Development of Water-Based Drilling Fluid in Mitigation of Differential Sticking Tendency

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Abstract

The objective of the study is to design a drilling fluid that prevents differential pressure pipe sticking tendency caused by drilling fluid with fly ash that is an industrial waste generated from the combustion of coal. To this end, drilling fluid samples were prepared with different particle sizes obtained through the sieving and grinding process and increasing concentrations of fly ash. Differential pipe sticking tests of the samples were performed by applying 3.447 MPa (500 psi) pressure and using a Fann Model 21150 Differential Sticking Tester in order to determine how the coefficient of sticking and torque reading varied with the fly ash. From the results, it was observed that the coefficient of sticking and torque reading of the water-based drilling fluids decreased up to a specific concentration as the concentration of fly ash increased. Furthermore, particle size analysis illustrated that the coefficient of sticking and torque of the drilling fluid differs depending on the particle size of fly ash introduced. The drilling fluid designed with ground fly ash demonstrated lower sticking coefficient and torque reading than that of drilling fluids formulated with raw and sieved fly ashes. The experimental study revealed that fly ash is a promising additive in the mitigation of differential sticking tendency caused by water-based drilling fluids.

Keywords:
differential sticking; fly ash; grinding; drilling fluids; differential sticking tester

1. Introduction

A stuck pipe occurrence is one of the major wellbore instability issues encountered during drilling operations and 36% of drilling problems are caused by a stuck pipe (**Reid et al., 2000; Jardine et al., 1992**). Moreover, problems caused by the stuck pipe account for 25% of the non-productive time and it is estimated that pipe sticking in the drilling industry costs more than several hundred million US dollars a year (**Muqeem et al., 2012**). The severity of problems with a stuck pipe can range from a minor inconvenience to major complications. The stuck pipe problem, as the worst case scenario, may cause consequences that can lead to the loss of the well. A quick review of literature will be enough to understand how important pipe sticking is.

Mechanical and differential pipe sticking are the two main categories of pipe sticking. This study focused on the differential pipe sticking challenge caused by a pressure difference in the well occurring between the mud col-umn and the formation fluid during over balance drilling. Therefore, keeping the over balance difference as low as possible is an important issue that needs to be analysed at the planning stage (**Rabia, 2002**). Apart from overbalance, the permeability of the drilled formation, the contact area between the permeable formation and pipe, hole angle, hole size, bottom hole assembly, drilling fluid type and its characteristics are the other factors affecting differential pressure pipe sticking (**Reid et al., 2000**). Another important factor is the thickness of the filter cake deposited on a permeable formation. Therefore, a good quality mud cake is required to prevent sticking. Differential pressure pipe sticking occurs when there is no pipe movement over a period of time (**Lake, 2006**). The time that the pipe is not moving is one of the other important factors affecting differential pressure pipe sticking.

The method to be applied to free the stuck pipe is also an important issue. Success in the freeing of a stuck pipe depends on the accurate diagnosis of the cause of the stuck pipe event. In freeing a stuck pipe, it is necessary to intervene according to the cause of the stuck pipe event, as an improper intervention can cause serious problems that may even lead to the abandonment of the

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well. Therefore, it is important to understand the conditions and symptoms that cause the pipe to get stuck. There have been many approaches to minimize the possibility of differential sticking, such as using drill collars with a square shape or with a spiral groove, maintaining the drill pipe in rotation at all times, using the lowest differential pressure as much as possible and keeping the drilling fluid properties at the optimum level (**Lake, 2006**). The most economical of these approaches is related to the characteristics of the drilling fluid. In this regard, it is desired to keep the solid content and fluid loss of the drilling fluid used as low as possible and to obtain a smooth, thin and impermeable filter cake. Various kinds of additives are used to keep the drilling fluid characteristics in those levels.

Fly ash, also known as pulverized fuel ash, is a byproduct of combustion of coal in coal-fired power plants. Depending on the properties of the type of coal burnt and combustion techniques, fly ash exhibits different chemical characteristics. The American Society for Testing Materials (ASTM) mainly defines types of Class F and Class C fly ash depending on their chemical content. While Class F fly ash was obtained with coal with a higher rank, such as anthracite, bituminous and semibituminous, Class C fly ash is generated from the combustion of coal with a lower rank, such as lignite semibituminous (**Ahmaruzzaman, 2010**).

Fly ash is one of the most abundant waste materials worldwide and its amount is increasing over time due to an increasing number of power plant and factories (**Gianoncelli et al., 2013**). On the other hand, fly ash is employed in many different applications, such as cement, concrete, ceramics, soil amendment, and road pavement (**Ferreira et al., 2003**). However, these applications are still not enough to fully use the produced fly ash. Since the unused portion becomes waste and is disposed in ash ponds or lagoons, fly ash has become a serious environmental issue (**Carlson and Adriano, 1993**). Therefore, there is an urgent need to research the usability of fly ash in different applications as a useful product.

