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Experimental Investigation of Naturally Extracted Henna Leaves and Boric Acid on the Drilling Water-Based Mud Rheological Behaviour in High-Pressure High-Temperature Condition

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Abstract

The key factor to the success of any drilling operation is formulating a good drilling fluid especially in deep, deviated, and horizontal wells. Hence, the application of various types of additives in various drilling fluids formulation is needed to provide different practical mud requirements. Therefore, plants additives have been used successfully in oil and gas industry. In this study, henna leaves with two different sizes and boric acid have been used with a concentration range of 0 – 6 g. The characterization of henna leaves was obtained throughout using EDX and VPSEM tests. The rheological properties were experimentally investigated before and after the aging process (250F/16 hours) for yield point, gel strength, filtration, and lubricity, API filtration, HPHT filtration and mud cake thickness. The API filtrate loss was reduced when adding 100 µm henna leaves. The results came in a harmonic fact that when obtaining a thicker mud cake, the lower filtrate loss is resulted. Increasing the concentration of the additives resulted a slight reduction in HPHT filtration. Both henna leaves and boric acid showed a prospective reduction in the fluid loss and the best result of 4.4 ml was achieved by adding 6 g of 100 µm henna leaves in the water based mud system.

Keywords: *Henna leaves; Boric acid; Drilling water based mud; Fluid loss.*

1. Introduction

Demand for oil and gas has had steadily increased over the last decade due to the growing population and industrialization. However many oilfields are becoming mature resulting in a rapid loss in production. New oilfields are being identified in challenging reservoir environments such as hard subterranean formations, extended- reach Drilling and many reservoir conditions making drilling fluid (or mud) design a challenge [1]. Furthermore, the safety of drilling process must be obtained through designing a (proper) drilling fluid that can perform in high efficiency. Base drilling fluids are classified into water based mud (brines) or (WBM), oil based mud (non-aqueous drilling fluid) or (OBM), and gaseous fluids such as foam agent mud. Because of the high expenses of the disposal matching with the current economic situation of oil and gas (industry), companies around the world are trying to invent a high efficiency drilling mud that has limited effects on the environment. Water based mud is highly recommended choice due to many advantages comparing with OBM and gaseous fluids [1-2].

As the crisis continues the development of a cost effective drilling operation has become a must. In order to do that the industry has to find new materials and additives to be added to the drilling fluids in order to solve the effect of drilling problems and minimize the overall cost of drilling. Nanotechnology is a very wide used solution in the oil and gas industry for these challenges due to its unique characteristics. Furthermore, green technology is a promising solution that has been under testing for a better drilling fluid additives which is environmentally safe and nontoxic. Green technology has been considered as an effective additive in petroleum industry as it has been employed to reduce fluid loss problems that is why the need of further investigation of the properties of green technology [3-4].

As drilling operations are getting very challenging because of the harsh environment and conditions, which expose new obstacles in terms of techniques, materials, and safe environment. On the other hand, it is complicated or nearly impossible to achieve specific functions in such difficult conditions without applying nanomaterials in the drilling fluids [2]. Many publications proved that it is important to utilize nanomaterials in the drilling fluid in order to optimize its properties and functions to make it able to handle and overcome certain drilling conditions and problems [5]. Moreover, nanomaterials most important advantage is assisting in eliminating the need of some expensive drilling mud additives. A recent study by was conducted on the usage of nanomaterials and its effect on the development of drilling functions as shown in Table 1 [6]

Table 1. Nanomaterials applications in drilling industry [6].

Application	Usage
Downhole drilling components	High strength nanostructures materials for the drilling components.
Drilling fluids	Formation fluid loss control. Stability of shale formation. Bit balling. Decrease CoF Torque and drag forces Toxic gases removal. Effective cooling in HPHT conditions.
Drilling bits	Nano-diamond polycrystalline diamond compact (PDC) with better effectiveness

Natural additives can be utilize in drilling in areas having stringent environmental controls in terms of disposing used drilling fluid and cuttings. Even though environmental control is not an important factor in some countries the cost to treat the drilling fluid prior disposal can be minimize or eliminated. It can be said that additives studied in this project are more flexible in terms of its usage in different countries with different environmental laws and also can reduce overall drilling cost [6].

