ISSN 2712-8008
Volume / Том 24 №3 2024
Journal Homepage: http://vestnik.pstu.ru/geo/

Perm Journal of Petroleum and Mining Engineering

UDC 622.24.063.2
Article / Статья

Ecological Biodegradable Additives for Improving Rheological and Filtration Characteristics of Water-Based Drilling Mud

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Экологические биоразлагаемые добавки для улучшения реологических и фильтрационных характеристик бурового раствора на водной основе

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Received / Получена: 05.03.2024. Accepted / Принята: 26.07.2024. Published / Опубликована: 30.08.2024

Keywords:
drilling fluids, drilling muds, water-based solutions, rheological characteristics, filtration, viscosity, hydrogen index, density, flocculation, water loss, temperature conditions, sedimentation stability, dispersion, clay cake thickness, biodegradable additives, food waste, agro-industrial waste.

Solutions used in well drilling must have a number of properties that ensure their functionality. Along with cleaning the bottomhole, removing drilling mud, cleaning and cooling the drill bit, they must maintain hydrodynamic pressures in the well to prevent formation fluids from entering the wellbore and absorption of the drilling mud, as well as regulate the formation of a thin filter cake that covers the pores in the rocks being drilled, which prevents them from crumbling. In drilling practice, drilling muds on water, hydrocarbon and aerated basis are used. From the point of view of environmental safety, water-based solutions are preferable. But to ensure the necessary properties of water-based drilling muds, a number of special chemical additives are used, which, being toxic products of long action, have a negative impact on the environment. Currently, the task is to develop new drilling muds that not only ensure the drilling process in any, including difficult conditions, but also do not harm the environment. The economic component of the issue should also be taken into account. In order to obtain new environmentally friendly drilling fluids, as well as to solve the problem of accumulation of food waste, it is proposed to use biodegradable additives obtained from plants or agro-industrial waste. The article presents studies of the effect of bioadditives on the rheological and filtration characteristics of water-based drilling fluids. The effect of plant additives on the viscosity, density, yield point, filtration of drilling fluids, as well as on the formation and thickness of the clay cake is shown. In addition, the possibility of using agro-industrial waste, such as orange and tangerine peel, sunflower seeds, rice and peanut husks, eggshells, as an alternative to polymers currently used to reduce and prevent absorption of drilling fluids is shown. The possibility of using biodegradable additives as potential environmentally friendly and inexpensive additives to drilling fluids is considered.

Ключевые слова:
буровые растворы, промывочные растворы, растворы на водной основе, реологические характеристики, фильтрация, вязкость, водородный показатель, плотность, флокуляция, водоотдача, температурные условия, седиментационная устойчивость, дисперсность, толщина глинистой корки, биоразлагаемые добавки, пищевые отходы, агропромышленные отходы.

Растворы, применяемые при бурении скважин, должны обладать рядом свойств, обеспечивающих их функциональность. Наряду с очисткой забоя, выносом бурового шлама, очисткой и охлаждением бурового долота, они должны обеспечивать поддержание гидродинамических давлений в скважине – для предотвращения проявления пластовых флюидов в ствол скважины и поглощений бурового раствора, а также регулировать образование тонкой фильтрационной корки, перекрывающей поры в разбуриваемых породах, что предотвращает их осыпание. В практике бурения применяют буровые растворы на водной, углеводородной и аэрированной основе. С точки зрения экологической безопасности растворы на водной основе являются предпочтительными. Но для обеспечения необходимых свойств буровых растворов на водной основе применяют ряд специальных химических добавок, которые, являясь токсичными продуктами длительного действия, оказывают негативное влияние на окружающую среду. В настоящее время стоит задача разработки новых буровых растворов, не только обеспечивающих процесс бурения в любых, в том числе затрудненных, условиях, но и не наносящих вред окружающей среде. При этом должна учитываться и экономическая составляющая вопроса. С целью получения новых экологически чистых буровых растворов, а также решения проблемы накопления пищевых отходов предлагается применять биоразлагаемые добавки, полученные из растений или агропромышленных отходов. В обзорной статье представлены исследования влияния биодобавок на реологические и фильтрационные характеристики буровых растворов на водной основе. Показано влияние растительных добавок на вязкость, плотность, предел текучести, фильтрацию, буровых растворов, а также на образование и толщину глинистой корки. Кроме того, показана возможность использования агропромышленных отходов, таких как апельсиновая и мандариновая корка, семена подсолнечника, шелуха риса и арахиса, яичная скорлупа, в качестве альтернативы полимерам, используемым в настоящее время для снижения и предотвращения поглощения буровых растворов. Рассмотрена возможность использования биоразлагаемых добавок в качестве потенциальных экологически чистых и недорогих добавок в буровые растворы.

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Please cite this article in English as:
Leusheva E.L., Morozov A.O., Morozov D.O. Ecological biodegradable additives for improving rheological and filtration characteristics of water-based drilling mud. *Perm Journal of Petroleum and Mining Engineering*, 2024, vol.24, no.3, pp.120-130. DOI: 10.15593/2712-8008/2024.3.3

Просьба ссылаться на эту статью в русскоязычных источниках следующим образом:
Леушева, Е.Л. Экологические биоразлагаемые добавки для улучшения реологических и фильтрационных характеристик бурового раствора на водной основе / Е.Л. Леушева, А.О. Морозов, Д.О. Морозов // Недропользование. – 2024. – Т.24, №3. – С.120–130. DOI: 10.15593/2712-8008/2024.3.3

Introduction

To ensure the necessary properties of drilling fluids, special chemical additives are used. However, such additives have a negative impact on the environment, also long-lasting toxic products. When drilling fluids are disposed after drilling operations, they, together with sludge and additives, are discharged into water bodies and cause their pollution. This is especially dangerous in the Arctic regions, as the natural ecological situation is most susceptible to disruption due to the inhibition of oxidation and evaporation processes, slowing down in the restoration of the environment. The task of Russian researchers is to develop new drilling fluids that not only facilitate the drilling process in any conditions, including challenging ones, but also do not pollute the environment. The economic aspect of the issue must certainly be taken into account as well.

