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New weighting agent for water-based mud, um-bogma area, central Sinai, Egypt

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Abstract. A successful oil well drilling depends largely on a good mud Program. During drilling, mud provides sufficient hydrostatic pressure, removes drill cuttings and cools drill bits. Mud additives are always required to provide sufficient hydrostatic pressure to ensure borehole stability. Barium Sulphate ($BaSO_4$) also known as barite is the prevalent weighting material but there is needed to develop local materials to augment the use of Barite. The present search is concerned on the early Carboniferous succession exposed in Um Bogma Formation, west central Sinai, Egypt as a new weighting agent in drilling fluids. The increases in the cost of drilling fluids and a shortage of using barite have introduced the locale dolomite as alternative weighting materials. The rheological properties of mud drilling samples weighted by local dolomite samples are being examined and investigated to know its potential to be used as a weighting material in drilling mud. Two mud samples were prepared which comprised of fresh water, caustic soda, bentonite and the weighting material. The weighting materials are added to achieve the required density. The first sample: Water-based mud with commercial barite of density between 10.00 lb/gm and 18.00 lb/gm. The second sample: Water-based mud with dolomite of density between 10.00 lb/gm and 18.00 lb/gm. These samples were analyzed and the density, rheological properties, aging of barite and dolomite and solid contents were investigated. At 10.00 lb/gm, the yield point of dolomite was 20.00 lb/100ft^2 and barite 22.00 lb/100ft^2 while the 10 second gel strength of dolomite was 30.00 lb/100ft^2 and 22.00 lb/100ft^2 for barite. Similarly, little difference was observed in plastic and apparent viscosities. At 10.00 lb/gm, the plastic and apparent viscosities of dolomite were 8.00 cp and 20.00 cp while barite was 8.00 cp and 24.00 cp. The result show that dolomite mud sample gave a little higher yield point and gel strength than barite mud sample. Therefore, dolomite has the potential to be used as weighting material in drilling mud in place of barite thereby enhancing the local content initiative of the government. When dolomite is sourced locally and used it will reduce overall mud and drilling costs.

Keywords: drilling fluid; weighting agent; rheology; density; barite; um bogma; dolomite

1. Introduction

Expected increase in drilling activities, has necessitated the search for alternative sources of drilling mud additives so as to minimize or stop the importation of weighting materials such as

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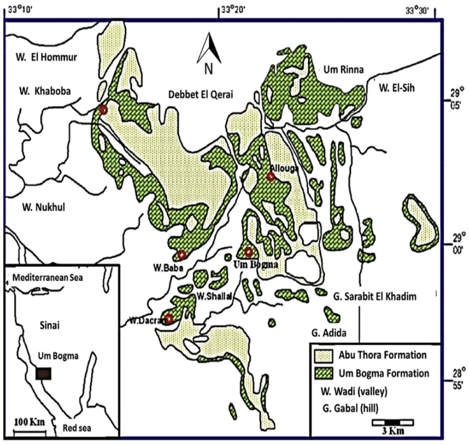

Fig. 1 Location map of Um Bogma formation

barite. There are many local materials which be investigated to know their suitability for use as weighting material (Mohamed and Chris 2012, Geria *et al.* 2016). This research was carried out on one of such weighting materials dolomite which is available in Um Bogma Formation, west central Sinai, Egypt. Drilling mud formulation comprises of water, bentonite and weighting materials. The drilling mud is usually formulated to have adequate hydrostatic pressure, normally in the range of 250 psi to 450 psi higher than the formation pressure. (Ismail *et al.* 2004). Imbalance between the hydrostatic pressure and the formation pressure may cause influx of formation fluid which may are environmentally friendly if the drilling fluid is to be disposed (Bruton *et al.* 2006). Weighting materials increase mud density as well as penetration rate during drilling (Blatel and Rupert 1982, Akpabio *et al.* 2012). When there is reduction in rig time due to fast penetration rate the overall drilling cost is reduced because the target is reached earlier.

