Petroleum and Coal

Article Open Access

Experimental Investigation of the Coefficient of Friction for Boric Acid and Henna Leaves as Alternatives to Commercial Water-Based Drilling Fluid Lubricants

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Received November 9, 2023; Accepted February 1, 2024

Abstract

Drilling fluids play an essential role in various drilling operations, including hole cleaning, lubrication, and maintaining wellbore integrity. The coefficient of friction is a vital parameter which effect the efficiency of drilling fluids. High coefficient of friction will increase torque and drag, reduced drilling rates, and cause formation damage. Experiments were conducted to evaluate the coefficient of friction of boric acid and henna leaves under various conditions, including different concentrations, HPHT filtration, and rotational speeds. The results were then compared to those of commercial lubricants (Radiagreen EME salt and Radiagreen EBL). It was observed the increasing of the additives concentrations resulted in reduction in the CoF of the WBM. When adding henna leaves with both sizes and boric acid, the CoF reduced further. However, 100 µm henna leaves showed more prospective reduction of CoF of WBM. It was found that the addition of 100 µm henna leaves reduced the CoF up to 11.4%. However, boric acid showed 7% reduction only. By comparing between the CoF values when taking the reading of the CoF after 5 minutes for the commercial lubricants, henna leaves, and boric acid, it was concluded that henna leaves are considered to be compatible in term of lubricity. The gel strength was slightly increased as a result of adding the additives except for Radiagreen EBL, the gel strength pattern showed almost a flat line. This suggests that Henna leaves & boric acid are less likely to alter the desired properties of drilling fluids. Based on the experimental findings, Henna Leaves & Boric Acid emerges as a promising alternative to commercial lubricants for reducing COF and enhancing drilling performance.

Keywords: *Henna Leaves; Boric acid; Radiagreen EME salt; Radiagreen EBL; Coefficient of friction; Drilling fluids; Lubrication.*

1. Introduction

Nowadays drilling operations and conditions have changed not only conventional vertical wells but also deep harsh directional wells, due to the increasing demand for oil and gas. In order to overcome the problems of these conditions the development of drilling fluid was a must, as it is one of the main components of the drilling operation. Drilling fluid is a mixture that consists of solids, liquids and gases distributed through a gaseous or liquid phase, which is used during the drilling operation as it is circulated through the wellbore. Drilling fluids consist of a fluid base which can be aqueous or gaseous, and according to the function of the mud to be used, additives are added to enhance the performance or solve any problems may occur in the future. In general drilling fluids in petroleum industry could be categorised according to the basis of the base fluid into three main groups: pneumatic drilling mud, water based mud (WBM), and oil based mud (OBM). In order to assess the drilling tools during the drilling operation, drilling fluids should have some requirements or functions without damaging the environment [1].

Water based mud (WBM) is the first drilling fluid used in drilling operation and it is considered the most commonly drilling fluid in the oil and gas sector. Water is the continuous phase in which minerals are dissolved. In any water based mu system the base fluid which consists of 90% of fresh water, seawater or brine with inert solids and chemical additives. The selection of additives are depending on the dispersive materials, formation to be drilled, environment and cost [2].

In order to cover the increasing demand of crude oil, the need of more complicated procedures to explore and produce oil and gas, has made drilling operations more complex. Directional drilling and extended reach drilling (ERD) are now applicable in many fields around the world, which make it an essential to choose the best additives to design a proper drilling fluid that can overcome the problems arising, such as torque and drag forces.

Drag and torque are the result of some sources, for instance more friction resulting between the drill string and the borehole, hole cleaning issues and wellbore tortuosity. Overabundance torque and drag are mainly raised by the friction between drill string and wellbore. Hole tortuosity and profiles determine the intensity of the friction. The frictional forces which will occur between the wellbore and the tubular depends on the coefficient of friction (CoF) between the two surfaces. When the cuttings are trapped this results in resistance that restrain the drilling string rotation and penetration; consequently developing surface torque. Subsequently, cautions must be considered in order to control the drag and torque within the safety limitations. By decreasing drag and torque several significant improvements on drilling operations will be achieved, such as higher rate of penetration (ROP) and improving in drilling interval [3].

Torque and drag are dependent on the coefficient of friction (CoF) that will occur between two surfaces such as wellbore and drilling pipe. The higher the CoF is, the higher the forces needed to free the tubular. Consequently, a solution for this problem should be introduced to prevent any damage may be caused to the equipment. One advantage of OBM and SBM that they produce low CoF and more stabilizing characteristics [4].

