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Evaluation of Possible Application of Powder Made from Fallen Tree Leaves as a Drilling Mud Additive

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ABSTRACT

Drilling muds play the essential role the drilling process as they perform many functions, such as the removing of drill cuttings and controlling well pressure. Water-based drilling muds, through the use of more environmentally friendly additives, can meet increased environmental requirements. Many researchers have studied the effects of different natural materials on drilling mud to find environmentally friendly and effective drilling mud materials. The popularity of using waste materials is mainly due to their cost and favourable environmental impact. Performed literature review showed that the rheological and filtration characteristics of water-based drilling muds are enhanced with the addition of leaves of various plants and trees. This article presents investigations of clay-free drilling mud with the addition of birch and aspen leaf powder. This is relevant in the autumn period, since fallen leaves are solid municipal waste and should be disposed of by removal to landfills. The obtained data indicate the possibility of using leaf powder in the drilling mud composition. Addition of leaf powder to the base mud increases the gel strength and plastic viscosity of the mud. In an extent reduces the yield point and filtration index. Rheological parameters increase by 10-30% and filtration index decreases up to 15-17%.

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Graphical Abstract

1. INTRODUCTION

Drilling wells is necessary to extract oil and gas from productive formations located deep underground (1-3). Drilling fluids play an essential role in the drilling process as they perform many functions, such as removing drill cuttings and controlling well pressure (4, 5). Several chemicals are often used as additivies to the drilling mud. These are the substances that increase viscosity and reduce filtration, clay swelling inhibitors, lubricants and bridging agents, etc. (6-8). In terms of cost, drilling mud can account for up to 20% of the total drilling expenditures (9, 10). Hydrocarbon-based drilling fluids have excellent performance characteristics and do not cause drilling complications. However, their use is not always possible, especially in areas with high environmental constraints (11-13).

Water-based drilling fluids can meet increased environmental requirements through the use of more environmentally friendly additives. Modern

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requirements to the environmental conditions during well construction in protected and nature conservation areas, as well as offshore, stimulated the development and improvement of drilling muds so to enhance their environmental safety (14).

Many researchers have studied the effects of various natural materials on drilling mud to find environmentally friendly and efficient drilling mud materials (15-17). The popularity of using waste materials is mainly due to their cost and favorable environmental impact (18, 19). Due to the necessity of using biodegradable additives as drilling mud additives due to their comparatively low cost and environmental friendliness, research on waste materials has started. Thus, Amanullah et al. (20) used Ziziphus seed powder (Zízíphus jujube, an agricultural waste) as an additive to reduce drilling mud filtration. Findings of the paper revealed that jujube seed powder reduces filtration in both fresh and salt water, whereas not affecting the rheological properties of drilling mud. The main components of wild ziziphus seeds are betulinic acid, betulin, etc., which contains about 32% fat, alkaloids, various amino acids and metallic elements (21). Wild ziziphus seeds contain alkaloid, cyclic ziziphus peptide, zeanotinic acid, alfitolic acid, daucoside and flavonoids. It also contains 17 amino acids and various metallic elements such as potassium and sodium. Also, Onwuachi-Iheagwara (22) studied the effect of banana peel on the performance of drilling mud. The results showed that the solution of banana peel powder was alkaline and could partially replace NaOH used in drilling mud. Iranwan et al. (23) studied the effect of corn cobs and sugarcane waste on drilling mud performance and the results showed that both corn cobs and sugarcane waste could increase the viscosity of drilling mud and improve the rheological properties. Investigations by Nmegbu and Bekee (24) showed that the cellulosic material obtained from corn cobs reduces the filtration index of drilling mud with high efficiency. Omotioma et al. (25) investigated the effect of cashew and mango extracts on the rheological properties of water-based drilling mud. Results of the conducted experiments indicated that both of them could reduce the corrosivity of drilling mud and have inhibitory properties. Al-Saba et al. (26) investigated the possibility of using biodegradable wastes as ecological additives to the drilling mud. These wastes, which were prepared by the authors, include grass, corn cobs, sugarcane, pomegranate peel, soybean peel, etc. Various concentrations and mixtures of the additives were evaluated. Then, such properties of investigated drilling fluids as filtration, pH and rheology were evaluated. The filtration properties were evaluated using a standard low pressure and low temperature API filter press. The results showed that some materials, such as soybean peel powder, reduced fluid loss up to 60% and improved the yield point and gel strength up to 330% and 640%, respectively, with insignificant or no effect on plastic viscosity, suggesting the applicability of using both additives as rheology modifier and filtration control agent. Other materials, such as the outer part of henna and tamarind gum, drastically reduce pH, suggesting their applicability as pH control agents, especially when cement is drilled. One of the waste products that can be used in drilling mud is grass. An environmentally friendly material, grass powder (GP) was used by Al-Hameedi et al. (27) in drilling mud preparation instead of starch. They investigated the possibility of reducing the filtration index of drilling mud by GP addition. The experimental results showed that GP reduced the drilling fluid filtration index and increased the strength of the filter cake formed on the wellbore wall. Another example of food waste utilization is potato peel powder (PPP) (28). They (28) studied its effect on the rheological and filtration parameters of drilling fluids. According to the results of experimental data, the conclusions were obtained that PPP addition to drilling mud does not change the density of the fluid. PPP in the mud increased the plastic viscosity and all rheological parameters in general and decreased the filtration index. Also, Al-Hameedi et al. (29) investigated the possibility of using mandarin peel powder in drilling mud. The comparison was made with polyanionic cellulose (PAC-LV), which is often used in drilling fluids. Experimental investigations carried out by the authors showed a decrease in filtration index and an increase in rheological parameters. The obtained data showed that mandarin peel powder can be used in drilling mud as an environmentally friendly additive. In continuation of the study with mandarin peel, Medved et al. (30) also evaluated the influence of mandarin peel powder particle size on filtration and rheological parameters of drilling mud. The separation into two sizes was made - powder particles less than 0.1 mm and powder particles from 0.1 mm to 0.16 mm. Also four concentrations of mandarin peel powder in the water-based drilling mud were studied - 0.5%, 1%, 1.5% and 2%. The results of the research showed a 42% decrease in the filtration index with increasing powder concentration. Rheological parameters at powder addition increased, but their values remained within the permissible technological limits. The authors also established that 1.5% of mandarin peel powder is an optimal concentration.

