

Experimental Investigation of the Effects on Rheological and Filtration Properties of Water-Based Drilling Mud of Fly Ash Addition with Different Particle Size and Concentration

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Abstract

Performance of the drilling fluid is a great concern in drilling operations. Recently, many studies have been carried out on how to perform drilling operations more economically and effectively. Herein this paper effect of the fly ash addition with different particle sizes and concentrations on rheological and filtration properties of drilling muds is studied. For this purpose, fly ash is sieved and 32 µm, 63 µm and 90 µm sub sieve samples are obtained. Each of these predetermined fly ash samples with different particle sizes are mixed with fly ash 1, 2, 3, 4, 5 % w/v. The physical properties of the drilling muds were determined based on API recommended methods including all filtration and rheological properties. It is observed that rheological properties and filtration properties are positively effected by fly ash addition. For rheological properties effect of particle size on related properties are similar while for the filtration properties particle size matters where lost circulation is decreased with smaller particle sizes.

Keywords: fly ash, drilling muds, rheological properties, filtration properties

Farklı Boyut ve Konsantrasyonlarda Uçucu Kül İlavesinin Su Bazlı Sondaj Çamurlarının Reolojik ve Filtrasyon Özelliklerine Etkisinin Deneysel Olarak Araştırılması

Öz

Sondaj akışkanlarının performansı sondaj operasyonları açısından büyük önem taşımaktadır. Son dönemde, sondaj işlemlerinin daha ekonomik ve etkin bir şekilde nasıl gerçekleştirilebileceği ile ilgili birçok çalışma yapılmaktadır. Bu çalışmada sondaj çamuruna farklı tane boyutunda ve farklı konsantrasyonlarda eklenen uçucu külün sondaj çamurunun reolojik ve filtrasyon özelliklerine etkisi incelenmiştir. Bu amaçla uçucu kül elekten geçirilerek 32 µm, 63 µm ve 90 µm elek altı örnekleri elde edilmiştir. Elde edilen bu farklı tane boyutlu uçucu kül numuneleri ağırlıkça % 1,2,3,4,5 konsantrasyonda olacak şekilde sondaj çamuruna eklenmiştir. Hazırlanan çamur sistemlerinin filtrasyon ve reolojik özellikleri API metotlarına uygun şekilde test edilmiştir. Çamurun reolojik ve filtrasyon özelliklerinin uçucu kül eklenmesinden pozitif etkilendiği gözlemlenmiştir. Farklı tane boyutlarının çamurun reolojik özellikleri üzerinde benzer etki gösterirken, tane boyutunun etkisi özellikle küçük tane boyutlu kül eklendiğinde filtrasyon kayıplarının azalması yönünde kendini göstermiştir.

Anahtar Kelimeler: uçucu kül, sondaj çamurları, reolojik özellikler, filtrasyon özellikleri.

1. Introduction

Oil exploration activities have increased as the world's energy demand increase and the tools used in the oil drilling operations becomes more of an issue. The main function of drilling fluid is to provide enough hydrostatic pressure, keeping the borehole clean by removing fragments and drill cuttings, cooling and lubricating drill bit and ensuring stability between formations (Abdo and Haneef, 2012). Therefore, selection of the relevant drilling fluids and the changes of the related properties of the selected fluid according to borehole conditions are some of the major concerns in drilling operations (Matho, 2010; Caenn et al., 2011). There are different types of drilling fluid based on their composition and use. Cost, technical specifications and environmental impacts are to be considered in selection of the convenient drilling fluid. Drilling mud is classified into three main group; as water-based, oil-based and air-based. Water-based fluids (WBFs) are the most widely used systems, and are considered less expensive than oil and air based systems. The water-based drilling muds contain bentonite and barite as base solutions, as well as various additives such as carboxymethyl cellulose, polymers, etc. (Benchabane and Bekkour, 2006). Additives are used in order to meet the desired properties of the fluid when subjected to borehole conditions. In this study, fly ash is added into drilling mud and rheological and filtration properties of the prepared mud system is investigated. Fly ash is a waste byproduct generated from coal combustion. Coal fired thermal power plants produces huge amount of fly ash and generates world's largest quantity of solid wastes (Giere et al., 2003). The annual amount of fly ash in Turkey is expected to exceed 50 million tons by 2020 (Fatih and