One of the drilling fluid additives is starch, it has been used and applied in drilling fluid for fluid loss control. They are typically used to diminish the filtration of mostly all types of WBM. It can be possible to manage filtration by an appropriate amount of starch ingredients and combination with bentonite or polymers. Starch can be obtained easily and cost effectively which make it a better option to be used as a fluid loss control [7-8].

A research has been done Samavati to study cassava derivative (fufu) as a fluid loss agent in WBM. The results were very promising and the rheological properties and the fluid loss behaviour of the formulated mud were compared with commercial products. However, in high temperature i.e. 300°F, most of the starches based mud failed and completely degraded [9].

Plant additives such as henna laves can be considered as an innovation in petroleum industry as it has not been applied in real drilling operations. The used of an efficient drilling fluid that can overcome drilling problems cost effectively and without harming the environment is essential. As nature resources plant leaves have been used for cosmetic productions and drugs in The Middle East and India. Furthermore, plants leaves are eco-friendly additives which according to many researches, they have shown a great potential in controlling the fluid loss [10,16].

A recent study targeted the application of henna leaves in improving shale swelling problems and cutting transportation. It has been reported that henna leaves diminished the swelling capacity of the shale sample effective. In addition, henna leaves inhibition properties are a function of its concentration and are comparable with polyamine and potassium chloride which are the most common clay stabilizers [11,17].

Some features including being a naturally occurring material with environmentally characteristics, inexpensive, widely available, anticorrosive in various metallic mediums, improving cement resistance against acid attack, a fluid control agent that can thicken the mud and seal off the pores and flow channels in the reservoir matrix and deflocculation as well as inhibition of clay particles are the most important reasons for more attention towards henna leaves in petroleum industry [12].

Boric acid is considered one of the low-toxicity, non-volatile minerals with fungicidal, insecticidal, and herbicidal properties. It has long been embraced as a safer alternative to highly volatile, synthetic chemical pesticides. Boric acid can occurs naturally in water, vegetables, fruits and forage crops. It is an essential nutrient for plants and an essential element for many organisms [13-14].

2. Experiment and methodology

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).

Table 2. Composition of water based mud material.

	Function	Quantity	Mixing time (min)
Distilled water	Base fluid	303 mL	-
Potassium chloride (KCl)	Water activity and density	30 g	3
Sodium hydroxide (NaOH)	PH control agent	0.2 g	2
Flowzan	Viscosifier	1 g	5
PAC-UL	Fluid loss agent	2 g	5
PHPA	Stabilize hydrate and cutting encapsulator	1 g	10
Barite	Weighting agent	125 g	30

The rheological properties of the drilling fluid with different additives in this experiment were determined and tested in the laboratory by referring to the Recommend Practice for Field Testing Water-Based Drilling Fluids, API RP 13-B1[15].The rheological properties which are tested before and after ageing are as follows: Mud ageing; Mud weight, ppg; Yield point, Ib/100ft²; Plastic viscosity, cP; Gel strength for 10 min and 10 sec, Ib/100ft² ;API filtration, mL ;High pressure high temperature (HPHT) filtration, mL ;pH measurement.

The aging process was done in the laboratory through using rolling oven and the procedures are as follows:

1. The sample of the mud was poured into the cell tube within ½ inch to top.
2. The top part of the cell tube was assembled.
3. The cell was rotated and heated in the rolling oven at 250°F for 16 hours.
4. After 16 hours, the cell tube was cooled in the water bath.
5. The mud sample was agitated prior to be tested for the mud weight, rheological and filtrate loss test.

The measurements of the mud weight was conducted in the laboratory throughout using mud balance. However, before using the equipment, it had to be calibrated first in order to obtain the efficient mud weight results from the experiment. The calibration procedures are given as follows:

1. First fill the cup entirely with distilled or pure water after taking off the cover from the top of the cup.
2. The lid was changed and dried.
3. Then the acute edge is resting on the fulcrum, the mud balance arm was sitting on the bottom of the box.
4. Finally the bubble in the balance has to be at the centre when the reading is to be equal to the water density (8.33 lb/gal). However, in case the reading was different the calibration

screw was used to modify the mud balance and it was located at the end of the balance arm.