The results presented above show that the use of various environmentally friendly additives, which are wastes, can become an alternative to some structure-forming additives used in water-based drilling muds. The use of waste additives in drilling mud compositions can contribute to reducing the negative effect of drilling mud on the environment and at the same time reduce its cost.

Based on the literature review, it was shown that dry leaves of various plants can be an additive in drilling mud. Addition of dry leaves can reduce filtration and increase rheological parameters of water-based drilling fluids. During the autumn period, leaves of such trees as birch and aspen fall. Some leaf disposal methods are harmful to human health or the environment. The most dangerous of them is incineration. In this process, in addition to carbon dioxide, several dangerous substances are released: carbon monoxide; nitrogen oxide/dioxide; products of thermal decomposition of various resins. Collected leaves of trees and shrubs are subject to removal of waste disposal areas, neutralization or utilization facilities. Therefore, taking into account the climatic peculiarities of the North-West region of Russia and the spread of deciduous trees in it, it was decided to study leaves as an additive in drilling fluid.

In most of the presented above works, clay mud based on bentonite was used as a base mud. However, the clay component of the mud does not have a negative impact on the environment, so for this study it was decided to investigate a clay-free composition of drilling fluid.

The purpose of present work is to investigate the possibility of using dry leaf powder in the composition of biopolymer clay-free mud. In addition, to evaluate the possibility of reducing the concentration of polymer reagents in drilling mud by replacing them with dry leaf powder.

2. MATERIALS AND METHODS

2. 1. Materials A dry pulverization process was used to make leaf powder. First, the collected leaves (birch and aspen) were dried for 3-4 days at room temperature. After drying, the leaves were pulverized into powder using a coffee grinder and then sieved through a 400 µm sieve to remove coarse particles. Figure 1 shows the dried and powdered form of the leaves used.

The drilling fluid is based on xanthan biopolymer and polyanionic cellulose (PAC), high and low viscosity (HV, LV). The solution also contains potassium chloride as an inhibitor, calcium carbonate as a weighting-bridging agent and potassium hydroxide as a pH-increasing agent. The concentration of structure formers, inhibitors, weighting agents and leaf powder was selected based on literature review on similar additives (16, 31-33). Recipes of the studied solutions are presented in Table 1.

Figure 1. Dried leaves and leaf powder

2. 2. Methods The feasibility of leaf powder application and its efficiency were investigated by conducting tests to measure the rheological parameters (plastic viscosity, yield point, Gel 10 s/10 min) and filtration index of drilling muds. The density of all samples is constant and is 1120 kg/m^3.