Umit, 2001). In general, the chemical composition of fly ash is typically consist of silicon, calcium, aluminum, iron, magnesium, and sulfur oxides along with carbon and various trace elements. According to percentage of forementioned constituents of the ash, it is classified as C and F class ash based on ASTM C618 standart (ASTM, 1998). Physically, fly ash is generally grey in color, abrasive, mostly alkaline, and refractory in nature. There are many industries utilizing fly ash like cement production, building materials and concrete (Ahmaruzzaman, 2010). Fly ash is used in oilfield and petroleum industry for many reasons such as stabilization of drilling wastes to prevent pollution (Thompson, 1994), solidification processes (Conner and Hoeffner, 1998), as riser in deepwater drilling operations (Totten et al., 1998), and to keep circulation losses under control (Matho and Jain, 2013). Fly ash utilization is advantageous both economically as it is a easy accessible combustion waste and environmentally as it is eco-friendly and even improves the soil quality for the growth of plants (Pandey and Singh, 2010). Mahto and Jain, 2013; conducted an experimental work developing an water based drilling mud system by using fly ash to bridge across the pore throat in order to control filtration losses. They observed that the filtration properties were improved where finer particles promote bridging effect and decrease cake thickness and circulation losses. They also observed that the effect of fly ash on rheological properties of fly ash is negligible. Terakulsatit 2015, also mixed drilling mud with fly ash at 3, 5, 7 % w/v concentrations at 30 °C, 60 °C and 90 °C and investigated the chemical and physical properties of the mud systems. The experiment show that drilling mud mixed with 3 % w/v concentration of fly ash is a

high potential additive for enhancement the rheological properties especially in increasing of apparent viscosity, yield point and gel strength. Ozkan et al., 2018; also investigated the effect of fly ash on drilling mud and observed that the results rheological properties such as plastic viscosity (PV) and apparent viscosity (AV) were slightly increasing up to 6 % fly ash ratio in the drilling fluid after that the viscosities tend to decrease (Özkan et al., 2018).

In this experimental work, fly ash is added into drilling mud in different concentrations (% w/v) and particle size and the changes in rheological and filtration properties are investigated based on API testing methods (API SPEC 13A).

2. Material and Methods

2.1. Sample preparation

Barite and bentonite are provided from Turkish Petroleum Corporation (TPAO). Fly ash is supplied from 600 MW imported coal fired power plant in Turkey. Coal type burning in the boiler, method of combustion and fly ash capture mechanism characterizes the fly ash (Fatih and Umit, 2001). The bentonite and the barite powders were weighed and mixed with water and then the fly ash was added at different concentration (1, 2, 3, 4, 5 %).

2.2. Analysis of the chemical and physical properties

Fly ash is sieved with FRISTCH model vibrating sieve and 32 μm , 63 μm and 90 μm subsieve samples are obtained. Blaine fineness of these samples are higher than 3000 cm^2/g . The elemental composition of the fly ash was determined using X-Ray Fluorescence (XRF) of ARL OPTIMX

model. The phase composition, functional groups and the morphological properties of the fly ash and the drilling fluids were analyzed by X-ray powder diffraction using Rigaku Miniflex 600 with $\text{CuK}\alpha$ (40 kV, 15mA, λ : 1.54050Å) radiation and LeO EVO40 scanning electron microscope, respectively.

The physical properties of the drilling mud were determined based on API standard, including all filtration and rheological properties. Fann Viscometer was used to measure dial readings of the solutions. Rheological properties such as plastic viscosity, apparent viscosity, yield point and 10 min gel strength were correlated according to the empirical formulas below;

$$\mu_p = \theta_{(600 \text{ rpm})} - \theta_{(300 \text{ rpm})}$$

$$\gamma_p = \theta_{(300 \text{ rpm})} - \mu_p \quad \mu_a = \frac{\theta_{(600 \text{ rpm})}}{2}$$

μ_p : Plastic viscosity (cp)

γ_p : Yield Point ($\text{lb}_f/100\text{ft}^2$)

μ_a : Apparent viscosity (cp)

API fluid loss test is used to measure the filtration properties of the prepared systems at ambient temperature and 100 psi pressure. Density of the mud was also measured using mud balance; consist of base and a balance arm with a cup for counterweight.

