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THE RHEOLOGICAL PERFORMANCE OF FLY ASH IN INHIBITIVE WATER-BASED DRILLING FLUIDS

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Abstract

Water-based drilling fluids are the most widely used systems in drilling operations and contain a different type of additive to achieve desired rheological and filtration properties. In this study, an experimental investigation was carried out according to API standards to examine the impact of the various concentration (1.0 wt.%, 3.0 wt.% and 5.0 wt.%) of two types of fly ash (Class F, Class C), which fly ash is a industrial waste product that is obtained after the combustion of coal in thermal power plants, on the gypsum/polymer water-based drilling fluid rheological and filtration properties including apparent viscosity, plastic viscosity, yield point, gel strength, fluid loss, mud cake thickness at room temperature. The results showed that the rheological properties, as well as filtration properties of the drilling fluid, were improved by adding the fly ash that is Class F into the drilling fluid. Adding 3.0 wt.% Class F fly ash (brown coal) increased the apparent viscosity, plastic viscosity, yield point and gel strength by 23 %, 28%, 9 % and 25%, respectively while adding the Class C fly ash (lignite) at the same concentration increased the apparent viscosity, plastic viscosity and gel strength by 12%, 21% and 25%, respectively. Filtration test indicated the fluid loss volume decreased by 23% and mud cake thickness also decreased by 75% with addition of 3 wt.% concentration of Class F type fly ash, whereas adding Class C type of fly ash at same concentration resulted in a decrease in fluid loss by 10% and a increase in mud cake thickness by 150%. Therefore, it can be concluded that the type of Class F fly ash can help in preventing or mitigating several problems that could encounter during a drilling operation.

Keywords*: Drilling fluids; Drilling fluids additives; Filtration; Fly ash; Rheology.*

1. Introduction

Drilling fluid is an inseparable part of the drilling process due to serving many functions such as removing drilled cuttings from the hole, controlling subsurface pressure, cooling, and lubricating drilling tools, maintaining the stability of wellbore, controlling corrosion [1-2]. The drilling fluid must have certain rheological and filtration properties, which the hydraulic performance of drilling fluids and flow characteristics are directly influenced by these properties to meet these tasks efficiently.

Drilling fluids are mainly classified as water-based muds, oil-based muds, and gas-based muds according to their continuous phase. [2-3]. Water-based drilling fluids are the most commonly used drilling fluids in oil and gas exploration due to its cheap in cost and relatively more environmentally friendly than oil-based drilling fluid and contain many different types of chemicals such as viscosifiers, fluid loss control agents, weighting agents, lubricants, emulsifiers, corrosion inhibitors, salts, and pH control agents to achieve desired rheology [4]. As it is well known that the effect of additive type and concentration has a great impact on the rheology of drilling fluid and this case needs to be investigated of suitable selection of drilling fluid additives in formulating drilling fluid to minimize the cost of well and reduce the risk of drilling problems such as sticking of pipes, gas kick and loss of circulation. Recently, the investigation of the effect of nano and micro-sized additives on drilling mud has attracted the researcher's attention.

Fly ash is a finely dispersed byproduct of coal combustion in thermal power plants. The particle size distribution of the fly ash mainly depends on the primary mineralogical composition of the fuel coal, the fineness of the coal, and the boiler conditions. The chemical characteristics of fly ash considerably depending upon the chemical ingredient of the coal burnt. American Society for Testing Materials [5] defines mainly two types of fly ash: Class F and Class C, which are classified depending on chemical composition of fly ash. Class F fly ash is produced after burning the harder, older anthracite and bituminous coal, while the Class C fly ash is produced when the younger lignite or sub-bituminous coal is burnt.