A locally obtained weighting material that can be used in place of barite would be a new innovation in the industry. The main objective of the research is to examine the properties of a locally sourced material, Dolomite of Um Bogma Formation west central Sinai, Egypt Fig. 1 to substitute the barite as weighting agent in drilling fluids. in Um Bogma Formation.

The origin of ancient massive dolomite of the Lower Carboniferous Um Bogma Formation attracted the attention of many geologists. it represents the oldest marine transgression during the Paleozoic in Sinai (Issawi *et al.* 1999) and positioned between two fluvial sandstone formations. The Paleozoic dolomites are dense, non-planar, ordered and near stoichiometric as they got enough time for stabilization. However, the initial dolomite deposits usually go through a numerous episodes of diagenesis such as stabilization and recrystallization. Esmat (2014). Um Bogma area is located in the southwestern Sinai between Longitudes 33°18′ and 33°27′E and Latitudes 28°55′ and 29°04′N. Um Bogma Formation was assigned to the middle carbonate series “about 45 m thick” from the Paleozoic sequence “up to 320 m”. The thickness of the whole formation and the individual members decrease from northwest (Wadi Khaboba) to southeast (Gebel Ghorabi). Um Bogma Formation unconformable overlies the sediments of the Naqus and Malik formations everywhere in Um Bogma area except in the western area of Wadi Khaboba, which rests directly over Araba Formation. Unconformable overlying it are the marine cross-bedded fine-grained sandstones with thin layers of kaolinitic and black shales of Ataqa Formation. Esmat (2014). Dolomite is a sedimentary rock composed primarily of the mineral dolomite, $CaMg(CO_3)_2$. The rheological properties are being examined and compared with that of barite (Mahto and Sharma 2004., Khodja *et al.* 2010, API 1978). The mineral dolomite is being investigated at different particle sizes (45 µm, 63 µm and 75 µm), with two concentration 4% and 6% and different temperature to know its potential to be used as a weighting material in drilling mud (Akeju *et al.* 2014). The samples were analyzed and the density, rheological properties and solid contents were investigated at different temperatures (Elkatateny *et al.* 2011, Watson *et al.* 2012). Other Alternative Weighting Materials that can be sourced locally to substitute barite would be a good innovation in the drilling industry (Jack *et al.* 2011, Omoiyi *et al.* 2014). In recent years ilmenite and hematite have been investigated. Both minerals meet the requirements for chemical inertness and availability, but they differ from barite in specific gravity and hardness. Scarf and Watts (1984) assessed the benefits of hematite as a weighting material in heavy oil base systems. This was achieved by conducting a laboratory investigation to obtain a comparative basis between barite and hematite. Rheological properties as well as abrasiveness were studied and field results were predicted. Results from experimental work show lower fluid rheology, density and slightly more abrasive nature of hematite. Walker (1983) presented experiences with mined iron oxide used as an alternative weighting material to barite. One of the observed advantages of the compound over barite was their high specific gravities.

In his conclusion, iron-based materials were recommended for use as a substitute for barite. According to (Saasen *et al.* 2001) ilmenite has been applied earlier as a weighting material (Blomberg and Melborg 1984, Idris and Ismail 1994). Recently, Manganese Tetra oxide ($M_{n3}O_4$) has been used as a weighting material for water based drilling fluids El-Yami and Nasr El Din (2007).

2. Methodology

This work involves the preparation of the raw material and mud slurry and the rheological tests of the drilling fluids, (Khodia *et al.* 2010).