However, the usage of OBM and SBM are not recommended because of the cost and environmental issues even though they give lower CoF than WBM. Furthermore, the usage of various lubricants with WBM is considered as an effective choice to give low CoF. These lubricants can be solid or liquids. Solid lubricants such as glass beads act like a ball bearing which interfere with the surfaces of the two bodies without bonding on them. For the liquid lubricants, they form a thick film to cover the surface, the concentration of these lubricants will affect their performance [5,15].

It was known that the best idea to decrease the surface torque is to use oil based mud (OBM) or synthetic based mud (SBM) instead of water based mud. On the other hand, it can also be possible to achieve a minimum surface drag and torque by decreasing the friction causes parameters by adding proper mud additives to water based mud (WBM). Researchers have found that it can be possible to minimize the torque force up to 24% by adding proper drilling mud additives to the water based mud. The mud formation type selection, whether water based or oil based lies on the economic and environment considerations.

As a result of a relative motion between some parts of any machine it was found that there are to be rubbing between the parts and against each other. The parts compress together with significant force, hence, lubricants are used between the two surfaces to prevent them from damage. Furthermore lubricants are used if the metallic surfaces need cleaning, heat is produced by the high speed of rubbing, if not then the dynamic parts scraping against each other will be damaged over time and the cost of maintenance and replacing parts will increase. In addition, the lubricants can be in a solid or liquid form.

Solid lubricants are commonly used as a fact that soft solids or liquids cannot be used properly such lubricants are like glass beads or boric acid . Solid lubricants can prevent the occurrence of the interface between metal and rocks or metal and metal. Furthermore, using lubricants reduce the CoF and contacts. Solid lubricants can then be mixed to improve their efficiency with oil, water or grease. Solid lubricants sometimes considered a better option than liquid lubricants, and that is because of the better performance which is independent of the efficiency of the film produced by the liquid lubricants [4,9].

Liquid lubricants are another type of lubricants that are chemically liquid These lubricants are categorized to adhere to the surface of a metal or a rock and form a firm and continuous film over these surfaces. They act to reduce the CoF between the sliding surfaces [6]. However, many studies proved that in many cases this film is destroyed and being emulsified by the presence of even small oil droplets which results in its removal. Knox and Jiang stated in their study that the environmental restrictions and the technical performance are controlling the criteria of choosing the correct lubricants for water based drilling mud. There are many commercial lubricants which are widely used in the industry, such as Radiagreen EME Salt and Radiagreen EBL. However, they have some drawbacks in terms of their cost compared to other alternatives [7,15].

The effect of chain length on the coefficient of friction (CoF) was experimentally studied by Jahanmir [8]. It was noticed that the kinetic coefficient of friction was reduced linearly with the increasing in the carbon chain length to (C8). At higher molecular weights, the coefficient of friction remained independent of chain length. Murray and Burwell obtained the same results, with the no expecting results that a larger chain length of (C10) was essential for minimum coefficient of friction [13]. Reduce the friction in WBDFs can decrease friction between the drill pipe and wellbore, allowing smoother running and potentially reducing the chance of inducing fractures within the formation that could lead to a kick [20].

Amanullah stated that the ability of nanomaterials can also help in reducing drag and torque problems while drilling deep or horizontal wells. In addition, nanomaterials usage required a very low concentration, hence, thin mud cake can be achieved by Nano based fluids which will not result in any stuck pipe problems, and the ability to form a firm, continuous, and thin lubricating film [10]. The wellbore wall and pipe surfaces participates in decreasing the CoF and hence the reducing the problems countered to the high drag and torque forced [11]. While reducing friction is beneficial, it can also delay the transmission of formation pressure to the surface. This can mask the initial pressure increase of a kick, making it harder to detect promptly [21].

Henna leaves is one of the natural worldwide product which came from the family of Lythraceae. Usually, this henna leaves commercially cultivated in Arab countries, North Africa, Western India which make it very easy to get. Furthermore, some of the fascinating properties of henna leaves are considered anti-corrosion in various metallic mediums and potential eco-friendly fluid loss agent as mentioned above which consists of starch that will enhance the rheological properties by aiding in the gelling process in which will increase the mud viscosity and thus reduces the fluid loss into the formation [12].

