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A New Insight into Formulation Approach for Water Based Drilling Fluids

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Abstract

The objective of this study is to develop a water-based drilling fluid with enhanced rheological and filtation characteristics by using a coal combustion by product which is known as fly ash (CCA). To this end, initially, bentonite drilling fluids were designed by CCA in various concentrations considering American Petroleum Institute (API) standards. Secondly, drilling fluid systems containing different concentration of bentonite and Xanthan Gum (XG) were prepared to analyze the effectiveness of CCA in different drilling mud compositions. In addition, the drilling fluid samples containing bentonite in the presence and absence of CCA were aged under different periods for a better analyzing the performance of CCA. Experimental outcomes showed that improvement in the drillling fluid depends on concentration of CCA introduced and developed drilling fluid systems contaning increasing bentonite and XG concentration in presence of CCA had better rheological behaviour. In addition, aging time also enhanced the rheological behaviour of the developed drilling fluid containing CCA. Through the study, a cost effective water based drilling fluid possessing superior characteristics was developed by CCA, thereby decrasing possibility of serious drilling problems and cost of drilling operatio.

Keywords: *: Drilling fluid; Fly ash; Fentonite; Rheology; Filtration; Aging; XG polymer.*

1. Introduction

Drilling fluid is an indispensable component in the success of well drilling due to performing utmost significant tasks such as cleaning bottom of the well, controlling the formation pressures, lubricating and cooling drilling string, stabilizing the wellbore, inhibiting corrosion, ensuring that the cuttings in the annulus are kept in suspension when circulation is interrupted, transmitting surface hydraulic power to drill bit [1-3] and constitutes a significant item of the total drilling cost [4]. A significant part of the problems that occur during drilling are due to the characteristics of the drilling mud [5]. The suitability of the circulated drilling mud and proper control of the drilling mud's properties greatly affect performance of the drilling operation [6-8]. A proper selection and special formulation of drilling fluid is essential for ensuring an efficient and relatively safe drilling operation to meet downhole conditions [4,9]. Otherwise, inappropriate drilling fluid selection and formulation may cause high cost to overrun and wellbore instability problems which may subsequently led to loss of the well.

Drilling fluids are usually classified as either water based or oil based muds [2]. However, water based drilling fluid is utilized in 80% of the wells drilled in the world due to its cost effective, environmentally friendly and non-hazardous nature as compared to oil-based drilling fluids [10]. In addition, bentonite mud is the most commonly used mud among water based muds. Conventionally various additives such as fluid loss controller and viscosifiers which are toxic and expensive materials have been introduced to the water-based bentonite mud to keep the rheological and filtration properties of the drilling mud at desired levels in accomplishment its job efficiently [11]. Besides the additives to fulfil their task effectively, cost, and environmental considerations also determine their selection as additive to be used in the drilling mud [12-13].

CCA is the waste materials generated by the combustion of hard coal or lignite coal, which are burned in thermal power plants established to generate energy. It is generally grey in colour, high temperature resistance and abrasive. According to the ASTM C 618 standard [14], CCA is divided into 2 groups as class of F and C. CCA of Class F is generated from semi-bituminous, bituminous and anthracite coal whereas CCA of Class C is produced from coals of semi-bituminous or lignite [15].

CCA is one of the most abundant waste and known that annually approximately 500 million tons of the ash is produced in worldwide [16]. Due to the increasing number of thermal power plants today, it is predicted that in the future amount of the ash in the world will increase even more. In recent years, comprehensive studies have been carried out to recycle CCA. For instance, 20% of CCA is used in cement and concrete industry due to its pozzolanic feature [17]. In addition, CCA is used in various fields such as ceramics, glass and glass-ceramic industry, soil amendment, road pavement, embankments, sorbent, and sludge conditioning [18]. However, current processes are insufficient to exactly consume the CCA produced. The disused part is waste and it requires disposing into ash ponds and lagoons. The disposal of CCA causes significant environmental pollution [19]. Environmental problems caused by CCA include pollination, damage to agricultural products, rain and wind erosion, toxic material transport due to leaching in the soil, and radiation. Due to these environmental problems, undesired consequences occur in terms of agricultural products, quality of water and air, natural life, economic situation of the region and environmental beauty. Therefore, development of new recycling technique that can further exploit CCA is essential, which CCA needs more consideration as a raw material with the potential to be turned into new products rather than waste.

To date, it is observed that utilization of CCA in drilling fluid has not been studied extensively [20-23]. Avci *et al.*, [24] studied the CCA of Class F (Brown coal) and Class C (lignite) in gypsum/polymer inhibitive water-based mud. They found that CCA of Class F shows better performance than Class C. In addition, CCA of Class F with optimum concentration has an improvement on the rheology, filtration as well as mud cake thickness while CCA of Class C negatively affected fluid loss and thickness of filter cake of the drilling fluid despite of enhancement in rheology. Mahto *et al.*, [25] developed a mud system blended with CCA having lower fluid loss and filter cake thickness by comparing and combining with $CaCO_3$. Mahto and Jain, [26] investigated capability of CCA in drilling fluid containing potassium chloride with addition of increasing concentration. They concluded that CCA has negligible effect on rheology while shows better filtration and thickness of filter cake.

Herein, an intense experimental analysis was performed to formulate a drilling fluid possessing superior flow properties based on application of CCA. The utilization of CCA of Class F in three water-based bentonite drilling fluid systems having different compositions was investigated by analysing gel strength (10 s, 1 min. and 10 min.), yield point, fluid loss volume, apparent viscosity, filter cake thickness of the mud and plastic viscosity under different aging time. To our best knowledge, this is the first study in analysing the use of CCA in different water based bentonite mud simultaneously by taking in to account different aging time.

2. Experimental procedures

All laboratory tests were conducted considering standard of the American Petroleum Institute (API) (API-RP-13B) for this study. Figure 1 illustrates a general workflow for the experimental process.

2.1. Materials

Main material used in the study is brown coal CCA and collected from an 900 MW power plant located in Tiszaújváros. The CCA was dried in a drying cabinet for 8 hours by being exposed to a temperature of 105°C to reach constant mass by removing moisture in the CCA content and sieved through a 106 µm sieve.