To date, there have been limited studies regarding to usage of fly ash in drilling fluid. (**Avci et al., 2019**) studied the utility of Class F and Class C type fly ash in gypsum/polymer inhibitive drilling fluid. The authors revealed that Class F fly ash has a superior performance over Class C fly ash based on the specific employed concentrations. On the other hand, (**Fliss et al., 2019**) studied the rheological behaviour of drilling fluid integrated with micro-sized fly ash (finer than 63 μm) and (**Mahto and Jain 2013**) examined the effect of fly ash on the rheological behaviour of drilling fluid containing potassium chloride. However, there is no data on what role fly ash plays on the differential sticking tendency of the drilling fluids.

2. Experimental Work

Herein, the differential sticking tendency of water-based drilling fluids was analysed in the presence of fly ashes with different particle sizes and concentrations by thoroughly performing an experimental analysis. In the experimental study, the differential sticking tendency of three different muds containing raw, sieved and ground fly ashes was analysed. To the best of the author's knowledge, this is the first research study on the analyses of fly ash with different particle sizes and concentrations on the differential sticking tendency caused by drilling fluids.

All measurements made in this study were performed by following the API-RP-13B-1 standards recommended by the American Petroleum Institute (API), (**American Petroleum Institute, 2003**). The steps followed in the study were given in **Figure 1**. First of all, fly ash to be used were obtained and some of the fly ash was sieved and some of it was ground in a stirred media mill for 2 hours in wet mode. Afterwards, particle size distribution and elemental analysis of the fly ash were performed. The consistency of the results was evaluated based on the characterization of the materials taking into account the possibility of incorrect sampling or mistakes made during the experiments. Finally, drilling fluids containing fly ash in raw, sieved and ground form at different concentrations were prepared and the differential sticking coefficient and torque values of the fluids were calculated. Moreover, apparent viscosity, plastic viscosity, yield point, density, standard fluid loss and cake thickness of each mud system were measured.

2.1. Materials

Fly ash is the main material employed in the study and was supplied from the Tiszaújváros Power Plant located in Hungary. The obtained fly ash was dried for 8 hours in a drying oven at 105ºC to reach a constant mass by removing the moisture content in the fly ash. This fly ash was termed as raw fly ash. The raw fly ash was sieved by using a 106 μm sieve and was classified as sieved fly ash. Finally, the sieved fly ash was ground with a stirred media mill for 2 hours in wet mode. After the completion of the grinding, the fly ash was left to dry for 72 hours. Finally, this fly ash was termed as ground fly ash.

2.2. Characterization of fly ash

Particle size distribution and elemental analysis (as oxides) of the fly ash were performed by using a laser diffraction analyser model "Horiba LA-950 V2" and Rigaku Supermini 200 type X-ray fluorescence spectrometer (XRF), respectively. The specific surface area (SSA) of fly ashes with a different particle size was calculated with laser sizer software using particle size distribution data.

2.3. Formulation of drilling fluid

API standards were followed in the preparation of drilling fluid samples. In the study, basic bentonite mud was prepared by using a Hamilton Beach multi mixer.
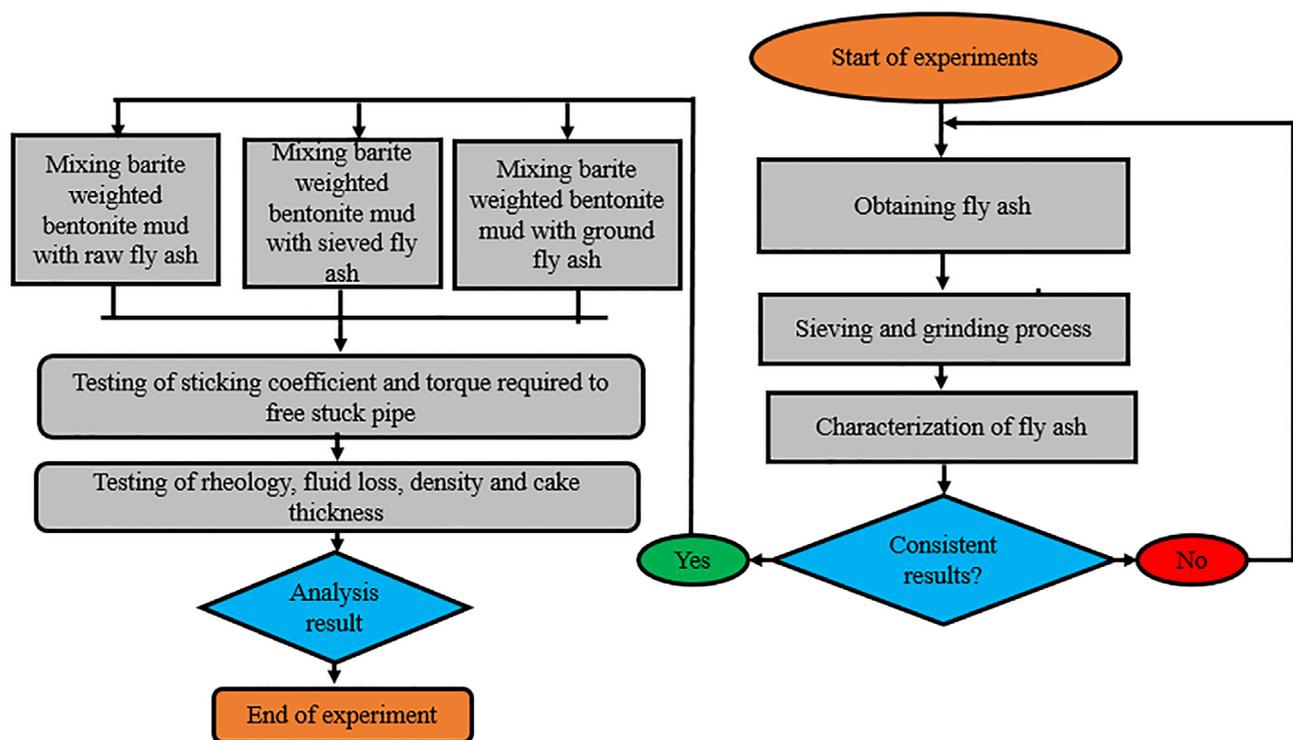
Figure 1. Flowchart of the experimental study