Moreover, over the past 30 years, the term dry powder lubricants has been employed in a variety of sliding contacts as an alternative to conventional liquid lubricants. These lubricants, such as boric acid, have excellent lubrication properties without health, economic, environmental, and disposal problems [13-15]. One of the most common naturally found plants in The Middle East is Henna Tree. Henna is one of many flowering plants which can grow 12-15 feet high. Furthermore, it comes from the sole species of the family Lawsonia genus. It is known that the English name "henna" comes from the Arabic word (ḥinnā). The name henna also can be referred to the dye prepared from the henna plant. In addition, the art of a temporary body tattooing based on those dyes . Henna leaves have been used for many centuries as a medicine and also to dye hair, skin, and fingernails, as well as fabrics including wool, silk, and leather [16].

Beyond that, many publications have shown that boric acid can be used as a solid lubricant to reduce the friction coefficient of two sliding surfaces [18]. The observed low friction coefficient of boric acid was assumed to be related to its layered triclinic crystal structure with weak bonding between the layers. During sliding, these layers were aligned parallel to the direction of relative motion and provided a low coefficient of friction as a result of slip between the layers. Boric acid is also used as an additive in cutting fluids for metals to reduce friction, increase corrosion resistance, and control microbial degradation [13-14,22].

2. Experimental

Henna leaves was brought from the Middle East in a form of leaves. Then, drying the leaves under the sun light for three days. After that, grinding the leaves using a grinder and make it into a powder form with separating the finer particles and choosing the required sizes using a sieve.

The characterization of henna leaves sample was conducted in UTM Lab throughout using different tests to know the crystalline structure and chemical composition of henna leaves. Furthermore, The morphology and Energy Dispersive X-ray (EDX) mapping analysis of the sample was examined by Variable Pressure Scanning Electron Microscopy (VPSEM)

2.1. Characterization of Henna leaves sample

The composition of the raw materials which were used in the formulated water based mud (WBM preparation procedures are as following:

1. First 30 g of potassium chloride (KCl) were added to 303 mL of distilled water and blended for 3 minutes by using a mixer.
2. Next 0.2 g of sodium hydroxide (NaOH) was added up into the solution and mixed for 2 minutes.
3. After that 1 g of Flowzan which acted as a viscosifier was added to the previously mixed solution and then stirred for 5 minutes.
4. Then 2 g of Pac UL a fluid loss agent was added to the solution and mixed for 5 minutes.
5. Later Hydro-Cap XP (PHPA) of 1 g was mixed into the solution for 10 minutes.
6. Finally 125 g of barite was added into the solution and stirred using high speed mixer for 30 minutes.

The measurements of the coefficient of friction was done throughout conducting the lubricity test by Fann Extreme Pressure/Lubricity Tester Model 212. The theory that the test was based on is to simulate the metal to metal study which is similar to the situation between the wellbore and the drill string. The instrument was took care of and mad sure to be cleaned from any materials could be left from the calibration processes or previous tests. The following are the normal experimental steps:

1. The prepared mud was stirred for 10 minutes before using.
2. The mud was placed into a cup mad of stainless steel and then put on the cup stand, after that the cup stand was lifted up until the test ring and block test holder were immersed in the mud. The stand was fastened with thumb screw.
3. The rotational speed, rpm was set to 60 which is considered standard and the torque meter was made sure to be zero with no load on the torque wrench.
4. 150 inch pounds (16.95 Nm) was applied. Turn on the machine for 5 minutes as standard procedure.
5. After 5 minutes torque results were reported. After that the torque was released and brought to zero.
6. Repeating Steps 1 – 5 for testing other mud samples.
7. After the test is over the electric source was switched off. The cup was put down. Releasing the torque arm clamp and turned up and far. Removing the test block when the torque arm was swung back.
8. Test block was removed with extreme care and rinsed thoroughly with ionised water. The sample fluid was discarded and cup was washed.
9. Cleanser, such as Comet or Ajax were used with chlorine, to clean the shaft, cup stand, shaft controlling the torque, block holder, test ring and nut.

Coefficient of friction (COF) was obtained by the following equations:

$$coefficient\ of\ friction = torque\ reading 100 \quad (1)$$

When the settings set at a pressure of 100 lbs, and 60 rpm

$$150\ in-lbs\ (torque\ wrench\ reading)/1.5\ inches\ (torque\ shaft\ lever\ arm) = 100 \quad (2)$$

$$correction\ factor (CF) = meter\ reading\ for\ water\ (standard) meter\ reading\ obtained\ in\ water\ calibration = 34 meter\ reading\ obtained\ (28\ to\ 48) \quad (3)$$

$$Lubricity\ coefficient\ of\ friction\ (COF) = meter\ reading\ x\ CF 100 \quad (4)$$

3. Results and discussions

In this study, two types of additives which are henna leaves and boric acid with different concentrations were added to water based mud and the effect on the coefficient of friction through adding different concentrations of henna leaves and boric acid to the water based mud was elaborated and then compared with the commercial lubricants Radiagreen EME Salt and Radiagreen EBL.