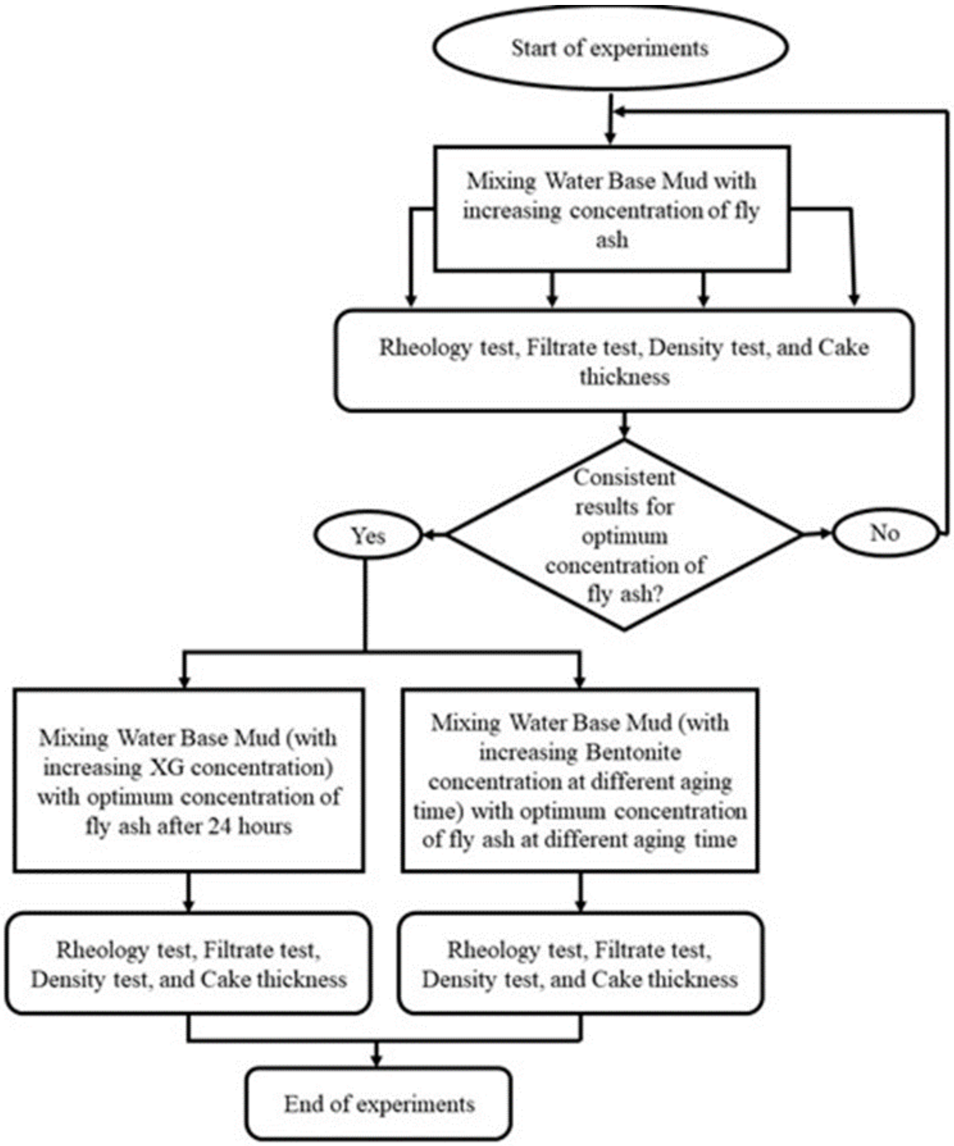


Figure 1. Flowchart of the experimental process

2.2. Formulation of water-based drilling fluids

In the study three fresh water-based mud systems with bentonite, water, XG, CMC and CCA based on specific concentrations at drilling laboratory were prepared. For the first mud system, after water weighted (350 cc) pouring into the Hamilton beach mixing cup, bentonite (6.4 wt%) was added and stirred for 20 minutes under stirring condition. Subsequently, XG (0.5 g) and CMC (1 g) were added into the mixing cup and stirring the mixture for 5 minutes sequentially and the mixture was rested for 24 hours before using it in the tests to ensure exact hydration of bentonite. Rheological and filtration properties of this mud system were measured and used as benchmark fluid for evaluation of performance of CCA. Afterwards, desired concentrations of CCA ranging from 1.0 wt% to 5.0 wt% were added to the mud system and continued to be mixed by the mixer for 10 minutes until homogeneity to monitor change in flow behaviour of the water-based mud and determine optimum concentration of CCA by analysing rheological reading (plastic viscosity, apparent viscosity), gel strength, density, fluid loss and cake thickness and comparing the benchmark fluid.

In the second step, same process was repeated by increasing bentonite concentration from 6.4 wt% to 8.0 wt%. In addition, first and second mud systems were rested for 48 and 72 hours at room temperature in absence and presence of optimum concentration of CCA determined in first step for a better understanding of performance of CCA based on different aging time by comparing first mud for 24 hours aging time and measuring rheological reading (plastic viscosity, apparent viscosity, yield point), gel strength, density, fluid loss and cake thickness. In third step, a mud system was developed in the same manner containing higher XG concentration (0.8 g) compared to the first and second mud systems resting for 24 hours. Thereafter, optimum concentration of CCA found in the first step was also introduced into the mud and stirring was continued again up to a homogeneous suspension was obtained. Plastic viscosity, apparent viscosity, yield point, gel strength, density, fluid loss and cake thickness of the muds were measured and compared with the benchmark fluid. It should be noted that the second and third mud systems were formulated to further analyse of feasibility of CCA at mud system with different composition. Formulation and code of the developed water-based muds were shown in Table 1.

Table 1. Composition and codes of the formulated mud system

Mud system	Composition					
	Water (cc)	Bentonite (g)	XG (g)	CMC (g)	CCA (wt%)	Aging time (hour)
B1-24	350	22.5 (6.4 wt%)	0.5	1	-	24
B1-48	350	22.5 (6.4 wt%)	0.5	1	-	48
B1-72	350	22.5 (6.4 wt%)	0.5	1	-	72
B2-24	350	28 (8 wt%)	0.5	1	-	24
B2-48	350	28 (8 wt%)	0.5	1	-	48
B2-72	350	28 (8 wt%)	0.5	1	-	72
XGM	350	22.5 (6.4 wt%)	0.8	1	-	24
B1-F4-24	350	22.5 (6.4 wt%)	0.5	1	4	24
B1-F4-48	350	22.5 (6.4 wt%)	0.5	1	4	48
B1-F4-72	350	22.5 (6.4 wt%)	0.5	1	4	72
B2-F4-24	350	28 (8 wt%)	0.5	1	4	24
B2-F4-48	350	28 (8 wt%)	0.5	1	4	48
B2-F4-72	350	28 (8 wt%)	0.5	1	4	72
XGM-F4	350	22.5 (6.4 wt%)	0.8	1	4	24

2.3. Rheological determination

By using a rotational Fann Viscometer (Model 35 SA) the rheology measurement of the mud samples to be tested was conducted at the ambient condition. Sample cup of the device was filled with the correct volume of mud sample according to the standards of the device and rotor was installed correctly. Then, the device was turned on and dial readings were recorded at different rotation speeds such as 3, 6, 100, 200, 300 and 600 (rpm). Thereafter, dial readings were recorded for the each speed with the mud stirred for ten seconds at 600 rpm between readings at different speeds to ensure same shear history for each rotation speed. In the computation of plastic viscosity (PV), apparent viscosity (AV) and yield point (YP) of the samples formulated following equations were used.