2. 2. 1. Measurement of Drilling Mud Density The mud density is determined with the help of mud balance as reported by Ahmadi et al. (34). Lever scales consist of a base and graduated lever with a cup, a cover, a supporting prism, a reiter, a built-in spirits level and a counterweight. A cup of constant volume is fixed at one end of the graduated lever and the counterweight at the opposite end. A schematic representation of the lever scale is shown in Figure 2.

2. 2. 2. Measurement of Rheological Properties The rheological behavior of drilling fluids in a wide range of shear rates is determined by a large number of rheological models (more than 30). American Petroleum Institute recommends predicting fluid behavior using a modified power law model (Herschel-Bulkley model). Rheological parameters of drilling fluids such as plastic viscosity, dynamic shear stress and Gel 10s/Gel 10min were determined on a rotary viscometer.

TABLE 1. Component composition of the solution

Reagent	Reagent function	Concentration, kg/m^3
Base mud:		
KOH	pH regulator	0.1
KCl	Inhibitor	120
Biopolymer	Increase of rheological parameters, water loss reduction	4
PAC LV	Water loss reduction	4
PAC HV	Increase of rheological parameters	3
Calcium carbonate	Increase of density, water loss reduction	100
Base mud + investigated additive		
Leaf powder	Increase of rheological parameters	6

Figure 2. Lever scales

Plastic viscosity (PV) of drilling fluid is defined in technical literature as the part of the resistance to flow caused by mechanical friction. The PV is influenced by many factors, but mostly by the concentration of solids, their size and particle shape. Another important factor is the viscosity of the liquid phase of the drilling fluid and the presence of polymers with a linear structure of macromolecules. When the content of solid particles in the mud (barite, calcium carbonate, cuttings particles, etc.) increases, PV will increase (35).

Plastic viscosity in centipoises (cP) or millipascals on second (mPa·s) is calculated as the difference between the Fann viscometer reading (θ) at 600 and 300 rpm:

$PV = \theta600 - \theta300$ [cP],

where θ600 and θ300 – values of the viscometer scale rotation angles at the sleeve rotation frequencies equal to 600 and 300 min^{-1}, respectively, deg.

The yield point (YP) of the drilling mud indirectly characterises the strength resistance of the drilling fluid to flow. YP indicates the force required to shear one layer of moving liquid relative to another. YP primarily affects the mud's carrying capacity (36).

Yield point in lb/100 ft^2 is calculated from the data of Fann viscometer by the following formula (37).

$YP = \theta300 - PV$ [lb/100 ft^2]

or

$YP = (\theta300 - PV) \times 4.48$ [dPa],

where θ300 – values of the viscometer at 300 rpm, PV – plastic viscosity; 4.48 –lb/100 ft^2 to dPa conversion factor.

A three-dimensional structural lattice is formed in the fixed drilling fluid, which hardens over time. As the mud flows, this lattice breaks down. Muds that have the ability to reversibly restore-destroy internal structure, the structures are called thixotropic. The value characterizing the strength of the resting mud structure is called gel strength (GL). This parameter affects the retention in suspension of drilled rock particles and weighting agent. The GL of drilling fluids should be minimal, but sufficient to hold the drilled rock and weighting agent particles in suspension at a given mud density (38).

To obtain the Gel 10 s/10 min value of the drilling fluid according to API, the rate of 3 rpm on the rotational viscometer must be switched on after 10 s and 10 min of rest, respectively. Prior to this, the mud is stirred at 600 rpm (39).

A 6-speed Fann rotary viscometer, model 35A, was used to determine the properties of the studied drilling muds in the laboratory of Mining University. The compositions of the investigated drilling muds were tested by rotating the outer cylinder at a rate of 600, 300, 200, 100, 6 and 3 rpm. Schematic representation of the used Fann viscometer is presented in Figure 3.

2. 2. 3. Measurement of the Filtration Index

Filtration index partially affects the penetration of drilling mud filtrate into the drilled rock particles, which in turn affects the risk of packing. Mud water loss directly affects the depth of filtrate penetration into permeable formations that will determine the future productivity of the well.

The API methodology (API filter press, HPHT filter press and dynamic HPHT filter press) evaluates the filtration index of the drilling fluid at ambient temperature, at a pressure of 100 lb/in^2 (0.7 MPa). The analysis consists of determining the flow rate of the liquid through the filter paper (37, 40, 41). The result is the volume of filtrate produced (mL) in 30 minutes. An image of the filter press is shown in Figure 4.