When the process of calibration was successfully accomplished, the mud density measurement was conducted by the following procedures:

1. After removing the lid from the cup, fill the cup completely with the drilling mud to be tested.
2. The lid was placed and rotated gently until firmly seated, some of the mud has to be expelled from the hole of the lid.
3. Cleaning the cup by washing the mud from the outside of the cup wall, then dried it.
4. The sharp edge of the balance should be sitting on the fulcrum, the arm balance was put on the bottom.
5. The reading pointer was adjusted until the bubble was on the correct position, in the centre of the arm balance.
6. The reading of the weight or density of the mud was reported.
7. The result obtained can be presented either in lb/ft^3, lb/gal, and psi/1,000 ft of the depth or specific gravity (SG). The values were taken to the nearest scale division.

The procedures for determining mud viscosity are as follows:

1. A recently agitated sample was placed in a cup.
2. The rotor sleeve was immersed exactly to the scribe line.
3. The mud sample was stirred until the dial reading reached a steady value.
4. The knob was shift at 600 rpm and the dial reading was recorded after the reading was stable.
5. The rotor speed was shifted at 300 rpm and the dial reading was recorded after the reading was stable.
6. The relationships used to obtain the plastic viscosity (PV), and yield point (YP)

The procedures to determine gel strength measurement are:

1. The tested sample was mixed at high speed of 600 rpm for 10 seconds. Then, the rotor was turned to stop position.
2. The sample should be allowed to stay uninterrupted for 10 seconds. After that the knob was switched in to the applicable direction, to the Gel position. The gel strength reading was taking in the initial maximum reading. For 3 rpm speed instruments, the maximum reading was obtained when the rotation of 3 rpm started recording the initial gel strength. Then the initial gel strength of (10 seconds) was reported in $lb/100\ ft^2$.
3. The mud sample should be re-stirred at high speed of 600 rpm for 30 seconds. Then, the knob was turned to the stop position and the mud had to be stayed undisturbed for 10 minutes.
4. Repeating step 2 to obtain the maximum reading, then the gel strength after 10 minutes is reported in $lb/100\ ft^2$.

Determination of API filtration and mud cake thickness

The mud filtration was decided in the API by means of filter press. The usual standard experimental steps are mentioned as follows:

1. Nitrogen or air pressure of 100 psi was set.
2. The lid of the clean and dry cell was removed from the bottom. Checking the O-ring and replacing it in an undestroyed groove, and then inverted the cell to fill. Making sure that there are no any mechanical damage because it could prevent from sealing.
3. Quarter inch of the O-ring groove was left and the mud was poured into the empty cell. On top of the rubber O-ring a filtrate paper was used. Then the lid was brought to sit on the filter paper and the flanges on the lid and the flanges of the cell should engage, and turned clockwise until firmly tight. Finally the cell was placed over the male cell with connecting was inserted to be engaged by turning either direction.
4. Proper graduated cylinder were put under the filtrate opening hole to collect the filtrate from the cell.
5. Pressure was applied at the inlet valve of the cell to be opened.

6. The total API test duration is 30 minutes. The valve was closed at the end of the test, and pressure was bleed automatically after shutting off the source, at the end the cell was removed.
7. Result of fluid loss was taken and reported in millilitres unless otherwise specified.
8. The installation of the cell was dismantled, and then the mud was deposited and the filter paper was extreme took care off when collecting with a lowest disruption of the cake. The mud cake was washed carefully to be cleaned from any excess mud. The measurements of the thickness of the filter cake was conducted and reported in a unit of per 32 of an inch

The determination of the mud filtration was done by means of filter press in the High Pressure and High Temperature condition. The procedures of standard experimental work are given as follows:

1. First preheating the heating jacket was obtained by connect the power source to the appropriate electric line. Then placed the thermometer (stem dial) in the thermometer hole in the heating jacket. Readjusting the thermostat setting to obtain the desired test temperature 250°F.
2. Loosening the six socket head set screws, and removing the cell end caps from up and bottom by pulling them straight out of the cell, using the valve stem as a handle. Making sure that the O-rings on the valve stems, cell body and caps were in a good condition, and replacing any damaged O-rings.
3. Assembled the down cap of the cell and placed a filter paper with making sure the six socket set screws were aligned and securely tightened and the valve stem was tight.
4. With the filter paper on the top cell, the cell was carefully filled with the sample to be tested leaving 1/2 to 3/4 inches from the top, making sure the six socket set screws were aligned and securely tightened and the valve stem was tight.
5. lowered the cell into the heating jacket. Then the cell assembly was rotated so that the locker pin located at the bed of the jacket engaged the opening located at the bottom of the cell. This will prevent the cell rotating when opening and closing the valve stem.
6. The gas or air pressure units were installed on the inlets (top and bottom) valves stem and the locking pins were inserted. First pressure of 200 psi was applied on the top and the valve stem was loosen, until the temperature of the thermometer on the cell indicated 250 °F. Then the top pressure was increased to 600 psi and pressure at the bottom of 100 psi was applied and the bottom valve stem was loosen.
7. The normal period is 30 minutes for HPHT test. At the end of the test, the valves stem were closed. Temperature and pressure were shut off at the sources, and the pressure was released. The cell was removed to be cooled.
8. The fluid loss was taken in millilitres unless it is specified.
9. The installation of the cell was dismantled, and then the mud was deposited and the filter paper was extreme took care off when collecting with a lowest disruption of the cake. The mud cake was washed carefully to be cleaned from any excess mud. The measurements of the thickness of the filter cake was conducted and reported in a unit of per 32 of an inch.

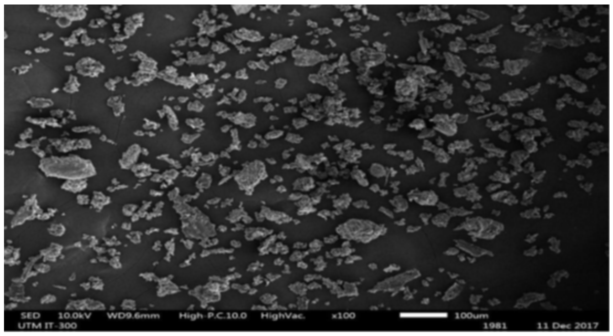
The measurement of the pH of the mud samples was done using pH indicator stick, the procedure is explained as follows:

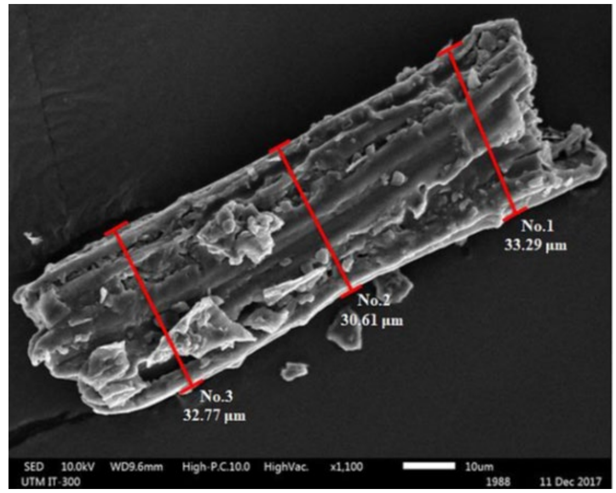
1. First the indicator stick paper was immersed in the mud sample for usually not more than 2 minutes to give time to the paper to soak there until the stabilization of the colour.
2. Then the colour of the pH paper was analysed and matched with the nearest standard colours given, so the estimation of the mud pH was resulted by the pH standard colour that was comparable to the mud pH.
3. Finally the resulted value of pH of the mud sample was reported to the approximate pH unit.

3. Results and discussions

Henna leaves powder was examined under VPSEM test to study, magnify and analyse henna leaves morphology and the physical structure. It can be noticed from the results that there are various different sizes of the particles with uniform structure and very tight fractions, as shown in Figure 1

Furthermore, spectrum 1 in Figure 2 has been examined under EDX test, and the results indicated that henna leaves chemical composition consists of a significant percentage of carbon compared to other components as shown in Figure 3.