$AV=\theta_{600}/2$ (1) PV in (cP):

$PV= \theta_{600} - \theta_{300}$ (2) YP in (lb/100ft^2):

$YP= \theta_{300} - PV$ (3)

where θ_{600}: dial reading 600 rpm θ_{300}: dial reading 300 rpm.

Gel strength was obtained from viscometer dial reading in lbs/100ft^2. For measurement of the gel strength firstly, the mud sample to be tested was rotated at 600 rpm for ten seconds. Secondly, the mixing was stopped for ten seconds, one minute and ten minutes sequentially. Finally, the device was turned on at 3 rpm and the highest deflection reading value reached was recorded for each stopping time with ensure to continuously mixing between the stopping times at a speed of 600 rpm for 10 seconds.

2.4. Analysis of density

Density of the drilling fluid samples formulated was measured with a Model 140 Fann Mud Balance device. Balance cup of the device was filled with the correct volume of mud sample according to the standards of the device. Thereafter, the balance of the device arm was achieved between the weight of the sample and the moving weight by centring the bubble between the two vertical black lines and value of density was noted from the ruler on balance arm.

2.5. Analysis of fluid loss

Fluid loss test of the mud samples formulated was conducted with Ofite API filter press (low pressure-low-temperature). Firstly, the metal cylinder of the device was loaded with the mud sample to be tested. Then, 100 psi nitrogen pressure was applied for the duration of 30 minutes at ambient temperature. Filtrate volume of the samples was collected with a graduated cylinder placed under the metal cylinder of the device in ml unit for 30 min. Thereafter, by using a graduated ruler thickness of filter cake of the drilling fluid was measured.

3. Results and discussion

3.1. Evaluation of concentration variation of fly ash on flow characteristic of drilling fluid

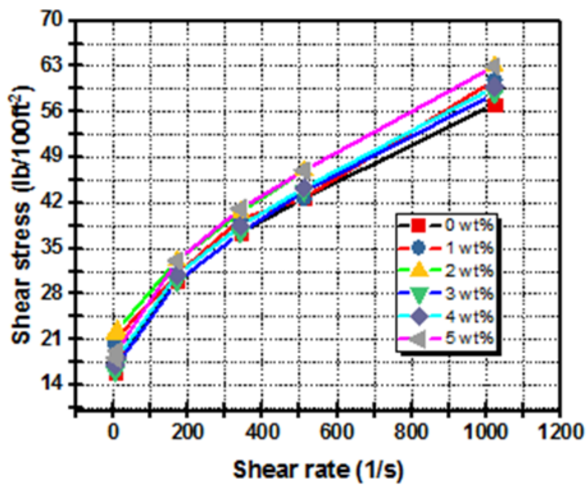


Figure 2. Reogram curve of water based drilling fluid at different concentration of CCA

Figure 2 shows shear stress against shear rate for the drilling mud when increasing concentration of CCA was introduced. As can be seen from the figure, addition of CCA into the base mud yielded an increase in shear stress magnitudes. However, the most significant increase was seen after 4 wt% concentration.

Figure 3 represents variation in AV, PV, YP and gel strengths, including Gel10s, Gel1min and Gel10 min of water based drilling fluid depending on increasing concentration of CCA. Test results indicate that YP, AV and PV of the drilling fluids show a fluctuation with increasing concentration CCA. AV of base mud increased with addition of up to concentration of 2 wt% CCA into the mud. However, again a reduction was observed with addition of 3 wt% CCA in AV. Beyond 3 wt%, AV started to increase. The PV decreased with concentration of CCA more than 1.0 wt%, the highest PV was obtained with addition of 1 wt% CCA. Beyond 3 wt% concentration, PV showed an increasing pattern slightly. In addition, employment of CCA at increasing concentration increased the yield point of the base mud except of 1.0 wt% concentration. On the other hand, addition of 2 wt% CCA raised the yield point significantly, and the highest yield point was achieved with 2 wt% and 5 wt% CCAs. Mud system containing 3 wt% and 4 wt% CCA concentrations had very close yield point values. The increased yield point can be explained as drilling fluid systems containing CCA with 2.0, 3.0, 4.0 and 5.0 (wt%) concentrations have higher attractive forces. When the gel strength was examined, resembling effects to AV was observed. Gel10s, Gel1min and Gel10 min increased up to concentration of 2 wt% CCA while the gel strengths decreased with the addition concentration of 3 wt% CCA. Beyond 3 wt% concentration of CCA, the gel strengths started to rise with further increasing concentration.

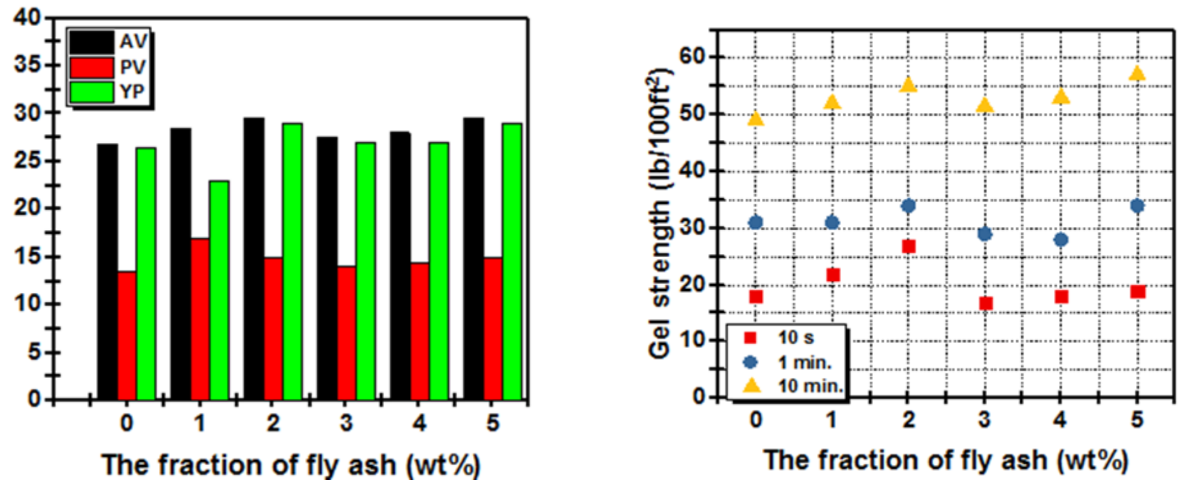


Figure 3. Rheological properties changes of samples with different concentration of CCA (AV [cP], PV [cP], YP[lb/100ft^2] (left), gel strength (right).