Drilling Fluids are normally characterised as non-newtonian fluids, that means the ratio of shear rate to shear stress in not constant. It is indicated that an increasing of shear stress over the shear rate will increase the plastic viscosity of the drilling mud. Figure 1 shows the effect of adding different additives with different concentrations to the water based mud. It can be observed that by adding henna leaves with both sizes (50 µm and 100 µm) until reaching the concentration of 4 g, the trend of the plastic viscosity is increasing as a reason of the attractive forces between the molecules. However, by increasing the concentration further to 6 g the plastic viscosity started to decrease. In addition, by increasing the concentration of boric acid the overall trend of the plastic viscosity increases. Consequently, henna leaves and boric acid are hydrophobic and tries not to exit from the mud which results increasing in the plastic viscosity of the mud.

Figure 1 shows a comparison between green technology additives (henna leaves and boric acid) and the commercial lubricants (Radiagreen EME Salt and Radiagreen EBL). It can be seen that the overall trend of plastic viscosity of the commercial lubricants are increasing with nearly the same value of the plastic viscosity. Furthermore the plastic viscosity of EME and EBL is slightly low compared to henna leaves and higher than boric acid

Figure 2 shows the effect of adding different additives to the water based mud on the yield point trend. It can be noticed that by adding henna leaves to the water based mud with both sizes the trend of yield point is increasing significantly, and the maximum yield point was achieved by adding 6 g of henna leaves with the size of 100 µm (51 lb/100ft^2). In the case of the addition of boric acid, the yield point trend is slightly increasing compared to henna leaves. The yield point trend for Radiagreen EBL is almost flat and gives the lowest yield point (28 lb/100ft^2). However, the addition of Radiagreen EME Salt to the water based mud results in a rising trend at first until reaching the point of 4 g concentration, and then by increasing the concentration to 6 g the value of the yield point is reduced. The explanation of the rising trend of the yield point can be indicated by the attractive forces in mud system. In general it can be said that all of the additives are producing attractive forces, and by increasing the concentration the solid started to accumulate which leads to the increase of the yield point. The high yield point of the drilling system is efficient in terms of providing dynamic suspension of drilling cuttings and effective wellbore cleaning while drilling process, which decrease the drilling problems and cost

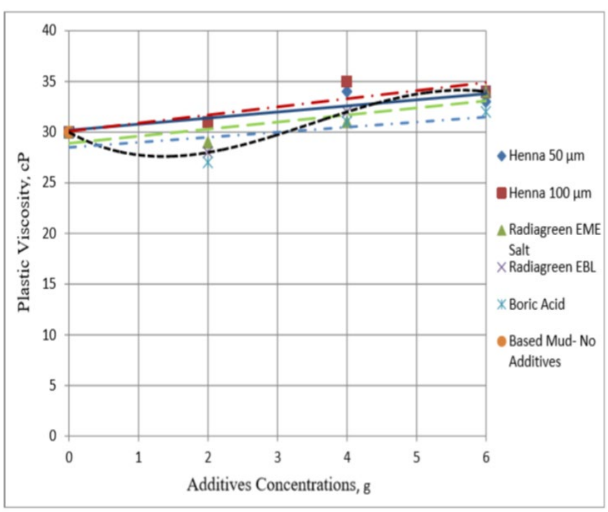

Figure 1 Effect of additives concentrations on plastic viscosity in WBM

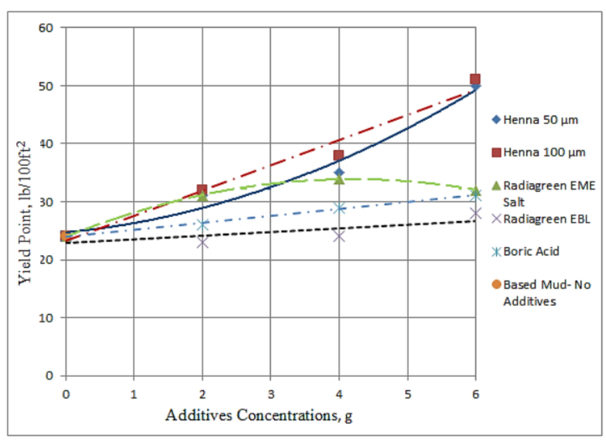

Figure 2. Effect of additives concentrations on yield point in WBM.