After the pouring of water into a stainless steel cup, bentonite was added and stirred for 20 minutes. Afterwards, Carboxymethyl cellulose (CMC) (fluid loss controller), Xanthan gum (XG) (viscosifier) and barite (weighting agent) were added slowly and sequentially to avoid a growth of agglomeration. The mud sample was stirred for 10 minutes for the addition of each of the additives and left to rest at room temperature for 16 hours to ensure complete hydration of the bentonite. At the end of 16 hours, raw, sieved and ground fly ashes with various concentrations were introduced to the mud. The composition of the mud is presented in **Table 1.**

Table 1. Composition of drilling fluid

Constituents	Units	Composition
Water	ml	400
Bentonite	g	25.71
CMC	g	0.6
XC	g	0.5
Barite	g	131.42

2.4. Testing of rheology

Viscosity test of the drilling fluids formulated was carried out with a Fann Model 35 rotational viscometer. The drilling fluid sample to be measured was placed in the sample cup, then the bob and rotor cylinders were immersed in the fluid. Thus, the mud sample was kept in the circular space between the two cylinders. When the rotor begins to rotate at specified speeds, a movement occurs in the drilling fluid sample, causing a torque in the spring. The displacement of the inner cylinder is proportional to the torque acting on its surface and the torque was read on the dial attached to the bob. Apparent viscosity (AV), plastic viscosity (PV) and yield point (YP) were computed in accordance with API standards (**American Petroleum Institute, 2003**).

The formulated drilling fluid sample was mixed at 600 rpm for 15 seconds in order to measure gel strength. Then, the rotation of the viscometer was stopped for the specified periods. In this study, the pause time was determined as 10 seconds, 1 minute and 10 minutes. After the specified pause time, the maximum dial reading that can be measured by running the motor at 3 rpm was recorded at 10 seconds, 1 minute, and 10 minute gel strength in Pa.

2.5. Testing of filtration

The filtration test simulates the process of depositing a filter cake in the wellbore caused by differential pressure. Thus, fluid loss, cake thickness and filter cake quality can be examined to some extent. The filtration test was performed by using a multiple-unit filter press consisting of a manifold, pressure regulator, hose, inlet/discharge valves, gauge and cell assemblies. The cell assembly consists of a cell and a cover combined with a screen. At the same time, the cell has an O-ring groove to prevent pressure from flowing, and a small opening at the bottom to expel the filtrate. During testing, the cell was filled with the drilling fluid samples and it was inverted and placed to the coupling of the manifold after the cell was closed. By opening the inlet valve, pressure

was applied to the cell, thereby a filter cake started to form. The filtration test was carried out at a pressure of 0.68 MPa (100 psi) and ambient temperature for 30 minutes. The fluid loss was recorded in ml unit by using a graduated cylinder to collect the filtrate while cake thickness was measured with a Vernier calliper in units of mm.

2.6. Testing of differential sticking tendency

Various equipment has been developed to determine the sticking tendency of drilling fluids. Although these devices may differ in the applicable temperature and pressure ranges, they all simulate the pipe-wellbore geometry and the filter cake forming process. The purpose of these tests is to determine the torque or pulling force required to free the stuck pipe. In this study, analysing the role of the concentration, different particle size and grinding technique of fly ash on differential sticking tendency of drilling fluid was carried out with a Fann Model 21150 Differential Sticking Tester. To this end, initially, a sample cup was filled with the formulated drilling fluid samples and then subjected to a nitrogen gas pressure of 3.447 MPa (500 psi). The pressure caused the loaded drilling fluid sample to be filtered for 10 minutes. The torque plate was then pressed using a lever against the screen for two minutes until the plate was enough to ensure the formed mud cake would stick. Later, the plate was rotated with a torque wrench and then the torque reading on the torque dial was recorded in lb-in. The torque reading was repeated 6 times after a 30-second pause and the sticking coefficient was calculated with Eq.4, by using the average of the torque values obtained and the stuck cake radius (in).

$$K_{SC} = \frac{0.001 * \text{average torque reading}}{\text{stuck cake radius}^3} \qquad (4)$$

Where:

K_{SC}: Sticking coefficient [-].