Table 1 Characteristics of weighting materials

Material	Empirical Formula	Spec. Gravity	Hardness
Dolomite	$CaMg(CO_3)_2$	2.9	3.5-4
Barite	$BaSO_4$	4.2-4.5	2.5-3.5

Table 2 show the XRF chemical analysis of the dolomite of Um Bogma Formation

Mineral Component	Ratio %
$CaMgCO_3$	48
$MgCO_3$	49
Fe_2O_3	0.81
Al_2O_3	0.11
SiO3	0.25
Moisture	0.77
L.O.I	41.5

3. Preparation of dolomite raw material

Dolomite of Um Bogma Formation was received in coarse form which its crushed, grinding and sieved to three different particle sizes 75 μm, 63 μm and 45 μm to meet the requirements of API specification. API(1978). The characteristics of weighting materials as in Table 1. Also, dolomite was chemically analyzed by XRF to determine the minerals component ratio as shows in Table 2.

4. Preparation of mud fluid

Two types of mud samples were prepared which comprised of fresh water, caustic soda, bentonite and the weighting material added to achieve the required density. The first sample is composed of water-based mud and barite but the second sample is composed of water-based mud and two concentration of bentonite 4.5% and 6%, weighted by dolomite of three particle sizes (45 μm, 63 μm and 75 μm).

The density of the all samples is ranged between 10.00 lb/gm and 18.00 lb/gm., the mixture was stirred in Hamilton mixer while bentonite is added slowly (Badawi *et al.* 2004, Dardir *et al.* 2014a). The pH of the mixture was recorded about 10.72 then the procedures are repeated for different mud weight lb/gal, (Kania *et al.* 2015), with the knife edge resting on the fulcrum. The rider was moved until the graduated arm was horizontal and the reading was taken. The cup was filled completely with mud after calibration. The expelled mud was washed and the balanced arm was replaced on the base

4.2 Rheological properties determination

4.2.1 Mud viscosity determination

The mud viscosity of the samples was determined using Fann V-G meter. The Fann VG meter was filled to the 350 cc mark and placed on the movable work table. The table was adjusted until the mud surface was at the scribed line on the rotor sleeve. The motor was started with a high speed position (600 rpm) and the reading was taken from a steady indicator dial value. The reading was also obtained at the low speed of 300 rpm. This was repeated for both samples and at different mud weights. API (1978)

4.2.2 Gel strength determination

The Fann V-G meter was also used to determine the gel strength of the mud samples. The mud samples were stirred thoroughly at 600 rpm. The lift gear was shifted slowly to the first position, and the motor was shut off. The motor switch was turned to low after 10 seconds. The dial was read at maximum deflection units in Ib/100ft^2 that is 10 second gel. The steps were repeated for 10 minutes. The Gel strength was obtained for the different mud weights.

4.2.3 Solid content determination

The sand content of the mud samples was determined using sand screen set (sand content kits). The glass tube was filled with mud sample to a mark labeled “Mud to here” and water was added to the next mark labeled “Water to here”. The mouth of the tube was closed over with the thumb and shaken vigorously. The mixture was poured onto the screen and more water was added to the tube, shaken and poured onto the screen. Funnel was fitted down over the top of the screen, inverted slowly and washed sand back into the tube. Then it was allowed to settle. The quantity of the sand settled in the graduated tube as the sand content of the mud in percent by volume was recorded. This was repeated at different mud densities.

4.2.4 pH determination

The pH meter which consists of a glass electrode system, an electronic amplifier and a meter calibrated in pH units was used to test the pH of dolomite mud. The electrical connection with the mud was established through saturated KCL solution contained in a tube surrounding the calomel cell. The electrical potential generated in the glass-electrode system by the hydrogen ions in the drilling mud was amplified and operated the calibrated meter which indicated the pH.

5. Results and discussion

The characteristics of weighting materials and XRF chemical analysis of the Egyptian dolomite (Um Bogma formation) are shown in Tables 1 and 2. The experimental investigations of mud density, solid content, rheological properties and filtration loss analysis were tested after ageing for 48 hours at (150℉) and the results are shown in Figs. 2-13. Results of the comparisons of the two mud samples were investigated, dolomite used was found to be able to generate similar mud weight as barite.