Figure 3. Fann rotary viscometer

Figure 4. API filter press

3. RESULTS AND DISCUSSION

At the first stage, investigations of mud compositions according to the formulations from Table 1 were carried out. Table 2 summarized the results of measurements of the drilling muds' main parameters.

Analyzing the obtained results, it is seen that the addition of dry leaves to the drilling mud increases the rheological parameters and decreases the filtration index.

Based on the data obtained, it was decided to investigate other concentrations of dry leaves, but to reduce the concentration of PAC HV and PAC LV. This was done to see if it was possible to replace some of the polymer reagents with an environmentally friendly additive (Figure 5).

The formulations of the investigated muds with the addition of leaf powder are presented in Table 3.

The same series of investigations were carried out for the presented formulations and the results obtained are presented in Table 4 and Figures 6-9.

The experimental results showed that the addition of leaf powder to the biopolymer clay-free mud increases the plastic viscosity and gel strength, but there is no increase in the yield point. With decreasing the PAC concentration in the mud (high viscous from 3 to 2 kg/m^3 and low viscous from 4 to 3 kg/m^3) and increasing the leaf powder content (up to 7 kg/m^3), the rheological parameters decrease. But with further decrease in PAC concentration (high viscous to 1 kg/m^3 and low viscous 2 kg/m^3) and increase in leaf powder addition (up to 8

TABLE 2. Measurement results

	Base mud	Base mud + leaf powder
Density (g/cm^3)	1.12	1.12
Viscometer readings		
600 rpm	100	121
300 rpm	79	88
200 rpm	64	74
100 rpm	45	54
6 rpm	12	17
3 rpm	9	13
Gel 10 s/10 min, dPa	10/14	13/15
PV, mPa·s	21	33
YP, dPa	58	55
Filtration index (ml/30 min)	9.2	7.6

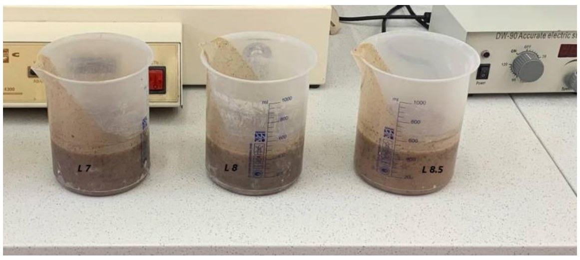

Figure 5. New muds

TABLE 3. Component composition of the new muds

	Mud L7	Mud L8	Mud L8.5
	Concentration of reagents, kg/m^3		
KOH	0.1	0.1	0.1
KCl	120	120	120
Biopolymer	4	4	4
PAC LV	3	2	1.5
PAC HV	2	1	0.5
Calcium carbonate	100	100	100
Leaf powder	7	8	8.5

TABLE 4. Measurement results of new muds

	Solution L7	Solution L8	Solution L8.5
Density (g/cm^3)	1.12	1.12	1.12
Viscometer readings			
600 rpm	65	66	47
300 rpm	47	48	34
200 rpm	39	39	28
100 rpm	28	27	21
6 rpm	9	11	9
3 rpm	8	10	8
Gel 10 s/10 min, dPa	8/9	10/11	8/9
PV, mPa·s	18	18	13
YP, dPa	29	30	21
Filtration index (ml/30 min)	8.0	7.6	7.6