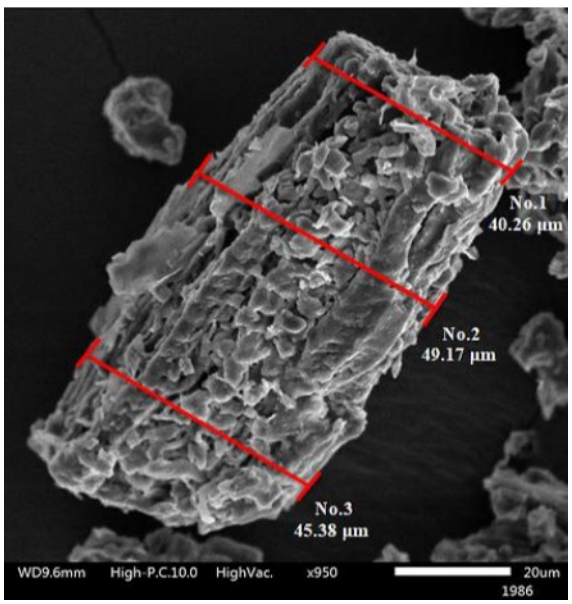


Figure 1a-c VPSEM test results of henna leaves powder at several magnifications.

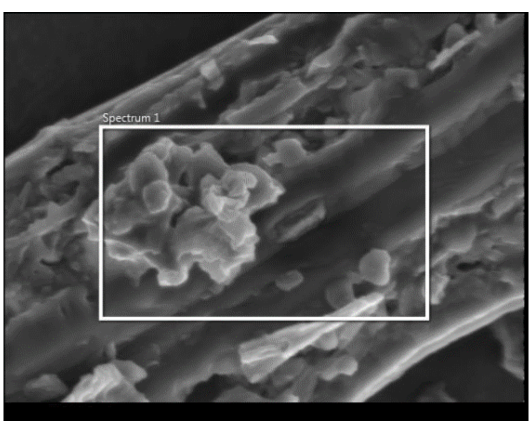


Figure 2. EDX test spectrum 1 result of henna leaves powder

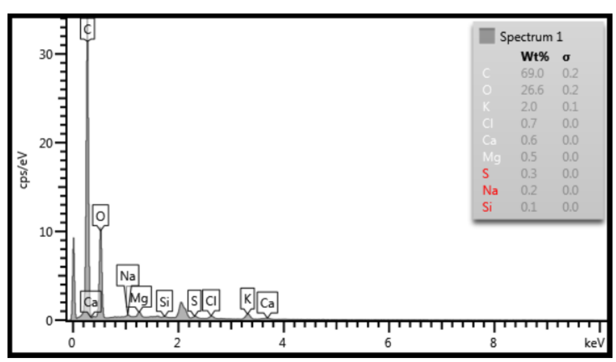


Figure 3. EDX test spectrum 1 result of henna leaves powder chemical compositions.

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The research describes the findings through explaining the possibility in solving certain drilling problems during operation. In this study, two types of additives which are henna leaves and boric acid with different concentrations were added to water based mud and further analysed. Then the rheological properties such as plastic viscosity, yield point, gel strength, API and HPHT filtration and mud cake thickness before and after aging have been investigated and will be discussed.

The effect of adding henna leaves with different concentrations on plastic viscosity after aging is shown in Figure 4. By increasing the concentration of henna leaves added to the water based mud, the overall trend of the plastic viscosity after aging is increasing. In comparison between before aging process and after aging process, it was noticed that the plastic viscosity reduced after the dynamic aging process. In the aging process the mud was exposure to high temperature of 250°F without special additives for high temperature condition, which made it difficult for the water based mud to sustain its rheological properties. The high temperature applied to the aging cell was the reason of lowering the resistance of the fluid to the flow and reducing the plastic viscosity. However, low plastic viscosity is preferred sometimes to lower the resistance to the flow in the wellbore or the annulus.

Figure 5 shows the comparison between the effect of adding henna leaves with different concentrations on the yield point before and after aging. It was observed that in the case of before aging process, the yield point expressed a noticeable increment by increasing the concentration of henna leaves. On the contrary, after aging process it shows a different trend, the yield point trend is slightly declining when the concentration of henna leaves is increasing. The reason behind this can be the absence of additives that are capable to sustain the rheological properties of the mud after being exposed to high temperature.