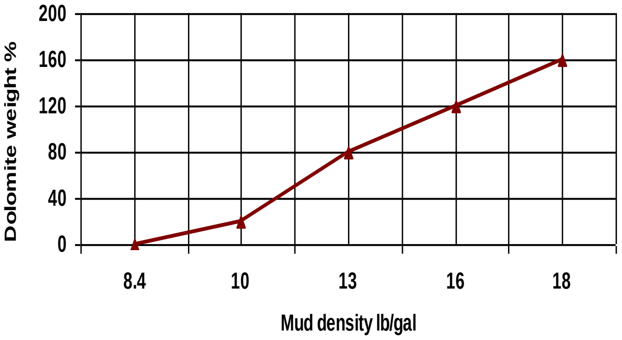

Fig. 2 Mud density vs. dolomite %

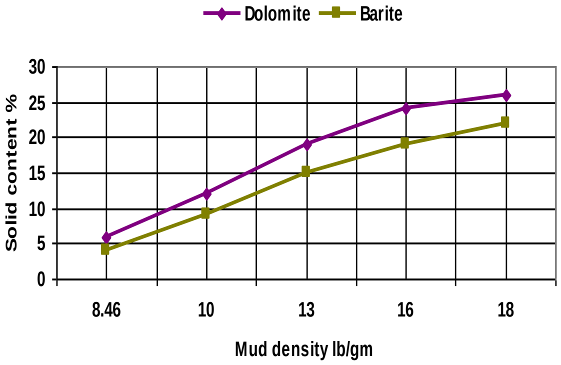

Fig. 3 Mud density vs. solid content % of barite and dolomite %

5.1 Mud density

Fig. 2 shows the increasing the mud density from 8.46 lb/gm to 18 lb/gm with increasing the weight ratio of dolomite.

5.2 Solid content

The quantity of barite used producing smaller solid content than the quantity of dolomite due to the high specific gravity of the barite than dolomite. Solid content analysis involves the measurement of weighting material and sand content of the mud in order to prevent abrasion. Fig. 3 shows that the solid content increased proportionally with mud density. At 8.46 lb/gm, the solid content of barite and dolomite was 4% and 5% while at 18 lb/gm; it was 16% and 18%.

5.3 Rheological properties

5.3.1 Plastic viscosity and mud density

The relationship between mud density and plastic viscosity, which is produced from the friction between the solid particles in the mud and the viscosity of the dispersed phase, is shown in Figs. 4 and 5. At 10.00 lb/gm, the plastic viscosity of dolomite was 7.00 cp while that of barite was 7.0 cp. At 18.00 lb/gm, the plastic viscosity of dolomite was 16.00 cp while that of barite was 11.00 cp. It was observed that both minerals had the same viscosity at 16.00 lb/gm It was observed that both minerals had the same viscosity at 10.00 lb/gm and then dolomite had a higher viscosity at 18.00 lb/gm.

Also Figs. 6-9 show the same parameters at 150˚F and three particle sizes, 45 μm, 63 μm and 75 μm with two concentration 4.5% and 6%. This change was due to the presence of large amount of suspended dolomite particles in the mud sample, which was more than barite. This effect continues with increase in mud weight. Generally, friction between particles becomes apparent with the increase in the number of particles in the mud sample which in turns increases the plastic viscosity. Therefore dolomite has the potential to be used as weighting material in heavy mud, as it could increase the rate of penetration and the well cleaning efficiency.