3. Results and discussion

According to ASTM, fly ash containing more than 70% of the total composition of silicon dioxide (SiO_2), aluminum oxide (Al_2O_3) and iron (III) oxide (Fe_2O_3) with calcium oxide (CaO) content less than Fe_2O_3 is classified as Class F. On the other hand, when fly ash includes the content of total composition of SiO_2, Al_2O_3, and Fe_2O_3 is between 50% and 70% with CaO composition more than Fe_2O_3 is defined as Class C. In the study, as can be seen in **Table 2**, total oxides of silicon, aluminum and iron were calculated as 88.31% and the content of CaO, which is 1.92%, less than Fe_2O_3, which is 5.51%. These results indicate that the fly ash used in the study is Class F.

The particle size distribution results of fly ash with raw, sieved and ground forms are presented in **Figure 2.**

The x-axis of the figure represents the particle diameter and the y-axis shows the cumulative undersize percent of particles. As can be seen from the figure, while the particle size of fly ash decreased, the specific surface area experienced an increase with both the sieving and grinding process. It should be noted that the grinding process had a much greater effect on both the specific surface area and the particle size distribution compared to the sieving process. While the sieving process reduced the mean particle size (d50) of raw fly ash from 84.11 to 67.89 μm by a magnitude of 1.23 times, with the grinding process, mean particle size of raw fly ash reduced to 0.270 μm by a magnitude of 311 times. On the other hand, while the specific surface area of raw fly ash increased from 1191.2 to 1349 cm²/cm³ by a magnitude of 1.13 times with sieving, the specific surface area of raw fly ash increased to 257230 cm²/cm³ by a magnitude of 216 times by grinding the fly ash for two hours.

In order to investigate the effectiveness of the drilling fluid to be developed, a reference fluid was prepared based on the composition given in **Table 1.** The sticking tendency characteristics, friction coefficient, rheological parameters and filtration characteristics of the drilling fluid was given in **Table 3.** The outcomes indicate that rheological and filtration characteristics of the drilling fluid are suitable in the case of application of this mud. However, a sticking tendency may occur due to its torque value of 6.77 Nm (60 lb·in) when it is applied for drilling operations. The sticking tendency may cause a reduction in rate of penetration and non-productive time. Therefore, fly ash with different particle size was introduced to this drilling fluid as a friction coefficient and torque reducer.

Drilling fluid formulated with raw fly ash provides a reduction in sticking tendency. **Figure 3** shows the effect of raw fly ash on the sticking coefficient and the torque required to free a stuck pipe of the drilling fluid under 3.447 MPa (500 psi) of differential pressure. As can be seen from the figure, depending on the concentration of both the applied sticking coefficient and torque showed a reduction until 0.25 wt% concentration. The introduction of 0.25 wt% concentration of raw fly ash reduced the coefficient of sticking of the drilling fluid from 0.06 to 0.045 with an increase of 25%, as well as the torque value from 6.77 to 5.08 (Nm) (60 to 45 (lb·in)). However, the concentrations higher than 0.25 wt% raw fly ash sticking coefficient and torque showed an increase and for 0.5 and 1.0 wt% concentrations exceeded the value of the sticking coefficient and torque of fly ash-free drilling fluid.

The experimental results show that the drilling fluid integrated with the sieved fly ash also reduced the differential pipe sticking tendency. **Figure 4** represents the variation of sticking coefficient and torque required to free a stuck pipe of the drilling fluid results when sieved fly ash with increasing concentrations is employed. From the figure, it is seen that for up to 1 wt% concentra-

Table 2. XRF analysis of fly ash

Oxides	Concentration of fly ash (wt%)
SiO_2	58.8
Al_2O_3	24.0
MgO	1.17
CaO	1.92
Na_2O	0.91
K_2O	1.53
Fe_2O_3	5.51
MnO	0.032
TiO_2	0.605
P_2O_5	0.053