Figure 6 shows the comparison between the effect of henna leaves concentrations on 10-sec gel strength before and after aging process. It can be noticed that before the aging process the trend was significantly increased by raising the concentration. On the contrary, after the dynamic aging process the trend was almost straight and was not much affected by increasing the concentration.

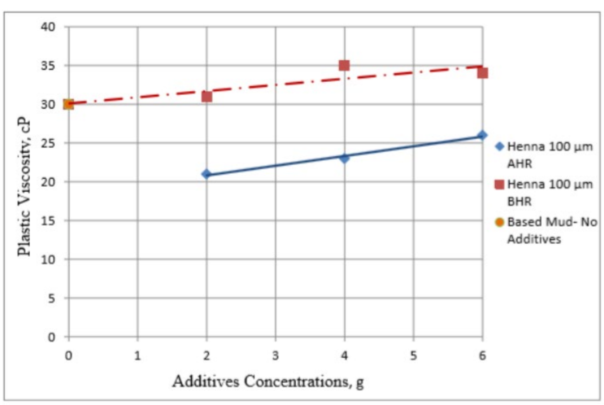

Figure 4. Comparison between the effect of henna leaves concentrations on plastic viscosity in WBM (before and after hot rolling).

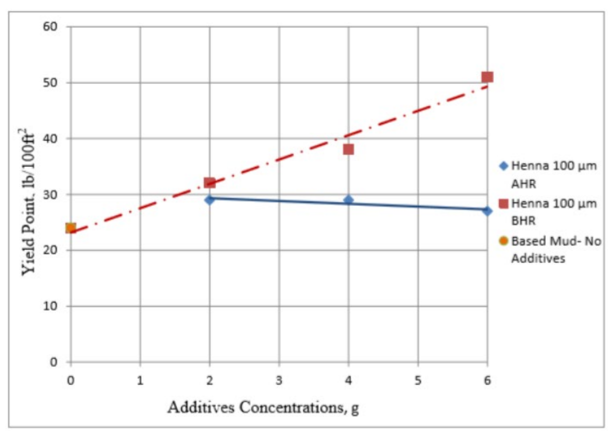

Figure 5 Comparison between the effect of henna leaves .concentrations on yield point in WBM (before and after hot rolling).

The effect of henna leaves concentrations on 10-min gel strength before and after the aging process is shown in Figure 7. It was observed that both trends were increasing. By adding 2 g of henna leaves to the water based mud, the value of the 10-min gel strength before the aging process was lower in comparison with the value of the10-min gel strength after the aging process. However, when adding 6 g of henna leaves to the water based mud the opposite happened since the 10-min gel strength before the aging process has a higher value now compared to the after aging process.

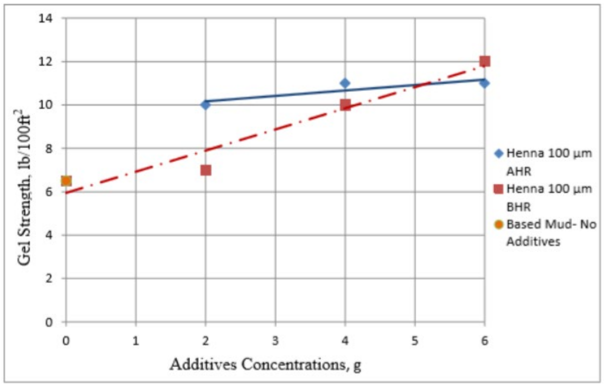

Figure 6. Comparison between the effect of henna leaves concentrations on 10-seconds gel strength in WBM (before and after hot rolling).