Fly ash can be considered as the world's fifth largest raw material resource [6]. The annual production of coal ash throughout the world is predicted by about 600 million tones, and the fly ash with 500 million tones constitutes around 75-80% of this rate [7]. Moreover, the amount of coal waste (fly ash), released by thermal power plants has been increasing worldwide, and the disposal of a huge amount of fly ash has become a serious environmental problem [7-8]. Several studies have been carried out regarding the effective utilization of fly ash [8]. However, there are currently only a few studies present in the literature to investigate how to effect fly ash the rheological characteristics of drilling fluids. Mahto and Jain [9] investigated effect fly ash on inhibitive drilling fluid including potassium chloride. Gautam *et al.* [10] studied the substitution of functionalized fly ash with API-grade drilling bentonite. Mahto *et al.* [11] developed a non-damaging inhibitive drilling system using fly ash. It is worth to be noted that in all of these study only one type of fly ash was used. Therefore, the effect of type of fly ash on the rheological and filtration properties of drilling fluids needs to be further investigated.

In this study, two types of fly ash (Class F and Class C) at different concentrations were employed as additives in gypsum/polymer water-based drilling fluid at ambient conditions. The study aims to investigate the effect of both different types of micro-sized-fly ash and their concentration on the rheological and filtration properties of gypsum/polymer water-based drilling fluids.

2. Experimental procedure

2.1. Materials used

Brown Coal Fly Ash (BFA) and Lignite Fly Ash (LFA) was obtained from 900 MW power plant of Tiszaújváros-Hungary and 950 MW Mátra Power Station Visonta-Hungary, respectively. The chemical compositions of both samples are shown in Table 2.

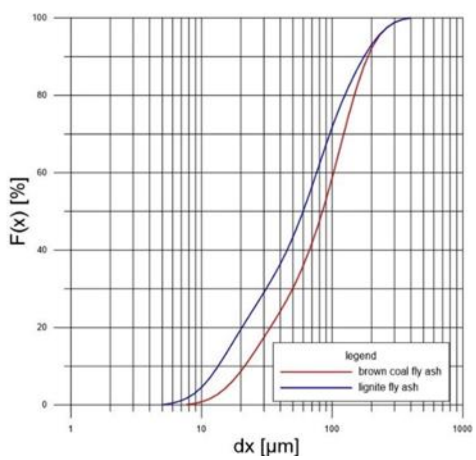


Figure 1. The particle size distribution of fly ash samples

The Brown Coal Fly ash supplied is with gray color and its specific surface area (SSA) 1191.2 cm^2/cm^3, while the Lignite Coal Fly Ash supplied is with light brown color, and its specific surface area is (SSA) 1799.3 cm^2/cm^3. Additionally, the average particle size distributions (D_{50}) of Brown Coal Fly Ash (BFA) and Lignite Fly Ash (LFA) are 84.11 µm and 59.82 µm, respectively, as shown in Fig. 1. The x-axis of the figure shows particle diameter of samples, and the y-axis denotes cumulative particle size distribution of samples. The gypsum/polymer mud sample supplied from one of drilling well that belongs to TDE company (Hungary), and the mud sample was produced by Newpark Drilling Fluid company. The composition of products used in formulating drilling mud and their functions can be seen in Table 1.

	Grain size, µm			
Samples	D_{10}, µm	D_{50}, µm	D_{90}, µm	SSA, cm^2/cm^3
Lignite Fly Ash	13.36	59.82	175.19	1 799.3
Brown Coal Fly Ash	21.28	84.11	187.89	1 191.2

2.2. Characterization of fly ash samples

Prior to the experimental work, both the types of fly ash samples were dried in a drying oven at 105°C to remove moisture from the samples. Afterward, the chemical composition of fly ash samples and their particle size distribution were measured with Rigaku Supermini 200 type XRF spectrometer and HORIBA LA-950V2 laser diffraction particle size analyzer, respectively. Additionally, the specific surface area values (SSA) of both fly ash samples were calculated by the laser sizer software using particle size distribution data.