2.3. Experimental work

The powdered form of bentonite and barite are weighed. Then a water based drilling mud is prepared using 500 mL water, 31,25 g of bentonite, 14,25 g of barite and all this suspension is well mixed for 20 minutes with a mixer. Fly ash with 32 μm , 63 μm and 90 μm subsieve samples and concentrations of 1, 2, 3, 4,5 % by weight per volume is added

slowly during mixing. After complete 16 hours prior to rheological and filtration mixing, prepared drilling muds are aged for tests.

Table 1. Composition of prepared drilling mud systems for each 32 μm, 63 μm and 90 μm particle sizes

Composition	Water (ml)	Bentonite (g)	Barite (g)	Fly Ash (g)
Spud	500	31,25	14,25	-
Mud + 1% FA	500	31,25	14,25	5,45
Mud + 2% FA	500	31,25	14,25	10,91
Mud + 3% FA	500	31,25	14,25	16,36
Mud + 4% FA	500	31,25	14,25	21,82
Mud + 5% FA	500	31,25	14,25	27,28

*FA: Fly Ash

3. Research Findings

3.1. Characterization of fly ash and drilling fluids

Chemical composition of fly ash depends mostly on coal being burned. Coals are classified according to its calorific values and four types (ranks) of coal are anthracite, bituminous, sub-bituminous, and lignite.

Herein this study bituminous coal fly ash is used. The elemental analysis of the fly ash determined by X-Ray Fluorescence is given in Table 2. It was seen that the main

composition of the fly ash consisted of silica and alumina. According to ASTM C 618-08a (Pandey and Singh, 2010).

Table 2. Composition of fly ash

Composition	(w %)
SiO ₂	56
Al ₂ O ₃	21.5
Fe ₂ O ₃	6.5
CaO	4.1
MgO	1.4
Na ₂ O	3
K ₂ O	1.8
TiO ₂	0.8

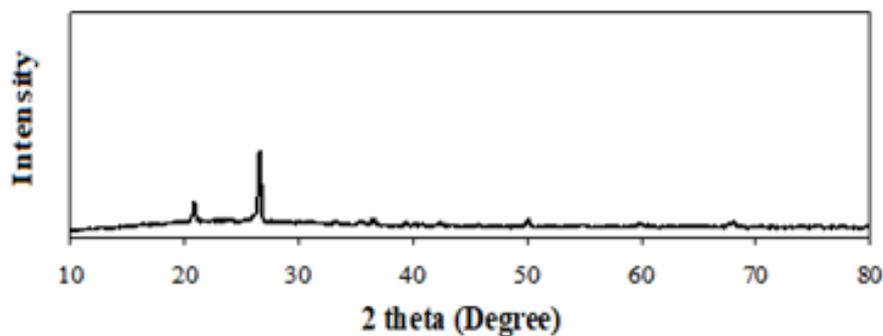


Fig. 1. The XRD patterns of the fly ash

The XRD results (Fig. 1) belonging to the fly ash showed that the main structure was quartz and the drilling fluids indicated that the quartz and bentonite structure. Morphological analysis of the fly ash and the

drilling fluids indicated that fly ash particles were spherical and amorphous in shape (Fig. 2). In drilling fluids, the Na-bentonite structure was identified and the spherical fly ash particles were also seen in the structure.