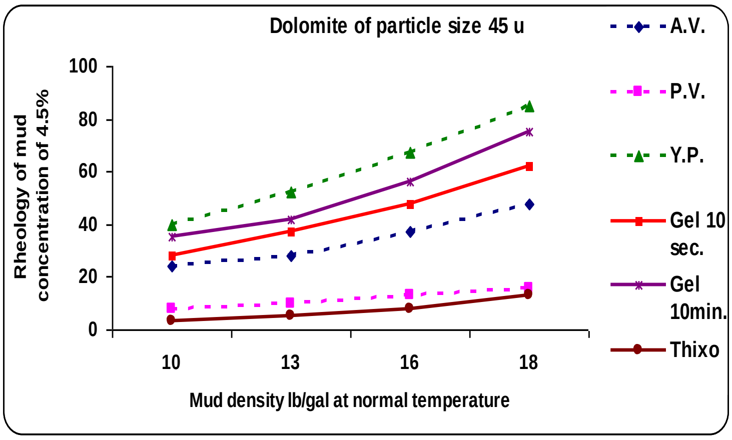

Fig. 4 The rheology of mud fluid of bentonite concentration 4.5% weighted by Um Bogma dolomite 45 μm at normal temperature

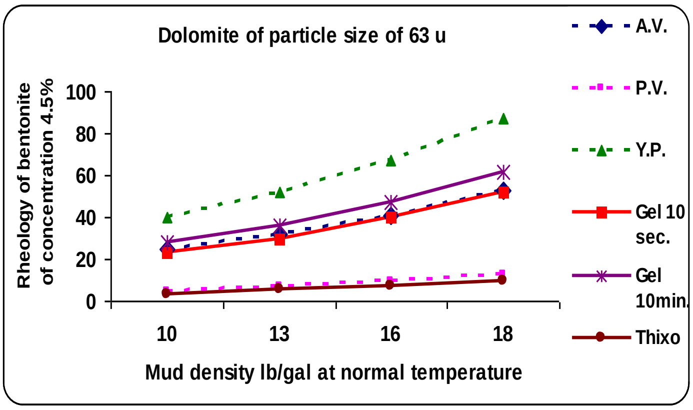

Fig. 5 shows the rheology of mud fluid at bentonite concentration 4.5% weighted by Um Bogma dolomite 63 μm at normal temperature

5.3.2 Apparent viscosity and mud density

Figs. 4 and 5 show the relationship between apparent viscosity and mud density. The plot shows that dolomite has higher apparent viscosity than barite. At 10.00 lb/gm, the viscosities of the dolomite and barite were 16.5 cp and 23 cp respectively and at 18.00 lb/gm, the apparent viscosities were 48 cp and 42 cp respectively. This a marginal difference of 5 cp between the mud samples; thus, dolomite could be used as barite substitute Also Figs. 6-9 show the same parameters at 150˚F and different particle sizes (45 μm, 63 μm and 75 μm) with two concentration 4.5% and 6%.

5.3.3 Yield point and mud density

Figs. 4 and 5 are the relationship between yield point and mud density. Yield point is the maximum stress that a solid can withstand without undergoing permanent deformation either by plastic flow or rupture. The result shows that dolomite has a higher yield point readings than the barite sample.

At 10.00 lb/gm, the yield point of barite and dolomite was 25.0 and 26.0 Ib/100ft^2 while at 18.00 lb/gm, it increased to 72.0 Ib/100ft^2 and 75.0 Ib/100ft^2 respectively. Also Figs. 6-9 show the same parameters at 150˚F and different particle sizes (45μm, 63μm and 75μm) with two concentrations 4.5% and 6%. This small difference might be because dolomite's attrition is the same with that of barite. The optimal yield point could carry cuttings to the surface in a more efficient and effective manner.

5.3.4 Gel strength and mud density

Figs. 4 and 5 show the relationship between gel strength at 10 seconds and 10 minutes with mud density respectively. Gel strength of drilling fluid is the measure of the shearing stress necessary to initiate a finite rate of shear. Dolomite sample has higher gel strength compared to barite sample. At 10.00 lb/gm, the 10 second gel strength of barite and dolomite was 16.0 and 28.0 Ib/100ft^2 while10 minutes gel strength was 19.0 and 30.0 Ib/100ft^2 respectively. At 18.00 lb/gm, the 10 second gel strength of barite and dolomite was 65.0 and 60.0 Ib/100ft^2 while10 minutes gel strength was 77.0 and 71.0 Ib/100ft^2 respectively. There was increasing in the values as the mud density increases. Also Figs. 6-9 show the same parameters at 150˚F and different particle sizes

(45 μm, 63 μm and 75 μm) with two concentrations 4.5% and 6%.