A fluctuation was observed for fluid loss with increasing concentration of CCA as well. Referring to Figure 4, initially, the fluid loss decreased up to 2 wt% concentration. After that addition of 3 wt% CCA caused an increase in the filtrate volume recorded end of the 30 minutes. However, addition 4 wt% CCA yielded a reduction in fluid loss amount. The fluid loss decreased by %12 by introducing 4 wt% CCA into the base mud, which is lowest filtrate volume obtained among the concentrations.

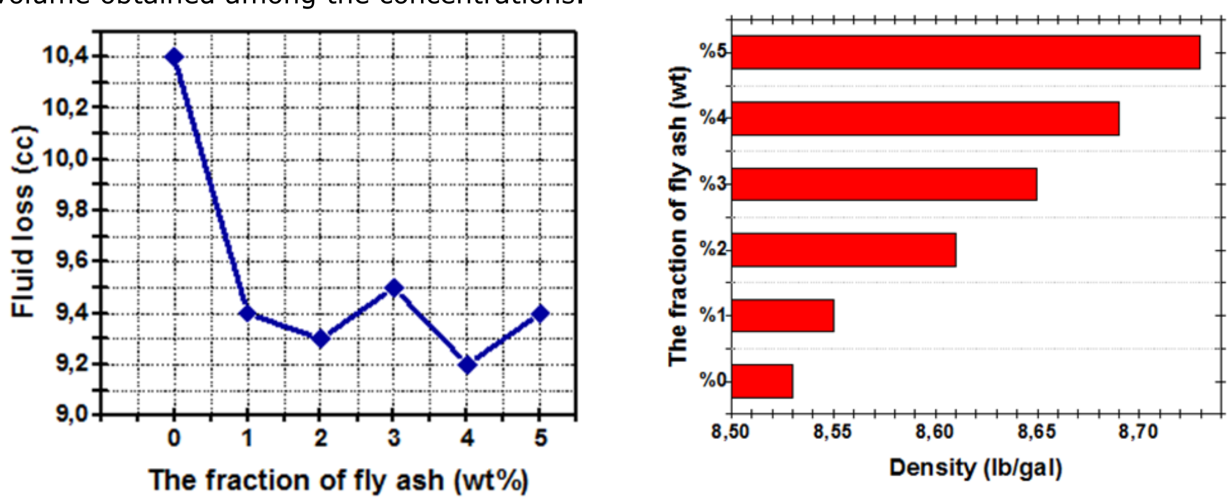


Figure 4. Change in fluid loss (left) and thickness of filter cake (right) of samples with different concentration of CCA

A fluctuation was also observed cake thickness depending on increasing concentration of CCA, as can be seen in Figure 4. Employing 2 wt% and 5 wt% concentration of CCA caused to increase mud cake thickness by 20% and 10%, respectively while mud cake thickness remained constant with the addition of 1 wt% and 3 wt% CCA compared with control base fluid. On the other hand, addition of 4 wt% CCA decreased the cake thickness by 10% that is the thinnest mud cake achieved.

From overall analysis with respect to rheology and filtration at increasing concentration of CCA, it can be said that mud system incorporates 4 wt% CCA has better flow characteristics with higher rheology, thinner mud cake and less filtrate volume compared to other mud samples. Success of drilling operation is largely affected from higher rheology, low fluid loss and thin filter cake by helping to clean the well efficiently, decreasing formation damage and

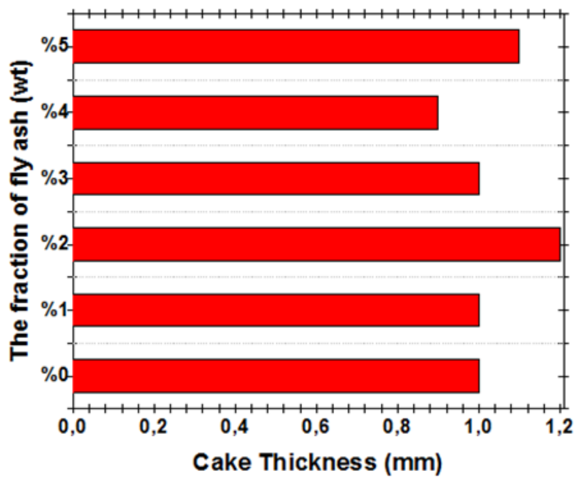


Figure 5. Density of water based drilling fluid including increasing concentration CCA

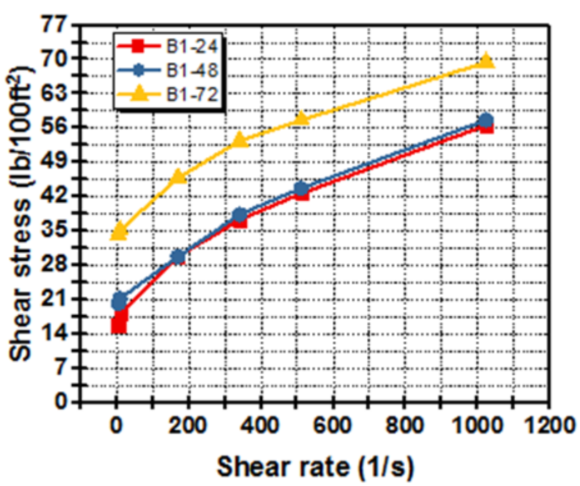
preventing serious drilling problems that may even cause the well to be abandoned. The mud system with these characteristics also provides some reduction in drilling and production cost.

From Figure 5, it was observed that with the employment of CCA at increasing concentration increased density of the bentonite mud. This is due to the increased solid mass in the drilling mud.

3.2. Evaluation of bentonite concentration and aging time on flow behavior of drilling fluid in presence of fly ash

To analyze effect of aging time and concentration of bentonite and XG on performance of CCA different mud systems were designed, which are given in Table 1.

Figure 6 demonstrates rheogram of B1 mud containing 4 wt% CCA and mud without CCA under 24, 48 and 72 hours aging time. It can be seen that increasing aging time produced a higher rheology profile for both B1 mud in presence of 4 wt% and absence of CCA. It worth's to be noted that mud samples with 72 hours aging time represents a crucial rising in shear stresses under both of two conditions. However, B1 mud samples with 4 wt% CCA experienced higher rheology profile under same aging times compared to the samples without CCA.