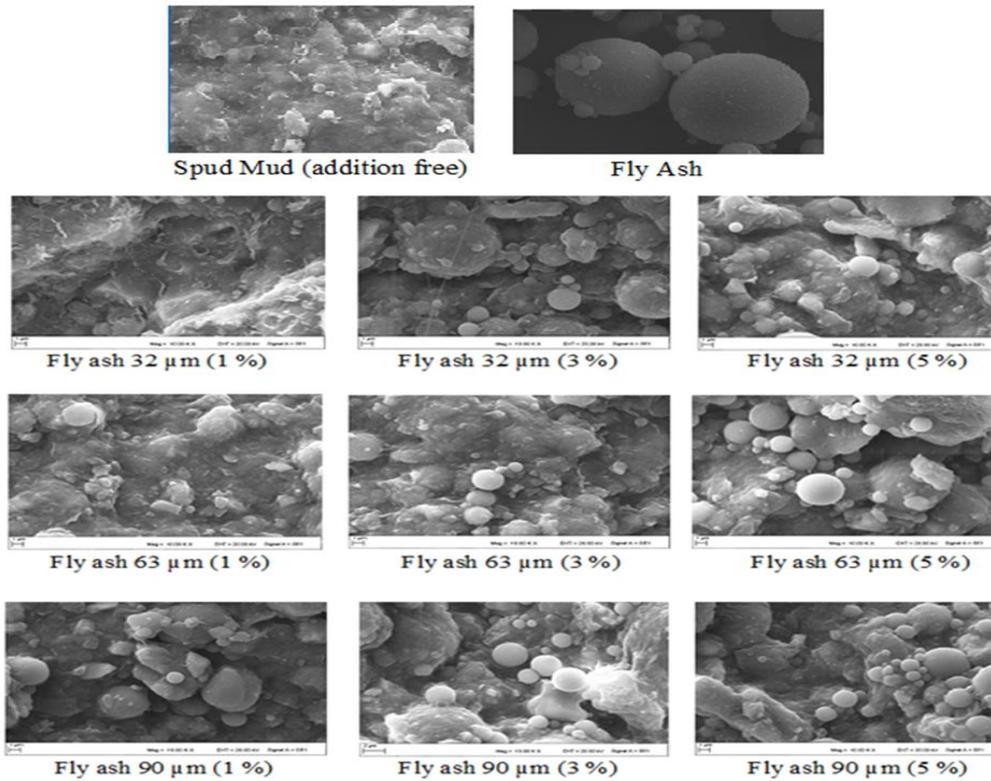


Fig. 2. SEM images of spud mud, fly ash and fly ash addition with different particle size and concentration

3.2. Changes in the physical and rheological properties of the prepared mud systems with fly ash addition

In the present study, 1, 2, 3, 4, 5 % (w/v) of fly ash ratio as additives with different particle

sizes were mixed with the drilling fluid separately and their effects on water-base drilling muds were investigated. Density of the prepared mud systems is increased with fly ash addition as seen in Fig. 3.

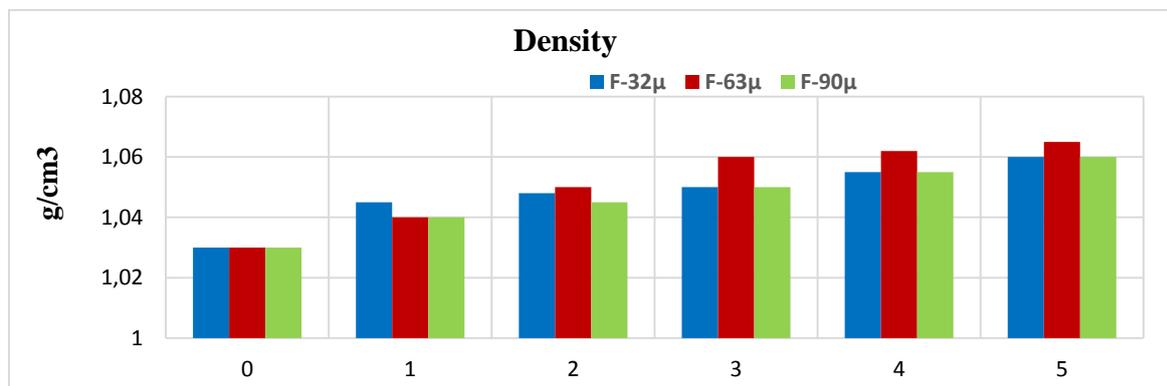


Fig. 3. Density of the prepared mud systems

Hydrostatic pressure (PH) of the drilling mud which is important for the control of formation pressure is adjusted by the density of the mud. Hydrostatic pressure of the

drilling mud is a function of borehole depth and mud density. From the figure above, density is increasing with particle size of the ash as well as concentration.

The findings of the experimental study were compared with API requirements which are shown in Table 3 below.