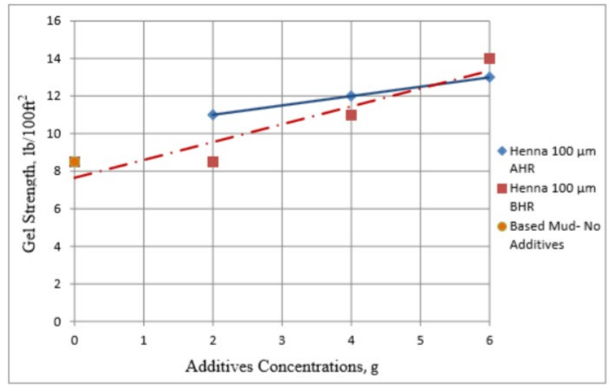

Figure 7. Comparison between the effect of henna leaves concentrations on 10-minutes gel strength in WBM (before and after hot rolling).

Figure 8 compares between the effect of adding different concentrations of henna leave on the fluid loss before and after the aging process. It can be noticed that the addition of henna leaves after aging process did not follow the same trend as before the aging process. Moreover, after the aging process by increasing the concentration of henna leaves from 2 g to 4 g the fluid loss value was constant, then when the concentration of henna leaves was raised to 6 g the fluid loss value decreased but still gave a higher value than the fluid loss before aging process. This could be explained by the absence of high temperature additives in the mud system, which affected the rheological properties of the drilling fluid.

Figure 9 shows the comparison between the effect of different concentrations of henna leaves before and after the aging process on the mud cake. It can be noticed that both trends are increasing by adding more concentration of henna leaves and the mud cake thickness after the aging process was bigger than before aging.

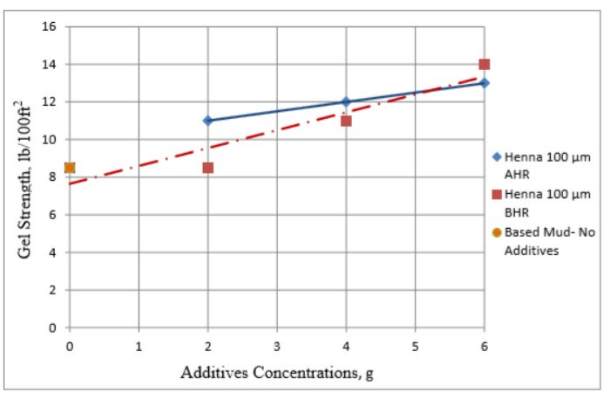

Figure 8. Comparison between the effect of henna leaves concentrations on API filtrate loss after 30 minutes in WBM (before and after hot rolling).

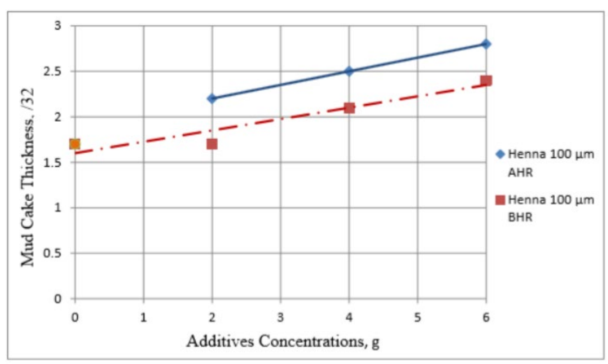

Figure 9. Comparison between the effect of henna leaves concentrations on mud cake thickness in WBM (before and after hot rolling).

Development of a good quality mud cake is very critical in order to prevent drilling problems from occurring. Figure 10 shows the mud cake formed with usage of henna leaves. It can be observed that the mud cake is thin, homogenous and tight. The addition of henna leaves helps in forming well dispersed mud cake, which have the potential to reduce drilling problems, such as pipe sticking.

After the aging process the effect of adding henna leaves with different concentrations on HPHT fluid loss is shown in Figure 11. It was noticed that the trends of the HPHT fluid loss after and before the aging process were both decreasing by increasing henna leaves concentration. However, the value of HPHT fluid loss after the aging process was higher than before the aging process. This can be explained by the absence of the high temperature additives in the water based mud system.

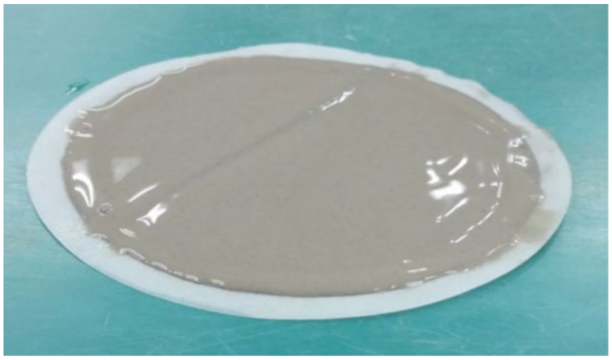

Figure 10. Mud cake of WBM with 6 g of henna leaves.