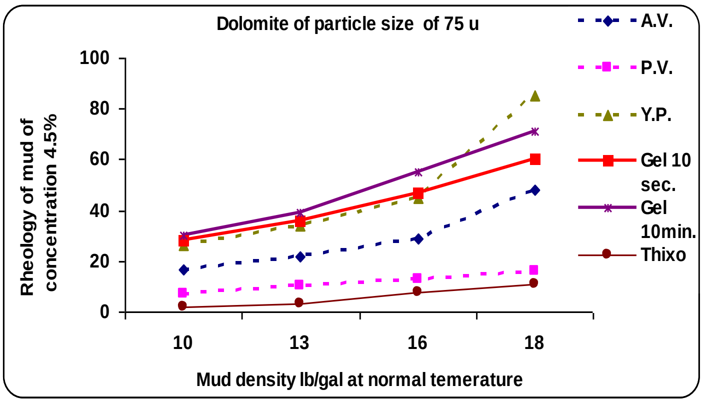

Fig. 6 The rheology of mud fluid at bentonite concentration 4.5% weighted by Um Bogma dolomite 75 μm at normal temperature

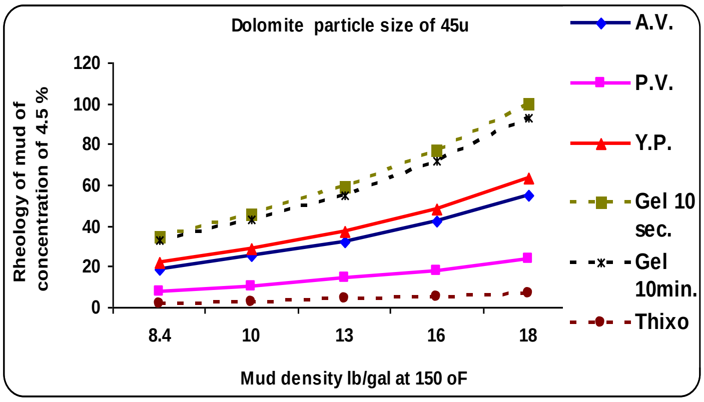

Fig. 7 The rheology of mud fluid of bentonite concentration 4.5% weighted by Um Bogma dolomite 45 μm at 150˚F

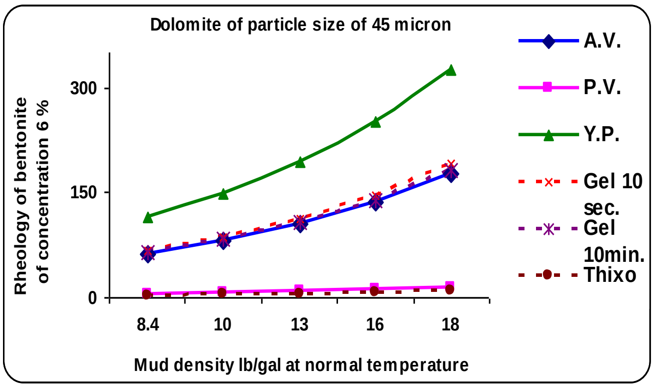

Fig. 8 The rheology of mud fluid of bentonite concentration 6% weighted by Um Bogma dolomite 45 μm at normal temperature