Sample	d10 [μm]	d50 [μm]	d90 [μm]	SSA [cm²/cm³]
Raw FA	21.280	84.110	187.890	1191
Sieved FA	21.257	67.893	117.907	1349
Ground FA	0.122	0.270	0.8783	257230
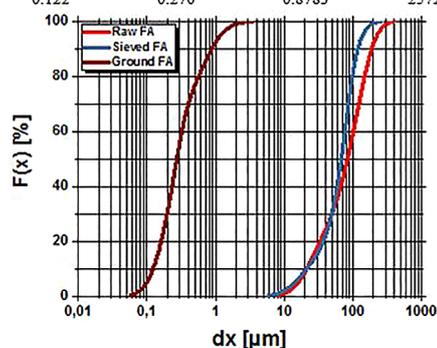
Figure 2. Particle size distributions of fly ashes

tion, both the coefficient of friction and torque experienced a reduction. It's worth to note that this sticking tendency reduction rate is greater than that of the rate observed in raw fly ash. The sticking coefficient decreased from 0.06 to 0.041 with an increase of 32% and the torque value reduced from 6.77 to 4.63 (Nm) (60 to 41 (lb·in)). However, when concentrations higher than 1 wt% sieved fly ash were introduced to the drilling fluid, the coefficient of sticking and torque began to increase, exceeding the coefficient and torque value of the drilling fluid without fly ash at a concentration of 3%.

Figure 5 demonstrates changes in the sticking coefficient and torque required to free a stuck pipe of the drilling fluid results in the presence of ground fly ash with increasing concentrations. The results show that ground fly ash reduced the differential pressure pipe sticking tendency significantly. The sticking coefficient decreased from 0.06 to 0.033 with an increase of 45%,

and also the torque required to free a stuck pipe reduced from 6.77 to 3.72 (Nm) (60 to 33 (lb·in)) when 0.3 wt% concentration ground fly ash was introduced. These results reveal that lower sticking coefficient values were obtained with 0.3 wt% ground fly ash than SAE 20W-40 and Linseed Oil lubricant which was found in the study performed by **Mahto** (**2013**) as 0.06 and 0.1, respectively in the presence of 1.0% (v/v) concentrations. Another observation is that the application of concentrations higher than 0.3 wt% demonstrated an increase compared to the 0.3 wt% results. However, they had a lower coefficient of sticking and torque values than drilling fluid without fly ash.

Figure 6 presents the comparative performance of fly ash with different particle size on a differential pressure pipe sticking tendency. These results show that the three forms of fly ash, which are raw, sieved and ground for 2 hours, are capable in the reduction of the differential pressure pipe sticking tendency, provided that they are used in the appropriate concentrations. And another important observation is that ground fly ash exhibited superior performance in comparison to both sieved and raw fly ash. It should be noted that sieved fly ash also presented better performance than raw fly ash.

Rheological and filtration properties of drilling fluid in the presence of raw fly ash with different concentrations were presented in **Table 4.** In the light of differential sticking tendency results, 0.25 wt% concentration as the determined optimum dosage showed an increase in the apparent viscosity, and plastic viscosity, whereas there was a decrease in the yield point of the drilling fluid and its effect can be neglected on the Gel10s, Gel1min and Gel10min strength. In addition, employment of the 0.25 wt% concentration of raw fly ash enhanced filtration properties of the drilling fluid. Fluid loss and mud cake thickness of the drilling fluid decreased by 4% and 50%, respectively.

Variations of the rheological and filtration properties of the drilling fluid with sieved fly ash are given in **Table 5.** From the table, it can be said that resembling rheological and filtration results were obtained with drilling fluid incorporated with the optimum concentration, which is 1 wt%, found based on differential pressure pipe sticking tendency results of sieved fly ash. However, a better quality of mud cake was formed and it was observed that the reduction in the Gel10s, Gel1min and Gel10min strength is slightly more noticeable with the relevant concentration of sieved fly ash compared to the analyzed raw fly ash results. Analyzing the results indicates that the formulation of the drilling fluid with 1 wt%

Table 3. Rheological, filtration and sticking tendency properties of drilling fluid

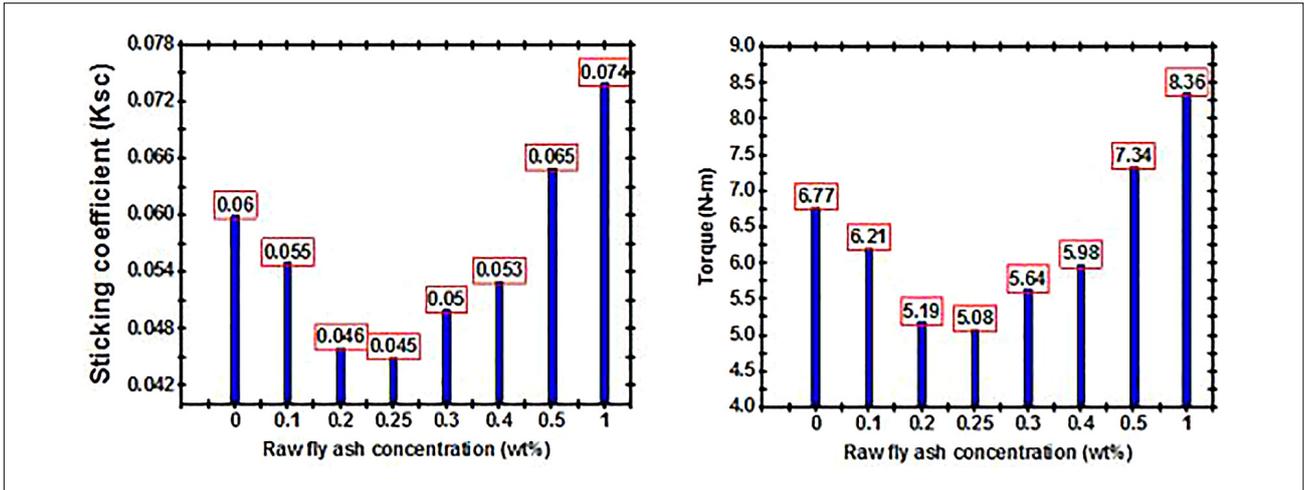| Parameters	Fluid loss ml/30min.	Cake thickness mm	AV mPas	PV mPas	YP Pa	Gel10s/Gel1min /Gel10min Pa	Friction coefficient	Torque Nm	Density kg/m³
Values	9.6	3	26	4	21.06	13.88/20.10/28.72	0.06	6.77	1222