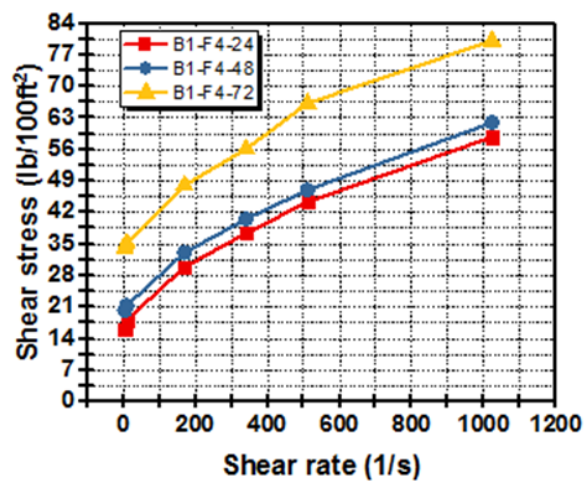


Figure 6. Change in shear stress versus shear rate of B1 mud in presence of 4 wt% (right) and absence of CCA (left) under different aging time.

Figure 7 shows shear stress versus shear rate of B2 mud containing 4 wt% CCA and mud without CCA under aging time of 24, 48 and 72 hours. As can be seen that increasing bentonite concentration caused a significant variation on rheology pattern. Contrary to B1 mud, increasing aging time caused a reduction of rheology profile of B2 mud compared to 24 hours aging time and the lowest shear stress magnitudes were observed in sample with 48 hours aging time. On the other hand, B2 mud in presence of 4 wt% CCA under increasing aging time yielded to rise in rheology profile. While B2 muds containing 4 wt% CCA under 24 and 72 hours aging time showed very close shear stress values, the sample containing 4 wt% CCA at 48 hours aging time experienced the highest shear stress values. Compared to B1 drilling fluid systems containing %4 wt% CCA and without CCA results, it can be said that B2 mud with 4 wt% CCA under 48 hours aging time has the highest shear stress values among all B1 mud (in presence of 4 wt% and absence of CCA) and other B2 samples studied.

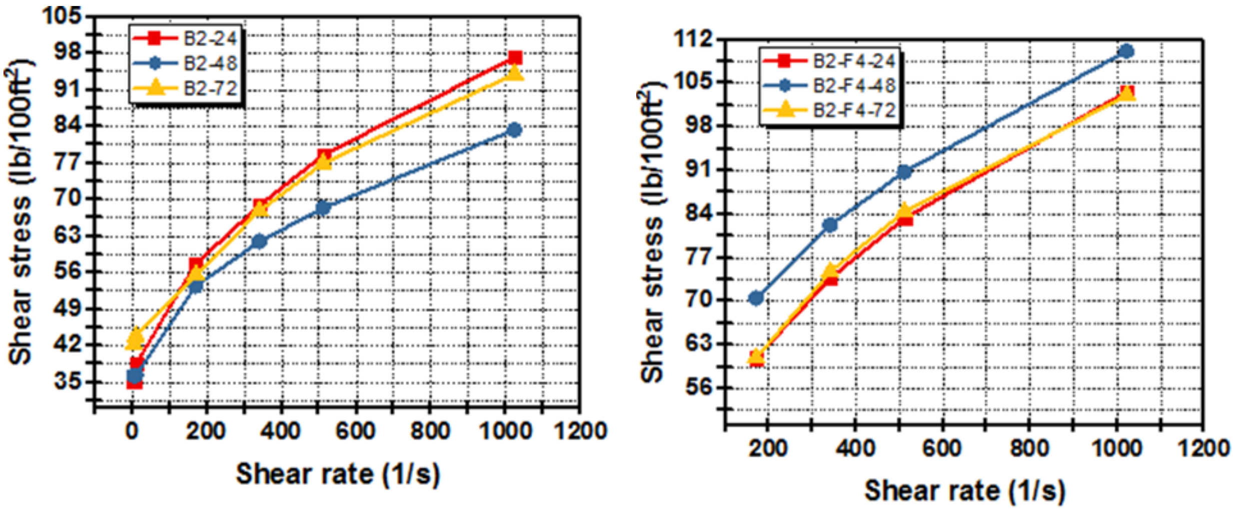


Figure 7. Change in shear stress versus shear rate of B2 mud in presence of 4 wt% (right) and absence of CCA (left) under different aging time

Bentonite amount and aging time play a crucial role on performance of CCA in bentonite mud. Figure 8 shows AV, PV, YP and gel strengths, including Gel10s, Gel1min and Gel10 min of water based drilling fluid samples incorporated with optimum concentration of CCA, which is 4 wt%, at increasing bentonite concentration under 24, 48 and 72 hours aging time. From Figure 8(a), it is clear that in B1 drilling fluid system (API bentonite mud), which is bentonite concentration is 6.4 wt%, performance of CCA increases with the increasing aging time. Addition of 4 wt% CCA into the base B1 mud AV, PV and YP of the B1 mud increased by 4%, 14%, 3%, respectively, for 24 hours aging time. On the other hand, for 48 hours aging time AV, PV and YP of the mud increased by 9%, 7%, 11%, respectively with the addition of 4 wt% CCA. However, the highest increase in AV and YP was observed in the sample with 72 hours aging time. AV and YP of the mud increased by 41% and 81%, respectively with the addition of 4 wt% CCA and no change was observed in PV for 72 hours aging time. When bentonite amount increased from 6.4 wt% (B1) to 8 wt% (B2) under same condition it was found that increasing bentonite concentration further enhances performance of CCA, which is given in Figure 8 (b). For 24 hours AV, PV and YP of mud containing 8 wt% bentonite increased by 83%, 46%, 118%, respectively with the addition of 4 wt% CCA. For 48 hours aging time, the AV and YP of the mud increased by 85% and 166%, respectively. And, no change was observed in PV. For 72 hours aging time AV, PV and YP of the mud increased by 81%, 34%, 128% respectively. By analysing these results, it was found that B2 drilling fluid system containing 4 wt% CCA under 72 hours aging conditions shows the optimum properties with respect to rheology results.

Figure 8(c) and Figure 8(d) shows that gel strengths of 10 second, 1 minute and 10 minutes of the B1 and B2 mud containing 4 wt% CCA and without CCA under 24, 48 and 72 hours aging time. Referring the Fig., the gel strengths increased with the increasing aging time for B1 and B2 muds both in presence and absence of CCA. Moreover, increasing bentonite concentration further increased gel strengths. While the increase in aging time led to increase thixotropy of B1 mud, thixotropy of the B2 mud decreased with the increasing aging time. Also, the addition of 4 wt% of CCA in all aging times, except B1-F4-72, caused an increase in thixotropy of B1 mud. However, B2 mud in presence of 4 wt% CCA has lower thixotropy under all studied aging time compared to the B1 mud. The gel strength results indicate that B2 mud with 4 wt% CCA under 72 hours aging time has lowest thixotropy among the other samples and decreased the thixotropy by 10% compared to control base mud (B1-24).