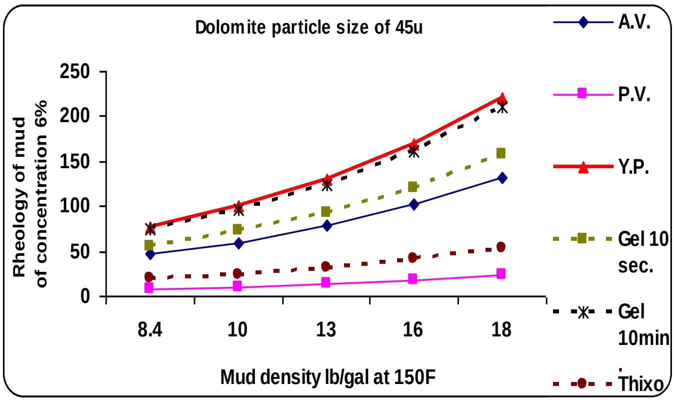

Fig. 9 The rheology of mud fluid bentonite concentration 6% weighted by Um Bogma dolomite 45 μm at 150˚F

5.3.5 Thixotropy and mud density

Figs. 4 and 5 show the relationship between thixotropy and mud density. The plot shows that barite has higher thixotropy than dolomite. At 10.00 lb/gm, the thixotropy of the dolomite and barite were 2 Ib/100ft^2 and 3 Ib/100ft^2 respectively and at 18.00 lb/gm, the thixotropy were 11 Ib/100ft^2 and 12 Ib/100ft^2 respectively. Also Figs. 6-9 show the same parameters at 150˚F and different particle sizes (45 μm, 63 μm and 75 μm) with two concentration 4.5% and 6%. This is a marginal difference of 1 Ib/100ft^2 between the mud samples; thus dolomite could be used as barite substitute Mahmoud and Hany (2013).

5.4 Aging of barite and dolomite

Figs. 10 and 11 shows rheology for barite and dolomite after aging, the drilling fluid with dolomite gives the highest rheology but mud with barite as weighting agent produced lowest rheology after aging, dolomite increasing the apparent viscosity, thixotropy and gel strength of the mud.

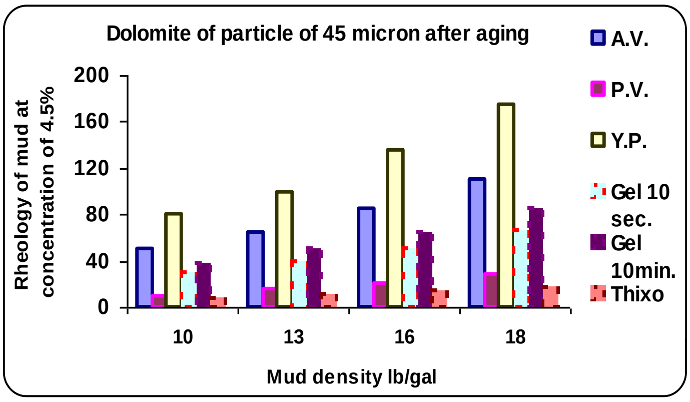

Fig. 10 The rheology of drilling fluid of bentonite concentration 4.5% weighted by Um Bogma dolomite 45 μm after aging

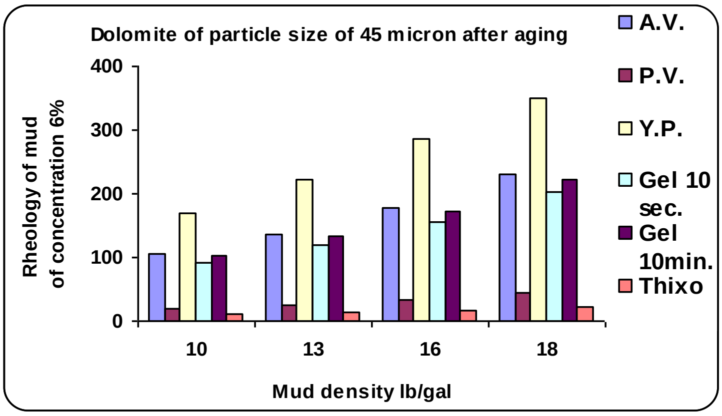

Fig. 11 The rheology of drilling fluid of bentonite concentration 6% weighted by Um Bogma dolomite 45 μm after aging