Table 1. The composition of the mud sample and the functions of additives used

Functions of additives	Concentration (kg/m^3)	Functions of additives	Concentration (kg/m^3)
Main phase	979	Fluid-loss control	4
Ca++ provider/Inhibitor	25	Viscosifier	1
Viscosifier	30	Corrosion inhibitor	1
Bactericide	1	Lubricant	5
Defoamer	1	Alkalinity control	0.5

2.3. Sample preparation

The mud sample, which is shown in Table 1 is used as a base mud. The Brown Fly Ash sample was added to the base mud at 1.0 wt.%, 3.0 wt.%, and 5.0 wt.% concentrations and was mixed using a five-spindle multi-mixer (model 9B) for 10 minutes to ensure a homogeneous mixture. This procedure was repeated for Lignite Fly Ash at the same concentrations with brown fly ash. Finally, a total of seven samples including base mud were used in this study.

2.4. Determination rheological and filtration properties

All experimental measurements were carried out in accordance with the standards of the American Petroleum Institute (API) throughout the study [12]. Before any rheological and filtration measurements, the samples were stirred at high shear for 5 min in order to achieve the same shear. The rheological properties, including apparent viscosity, plastic viscosity and yield point of samples were measured by Fann Model 35 viscometer. The viscometer that is a concentric-cylinder has six standard rotation speeds, including 600, 300, 200, 100, 6, and 3 rpm, which are switch selectable with the RPM knob. According to the Bingham-plastic model, the apparent viscosity, plastic viscosity, and yield point were calculated from 600 and 300 rpm dial readings by using the following equations.

$$AV, (cP) = \theta_{600}/2 \quad (1)$$

$$PV, (cP) = \theta_{600} - \theta_{300} \quad (2)$$

$$YP, lb/100ft^2 = \theta_{300} - PV \quad (3)$$

The gel strength of samples also obtained with the rotating viscometer. After standing mud in a static condition for 10-seconds, 1-min and 10-min, the maximum dial deflection at 3 rpm was recorded as 10-second (initial) gel strength, 1-minute gel strength, and 10-minute gel strength, respectively. Prior to reading the gel strength, the samples were stirred at 600 rpm for 10 seconds.

The fluid loss tests were monitored by a low-pressure low-temperature filter press at 100 psi pressure and ambient temperature for 30 minutes. The volumes of filtrate collected in graduated cylinder versus time was recorded at 2 min intervals for the first 10 minutes. Thereafter, it was recorded at 5 minutes intervals for the remaining 20 minutes. As mud cake thickness and density play an important role in the efficiency of drilling fluid, the effect of adding different concentrations of fly ash on the mud cake thickness and density of the samples were also measured by vernier caliper and Fann mud balance model 140, respectively.

3. Result and discussion

3.1. Classification of fly ash

When the total composition of SiO_2, Al_2O_3, and Fe_2O_3 that present in fly ash is more than 70%, and the content of CaO is less than Fe_2O_3, the fly ash is termed as Class F type. Whereas, in case the total composition of SiO_2, Al_2O_3, and Fe_2O_3 that present in fly ash is between 50% and 70% and the content of CaO is higher than Fe_2O_3 the fly ash is defined as Class C type. Results observed in Table 2 shows that the total composition of SiO_2, Al_2O_3 and Fe_2O_3 is 88.31% and also the percentage of CaO, which is 1.92%, is less than that of Fe_2O_3, which is 5.51% for Brown Coal Fly Ash, while the total composition of SiO_2, Al_2O_3 and Fe_2O_3 is 65% and also the content of CaO, which is 12.1%, is higher than that of Fe_2O_3, which is 11.2% for Lignite Fly Ash. Therefore, the type of Brown Coal Fly Ash and Lignite Fly Ash used in this study was determined as Class F and Class C, respectively.