For this purpose, it is currently proposed to use biodegradable additives instead of chemical additives, obtained, for example, from agro-industrial waste, from plant processing or from wood waste. The paper discusses research conducted in this field.

Drilling fluids. Rheological characteristics

Fluids used in well drilling must have a number of properties to ensure their functionality. Along with cleaning the bottomhole, removing cuttings, cleaning and cooling the drill bit, drilling fluids must ensure the maintenance of hydrodynamic pressures in the well to prevent formation fluids from entering the wellbore and absorption of the drilling fluid. They also regulate the formation of a thin filter cake that seals the pores in the drilled rocks, preventing their collapse [1]. In drilling practice, drilling fluids based on an water, hydrocarbons and air are used. From an environmental safety perspective, water-based solutions are preferable. However, to obtain the necessary properties, they also include additives that can have a toxic impact on the environment. To achieve the necessary rheological properties of water-based fluids and ensure their environmental friendliness, environmentally safe biodegradable additives are currently being proposed for use.

Rheological characteristics of drilling fluid show how it will work at different temperatures, pressures, and shear rates. Viscosity generally characterizes the ability of the solution to resist flow. It is necessary to consider not only the viscosity properties of the fluids, but also their plastic and thixotropic properties.

Plastic viscosity represents the specific resistance to flow caused by friction between solid particles in drilling fluids and fluid layers. It depends on the viscosity of the base liquids, i.e. water and oil, as well as the concentration and size of solid particles. A significant increase in plastic viscosity in drilling fluids can lead to a slowdown in the fluid movement and a decrease in the drilling rate. Reduction of plastic viscosity is achieved by using diluting additives [2]. Drilling fluids with high viscosity are preferable in conditions of deep well drilling, wells with high pressure and high temperature, where viscosity will decrease.

Density is the weight of drilling fluid per unit volume. Density improves wellbore stability and maintains reservoir pressure. Low drilling fluid density can lead to breakthrough and wellbore failure. Excessively high drilling fluid density can result in circulation loss, reduced drilling rate, and formation damage [2].

Filtration indicates the amount of drilling fluid that penetrates into the wellbore formations as a result of the hydrostatic pressure of the liquid exceeding the pore pressure. As the pores are filled with weighted solids from the drilling fluid, a mud cake is formed. Filtration rate and mud cake thickness decrease as the concentration of solid particles in the fluid increases.

Dynamic shear stress characterizes the ability of the fluid to carry drilling cuttings in a suspended state during circulation in the wellbore and behind the casing. The yield strength increases with decreasing particles size of the additive. This is due to the increased attractive forces between solid particles, which enhance the carrying capacity of the drilling cuttings and clean the wellbore [2, 3].

Gel strength (static shear stress) characterizes the ability to retain drill cuttings in a suspended state under static conditions. The more the gel strength increases over time, the greater the pressure required to overcome the accumulated gel strength and initiate circulation.

Application of biodegradable additives derived from plants to enhance the characteristics of water-based drilling fluids

It is proposed to use derivatives of lignin obtained during wood processing as additives that improve the rheology of fluids. The Russian Federation ranks first in the world in terms of forest resources. During the harvesting and processing of wood, tens of millions of tons of waste are generated annually – bark, sawdust, technical lignins. Approximately half of such waste is burned, the other part is taken to dumps, which pollute the soil and often cause fires. Today, there are practically no high-tech methods for the disposal of large-tonnage waste from wood processing enterprises, including lignins. The use of lignin derivatives as additives to drilling fluids will solve the problem of utilizing "difficult" waste and allow obtaining environmentally friendly and functional fluids.

Currently, additives of lignosulfonates modified with chromium salts are used. However, due to high toxicity of these salts, scientists are working on replacing them non-chromium compounds. A.V. Minakov, E.I. Mikhienkova, A.D. Skorobogatova and others suggest using hydrolytic lignin as an effective additive – a waste product of biochemical plants producing ethanol from wood raw materials [4]. This is a complex mixture of products from hydrolytic breakdown of wood, which consists of modified lignin of plant fiber, polysaccharides, mineral and organic acids, ash elements and a number of other substances. It has been proven that additives of modified lignin in clay-based drilling fluids help control clay flocculation and reduce the fluid viscosity. Samples of oxidized hydrolytic lignin NO_3 and NO_4 have the greatest effect on the fluidity of drilling fluids. Experiments have shown that at a concentration of 2 % by weight, the fluid viscosity decreases more than 5 times at low shear rates. At concentrations above 2 % by weight, complete lthinning of drilling fluids is observed. In addition, additives of modified hydrolytic lignin allow to reduce filtration losses, lower the friction coefficient, inhibit swelling processes and increase the stability of clay-based drilling fluids.

