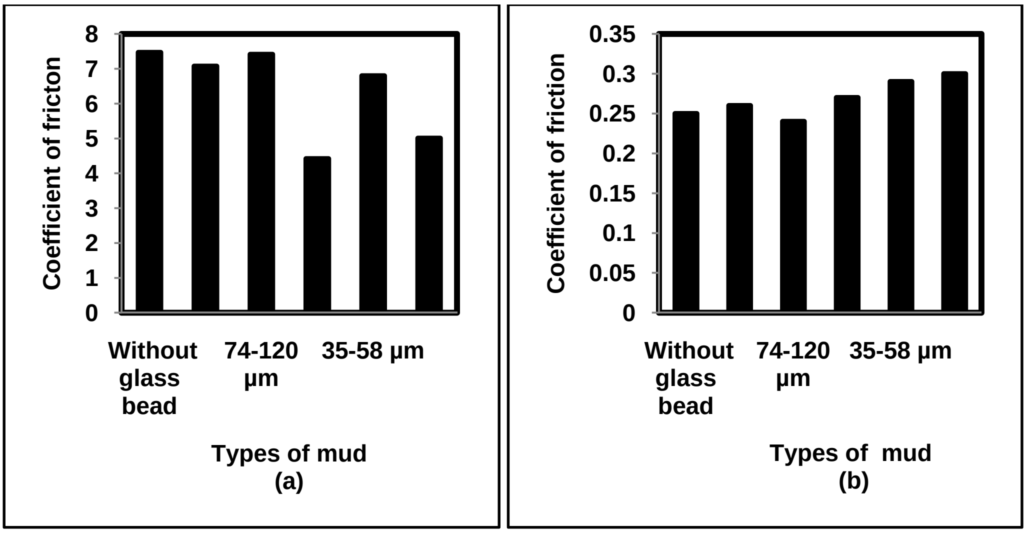

Figure 8 Average coefficient of friction value using (a) LEM-4100, and (b) Fann lubricity tester

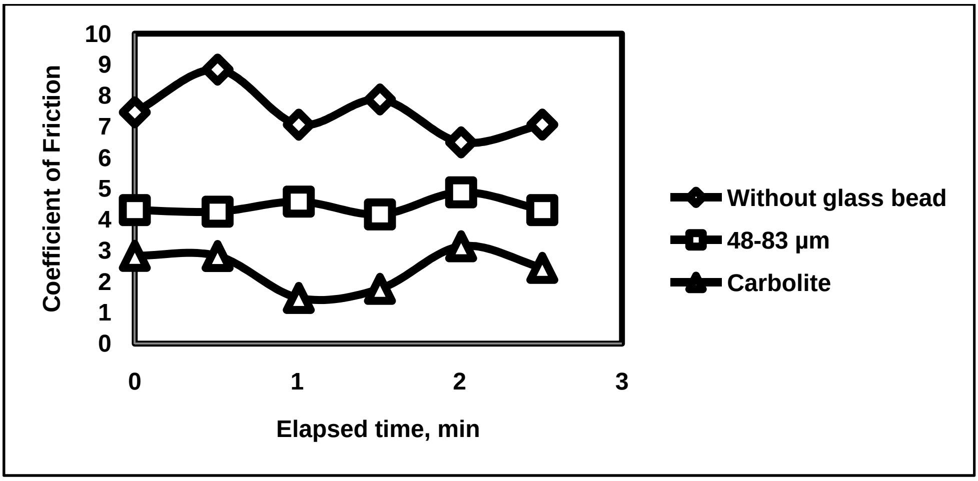

Figure 9 Comparison the coefficient of friction between glass beads and carbolite

4.0 CONCLUSION

The following conclusions were derived from this research study:

(1) This research work revealed that the optimum size of glass beads in water-based mud in reducing the coefficient of friction was 48-83 µm with 41% of frictional reduction.

(2) The rheological properties of water-based mud with 48-83 µm glass beads were found to within the recommended values.

(3) The CoF values produced by LEM-4100 were to be more accurate and reliable.

(4) Carbolite gave 67% reduction of CoF compared to mud without glass beads. The experimental results showed that glass beads and carbolite have the potential to be used as lubricating agent but price factor may hinder the use of carbolite.

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