Table 2. The chemical analysis of fly ash samples

Oxides	Brown coal fly ash (wt.%)	Lignite fly ash (wt.%)
SiO_2	58,8	39,8
Al_2O_3	24,0	14,0
MgO	1,17	3,41
CaO	1,92	12,1
Na_2O	0,91	0,54
K_2O	1,53	1,61
Fe_2O_3	5,51	11,2
MnO	0,032	0,176
TiO_2	0,605	0,495

3.2. The effect of fly ash type and concentration on the rheological and filtration properties of drilling muds

The apparent viscosity, plastic viscosity, yield point, and gel strength were noted from Fann viscometer readings, and the details of these readings are shown in Fig. 2 and Fig. 3. Fig. 2 shows the effect of fly ash types and their concentration on the AV, PV, and YP of gypsum/polymer water-based mud. As can be seen in Fig. 2, as the fly ash concentration increases the AV and PV increase for both types of fly ash. On the other hand, the highest AV and PV values are observed with Brown Coal Fly Ash. Moreover, the yield point also increases with increasing concentrations of Brown Coal Fly Ash. However, the yield point decreased with lignite type fly ash at 3.0 wt.% concentration. Fig. 3 has revealed that the 10s gel strength, 1 min gel strength and 10 min gel strength increase at 1 wt.% concentration for both types of fly ash, while neither the concentrations nor the type of fly ash has any effect on the gel strengths, after 1 wt.% concentration.

The effect of fly ash types and their concentration on fluid loss are presented in Fig. 4. Fig. 4(A-C) shows that filtrate volume against time for 1.0 wt.%, 3.0 wt.%, and 5.0 wt.% concentration, respectively, for Brown Coal Fly Ash, Lignite Fly Ash, and base mud. As can be seen from the figures, the samples with Brown Coal Fly Ash show less fluid loss than the samples with lignite fly ash at all concentrations. Fig.4D shows filtrate volume collected for 30 min. From the figure, it can be seen that the 30 min of fluid loss of base mud decreases with increasing concentration of both types of fly ash samples. On the other hand, the percentage of decrease in filtrate volume collected increased up to 3.0 wt.% for both types of fly ash. However, thereafter the percentage of reduction in fluid loss remains constant for Brown Coal Fly Ash samples, whereas it increases slightly for Lignite Fly Ash samples.

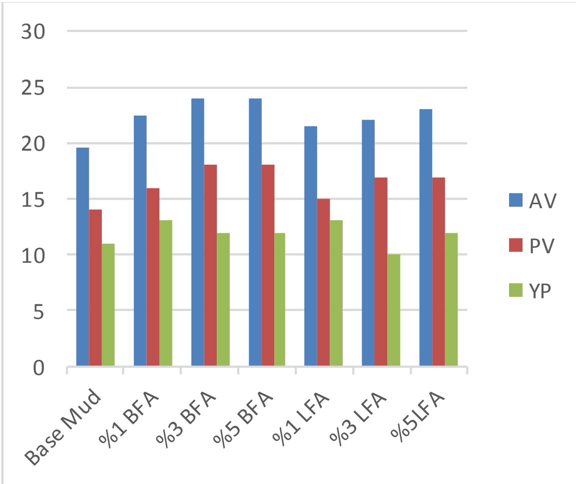


Figure 2. Effect of fly ash type and concentration on the apparent viscosity, plastic viscosity and yield point of gypsum/polymer mud

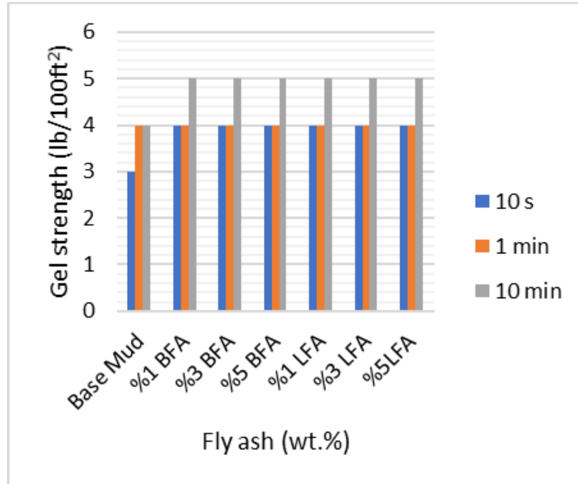


Figure 3. Effect of fly ash type and concentration on the gel strength of gypsum/polymer mud