Deep well drilling is carried out at elevated temperatures, which can lead to flocculation of clay particles in the drilling fluid and deterioration of the properties of drilling additives, thus altering the properties of the drilling fluid. Therefore, additives are used to control clay flocculation (deflocculants). which reduce the viscosity, yield strength and of the gel

Table 1

Dependency of rheological characteristics of water-based drilling fluid on the concentration of calcium tannate [7]

Calcium tannate content, g/100 ml	Fluid Property					
	apparent viscosity, cP	plastic viscosity, cP	gel strength, lb/100 ft2	yield strength, lb/100 ft2	density, pounds per gallon (ppg)	fluid loss, ml
0	7.9325	5.884	2.544	4.097	8.7	12.1
0.5	7.4365	5.675	2.517	3.523	8.715	12.2
1	6.175	4.914	2.348	2.522	8.75	12.2
2	5.088	3.914	1.761	2.348	8.8	12.2
3	4.8925	2.936	1.37	2.1913	8.87	12.2

Table 2

The influence of additive concentration and temperature on the fluid properties [10]

Property	Basy fluid	+ 1.5 % palm leaf powder		+ 3 % palm leaf powder	
		at normal temperature	after aging	at normal temperature	after aging
Plastic viscosity, cP	8	9	9	12	9
Yield strength, lb/100 ft2	12	5	6	5	5
Initial gel strength	15	6	6	7	6
Final gel strength	20	11	12	12	11
pH	11	8.8	8.7	8	8.1
Filtrate 7.5 min	6	4	4.25	3.25	4
Filtrate 30 min	12.5	9.25	9.5	8.5	9
Mud cake thickness of, mm	3	1.9	2	2	2

strength. M.K. Fokuo, W.N. Aggrey, M.A.D. Rockson, and others demonstrated the possibility of using tannin-based additives as environmentally friendly deflocculants in their article [5]. Tannins are able to withstand high temperatures, which is an important property for additives in drilling fluids for deep well drilling. Tannins are found in the bark, wood, leaves, fruits of many trees – both exotic and common such as oak, pine and chestnut. Tannins can also be obtained from agricultural and food industries waste. For example, a study of the effect of an water-alcohol extract of black myrobalan (common in South and Southeast Asia) on the rheological properties of the solution showed that it acts as a deflocculant (at a low concentration – up to 0.6 % by weight), reducing the strength of the gel strength, viscosity and yield strength of the fluid, but increasing the filtrate volume, which is undesirable [5]. It has also been shown that tannin-based additives extracted from oak seeds are capable of limiting the solution's tendency to flocculate and thicken, even at high temperatures (up to 149 °C). A decrease in the yield strength, gel strength and fluid loss was observed [5].

Additionally, A.R. Ismail, M.N.A. Mohd Norddin, N.A.S. Latefi conducted studies on the effects of tannin extract-based additives obtained from red mangrove bark waste (found in tropical and subtropical zones of West Africa, North and South America) at high temperatures. It was demonstrated that this additive is effective at high temperatures. [6].

P. Talukdar, S. Kalita, A. Pandey studied the influence on the rheological properties of a water-based drilling fluid of calcium tannate derived from waste tea leaves [7]. They found that with an increase in the concentration of calcium tannate, there is a gradual decrease in the plastic viscosity and gel strength, and a gradual increase in density is observed with a practically unchanged liquid loss values (Table 1).

Furthermore, at a minimal concentration of calcium tannate (up to 1 %), a sharp decrease in the yield strength occurs, followed by a further gradual decrease with additions of 1–3 %. Further research is of interest regarding the influence of calcium tannate additives on the drilling fluid at high temperatures, as well as its interaction with other additives.

L. Guan, Y. Ma, Fulai Yu et al. showed in their paper that drilling fluids with addition of basil seed gum (derived from basil seeds found in South Asia and Africa) are easily pumpable and suitable for wellbore cleaning, as they can transport a large amount of solid particles and rock cuttings [8]. Basil seed gum improves filtration control, prevents the bentonite particles adsorption and reduces flocculation, thereby increasing the stability of drilling fluids. The improvement in thixotropic properties and filtration characteristics after adding basil seed powder is attributed to its transformation into a water gel in suspensions, which reduces friction and retains water due to its nanoscale three-dimensional mesh structure. Additionally, the gel can adsorb onto the surfaces of bentonite and metallic materials, thereby improving thixotropic and lubricating properties, as well as the filtration characteristics of the materials. Therefore, basil seed gum can be used as an additive in highly efficient water-based drilling fluids [8].

A study by M. Omotioma et al. on the effect of cashew and mango extracts on the properties of water-based drilling fluids showed that they are good corrosion inhibitors, while improving the rheological properties of the drilling fluid [9]. In this case, mango shows a more significant improvement in rheological properties. With an increase in the concentration of additives, the yield strength and gel strength increase. However, an increase in plastic viscosity is observed, additionally, studies have shown that an increase in temperature reduces the rheological properties of the drilling fluid [9].

A.T.T Al-Hameedi, H.H. Alkinani, Shari Dunn-Norman conducted a study on the use of additives of crushed palm leaf powder to improve the functionality of drilling fluids to control viscosity, pH reduction of the solution, and filtration volume [10]. In order to identify the temperature effect, experiments were conducted after keeping the samples in a roller oven at a temperature of 55 °C for 24 hours. It was found that palm leaf powder helps to reduce the thickness of the mud cake and significantly reduce the filtrate after exposure to temperature (Table 2).