Effect of fly ash on plastic viscosity, apparent viscosity and yield point of the prepared mud systems are shown in the figures given below.

Table 3. API Standart Specifications (16)

Rheological Properties	
Ø600	30 Minimum
Ø300	23 Minimum
Plastic Viscosity (cP)	6-8 Minimum
Apparent Viscosity (cP)	12-15 Minimum
Yield Point (lb/100 ft ²)	3*PV or 50 Maximum
Filtrate Loss (mL)	30

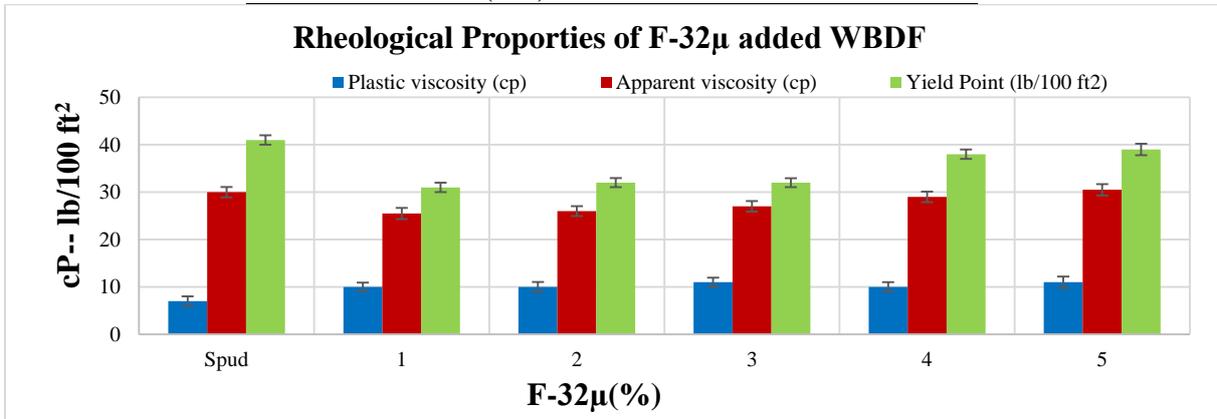


Fig. 4. PV, AV and YP of the 32µ FA added mud system

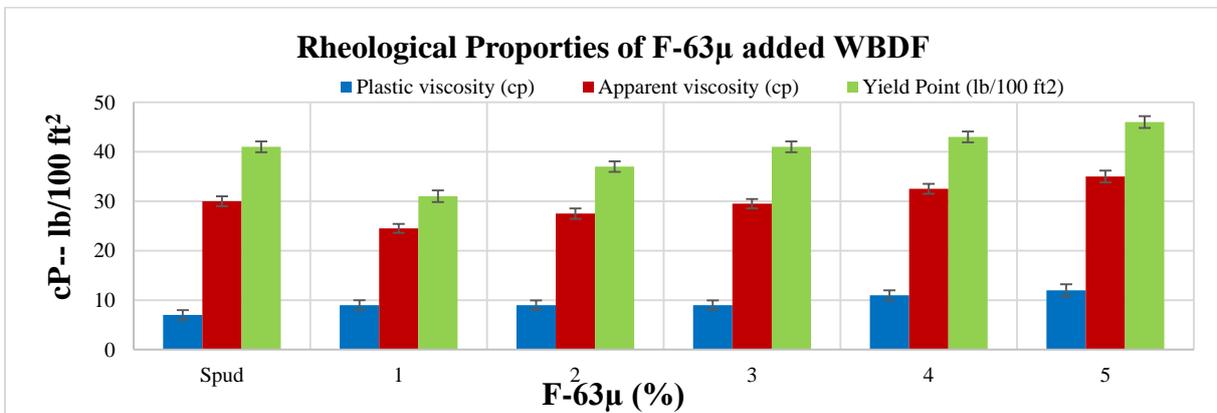


Fig. 5. PV, AV and YP of the 63µ FA added mud system

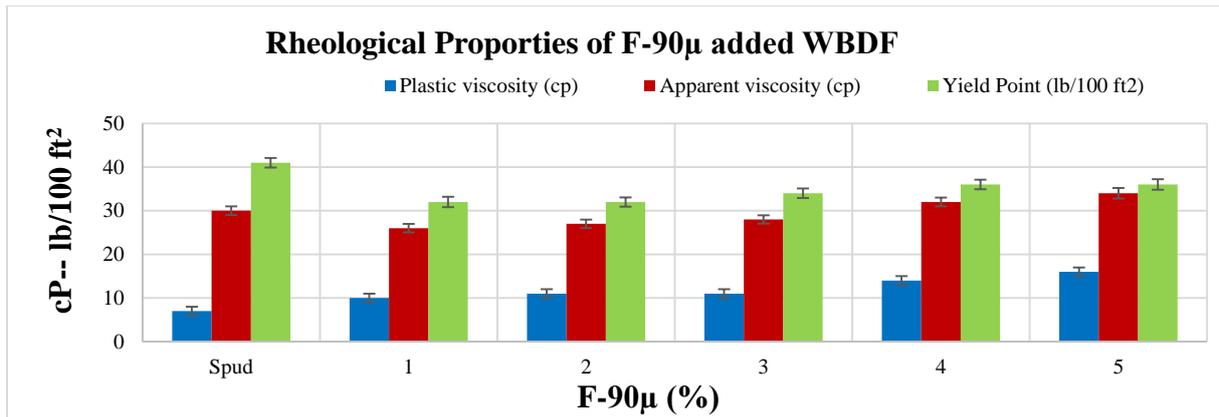


Fig. 6. PV, AV and YP of the 90µm FA added mud system

Viscosity is highly effected from the base liquid and the amount of additives especially of solids. For example barite is a heavy material and the fluid including higher amount of barite performs higher viscosity. Typically, big holes require thicker fluids, on the other hand smaller diameter holes require thinner fluids. As seen from the figures above, plastic viscosity and apparent viscosities of the prepared mud systems are increasing with increasing fly ash concentration. According to API standart yield point should not pass the value of 50 for the quality of drilling operation. Fig. 4 shows that PV, AV and yield point of the 32 µm fly ash addition are not effected up to 3 % concentration, after then viscosities are slightly increasing. For 63 µm fly ash addition PV is effected after 3% concentration while the increase of AV and yield point is initiated from 1% concentration (Fig. 5). For 90 µm fly ash addition, behaviour of the viscosities and yield point change is similar to 63 µm fly ash addition as seen in the

Fig. 6. For all particle sizes, it was seen that YP was improved with the increase in fly ash addition, which greatly affects carrying capacity and hole cleaning (Bourgeyne et al., 1986). The ratio of YP to PV is a critical parameter for stable and optimal mud performance (Chilingarian et al., 1986). Gel strengths is the shear stress needed to initiate flow after the drilling fluid has been static for some time. Gel strength determines the pressure required to “break circulation” and the ease of releasing entrained gas or air. Measurement is done using the same rotational viscometer like viscosity measurements. Gel strength measurement is made with viscometer according to readings after 10 minutes and 10 seconds stirring of the mud. Effect of fly ash on gel strength of the prepared mud systems are shown in the figures below.