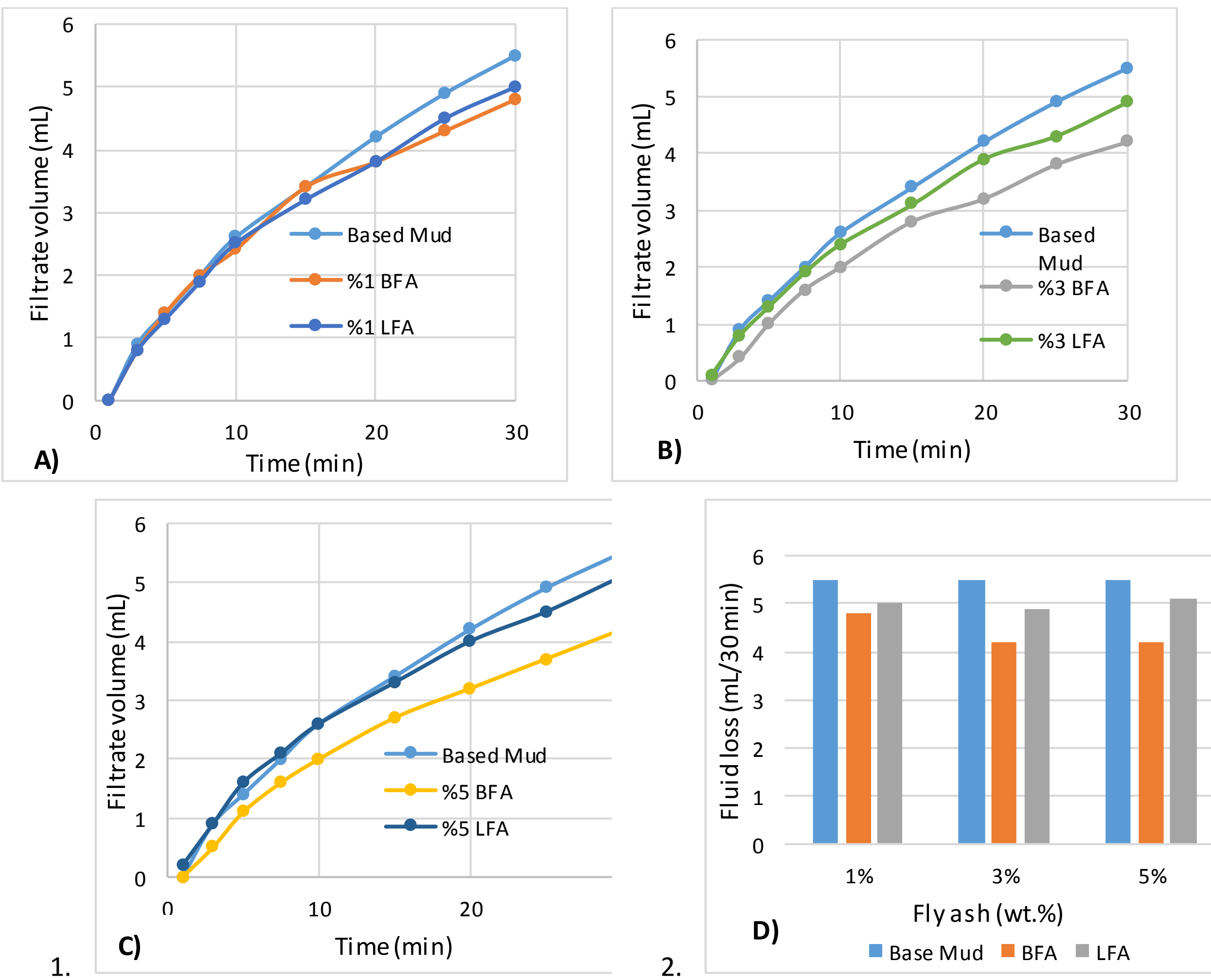
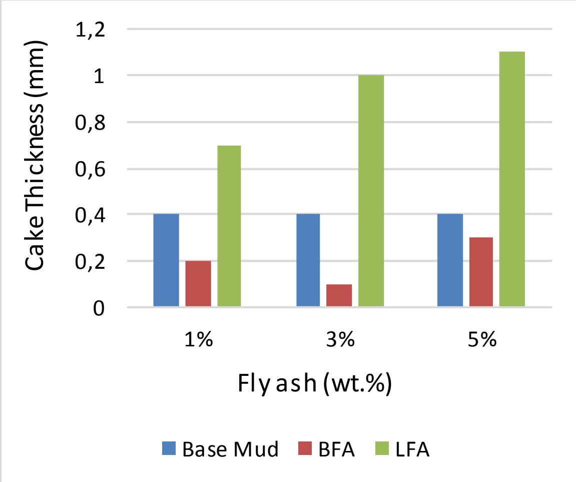