From Figure 9 (a, b), it is seen that increasing aging time and bentonite concentration improves performance of CCA with respect to filtration properties by decreasing filtration of both B1 and B2 drilling fluid systems. It should be noted that lower fluid loss was obtained with B2 mud compared to B1 mud under constant aging time, except for 72 hours. The filtrate volume recorded at the end of 30 minutes of B2 mud is 12% and 6% lower than B1 mud for 24 and 48 hours aging time, respectively. Moreover, addition of 4 wt% CCA into the muds provides further reduction in fluid loss with increasing aging time. The B2 sample containing 4 wt% CCA under 72 hours aging time experienced the lowest fluid loss by decreasing the fluid loss by 24% compared to base mud (B1-24).

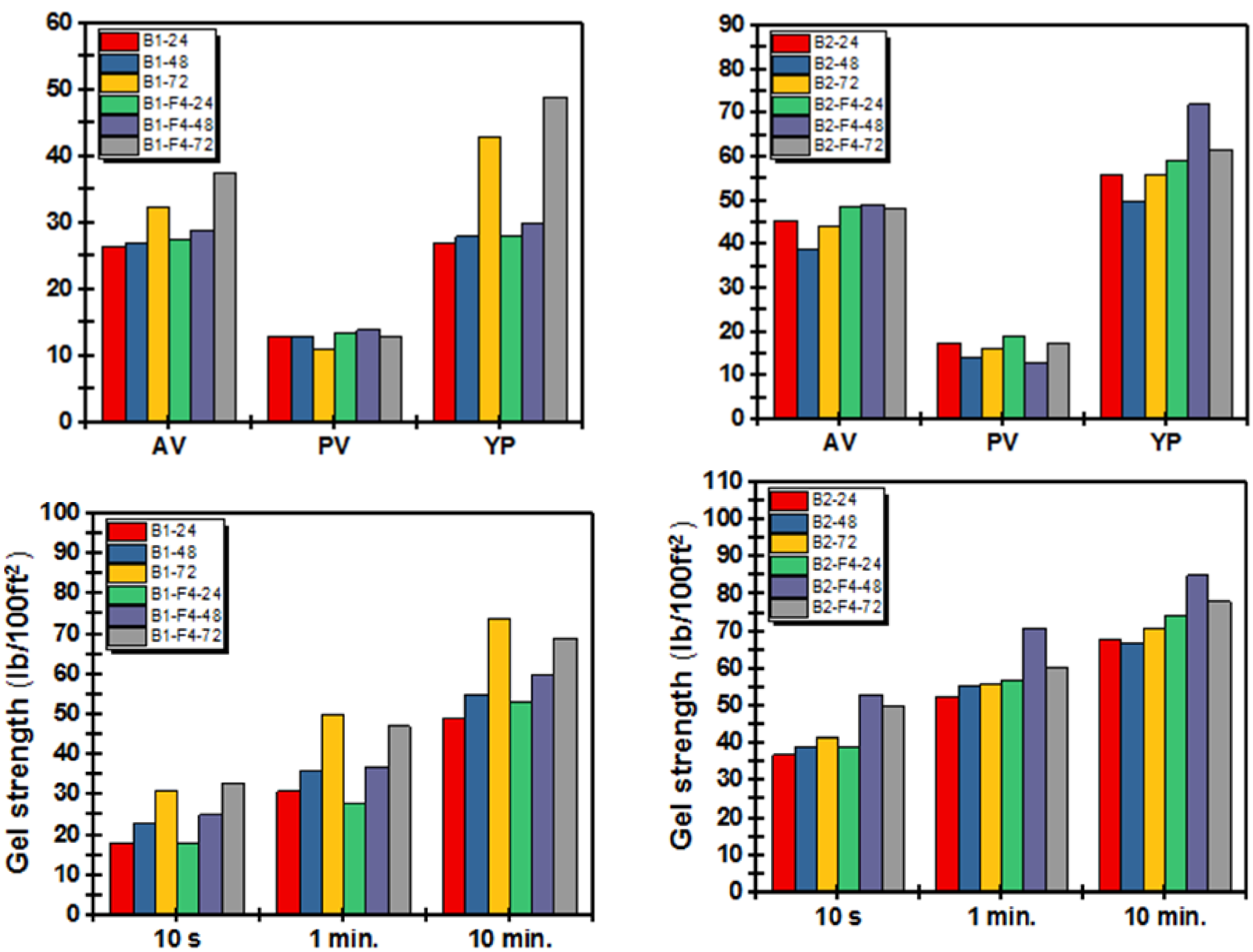


Figure 8. Rheological properties of B1 and B2 systems under different aging time and in presence of 4 wt% CCA, AV [cP], PV [cP], YP [lb/100ft^2] for B1 (a) B2 (b) Gel strengths for B1 (c) B2 (d)

Figure 9(c) and Figure 9(d) shows that increasing aging time cause a thicker mud cake for B1 mud containing lower bentonite concentration, 6%, compared to the base mud with 24 hours aging time while decreases cake thickness of B2 mud containing 8 wt% bentonite concentration even for samples without CCA. On the other hand, aging B1 muds in presence of 4 wt% CCA provide thinner mud cake than that of mud without CCA under constant aging times. For instance, introducing 4 wt% CCA into the B1 mud for 48 hours aging time and 72 hours aging time decreased the mud cake thickness by 40% and 36%, respectively compared to the

B1-48 and B1-72 samples without CCA under constant aging time. It is worth mentioning that thickness of mud cake for all samples containing 4 wt% CCA and under different aging times is higher than base mud (B1-24). In addition, cake thickness of B2 mud is thinner than that B1 mud both in presence of 4 wt% and absence of CCA for aging time of 48 and 72 hours.

It worth to note that while less the fluid loss volume was obtained with increasing aging time and bentonite concentration, thinner mud cake was not achieved by applying those conditions. However, mud cake thickness B2 mud containing 4 wt% CCA for 72 hours was found to be the same as the cake thickness of B1-24 mud. To sum up, analysis results shows that mud containing 8 wt% bentonite concentration with 72 hours aging time has optimum properties among others.