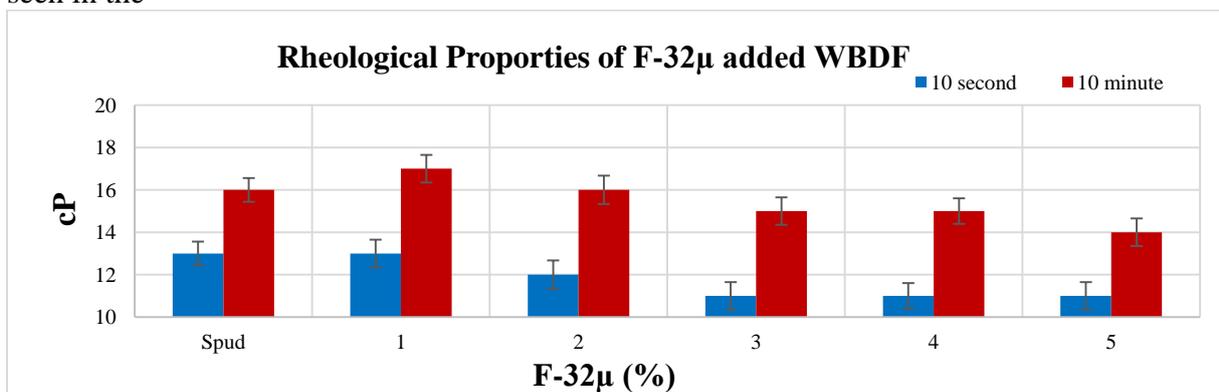


Fig. 7. Gel strength of the 32µm FA added Mud System

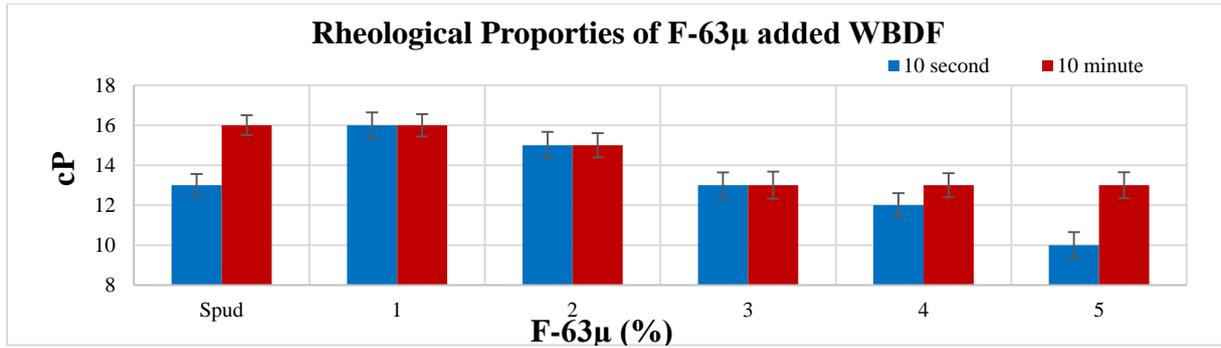


Fig. 8. Gel strength of the 63µm FA added Mud System

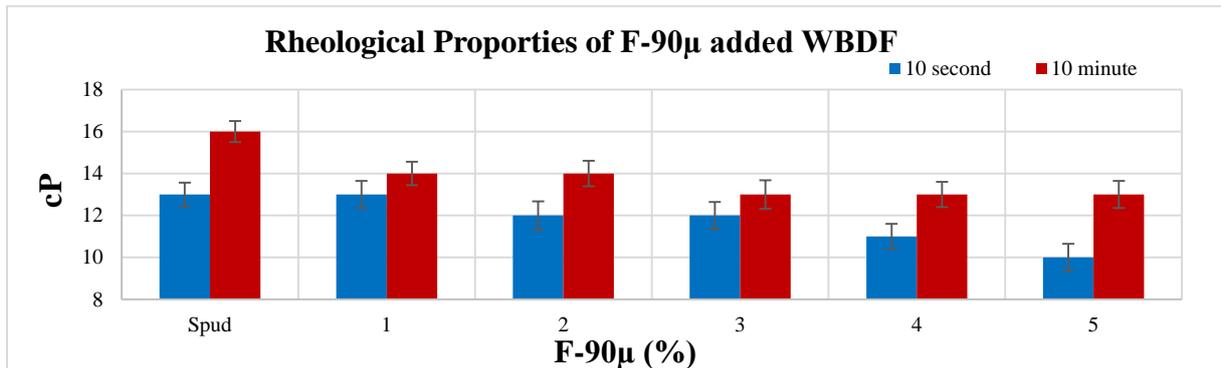


Fig. 9. Gel strength of the 90µm FA added Mud System

Gel strength of the prepared mud systems meet the API requirements. It is observed that for all particle sizes, 10 seconds and 10 minutes gel strengths are decreased with increasing fly ash concentration. For 63 µm and 90 µm fly ash additions 10 minutes gel strength of the systems are constant after 3% fly ash concentration.

The filtration loss of the drilling fluid decreased with increasing the fly ash concentration. Since, the fly ash consist of ultra-fine particles, these particles penetrate into holes and decrease permeability of the drilling fluid into formations. Filtration losses of the prepared mud systems are shown in figure 10 below.