Table 3

The influence of concentration and particle size of herbal additive on the rheological properties of the solution [20]

Characteristic	Grass additives, microns											
	300				90				35			
Additive concentration, 10–9 %	0.25	0.5	0.75	1.0	0.25	0.5	0.75	1.0	0.25	0.5	0.75	1.0
Apparent viscosity, 0.001 Pa·s	10.5	10.5	10.75	11	10.25	10.25	10.5	11	10.2	10.4	10.5	11
Plastic viscosity, 0.001 Pa·s	8.5	8.5	8.5	8.5	8.0	8.0	8.5	8.5	8.5	8.5	8.5	9.0
Yield strength, Pa	1.91	1.91	2.15	2.39	2.15	2.15	1.91	2.15	1.67	1.91	2.15	2.15
Filtrate, cm3	13.5	12.0	11.5	11.25	14.2	14.0	11.9	11.6	14.6	13.8	12.5	12.0
Optimal concentration of the additive	0.75				0.1				0.75			

Table 4

Dependence of drilling mud characteristics on the concentration of modified rice husk [22]

Solution No.	Composition of the solution	Density, kg/m^3	Conditional viscosity, s	Water loss, cm^3/30 min	Thickness of clay crust, mm	pH
1	1000 ml water + 100 g bentonite (original)	1080	20	40	6.0	7.0
2	1 + 1 % MRS	1080	22	30	9.5	8.0
3	1 + 3 % MRS	1075	30	25	2.5	9.0
4	1 + 5 % MRS	1070	40	20	2.0	9.5
5	1 + 7.5 % MRS	1060	50	16	1.5	10.5
6	1 + 10 % MRS	1050	60	12	1.5	11.5

Also A.R. Ismail, N.M.N.A. Mohd, N.F Basir showed that extracts from henna leaf and hibiscus leaves improve rheological and filtration properties of water-based drilling fluid [11]. In addition, henna leaves were effective in improving the rheological and filtration properties of the fluid under elevated temperature conditions. Studies have shown that such plant-based additives are compatible with conventional drilling fluid additives. Also, in the article A. Moslemizadeh and S.R. Shadizadeh showed that henna extract increases the hydrophobicity of shale formations and effectively reduces the swelling capacity of clay [12].

It should be noted that for water-based drilling fluids, additives that can prevent or reduce the interaction between clay and water, thereby reducing clay swelling and, consequently, borehole instability, are crucial. Currently, additives such as KCl are used for this purpose, but they can have a negative impact on the environment. Therefore, S.R Shadizadeh, A. Moslemizadeh and A. Shirmardi proposed using a new non-ionic surfactant as an inhibiting additive – biodegradable extract of Ziziphus spina-christi leaves – at a concentration of 3.5 % by weight, which effectively prevents clay swelling (compared to KCl and polyamine). It was also found that the Ziziphus extract is compatible with conventional additives of water-based drilling fluids and tends to reduce filtration losses. However, a disadvantage of this additive may be a decrease in activity at elevated temperatures [13].

To enhance oil recovery from reservoirs, surfactants are used. Flooding with water-based fluids of surfactants is aimed at reducing the interfacial tension of the water-oil interface. As a result, oil droplets can easily pass through the deformation and filtration of pores, thereby increasing the mobility of oil in the reservoir and improving its displacement [14].

Thus, the studies of S. Shadizadeh and R. Kharrat show that natural surfactants based on chamomile (at concentrations of up to 12%) can reduce the interfacial tension of oil and water from 30.63 to 12.57 mN/m, and also decrease the contact angle of the sample surface wetting [15, 16]. In addition, F. Razzaghi-Koolaee, G. Zargar, B.S. Soulgani, and A. Moslemizadeh, A.F Dehkordi et al. in their articles suggest using mulberry leaf and acanthophyll root extract (at a concentration of 1.4 % by weight) as an inhibitory additive. The results of the studies showed that mulberry leaf extract is an effective surfactant that can significantly reduce clay swelling [17, 18]. For example, the research has shown that a surfactant containing 1 % by weight of mulberry leaf particles reduced the interfacial tension between kerosene and water from 44 to 17.9 dyn/cm.

Also, V. Prakash, N. Sharma, M. Bhattacharya et al. proved that litchi leaf powder improves the filtration properties of drilling fluid [19]. In addition, they showed that litchi powder as an additive is capable to withstand temperatures up to 100 °C. Thus, at a litchi leaf concentration of 4 and 5 % and a temperature of 100 °C, filtration losses are reduced by 70.6 %, and the mud cake thickness by 37.14 and 48.57 % respectively. In addition, the lychee leaf powder additive reduces the pH of the fluid [19].

M.E. Hossain and M. Wajheeuddin showed in their article that grass powder can be used as a rheology modifier for water-based drilling fluids [20]. The studies were conducted with grass powder additives of different concentrations and different particle sizes (300, 90 and 35 μm). As a result, the rheological properties of the fluid, such as apparent and plastic viscosity, as well as gel strength, were improved (Table 3). In addition, the grass additives reduces filtrate loss and the pH of the fluid.

The optimum grass concentration was determined. For additives with particles of 35 and 300 microns, it was 0.75 ppb, and for particles of 90 microns, it was 1 ppb.

In addition, M. Wajheeuddin and M.E. Hossain conducted studies of grass ash of different fractions as additives to drilling fluid, which also contribute to a significant increase in viscosity, yield strength and gel strength. At the same time, there is a decrease in filtration losses by 19 % [21]. The next stage of the research may be to study the effect of grass additives on water-based drilling fluid at elevated temperatures.

To prevent the absorption of drilling fluids, T.O. Komilov and D.R. Makhamatkhodjaev proposed adding rice husk into water-based drilling fluids on bentonite [22]. Studies were conducted with the addition of modified rice husk (MRH) in the form of a solution of biopolymers and insoluble rice husk particles obtained as a result of alkaline extraction and dry polymer filler (PF), rice husk processed by a chemical-mechanical method. It has been shown that rice husk additives significantly improve the characteristics of the drilling fluid by reducing fluid loss, but may lead to undesirable results in terms of viscosity (Table 4 and 5).