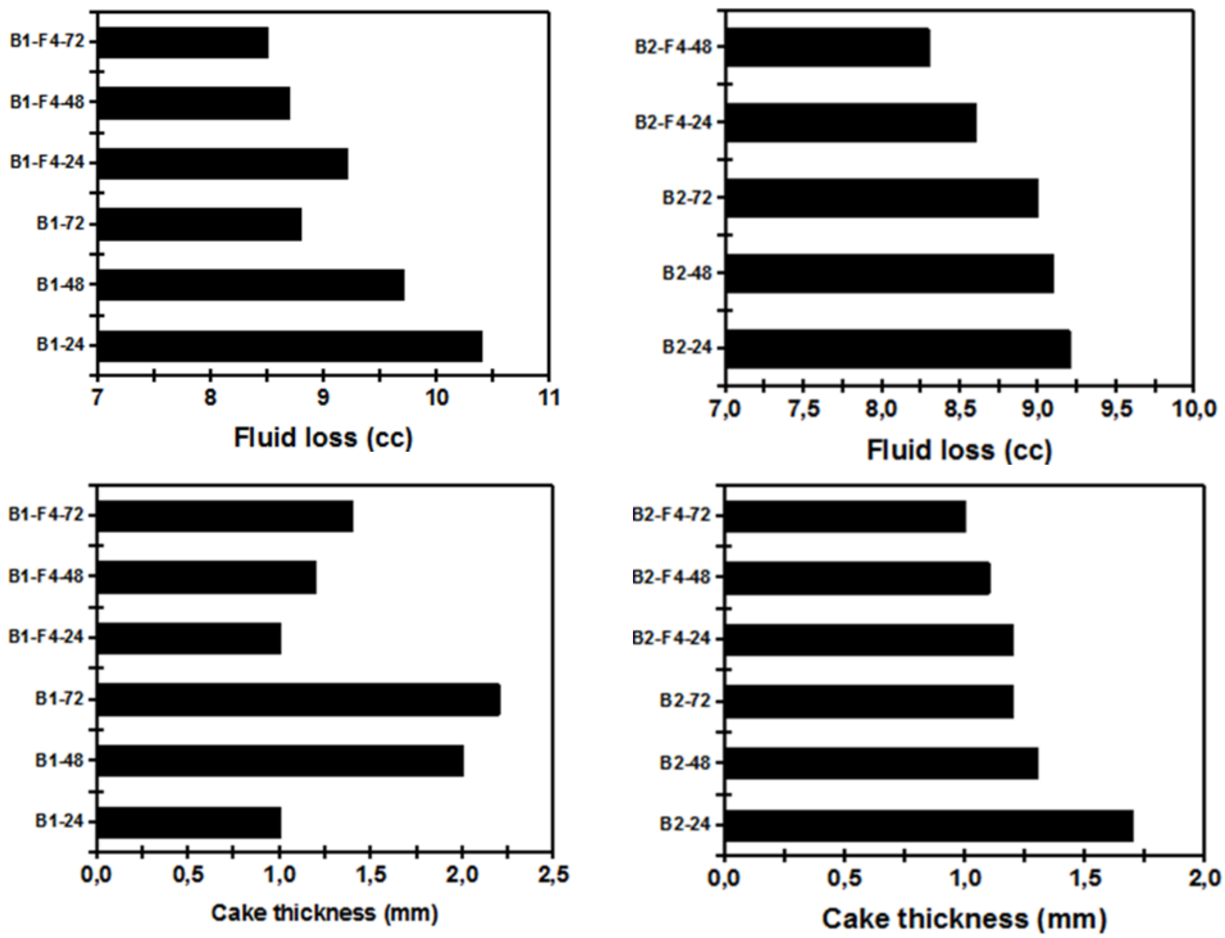


Figure 9. Filtration properties of B1 and B2 systems under different aging time and in presence of 4 w% CCA, Fluid loss for B1 (a) for b2 (b) cake thickness for B1 (c) B2 (d)

3.3. Evaluation of XG concentration on flow behavior of drilling fluid with fly ash

To analyse performance of CCA in presence of higher XG concentration, amount of XG increased and optimum concentration of CCA obtained that is 4 wt% was introduced into the mud system which is coded as XGM and composition of the mud system can be found in Table 2. Referring Figure 10, increasing XG concentration resulted in higher rheology profile by rising shear stress values compared to base fluid (B1-24). Also, analysis results show that increasing XG concentration in presence of 4 wt% CCA experienced higher shear stress magnitudes than those of the mud system containing lower XG amount and 4 wt% CCA (B1-F4-24).

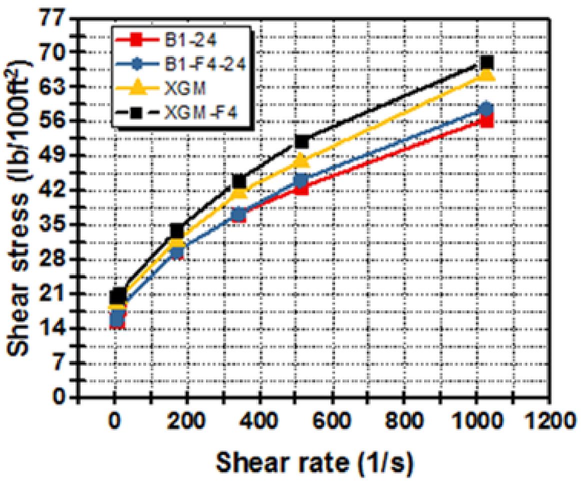


Figure 10. Plot of shear rate versus shear stress of XGM mud system in presence of 4 wt% and absence of CCA compared to base muds (B1-24, B1-24-F4)

Experimental results show that increasing XG concentration improves rheology performance of CCA. Figure 11 demonstrates rheological properties of water based drilling fluid system (XGM-F4) with optimum concentration of CCA, which is 4 wt%, and increasing XG concentration compared to B1-24 and B1-F4-24 muds. From the figure, it can be said that not only increasing XG concentration but also introducing 4 wt% CCA increased the AV, PV and YP of water based drilling fluids (B1-24 and B1-F4-24). AV, PV AV, PV and YP increased by 21%, 14% and 26%, respectively for mud system containing increased XG concentration and 4 wt% CCA compared to B1-24 base fluid. while the AV, PV and YP of the XGM-F4 mud system raised by 14%, 10% and 18%, respectively compared to B1-F4-24. It worth's to be noted that while higher AV and YP was obtained with sample containing 4 wt% CCA and increased XG concentration (XGM-F4) than those of mud system containing only increased concentration XG without CCA (XGM), lower PV was achieved with the addition of 4 wt% CCA into the XGM mud.