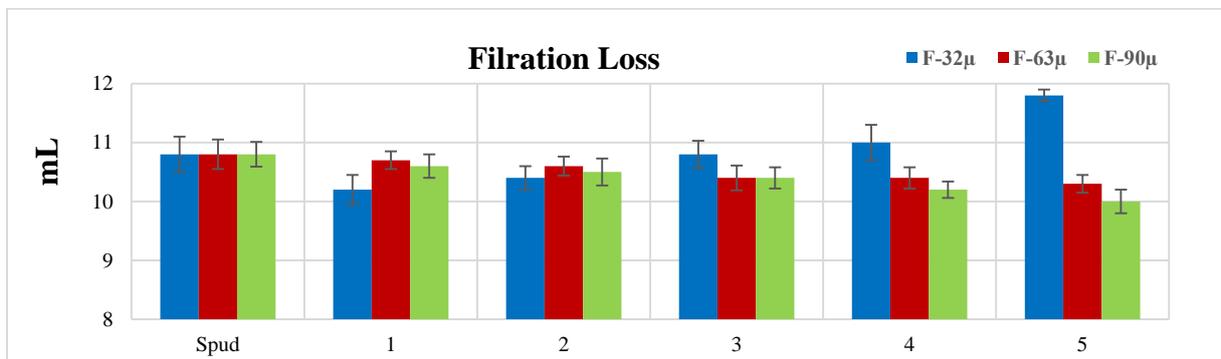


Fig. 10. Filtration Loss of the FA added Mud Systems

Fly ash addition is decreased the filtration losses which is a highly desirable property and leads to reduce drilling cost. 32 µm fly

ash addition most contributed to decrease filtration loss.

4. Results

In this experimental study; Changes in rheological and filtration properties were

investigated by adding fly ash to the drilling mud at different concentrations (w/v %) and particle size. The results of the study are presented in Table 4.

Table 4. . Analysis Results of Fly Ash Additive Water Based Drilling Mud

		Properties						
		PV (cP)	AV (cP)	YP (lb/100 ft ²)	10 second	10 minute	Filtration Loss (mL)	Cake Thickness (mm)
API Std.		Min 7	Min 15	Max 50	15	31	10-15	Max 4
Spud Mud		7	30	41	13	16	10.8	0.37
% 1	32 µm	10	9	10	13	17	10.2	0.4
	63 µm	25,5	24,5	26	16	16	10.7	0.42
	90 µm	31	31	32	13	14	10.6	0.45
% 2	32 µm	10	9	11	12	16	10.4	0.43
	63 µm	26	27,5	27	15	15	10.6	0.45
	90 µm	32	37	32	12	14	10.5	0.48
% 3	32 µm	11	9	11	11	15	10.8	0.45
	63 µm	27	29,5	28	13	13	10.4	0.48
	90 µm	32	41	34	12	13	10.4	0.53
% 4	32 µm	10	11	14	11	15	10.4	0.47
	63 µm	29	32,5	32	12	13	10.4	0.5
	90 µm	38	43	36	11	13	10.2	0.55
%5	32 µm	11	12	16	11	14	10.3	0.48
	63 µm	30,5	35	34	10	13	10.3	0.53
	90 µm	39	46	36	10	13	10	0.56

When examined in Table 4; The following conclusions have been drawn from this experimental study.

1. Densities of the prepared mud systems are increased with fly ash concentration
2. PV, AV and YP of the 32 µm fly ash addition are not effected up to 3% concentration, after then viscosities are slightly increasing. For 63 µm fly ash addition PV is effected after 3% concentration while the increase of AV and yield point is initiated from 1% concentration. For 90 µm fly ash addition, behaviour of the viscosities and yield point change is similar to 63 µm fly ash addition

3. It is observed that for all particle sizes, 10 seconds and 10 minutes gel strengths are decreased with increasing fly ash concentration. For 63 µm and 90 µm fly ash additions 10 minutes gel strength of the systems are constant after 3% fly ash concentration.
4. Filtration losses of the prepared mud systems are decreased with fly ash addition in all particle sizes, for 32 µm fly ash addition minimum lost circulation is observed.

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