Table 5

Dependence of drilling mud characteristics on the concentration of dry polymer filler [22]

Solution No.	Composition of the solution	Density, kg/m3	Conditional viscosity, s	Water loss, cm3/30 min	Thickness of clay crust, mm	pH
1	Original	1080	20	40	6	7
2	1 + 1 % PN	1080	35	22	2	5
3	1 + 2% PN	1080	45	16	2	9
4	1 + 3% PN	1075	60	12	1.5	10
5	1 + 4% PN	1070	80	8	1	11
6	1 + 5% PN	1060	100	5	1	12

Table 6

Effect of rice husk ash concentration on mud cake permeability [23]

Additive concentration, %	Permeability coefficient of mud cake
0	1
2	0.913
4	1.187
7	1.191
9	1.130
12.5	1.394
15	1.324

Table 7

Effect of coconut charcoal powder additive on drilling fluid properties at normal and high temperature [27]

Characteristics	Base drilling fluid	Drilling fluid with coconut powder additive
Volume weight	1.4 g/cm^3	1.4 g/cm^3
Conditional viscosity, measured with a Marsh funnel viscometer with a volume of 946 cm^3.	24.480 s	25.560 s
pH	11	12
Filtrate, under pressure 100 psi at normal temperature	After 15 min – 3.9 cm^3, after 30 min – 12.9 cm^3	After 15 min – 3.7 cm^3, after 30 min – 12.5 cm^3
Filtrate, under pressure of 1500 psi at a temperature of 270° F (132.22 °C)	After 15 min – 13 cm^3	After 15 min – 11.5 cm^3
Mud cake	2.381 mm	0.794 mm
Aging in a roller oven	16 h	16 h

E. Yalman, T. Depci et al. studied the effect of rice husk ash on the rheological properties of water-based fluids [23]. It was observed that at a concentration of rice husk ash up to 7 %, there is a decrease in plastic viscosity, which will contribute to reducing pressure losses due to friction during circulation of the drilling fluid. Furthermore, after the increase in plastic viscosity at a concentration of 9 % additive, its decrease to a minimum value occurs again at a concentration of rice husk ash of 15 % by weight (by 53 %). In addition, there is an increase in the yield strength which should ensure the bearing capacity of the fluid, and therefore good well cleaning. The yield strength increased to the maximum value at a concentration of 15 % (an increase in the yield strength by 183 %). Also, the addition of rice husk ash up to 9 % by weight provides good filtrate properties (the lowest fluid loss (up to 10 %) – at a concentration of 4 % by weight). However, a tendency to an increase in the mud cake is observed (while maintaining it within normal limits of 1–2 mm at a concentration of up to 12 %). In addition, the rice husk ash additives had a negative effect on the permeability of the mud cake. With the exception of a solution with an additive concentration of 2 % by weight, the permeability coefficient is greater than one, and a stable tendency for it to increase is observed (Table 6).

Also, the addition of rice husk ash increases the density of the drilling fluid.

A.S. Rohan, P. Joshi, S. Goyal studied the effect of tamarind seed powder (East Africa, tropical Asia) on the density of drilling fluid [24]. It was found that the density of the drilling fluid sample increases when the tested additive (powder of tamarind seeds with bentonite and barite) is introduced. The average density of the drilling fluid obtained during the tests was 8.662 pounds per gallon, which is a good indicator [24].

In order to find environmentally friendly additives, O.E. Agwu, J.U. Akpabio and G.W. Archibong conducted a comparative study of the thickness and characteristics of the mud cake formed when adding rice husk powder and ground wood chips to water-based bentonite fluids [25]. The authors noted the importance of cleaning the materials (rice husk and wood chips) from foreign impurities and contaminants. Studies have shown that as the concentration of the additive in the fluid increases, the filtrate loss decreases, and for a satisfactory result, an additive of more than 0.01 kg of rice husk and more than 0.015 wood chips is required. When rice husk was added to the drilling fluid, a mud cake with a thickness of 2.8–3.8 mm was formed. It is smooth and even, which means that the solution will help prevent pipe sticking, unlike the solution with wood chips, where the clay crust is solid and almost dry (thickness 2.6–3.3 mm).

High temperatures at the bottomhole contribute to a decrease in the viscosity and density of the drilling fluid, which negatively affects the functional capabilities of the drilling fluid [26]. To improve the properties of the drilling fluid under high temperatures, H. Widodo, M.R. Setyarto et al. proposed using additives of coconut shell powder – ground coconut charcoal [27]. It has been noted that the drilling fluid with coconut shell powder additive provides better rheological properties compared to the same drilling fluid without additives, both at normal temperature and under high-pressure high-temperature conditions (Table 7).

In addition, with increasing temperature, the value of plastic viscosity and yield strength decreases [27].

Table 8

Effect of the fraction of wild marmalade seed additive on the viscosity, yield strength and gel strength of the fluid [33]

Particle size, μm	Apparent viscosity, mPa s	Plastic viscosity, mPa s	Yield strength, Pa	Gel strength 10 sec/10 min/ Pa/ Pa(thixotropy)
Base fluid	3	2	1	1.5/2
100–150	4.5	3	1.5	0.75/1.5
75–100	6	4	2	2.0/3.5
54–75	6.5	4	2.5	2.0/3.5

Also, X. Chen, X. Gao, Y. Liu et al. found that ground psyllium husk improves the rheological properties of bentonite-based drilling mud, providing good fluidity and being effective in reducing filtrate through the clay crust, including at high temperatures (up to 160°C) [28]. Psyllium husk helps to obtain a mud cake with a relatively dense structure, which reduces the permeability of the mud cake and fluid loss. It was also noted that the optimal concentration of the additive for maintaining good rheological properties is 1.0 % by weight. At a higher concentration, there is a sharp increase in the fluid viscosity. Studies also show that the psyllium husk additives works effectively at temperatures up to 160 °C, as further temperature increases result in a sharp decrease in viscosity and yield strength [28].