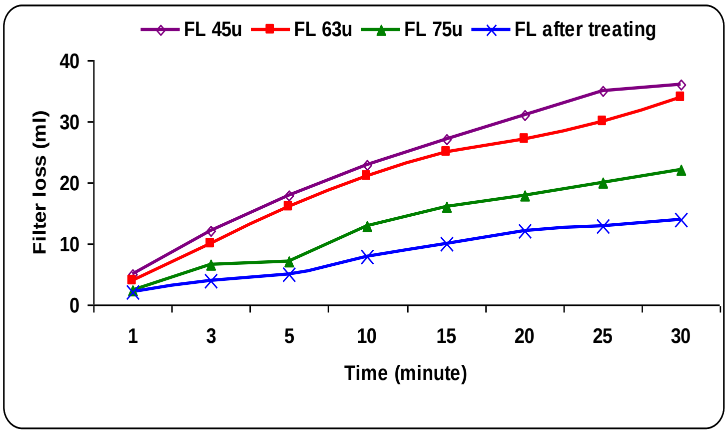

Fig.12 Filtration loss (FL) of drilling fluid of bentonite concentration 4.5% with three particle sizes and PAC treatment

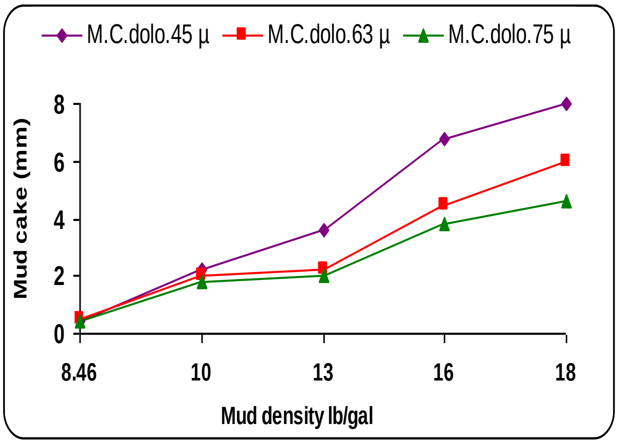

Fig.13 Mud cake of drilling fluid of bentonite concentration 4.5% with three particle sizes

5.5 Filtration loss and mud cake

API filtration test is an indication of the rate at which permeable formations are sealed by the deposition of a mud cake after being penetrated by the bit. Cake buildup during drilling is desirable as it protects the formation from being contaminated by fluid invasion, Watson *et al.* (2012).

Thus it reduces formation damage during drilling operation. Thickness of the mud cake also says something about the formation. Porous rock usually produces thicker mud cake as it is easier for fluid to invade into the formation. Non porous rock such as shale will produce very thin mud cake since it is nonporous and fluid invasion is very weak, Elkatatny *et al.* (2011).

Figs. 12 and 13 show the thickness of mud cake and the volume of the collected mud filtrate from all tested samples of bentonite concentration 4.5% weighted by dolomite of three particle sizes 45 μm, 63 μm and 75 μm which the blank sample produces the thinness cake which is about 0.4 mm. It is also noted that the cake thickness seems to reduce with the increase of dolomite grain size. The filtration loss decrease with increase the particle size of dolomite ranged from18 mm to about 35 mm, therefore to decrease the filtration loss its need to treatment with chemical additive (PAC) to adjust the filtration rat at 14 mm, (Negm *et al.*, 2014).

6. Conclusions

- The rheological properties of dolomite are similar to that of barite and therefore could be used in place of barite.
- Dolomite of has the potential to be used as weighting agent in drilling fluid.
- Solid content of barite is small than the solid content of dolomite of the same quantity of dolomite could produce same mud density as barite.
- Dolomite tends to increase the plastic viscosity.
- Filtration loss of dolomite may treated by PAC additive.
- Rheology of the drilling sample included bentonite with concentration 4.5% and dolomite weighting agent with grain size 45 μm is more potential than the drilling sample included bentonite with concentration 6% and two grain sizes 63 μm and 75 μm.

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