kg/m^3) and increase in leaf powder addition (up to 8

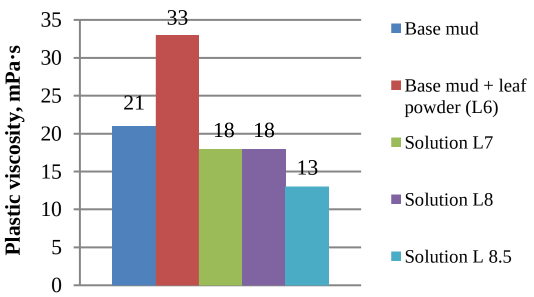

Figure 6. Plastic viscosity values

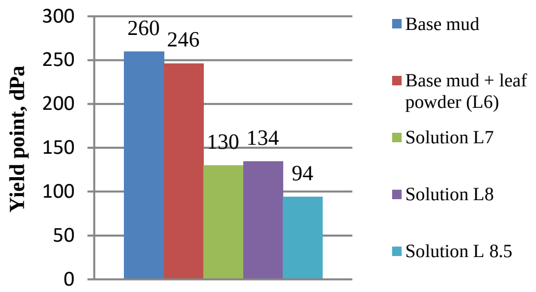

Figure 7. Yield point values

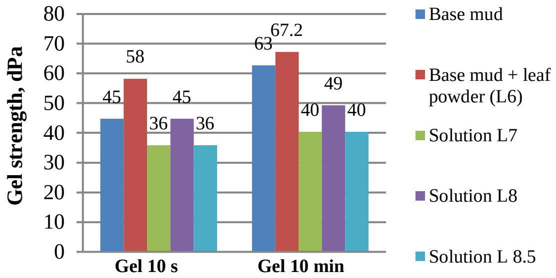

Figure 8. Gel strength values

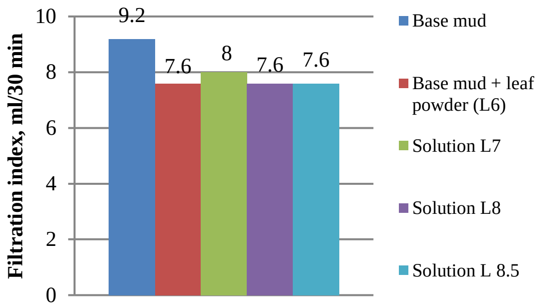

Figure 9. Filtration index values

kg/m^3) there was no decrease, which shows the possibility of using this kind of additives.

However, the measurement of parameters with even greater reduction of PAC concentration and increase of leaf powder showed a decrease in rheological parameters.

The filtration index of investigated muds with the addition of leaf powder is approximately at the same level and lower than the filtration of the base mud (Figure 9). This is due to an increase in the content of solid phase in the drilling mud and the formation of filter cake occurs faster.

4. CONCLUSION

The obtained results showed the possibility of using leaf powder as part of biopolymer clay-free mud.

By addition of leaf powder to the base mud increases the plastic viscosity and gel strength of the mud and reduces the yield point and filtration index to a small extent. Rheological parameters increase by 10-30% and filtration index decreases up to 15-17%.

Further experiments showed that it is possible to reduce the concentration of PAC HV and PAC LV and "replace" them with leaf powder. The solution "L8" consisting of biopolymer (4 kg/m^3), potassium chloride (120 kg/m^3), calcium carbonate (100 kg/m^3), potassium hydroxide (0.1 kg/m^3), PAC HV (1 kg/m^3), PAC LV (2 kg/m^3) and leaf powder (8 kg/m^3) showed the most optimal performance in terms of plastic viscosity, gel strength, yield point and filtration index. Further reduction of PAC concentration leads to a significant decrease in rheological parameters, which will adversely affect the carrying capacity of the drilling mud.

The presented investigations are only the first step in studying the possibility of using leaves in drilling muds. Further investigations should be devoted to the evaluation of thermostability of drilling muds with the addition of leaf powder, as well as the influence of the size fraction of the added leaf powder. However, even based on the first experiments it is clear that it is possible to use leaf powder for improvement of environmental friendliness of drilling muds.

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Persian Abstract

چکیده

استفاده از گل های حفاری بخشی جدایی ناپذیر از فرآیند حفاری است و عملکردهای زیادی مانند انتقال کنده‌های حفاری و کنترل فشار چاه را انجام می دهد. گل حفاری مبتنی بر آب، از طریق استفاده از افزودنی‌های سازگار با محیط زیست، می‌تواند الزامات زیست‌محیطی افزایش یافته را برآورده کند. بسیاری از محققان اثرات مواد طبیعی مختلف بر گل حفاری را برای یافتن مواد گل حفاری دوستدار محیط زیست و موثر مطالعه کرده اند. محبوبیت استفاده از مواد پسماند عمدتاً به دلیل هزینه و تأثیر مطلوب زیست محیطی آنها است. با انجام بررسی ادبیات گذشته، مشخص شد که افزودن برگ‌های گیاهان مختلف ویژگی‌های رئولوژیکی و فیلتراسیون گل‌های حفاری مبتنی بر آب را بهبود می‌بخشد. این مقاله به بررسی گل حفاری بدون رس با افزودن پودر برگ توس و آسپن می پردازد. این امر در دوره پاییز امکانپذیر است، زیرا برگ های ریخته شده پسماند شهری جامد هستند و باید با انتقال به محل های دفن زباله دفع شوند. داده های به دست آمده حاکی از امکان استفاده از پودر برگ در ترکیب گل حفاری است. افزودن پودر برگ به گل پایه باعث افزایش ویسکوزیته پلاستیک و استحکام ژل گل می شود و تا حدودی نقطه تسلیم و شاخص فیلتراسیون را کاهش می دهد.