One of the problems caused by drilling wells is the corrosion of drill pipes. Corrosion leads to decreased drilling efficiency, equipment failure and safety hazard. P. Jaf, J. Ali and A.A.A. Razzaq studied ground pods of Prosopis farcta as an anti-corrosion additive in drilling fluid to control pH [29]. Adding fine particle size of Prosopis farcta powder at a concentration of 15 parts per billion reduced the pH from 12 in the reference solution to 9.5. The weight loss of the coupon due to corrosion was 0.002 g in 20 hours, and the results showed a corrosion rate of 0.0029 mm/year in drill pipes using the tested additive [29].

M. Amanullah, J. Ramasamy, and others proposed the use of date seed powder to control fluid loss in drilling fluids based on fresh and salt water. Date seed powder contains minerals such as potassium, calcium, magnesium, phosphorus, and iron. The additive leads to a significant reduction in fluid loss (by 20 %), increased viscosity, and gel strength [21, 30].

In addition, S. Davoodi, S.A. Ramazani, V. Rukavishnikov and K. Minaev showed in their article that adding acorn shell powder to water-based drilling fluid significantly improves its rheological and filtration properties. For example, adding 9 pounds per barrel of the powder to the sample fluid resulted in a sharp decrease in filtrate volume by 80.1 % at high pressure and high temperature and by 63.3 % at low pressure and low temperature [31].

In addition, E.B. Ekeinde, E.E. Okoro et al. studied the powder of dried starfruit and detarium fruits as a thickener [32]. It was shown that the addition of carambola allows obtaining values of plastic viscosity, yield strength and gel strength (10 s) very close to the PAC.

Also, studies by G. Zhou, Z. Qiu, H. Zhong and Xin Zhao show that when adding Ziziphus oenopolia seed powder of different fractions to the drilling fluid, the viscosity and yield strength increase, and fluid losses decrease. This is especially true for fine fraction additives (Table 8) [33].

Also UI Duru, I M. Onyejekwe, D. Isu, showed that mucuna solannie seeds can be effective as a thickening agent without affecting the properties of other biomaterials in drilling fluid [34]. Furthermore, N. Uwaezuoke, K.C. Igwilo, S.I. Onwukwe, and B. Obah found that drilling fluid properties with the addition of mucuna seed powder have a similar trend of change at elevated temperatures as with other additives [35]. The density of the fluid remains unchanged at elevated temperatures.

I. Ali, M. Ahmad and T. Al-Arbi Ganat studied the effect of adding cypress cone powder on the filtration properties of drilling fluid [36]. They reduced the volume of fluid loss and the thickness of the mud cake. Thus, the additive is suitable for filtration control. However, the plastic viscosity showed a steady upward trend, so it is necessary to select the optimal concentrations of the additive. Studies have shown that the optimal concentration of the additive is 4 % [36].

The rowanberry tree is widely spread in the temperate zone of the Northern Hemisphere, and the polysaccharide pectin can be relatively easily extracted from the rowanberry plant.

In the article by S.L. Adzhiakhmetova, L.P. Mykots, N.M. Chervonna, and others, a study of water-based fluids of pectin substances obtained from the leaves of the rowanberry tree was carried out, which showed that with an increase in concentration, there is a stable increase in the viscosity of the solution [37]. In addition rowanberry, being a pectin substance, has a pronounced sorption capacity – the ability to absorb. Similar studies were conducted for fluids of pectin isolated from the fruits of the common viburnum [38], from wild garlic [39], from the peel of lupine seeds [40], and from the gooseberry [41].

Further research is proposed to study the effect of these additives on water-based drilling fluid.

Application of agro-industrial waste to improve the properties of drilling fluids

In order to find an environmentally friendly, effective and inexpensive additive, studies were conducted on the possibility of using food waste in well drilling. Thus, A.T.T. Al-Hameedi, H.H. Alkinani, S. Dunn-Norman and others studied the effect of mandarin peel powder on the rheology of drilling fluids [42]. When adding mandarin peel powder, a decrease in the mass of the fluid is observed due to the formation of foam. In order to minimize foaming, it is proposed to use environmentally friendly defoaming agents. The addition of mandarin peel powder significantly increases the plastic viscosity and yield strength, especially at 3 and 4% concentrations. Thus, the additive can be used as a viscosity modifier at 1 and 2 % concentrations during normal drilling operations and to control partial fluid losses at 3 and 4%. The additive also provides good gel strength performance, as the difference between the initial and final gel strength does not exceed 5 lb/100 ft^2, which has a positive effect on drilling operations. In addition, a significant reduction in filtrate loss and mud cake thickness is observed especially at 3–4 % concentration and a certain pH value (Table 9) [42].

During the research it was noted that in addition to concentration, the particle size of the added substance affects the properties of the fluid.