The effect of additives concentrations on gel strength 10-sec is shown in Figure 3. For the water based mud with 100 µm henna leaves, 10-sec gel strength has increased sharply as the concentration was increased. In addition, the trend of 50 μm henna leaves and boric acid is almost the same and also has increased but slightly lower compared to 100 μm henna leaves trend. In the case of the addition of Radiagreen EME Salt, 10-sec gel strength has increased at first, and after the addition of 2 g Radiagreen EME Salt the trend is almost constant. On the other hand, by increasing the concentration of Radiagreen EBL the 10-sec gel strength did not change and the trend was almost flat.

Figure 4 shows the effect of additives concentrations on 10-min gel strength. It can be observed that the trends of henna leaves with both sizes and boric acid all have increased. Furthermore, it was found that the water based mud with 6 g of 100 μm henna leaves indicated the highest value of 10-min gel strength (14 lb/100ft^2). The overall trend of Radiagreen EME Salt was increasing, and it can be explained that the point of 4 g concentration of Radiagreen EME Salt gave a lower reading could be due to experimental error. The increase in gel strength can be resulted due to the attractive force introduced by the additives mentioned above to link with the based mud to form a rigid structure. On the other hand, the addition of Radiagreen EBL shows a straight horizontal trend which means that the increase in the concentration of Radiagreen EBL has no major effect on 10-min gel strength.

Generally, it is noticed that the 10-min gel strength is higher than 10-sec gel strength, which infers to the ability of the designed mud system to retain the gelling effect after certain duration of rest like 10-min and hence its ability to suspend the weighing materials and cuttings in the wellbore

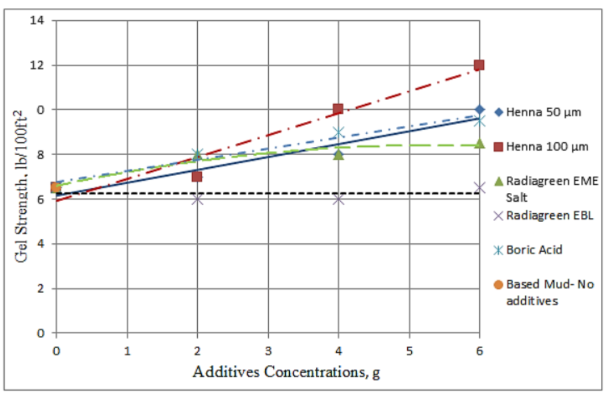

Figure 3. Effect of additives concentrations on 10-seconds gel strength in WBM.

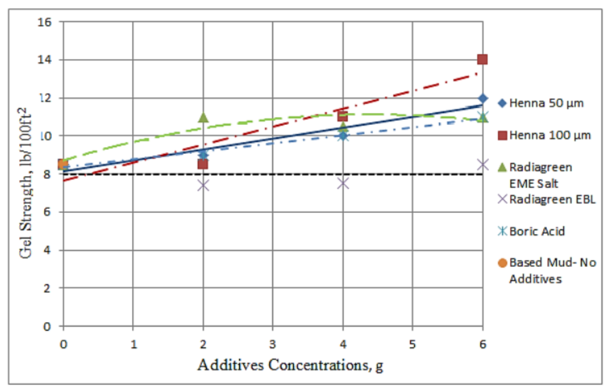

Figure 4. Effect of additives concentrations on 10-minutes gel strength in WBM.

Filtration property is dependent upon the physical state of colloidal materials which are used in the mud system. Fluid loss and specifically the spurt loss of the drilling mud is one of the major problems that can cause serious problems to the production zone. Filtration invasion into the formation can cause blockage of the pores as a result of the mud cake formation around the wellbore, and hence reduce the permeability and the ability of the desired flow from the formation interval.

