ISSN 2712-8008
Volume / Том 23 №1 2023
Journal Homepage: http://vestnik.pstu.ru/geo/

Perm Journal of Petroleum and Mining Engineering

UDC 622.24.063.2
Article / Статья

Increasing the Environmental Friendly of Process Fluids Used for Well Drilling

Yuriy S. Lavrentiadi, Ekaterina L. Leusheva

Saint Petersburg Mining University (2 21st line, Vasilyevsky island, Saint Petersburg, 199106, Russian Federation)

Повышение экологичности технологических жидкостей, применяемых для бурения скважин

Ю.С. Лаврентиади, Е.Л. Леушева

Санкт-Петербургский горный университет (Россия, 199106, г. Санкт-Петербург, Васильевский остров, 21-я линия, 2)

Received / Получена: 12.09.2022. Accepted / Принята: 19.12.2022. Published / Опубликована: 31.05.2023

Keywords:
drilling washing fluids, drilling fluids, green additives, biowaste, environmentally friendly additives, drilling fluid properties, water-based fluids, drilling fluid density, fluid filtration, rheological parameters.

An important aspect of hydrocarbon drilling is the use of drilling fluids that remove cuttings and stabilize the wellbore, providing better filtration. The properties of drilling fluids are essential to the success of any drilling operation. Fluids were originally developed to enable and cost effectively rotary drilling in subterranean formations. In addition, drilling fluids were designed to form a filter cake, which was primarily designed to reduce filtrate loss to the formation, was thin, and retained the drilling fluid in the wellbore. One of the most important functions of drilling fluids is to minimize the amount of drilling fluid filtrate entering a hydrocarbon containing formation, which can cause damage to the formation due to changes in rock wettability, fines migration, mud plugging with solids, and formation water incompatibility. To stabilize these properties, a number of additives are used in drilling fluids to ensure satisfactory rheological and filtration properties of the fluid. However, the commonly used additives are hazardous to the environment: when drilling fluids are disposed of after drilling operations, they, together with drill cuttings and additives, are discharged into water bodies and cause unwanted pollution. Therefore, these additives should be replaced with additives that are environmentally friendly and provide superior performance. In this regard, biodegradable additives are needed for future research. The review article presents an investigation into the role of various biowastes as potential additives for use in water-based drilling fluids. The use of waste-derived nanomaterial was considered, and rheological and filtration studies of water-based drilling fluids were carried out to evaluate the effect of waste additives on the performance of drilling fluids.

Ключевые слова:
буровые промывочные жидкости, буровые растворы, «зеленые добавки», биоотходы, экологически чистые добавки, свойства бурового раствора, растворы на водной основе, плотность бурового раствора, фильтрация раствора, реологические параметры.

Важным аспектом бурения углеводородов является использование буровых растворов, которые удаляют буровой шлам и стабилизируют ствол скважины, обеспечивая лучшую фильтрацию. Свойства буровых растворов важны для успеха любой буровой операции. Жидкости изначально были разработаны для обеспечения возможности и экономичности вращательного бурения подземных пластов. Кроме того, буровые растворы предназначены для образования фильтровальной корки, которая в основном предназначена для уменьшения потерь фильтрата в пласт, является тонкой и удерживает буровой раствор в стволе скважины. Одной из наиболее важных функций буровых растворов является сведение к минимуму количества фильтрата бурового раствора, поступающего в углеводородсодержащий пласт, что может привести к повреждению пласта из-за изменения смачиваемости породы, миграции мелких частиц, закупорки бурового раствора твердыми частицами и несовместимости с пластовой водой. Для стабилизации этих свойств в буровые растворы применяют ряд добавок, обеспечивающих удовлетворительные реологические и фильтрационные свойства жидкости. Однако обычно используемые добавки опасны для окружающей среды; при утилизации буровых растворов после буровых работ они вместе с буровым шламом и добавками сбрасываются в водоемы и вызывают нежелательное загрязнение. Следовательно, эти добавки следует заменить добавками, которые не наносят вреда окружающей среде и обеспечивают превосходные характеристики. В связи с этим биоразлагаемые добавки необходимы для будущих исследований. В обзорной статье представлено исследование роли различных биоотходов в качестве потенциальных добавок для использования в буровых растворах на водной основе. Рассмотрено использование наноматериалов, полученных из отходов, а также проведены реологические и фильтрационные исследования буровых растворов на водной основе, чтобы оценить влияние отходов в качестве добавок на характеристики буровых растворов.

© **Yuriy S. Lavrentiadi** – Student at the Well Drilling Department (tel.: +007 (918) 051 55 75, e-mail: lavrentiadi.yury@yandex.ru).
© **Ekaterina L. Leusheva** (Author ID in Scopus: 56609312400; ORCID ID: 0000-0002-0510-7769) – PhD in Engineering, Associate Professor at the Well Drilling Department (tel.: +007 (911) 709 71 47, e-mail: Leusheva_EL@pers.spmi.ru). The contact person for correspondence.