Figure 4. Effect of fly ash type and concentration on the fluid loss of gypsum/polymer mud, A. Fluid loss versus time for %1 percent concentration, B. Fluid loss versus time for %3 percent concentration



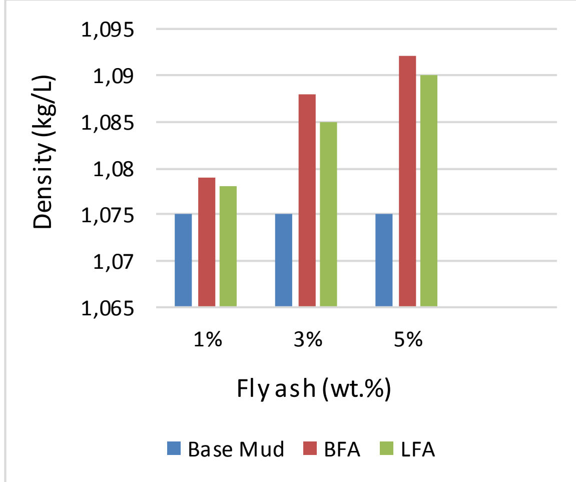


Figure 5. Effect of fly ash type and concentration on the cake thickness of gypsum/polymer mud

Figure 6. Effect of fly ash type and concentration on the density of gypsum/polymer mud

It can be observed from Fig.5 that adding the Brown Coal Fly Ash decreases the cake thickness of base mud. The minimum cake thickness value was obtained with 3.0 wt.% concentration of brown coal fly ash, whereas the mud cake thickness increases with increasing concentration of Lignite Fly Ash, which may cause various problems such as sticking of pipes, high swab, and surge pressures, and excessive torque and drag.

From Fig. 6, it is clear that adding both Brown Coal Fly Ash and Lignite Fly Ash to the base mud increases the density and, the samples with Brown Coal Fly Ash show higher density than that of samples with lignite fly ash.

4. Conclusions

In the present study, the Brown Coal Fly Ash (Class F) and Lignite Fly Ash (Class C) were used at 1.0 wt.%, 3.0 wt.% and 5.0 wt.% concentrations, and the effect of their type and concentration on the rheological and filtration properties of gypsum/polymer water-based mud was experimentally investigated. Based on this study, it is found that the rheological and filtration properties of the drilling fluid were improved by the utilization of the Brown Coal Fly Ash (Class F), and its rate of enhancement of these properties is higher than the Lignite Fly Ash (Class C). In contrast, the Lignite Fly Ash negatively affected the mud cake thickness, which may cause severe problems during drilling. Moreover, the Brown Coal Fly Ash with 3.0 wt.% ratio showed the best result among other concentrations in terms of both rheological and filtration properties of the drilling fluid. Consequently, it can be concluded that the Brown Coal Fly Ash (Class F) is an alternative additive for improving the rheological and filtration properties of gypsum/polymer water-based drilling fluids.

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