The fluid loss after 30 minutes of the water based mud with different additives and concentrations is shown in Figure 5. It can be noticed that the overall trend of the fluid loss of the additives is declining by increasing the concentration and gives lower values of fluid loss compared to the water based mud with no additives. The illustration behind that could be the addition of the additives Henna 50 with different particles sizes filled and blocked the micro and macro sized pores of the mud cake and prevent the filtrate to be lost [19]. By comparing the two sizes of henna leaves, it can be observed that by increasing the concentration, 100 μm henna leaves gave a lower trend of fluid loss than 50 μm henna leaves. Furthermore, by adding 6 g of 100 μm henna leaves to the water based mud, the minimum fluid loss can be achieved (4.4 mL), as a result of the different particles sizes of henna leaves used, which proves the results that were obtained from the characterization. When Radiagreen EME salt and boric acid are added to the water based mud, both additives had almost the same fluid loss trend and the fluid loss was reducing by raising the concentration. On the other hand, the fluid loss with the usage of Radiagreen EBL has reduced with increasing the concentration to 2 g which is the optimum value of fluid loss, and by adding more concentration of Radiagreen EBL there was no further effect on the fluid loss and the trend was flat.

Figure 6 shows the illustration of the effect of different concentrations of the mud additives on the mud cake thickness. When 50 µm henna leaves, boric acid and Radiagreen EBL were added to the based mud the trends are almost the same and the mud cake thickness increased by increasing the concentrations. This implies also that, the thicker the mud cake, the less fluid to be lost. The explanation can be due to the fact that when the mud cake thickness is higher, it fills the pores and prevents the fluid to be lost. In the case of adding 2 g of 100 µm henna leaves, the mud cake thickness did not change. However, when increasing the concentration to 4 g the trend of the mud cake thickness increased. On the other hand, by adding 2 g of Radiagreen EME Salt to the water based mud the mud cake thickness increased to the optimum value, but after adding the concentration of Radiagreen EME Salt, the value of the mud cake thickness reduced slightly.

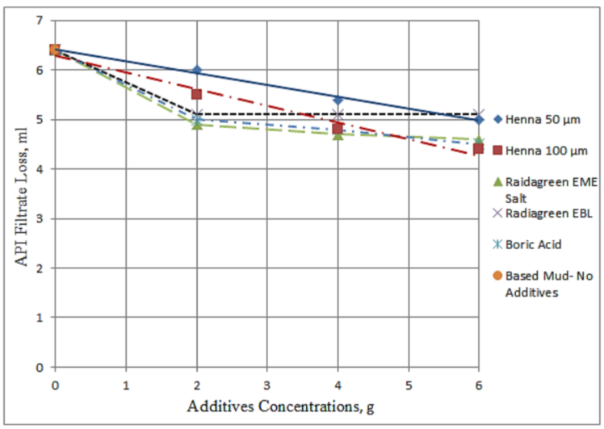

Figure 5. Effect of additives concentrations on api filtrate loss after 30 Minutes in WBM.

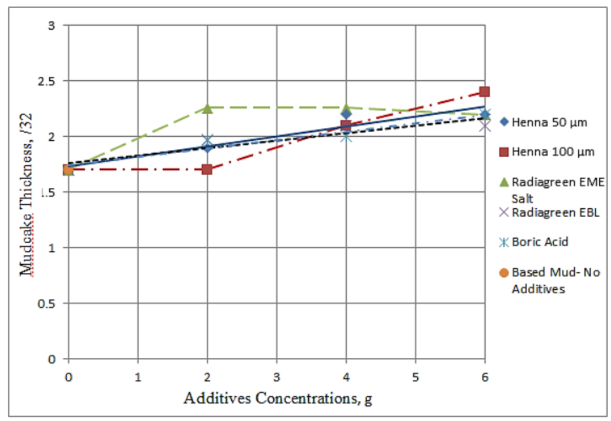

Figure 6. Effect of additives concentrations on mud cake thickness in WBM.

The filtration volume was collected and measured after 30 minutes in HPHT static filtration test by using HPHT filter press. Figure 7 shows the effect of different additives concentrations on HPHT filter loss. The HPHT fluid loss trends for henna leaves with both sizes were decreasing by increasing the concentration of henna leaves added to the water based mud and the lowest value of HPHT fluid loss can be obtained by adding 6 g of 100 µm henna leaves to the water based mud (9.2 mL). On the other hand, Radiagreen EME Salt addition to the water based mud caused an increase in the HPHT fluid loss, and the highest HPHT fluid loss was achieved by increasing the concentration of Radiagreen EME Salt in the water based mud to 6 g (11.5 mL).