Table 9

Dependency of rheological properties of drilling fluid on the concentration of mandarin peel powder [42]

Composition	Fluid density, ppg	Plastic viscosity, cP	Yield strength, lb/100 ft²	Gel strength initial	Gel strength final.	pH	Filtrate 7.5 min, cm³	Filtrate 30 min, cm³	Thickness of mud cake, mm
Base fluid	8.6	7	11	12	17	10	6	12.5	3
Base +1 % MP	8.4	14	14	10	14	8	3.5	7	1.6
Base +2 % MP	8.2	24	17	10	14	7.7	2.75	6	1.4
Base +3 % MP	8	38	33	12	17	7	2	4.5	1.35
Base +4 % MP	8	63	57	24	28	6.8	1.75	4	1.35

Table 10

Dependency of the mud cake thickness on the particle size of additives [43]

Sunflower husk concentration, %	Thickness of mud cake for samples with orange peel additive, mm				Thickness of mud cake for samples with sunflower seed additive, mm			
	finel size	medium size	fine and medium particles	large size	finel size	medium size	finel and medium particles	large size
0.8	1.1	1.18	1.2	1.3	0.9	1.1	1.2	1.2
1.3	1.12	1.29	1.25	1.4	1.2	1.25	1.31	1.36
2.2	1.24	1.34	1.32	1.55	1.4	1.31	1.33	1.56
2.7	1.36	1.45	1.4	1.65	1.43	1.45	1.45	1.7
4.0	1.45	1.55	1.5	1.72	1.5	1.7	1.6	1.9

Table 11

Effect of different concentrations of banana peel, corn cob and PAC additives on the pH of drilling fluid [45, 46]

Additive concentration, %	pH		
	banana peel additive	corn cob additive	PAC additive
0	8.6	8.6	8.6
1	8.58	8.61	8.63
2	8.55	8.62	8.7
3	8.54	8.63	8.75
4	8.53	8.8	8.8
5	8.5	8.85	9
6	8.48	9	9.1

In order to study these patterns, M. Idress and M.L. Hasan conducted studies of food waste – sunflower seeds and orange peel – additives of coarse (>200 μm), medium (74–200 μm) and fine (44–74 μm) grind sizes [43]. It was observed that the plastic viscosity increases with increasing concentration. Analysis of the effect of particle sizes shows that higher plastic viscosity values are observed with fine-sized additives. The highest plastic viscosity value was observed at a concentration of 4 % of fine grind orange peel – 18 cP and at a concentration of 4% of fine grind sunflower seeds – 19 cP.

The yield strength also increases with increasing concentration of additives, with orange peel giving a higher yield strength. In addition, finer particle size additives at higher concentrations result in a higher yield strength. For example, at a concentration of 4 % of coarse grind orange peel, the yield strength was 22 pounds/100 square feet, and for fine grind, it was 31 pounds/100 square feet. At a concentration of 4 % of coarse grind psyllium husk, the yield strength was 14 pounds/100 square feet, and for fine grind, it was 17 pounds/100 square feet.

It was also observed that the studied additives reduce fluid loss, including at elevated temperatures (up to 120°C). Finer particle size additives allow for even lower fluid loss. For example, at a concentration of 4 % of coarse grind orange peel, fluid loss was reduced to 13.5 cm^3, and for fine grind, it was reduced to 13.2 cm^3. At a concentration of 4 % of coarse grind psyllium husk, fluid loss was reduced to 11.8 cm^3, and for fine grind, it was reduced to 11.5 cm^3. When using a similar concentration of a mixture of medium and fine grind additives, the lowest fluid loss values were obtained – for orange peel additives – 12.5 cm^3, and for psyllium husk – 11.0 cm^3.

M. Rizqi Al Asy'ari studied the effect of eggshell on the rheological and filtration properties of drilling fluids [44]. It is noted that this increases the density of the drilling fluid (since eggshell is 95 % weighted $CaCO_3$). Eggshell powder can also significantly reduce fluid loss and reduce the thickness of the filter cake. This is possible due to the function of $CaCO_3$ as a fluid loss control agent. Thus, eggshell can be used to control fluid loss.

The study of the effect of dried banana peel powder in different concentrations on the rheology of drilling fluids is described in the article by A.H. Assi, A.A. Haiwi and A. Lami [45]. It is shown that with a banana peel concentration of 5–6 %, the rheological and filtration characteristics, as well as the mud cake thickness, are close to the indicators when using high-viscosity polyanionic cellulose PAC as an additive. It is noted that additives of corn cob powder of the same concentration give lower viscosity, yield strength and fluid density, but at the same time they also affect the filtration rate to a lesser extent.

In addition, banana peel helps to reduce the pH of the fluid, while corn cob, on the contrary, increases the pH (Table 11) [45, 46].

Corn cob additives can thus be used as an alternative to synthetic polymers for preparing low-viscosity drilling fluids, in order to obtain a good drilling speed and reduce pressure losses due to friction. Dried banana peel powder can be used to prepare high-viscosity drilling fluids.

Also, S. Irawan, A. Zakuan, A. Azmi and Mohd. Saaid in their article note that addition of crushed sugarcane waste increases the density and plastic viscosity of drilling fluid [47].

It was also noted that the effect of adding banana peel ash was similar to that of dried banana peel (Table 12) [46].

Table 12

Effect of gum arabic powder, potato and banana peel and banana peel ash additives on the rheological characteristics of the fluid [46]

Fluid composition	Fluid weight, ppg	Plastic viscosity, cP	Yield strength, lb/100 ft^2	Gel Strength, lbs/100 ft^2	Fluid loss, ml/30 min	Mud cake thickness, inch
Base	8.6	8	15	12	59	0.283
Base + 5g (1%) banana peel powder	8.6	7.5	9	11	22	0,150
Base + 5 g banana peel ash	8.6	7.5	9	8	23	0.141
Base + 5g gum arabic powder	6.7	11	6	8	30	0.196
Base + 5g potato peel powder	7.8	10	16	13	13	0.162

The addition of gum arabic powder and potato peel significantly reduced the mass of the fluid due to foaming by 22 and 9 %, respectively.