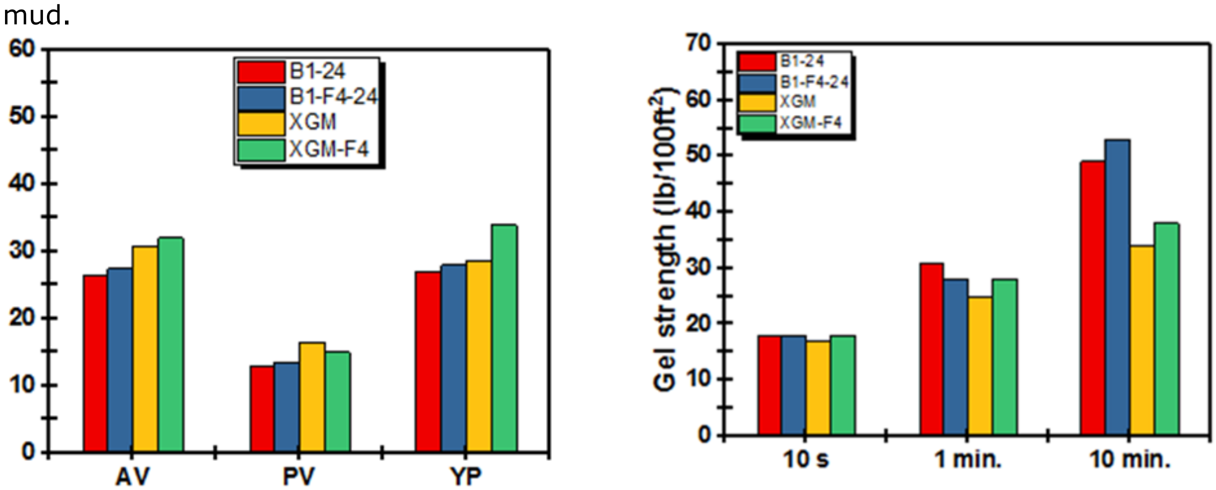


Figure 11. Rheological properties of mud system XGM mud system in presence of 4 wt% and absence of CCA compared to base muds (B1-24, B1-24-F4), AV [cP], PV [cP], YP[lb/100ft2] (left) Gel strength (right)

Increasing XG concentration also improves gel strength of the muds, as can be seen in Figure 11. The gel strengths of the muds increased with the increasing concentration of XG. And the gel strengths further increased with employment of 4 wt% CCA into the mud system containing increased XG dosage. In addition, the thixotropies of B1-24 and B1-F4-24 muds decreased by 35% and 42%, respectively with the increasing XG concentration in presence of 4 wt% CCA. These results indicate that mud system incorporated with increasing XG concentration and 4 wt% CCA will require lower pump pressure in order to restart to drilling operations, thereby reducing cost of drilling process.

Figure 12 presents the filtration properties of the mud system with optimum concentration of CCA and increasing XG concentration compared to B1-24 and B1-F4-24 muds. Results show that both increasing XG concentration and addition of 4 wt% CCA into the XGM system improve the filtration characteristics of the drilling fluids. Increasing XG concentration decreased the fluid loss by about 3% whereas mud system incorporated with 4 wt% CCA and increased XG concentration decreased the filtrate volume by 11% compared to B1-24 mud. On the other hand, it was observed that there is a little difference between the XGM-F4, and B1-F4-24 mud with respect to filtrate volume. Moreover, results also indicate that mud system containing increased concentration of XG, and 4 wt% CCA improves cake thickness of the mud decreasing mud cake thickness by 10 % compared to base control fluids B1-24 and B1-F4-24.

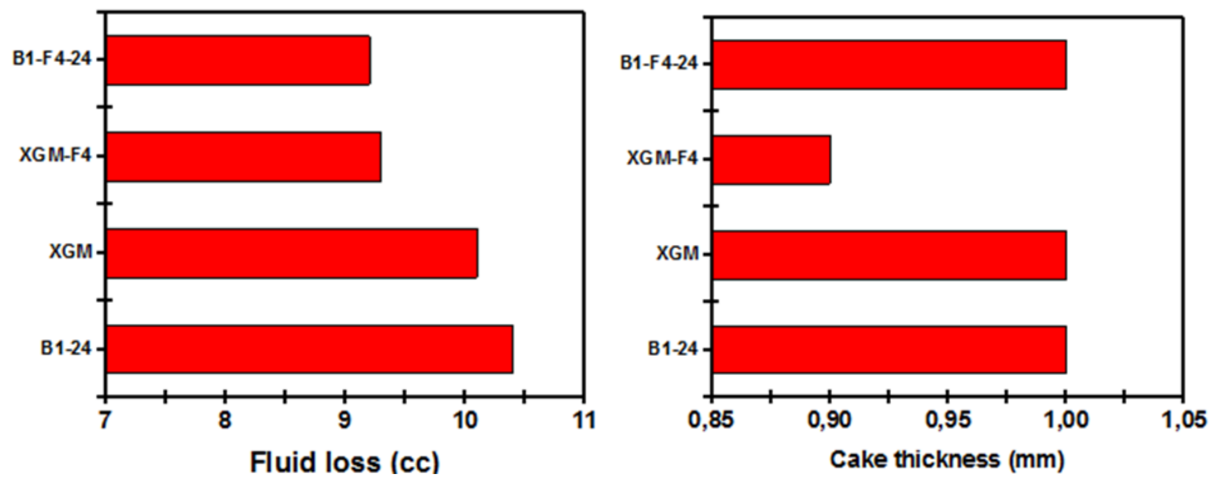


Figure 12. Change in fluid loss (left) and mud cake thickness (right) of XGM mud in presence of 4 wt% and absence of CCA compared to base muds (B1-24, B1-24-F4)

4. Conclusions

In the present study, a comprehensive laboratory experiment was carried out in order to determine optimum fluid formulation for water based drilling fluids with enhanced characteristics by employing industrial waste product CCA. Initially, drilling mud samples were formulated with various concentration of CCA. After determination of optimum concentration of CCA by conducting rheological and filtration measurements of the drilling fluid systems, under different bentonite and XG concentration as well as different aging time conditions drilling fluid systems were formulated with CCA. Rheological and filtration tests of the drilling fluid systems were performed and analysed. Experimental results indicate that these novel drilling fluid systems with specific concentrations of CCA have shown enhancement in flow characteristics of water based drilling fluids by increasing rheology, decreasing fluid loss and building thinner mud cake thickness. Moreover, the rheological properties, filtration control as well as mud cake characteristics of the drilling fluid system have been enhanced significantly by increasing bentonite and XG concentration in presence of CCA. Experimental outcomes also reveal that the simultaneously adding increasing concentration of bentonite to the water based drilling fluid system containing optimum concentration CCA, which is found as 4 wt%, and exposing the drilling fluid system to increased aging time has yielded better drilling fluid performance. From the study, it was deduced that achieving the improvement in the flow characteristics of the water based drilling fluid with the CCA instead of expensive additives provides a reduction in the cost of the well and a new recycling technique has been developed for CCA.

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