Figure 3. Effect of raw fly ash concentration on the sticking coefficient of drilling mud
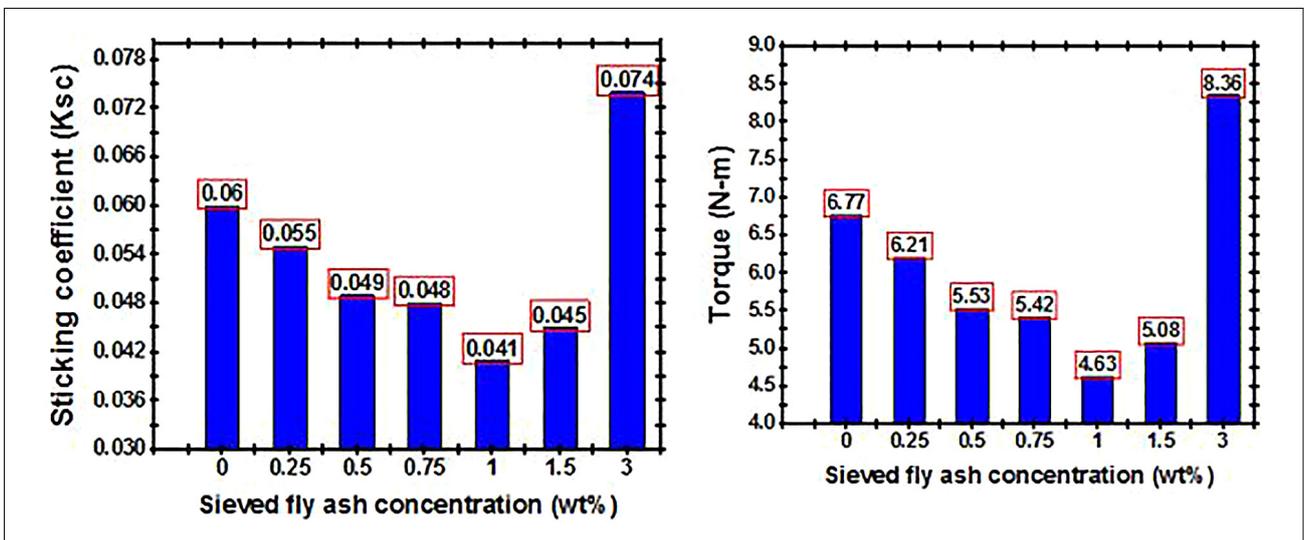

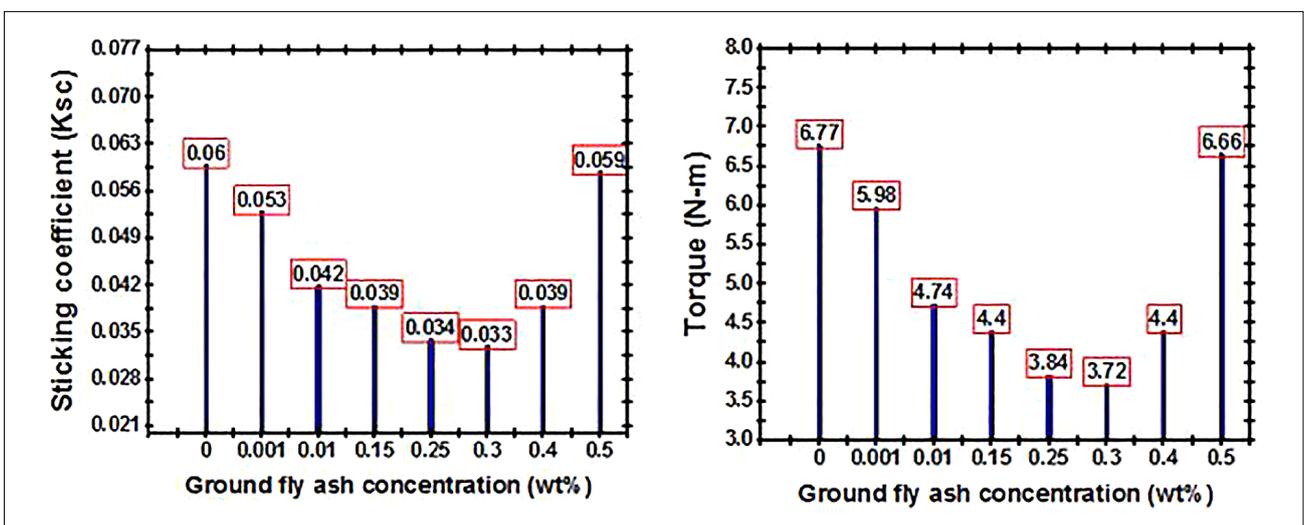**Figure 4.** Effect of sieved fly ash concentration on the sticking coefficient of drilling mud