In the case of adding Radiagreen EBL to the water based mud a constant trend of HPHT fluid loss was observed which means there was almost no effect on the HPHT fluid loss when increasing the concentration of Radiagreen EBL. However, by increasing the concentration of boric acid from 0 g to 2 g, the HPHT fluid loss trend increased, but by adding more concentration of boric acid the value of HPHT fluid loss reduced. That could be explained by increasing the concentration of boric acid more particles filled and blocked the pores of the mud cake and prevented the filtration to be lost

Figure 8 shows the effect of adding different additives with various concentrations to the water based mud on the coefficient of friction (CoF). The metal to metal friction was done to simulate the friction produced between the drilling tabular and the wellbore. The values of CoF were taken after 5 minutes.

It was observed that before adding the additives to the water based mud, the CoF was about 0.254. Furthermore, the addition of henna leaves and boric acid with different concentrations enhanced the lubricity and reduced the CoF. When raising the concentration of boric acid, the value of CoF reduces linearly, and by increasing the concentration of boric acid to 6 g in the water based mud the reduction percentage of CoF was 7%. This can be a further evidence to the findings by Erdemir [13-14,18]. On the other hand, henna leaves with both sizes gave a better result, and the maximum CoF. Reduction percentage was achieved by adding 6 g of 100 μm of henna leaves (11.4%). This could be illustrated by the effect of the length of the carbon chain on the CoF [8]. Furthermore, EDX test has proved that henna leaves additives consist of a significant percentage of carbon. In the case of the commercial lubricants, it was noticed that Radiagreen EBL is slightly better in term of lubricity than Radiagreen EME Salt and at the concentration of 6 g of Radaigreen EBL the minimum CoF was reported (0.194), with a reduction percentage of (23.6%). Comparing between the CoF values when taking the reading of the CoF after 5 minutes for the commercial lubricants, henna leaves, and boric acid, it was concluded that henna leaves are considered to be compatible.

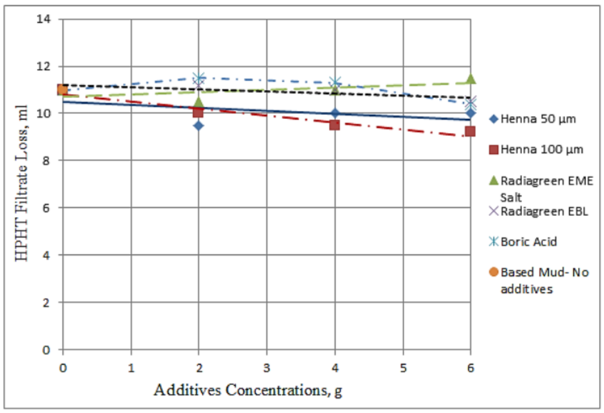

Figure 7. Effect of additives concentrations on HPHT filtrate loss after 30 Minutes in WBM.

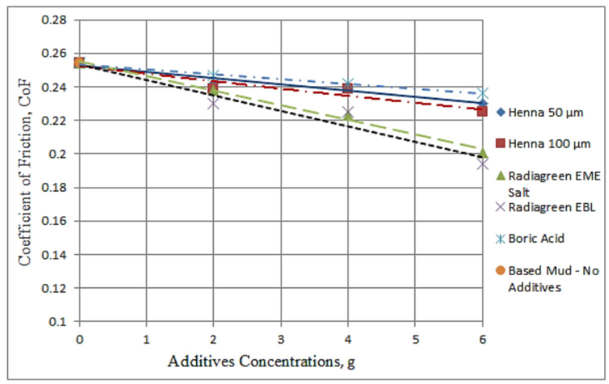

Figure 8. Effect of additives concentrations on coefficient of frication after 5 Minutes in WBM.

The effect of adding different additives in water based mud on the CoF after 30 minutes are shown in Figure 9. It can be observed that after sometime the values of CoF of the commercial lubricants changed widely. In contrary, for henna leaves and boric acid, the values changed slightly. This can be illustrated by the effect of heat that was generated in the mud as a result of the shear and friction forces.

The relation between time and the CoF when adding different additives with 2 g concentration is shown in Figure 10. It can be seen that as the time elapsed, the values of CoF reduced. This can be explained by the fact that it needs time to the structured layers of the additives to be aligned parallel to the direction of the relative motion during sliding and provided a lower coefficient of friction [13-14,18].