The comparison between the effect of different concentrations of henna leaves before and after the aging process on the CoF is shown in Figure 12. Before the aging process a slight decrease in the CoF trend occurred when increasing the concentration of henna leaves. However, after the aging process the value of CoF reduced in general, even though there was almost no effect of increasing the concentration of henna leaves on the CoF. This could be the result of lacking high temperature additives in the water based mud system.

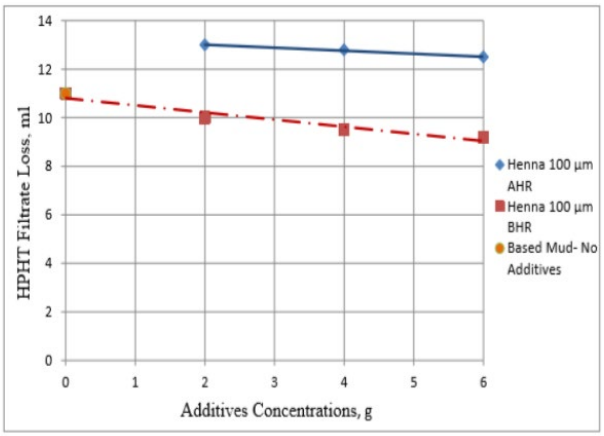

Figure 11. Comparison between the effect of henna leaves concentrations on HPHT filtrate loss after 30 minutes in WBM (before and after hot rolling).

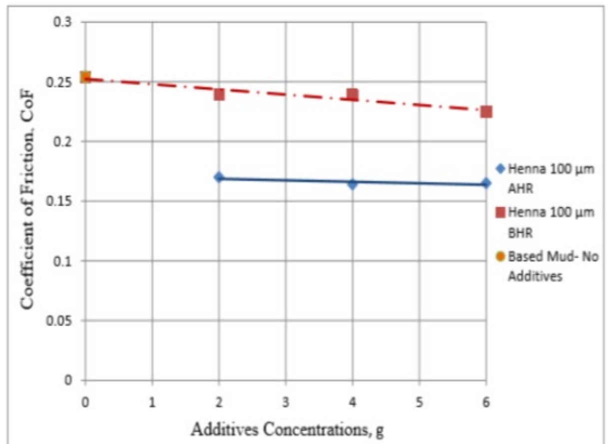

Figure 12. Comparison between the effect of henna leaves concentrations on coefficient of friction after 5 minutes in WBM (before and after hot rolling).

4. Conclusions

Various conclusions can be resulted based on the conducted experimental tests of two types of additives which are henna leaves and boric acid with different concentrations added to water based mud and further analysed before and after aging process to high temperature of 250^{o}F.

The plastic viscosity reduced after the dynamic aging process. The high temperature applied to the aging cell lowered the resistance of the fluid to the flow and reducing the plastic viscosity. The yield point had a noticeable increment by increasing the concentration of henna leaves. On the contrary, after aging process it shows a different trend, the yield point trend is slightly declining when the concentration of henna leaves is increasing The 10-min gel strength before the aging process was lower in comparison with the value of the10-min gel strength after the aging process. However, when adding 6 g of henna leaves to the water based mud the opposite happened since the 10-min gel strength before the aging process has a higher value.

The API filtrate loss was reduced when adding the additives. Furthermore, 100 µm henna leaves is the most effective additive in minimizing the filtrate loss. Moreover, the results came in a harmonic fact that when obtaining a thicker mud cake, the lower filtrate loss is resulted. Before the aging process a slight decrease in the CoF trend occurred when increasing the concentration of henna leaves. However, after the aging process the value of CoF reduced. Increasing the concentration of the additives resulted a slight reduction in HPHT filtration. Furthermore, 100 µm henna leaves gave the lowest value of HPHT fluid loss.

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