Figure 5. Effect of ground fly ash concentration on the sticking coefficient of drilling mud
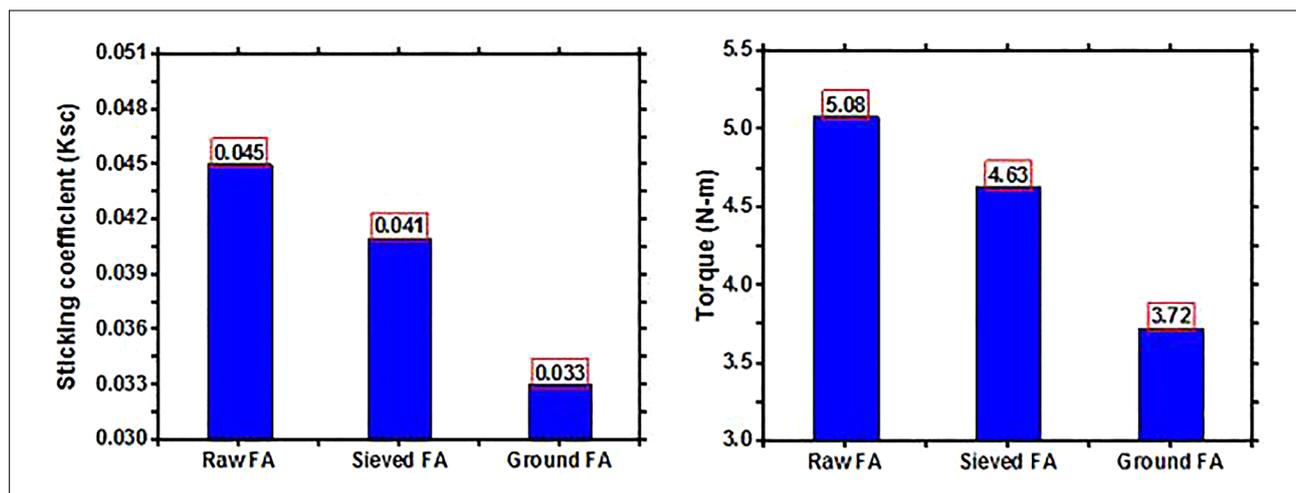
Figure 6. Comparative results of fly ash with different particle size on differential sticking tendency

Table 4. Effect of raw fly ash concentration on drilling fluid properties

Concentration of fly ash (wt%)	Fluid loss ml/30min.	Cake thickness mm	AV mPas	PV mPas	YP Pa	Gel10s Pa	Gel1min Pa	Gel10min Pa
0.1	9.5	1.9	26.5	10	15.80	12.93	18.67	27.29
0.2	9.3	1.8	27	11	15.32	12.93	19.15	27.77
0.25	9.2	1.5	27.5	11	15.80	12.93	19.15	28.25
0.3	9.6	1.9	28	11	16.28	13.89	20.11	28.73
0.4	9.8	2	27.5	13	13.89	11.97	17.72	26.33
0.5	9.6	2	28.5	1	26.33	14.84	20.59	29.21
1	9.4	2.2	29.5	10	18.67	15.32	21.55	30.64

Table 5. Effect of sieved fly ash concentration on drilling fluid properties

Concentration of fly ash (wt%)	Fluid loss ml/30min.	Cake thickness mm	AV mPas	PV mPas	YP Pa	Gel10s Pa	Gel1min Pa	Gel10min Pa
0.25	9.4	1.7	27.5	11	15.80	12.93	19.15	26.81
0.50	9.4	1.6	28	11	16.28	13.89	19.63	28.73
0.75	9.1	1.3	27.5	8	18.67	13.41	19.15	27.29
1	9.2	1	27.5	10	16.76	12.45	18.67	26.81
1.50	9.4	1.9	27	11	15.32	12.45	18.19	26.81
3	9.3	2.1	27.5	11	15.80	12.45	18.67	27.29