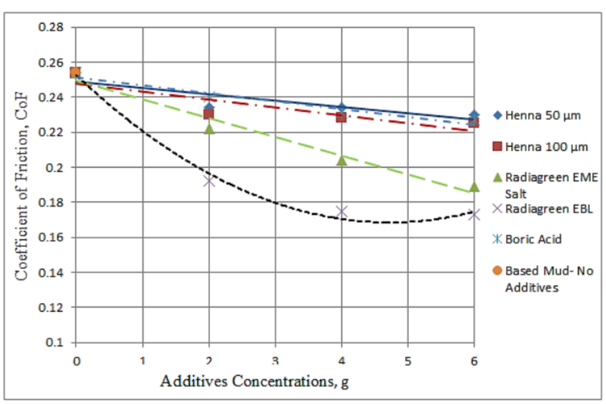

Figure 9. Effect of additives concentrations on coefficient of frication after 30 Minutes in WBM.

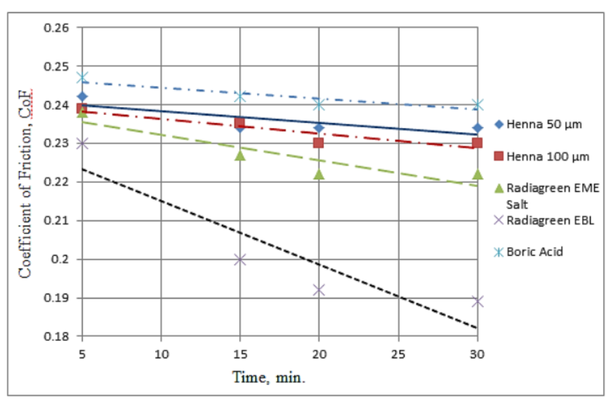

Figure 10 Relation Between Time and CoF

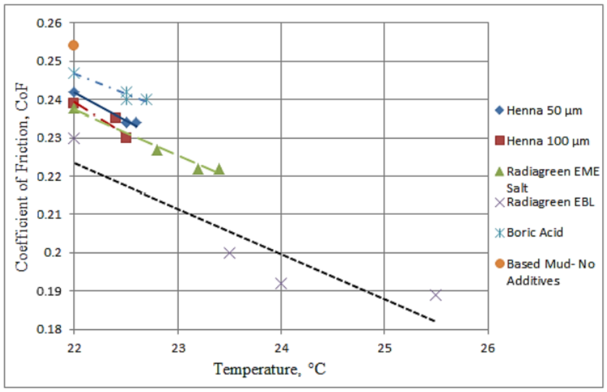

Figure 11. Relation between temperature and CoF.

Figure 11 shows the relation between the temperature and the CoF when 2 g of the additives were added to the water baser mud. The test was conducted in room temperature (22°C) and the reading of the temperature and CoF were taken after 5, 15, 20, and 30 minutes. The drilling fluid with henna leaves as well as boric acid did not generate much heat in comparison with the commercial lubricants. On the other hand, it was noticed in the case of adding Radiagreen EBL to the water based mud, the maximum temperature of 25.5°C was achieved after 30 minutes.

4. Conclusions

The experimental tests conducted on two water-based fluid additives, boric acid and Henna leaves, compared to two commercial additives, Radiagreen EME Salt and Radiagreen EBL, with different concentrations under various conditions have yielded several significant conclusions. Henna leaves, boric acid, and Radiagreen EME Salt to water-based mud increased the 10-min gel strength, with henna leaves with a size of 100 μm exhibiting the highest value (14 lb/100ft^2). In contrast, the addition of Radiagreen EBL had no significant effect on the 10-min gel strength.. Henna leaves to water-based mud significantly increased the yield point by up to 51 lb/100ft^2, while boric acid and Radiagreen EBL increased the yield point by 28 lb/100ft2 and 25 lb/100ft^2, respectively. A high yield point is important for drilling operations as it helps to suspend cuttings and clean the wellbore, reducing drilling problems and costs

The increasing of the additives concentrations resulted in reduction in the CoF of the WBM. When adding henna leaves with both sizes and boric acid, the CoF reduced further. However, 100 μm henna leaves showed more prospective reduction of CoF of WBM.Henna leaves and boric acid to water-based mud reduced the coefficient of friction (CoF) by up to 11.4% and 7%, respectively, while Radiagreen EBL reduced the CoF by 23.6%. Henna leaves are considered to be a compatible additive for water-based mud due to their effectiveness in reducing friction and compatibility in term of lubricity. The addition of 6 g of 100 μm henna leaves to water-based mud reduced HPHT fluid loss to 9.2 mL, while the addition of 6 g of Radiagreen EME Salt increased HPHT fluid loss to 11.5 mL. Radiagreen EBL had no significant effect on HPHT fluid loss, while boric acid initially increased HPHT fluid loss but then reduced it to 10.6 mL at a concentration of 6 g.

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