In addition, the gum arabic and potato peel powder additives significantly increase plastic viscosity (by 38 and 25 %, respectively). At the same time, gum arabic powder significantly reduces the yield strength and gel strength (after 10 s), while potato peel powder increases these parameters [46].

Potato peel powder also reduces the mud cake thickness and the filtrate loss by 78 %, compared to the base fluid, banana peel powder and banana peel ash – 61%, and gum arabic powder – 49 %.

It should be noted that these comparisons were carried out at a constant concentration of additives (1 %). A.T Al-Hameedi, H.H. Alkinani, S. Dunn-Norman et al. studied the dependence of rheological and filtration properties on the concentration of potato peel additive [48]. The studies showed that with an increase in the concentration of the additive, the decrease in fluid losses continues. Fluid losses decreased by 12, 20, 28 and 30 % at additive concentrations of 1, 2, 3 and 4 %, respectively, the mud cake thickness decreased by 43.33, 41.66, 40 and 40 % at concentrations of 1, 2, 3 and 4 %, respectively. Also, with an increase in concentration, the increase in plastic viscosity continues, but the yield strength and gel strength remain almost unchanged with an increase in concentration. [48]. (yield strength decreased by 36.36% at a concentration of 1 % additive and by 45.45% at a concentration of 2, 3 and 4 %; gel strength decreased by 25 % at a concentration of 1 % and by 33.33 % at a concentration of 2, 3 and 4 %). In addition, potato peel powder reduces the pH of the solution [48]. Thus, it was found that potato peel can be used as a diluent, pH reducer and fluid loss control additive.

A.K. Patidar, A. Sharma and D. Joshi in their paper showed that cellulose extracted from peanut husk shows good effect on filtration properties of fluids [49]. The best results were obtained with the addition of small-sized particles. For example, the addition of peanut shell powder with particles of 63-74 microns and a concentration of 4 % reduces fluid loss at high temperatures and pressures (after being held in a roller oven) by 91.88 %. At the same time, the viscosity, yield strength and gel strength of the fluid differ insignificantly from the base fluid. With an increase in the concentration of additives from 1 to 4 %, their gradual increase occurs [49].

G.C.J Nmegbu and B. Bari-Agara also showed that corn cob cellulose effectively reduces fluid losses in drilling fluid, compared to PAC [50]. The effect of three additive compositions on fluid losses was studied: A – 2.0 g PAC + 2.8 g xanthan gum; B – 2.8 g xanthan gum + 2.0 g corn cob cellulose; C – 2.8 g xanthan gum + 3.0 g corn cob cellulose. It was found that in sample C the mud cake settles faster, compared to samples A and B. Accordingly, the filtrate losses in sample C are the lowest.

Starch is used as an effective salt-resistant filtration reducer in drilling fluids. It is known that starches obtained from different raw materials and modified in different ways exhibit significantly different properties [51]. Thus, the maximum viscosity of the fluid will depend on the type of starch, the concentration of its suspension, and the rate of temperature increase [52]. The disadvantage of starch reagents is their enzymatic instability. Drilling fluids have a large number of microorganisms that enter them from clay, water, the atmosphere, and the drilled rocks. To prevent decay, pH is increased to 11.5–12, salinity is increased (not less than 20 %), and bactericides are added in practice. Currently, there is a constant search for new effective starch-based additives.

Thus, X. Li, G. Jiang, Y. He and G. Chen combined starch with lignin (sodium lignosulfonate) and tea polyphenol to obtain a highly effective salt-resistant additive for controlling the filtration of water-based drilling fluid – improving the quality of the filter cake, reducing fluid loss [53]. The obtained additive significantly reduced the volume of filtrate both at normal and elevated temperatures while maintaining stable viscosity and yield strength values under high-temperature conditions. In addition, at elevated temperatures in the presence of salts (NaCl and $CaCl_2$), the filtration volume decreased by more than 2 times when the tested additive was added.

To stabilize the properties of water-based drilling fluids, the use of natural pectin additives has been proposed. Pectins are high molecular weight compounds of plant origin, consisting of uronic acid residues and monosaccharides. Pectins are completely non-toxic. The stabilization of the fluid properties occurs due to the interaction between pectin and bentonite [54]. As a result, an adsorption shell of high molecular weight compounds is formed around the colloidal particles of bentonite. This leads to a decrease in the absorption of the drilling fluid (due to the ability of pectin to absorb water and its low water yield, as well as its ability to plug pores). It should be added that the thicker the clay cake, the more pectin is added.

A.Zh. Isakov and N.N. Kubatov found that the best results were achieved when adding pectin from 0.1–1 to 5 %. Studies have been conducted on the effect of sodium pectate, technical pectin, and beet pectin on the drilling fluid [55].

Conclusion

Drilling operations in challenging conditions are impossible without modern and effective drilling fluids, for which special additives are required to improve their rheological and filtration properties [56, 57]. In order to reduce the harmful impact on the environment, the possibilities of replacing chemical additives with environmentally friendly biodegradable plant additives are being studied. As research analysis shows, such additives can provide properties that are at least not inferior to modern chemical additives. There is no doubt that the use of organic additives is a promising area of research. Agro-industrial waste, such as orange and mandarin peels, sunflower seeds, rice and peanut husks, and eggshells, can be used as an alternative to additives currently used to reduce and prevent the absorption of drilling fluids. The use of these materials is environmentally safe and, importantly, economically viable [58]. In addition, the use of food waste helps to solve the problem of accumulating food waste, which harms both humans and the environment.

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Funding. The study had no sponsorship.
Conflict of interest. The authors declare no conflict of interest.
The authors' contribution is equivalent.