Table 6. Effect of ground fly ash concentration on drilling fluid properties

Concentration of fly ash (wt%)	Fluid loss ml/30min.	Cake thickness mm	AV mPas	PV mPas	YP Pa	Gel10s Pa	Gel1min Pa	Gel10min Pa
0.001	9.6	2	26	10	15.32	11.49	17.72	25.38
0.01	9.6	1.9	26.5	11	14.84	11.97	17.72	26.09
0.15	9.5	1	26.5	11	14.84	11.49	17.72	25.86
0.25	9.6	0.9	27	11	15.32	12.21	18.19	27.29
0.3	9.7	0.8	27.5	11	15.80	12.93	18.67	27.29
0.4	9.9	1.9	26.5	11	14.84	11.97	17.72	26.33
0.5	9.6	2.4	27	11	15.32	12.45	18.19	27.29

concentration of sieved fly ash decreased the mud cake thickness by 67% compared to the drilling fluid without fly ash.

The experimental results show that the drilling fluid with 0.3 wt% concentration of ground fly ash exhibits resembling rheological results to raw and sieved fly ash, as can be seen in **Table 6.** Nevertheless, different behavior was observed on the filtration properties of the drilling fluid compared to other fly ashes. While fluid loss variation can be neglected, the mud cake thickness decreased by 73%, resulting in a superior filter cake.

The rheological and filtration results indicate that three forms of fly ash are compatible with the drilling fluid. In addition, a reduction in filter cake thickness and fluid loss volume are also desired properties. This helps to avoid some serious issues, such as formation damage, evaluation problems with wireline logs, increased pressure surges and excessive drag.

4. Conclusions

In this study, the differential sticking tendency of drilling fluids designed with fly ash under various concentrations and three different sizes obtained as a result of sieving and grinding processes was investigated experimentally. The experimental results showed that the formulated drilling fluids significantly reduced the differential sticking tendency in the presence of 0.25 wt% raw fly ash, 1.0 wt% sieved fly ash and 0.3 wt% ground fly ash. Particle size analysis results demonstrated that as the particle size of fly ash decreases, the differential sticking tendency of the drilling fluid also decreases. The drilling fluid designed with 0.3 wt% ground fly ash was found to be the least prone to the differential sticking tendency when compared to the drilling muds containing coarser particle sizes of the fly ashes and to the reference mud. This demonstrates the potential of the developed drilling fluid in the mitigation of differential sticking tendency. In addition, while the filtration properties of the formulated drilling fluid with 0.3 wt% ground fly ash were improved, rheological properties of the drilling fluid were also found at the appropriate levels. Consequently, based on the study, it was concluded that by the proper combination of fly ash, the differential sticking tendency can be significantly reduced without compromising the rheological properties of the drilling fluid, as well as improving the filtration properties. The novel findings from this study indicate that exploitation fly ash with the appropriate concentration and particle size in the water-based drilling fluid not only provides a reduced friction coefficient and torque values, but also contributes to the reduction of the environmental impact.

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SAŽETAK

Priprema i ispitivanje isplake na bazi vode u svrhu smanjenja sklonosti diferencijalnom prihvatu

Cilj je ovoga istraživanja pripremiti isplaku uz dodatak lebdećega pepela, koji je industrijski otpad dobiven izgaranjem ugljena, koja će spriječiti pojavu diferencijalnoga prihvata bušaćih alatki. Ispitani su uzorci isplake koji su pripremljeni s različitim koncentracijama i veličinama čestica lebdećega pepela, dobivenim mljevenjem i prosijavanjem. Ispitivanje sklonosti diferencijalnom prihvatu u različitim uzorcima isplake provedeno je pri tlaku 3,447 MPa (500 psi) korištenjem uređaja Fann Model 21150, pri čemu je praćena promjena koeficijenta ljepljivosti i očitanja torzije s dodavanjem lebdećega pepela. Iz rezultata je vidljivo da se koeficijent ljepljivosti i očitanje torzije smanjuju s povećanjem koncentracije lebdećega pepela u isplaci. Nadalje, istraživanje je pokazalo da i koeficijent ljepljivosti i torzija ovise o raspodjeli veličine čestica lebdećega pepela u isplaci. Isplaka pripremljena s mljevenim lebdećim pepelom pokazala je niži koeficijent prianjanja i manje očitanje torzije u odnosu na isplake pripremljene s nemljevnim („sirovim") ili prosijanim lebdećim pepelom. Istraživanje je pokazalo da bi se lebdeći pepeo mogao koristiti kao aditiv za smanjenje sklonosti diferencijalnom prihvatu u isplakama na bazi vode.

Ključne riječi:
diferencijalni prihvat, lebdeći pepeo, mljevenje, isplake, uređaj za ispitivanje sklonosti diferencijalnom prihvatu

Author's contribution

Emine Yalman (PhD Student-Researcher, Petroleum Engineer) conducted the laboratory tests and wrote the manuscript **Gabriella Federer-Kovacs** (Assoc. Prof. Dr., Petroleum Engineer) and **Tolga Depci** (Prof. Dr., Mining Engineer) supervised and provided analyses of the results.