© **Лаврентиади Юрий Семенович** – студент кафедры бурения скважин (тел.: +007 (918) 051 55 75, e-mail: lavrentiadi.yury@yandex.ru).
© **Леушева Екатерина Леонидовна** (ORCID ID: 0000-0002-0510-7769) – доцент кафедры бурения скважин, кандидат технических наук (тел.: +007 (911) 709 71 47, e-mail: Leusheva_EL@pers.spmi.ru). Контактное лицо для переписки.

Please cite this article in English as:
Lavrentiadi Yu.S., Leusheva E.L. Increasing the Environmental Friendly of Process Fluids Used for Well Drilling. *Perm Journal of Petroleum and Mining Engineering*, 2023, vol.23, no.1, pp.32-43. DOI: 10.15593/2712-8008/2023.1.5

Просьба ссылаться на эту статью в русскоязычных источниках следующим образом:
Лаврентиади Ю.С., Леушева Е.Л. Повышение экологичности технологических жидкостей, применяемых для бурения скважин // Недропользование. – 2023. – Т.23, №1. – С.32–43. DOI: 10.15593/2712-8008/2023.1.5

Introduction

Drilling operations are carried out to extract oil and gas from natural reserves deep underground [1]. To facilitate the extraction of hydrocarbons from the ground a deep well is drilled, forming its wellbore. The use of process fluids is an important factor in the drilling process, and these fluids play many roles, for example, for cuttings removal and reservoir pressure control [2, 3]. There are chemical additives used in drilling mud which have shown desirable properties. However, these additives are not biodegradable and are hazardous to the environment [4]. As a result, researchers have sought to find alternative additives that are environmentally friendly, biodegradable and sustainable while maintaining the effective properties of drilling fluids [5].

The rheological properties of drilling fluids are vital to making the right choice for any well. The rheological properties of drilling fluids are related to processes such as hole cleaning, erosion control, cutter removal, hydraulic design and pumping. The success of any drilling operation is highly dependent on the performance and cost effectiveness of the used drilling fluid.

Drilling fluids are generally categorised as:

1. Air or foam based fluids used where liquid drilling fluid is not the most desirable circulating medium.
2. Hydrocarbon-based fluid.
3. Water-based fluids.

For environmental and cost reasons, water-based fluids have properties which are generally preferable to hydrocarbon-based fluids. Drilling fluids should be environmentally friendly and contain the lowest possible amount of contaminants. Therefore, care must be taken in the selection of raw materials. Various polymers are currently used to control fluid loss and viscosity of drilling fluids, which can be in the form of natural (e.g. starch), synthetic and/or modified (e.g. carboxymethylcellulose, or CMC) polymers [6, 7].

In oil wells drilling oil these polymers reduce filtrate, alter rheological properties, stabilise shale and reduce drag and can be used in enhanced oil recovery processes [8]. The influx of the liquid phase, known as filtrate, into the productive zones can lead to a significant decrease in permeability and hence a decrease in well performance. The inclusion of natural resins and starch-based materials in drilling fluid formulations has been the main solution to control this phenomenon.

Drilling fluids must address several problems which arise during the drilling process. For example, the drilling structures erected during this process are made of metal and are thus susceptible to corrosion, which in turn affects the overall drilling operation. A drilling fluid additive with good anti-corrosion properties can effectively solve this problem. Another problem is excessive loss of fluids circulation to the filtrate medium, which is relatively expensive. To solve this problem, the addition of drilling fluid should contribute to good control of circulation, as well as the formation and thickness of clay crust. Wellbore collapse can also occur due to the interaction and reaction of drilling fluids with reservoir fluids. The drilling fluid should contain an additive that forms a clay crust of suitable thickness to prevent pipe sticking and maintain the stability of the wellbore [7].

Other possible drilling scenarios include equipment failure during wellbore completion as a process of preparing the wellbore before the production stage to ensure that the desired hydrocarbons escape from the reservoir to the wellbore and then to the outside. In this situation there are required additives to the drilling fluid which can control the well and prevent any significant damage until the equipment is repaired. Another important aspect of drilling fluid is its ability to control pH, rheology, and in particular plastic viscosity, yield strength, and gel strength. The pH affects the dispersion process and can greatly affect such physical properties of the drilling fluid as the properties of the filter cake.

Thus, it was determined that tamarind gum and polyanionic cellulose showed better rheological properties and effectiveness in controlling filtrate loss in oil well and significantly reduced reservoir damage.

The scientists also found that cashew and mango extracts improve the corrosion resistance of water-based drilling fluids, proving that these materials are good corrosion inhibitors, and concluded that the use of plant leaf extracts improves the effectiveness of the additives. Similarly, they determined that fibrous food waste is environmentally friendly and improves the performance of water-based drilling fluids in terms of a wide range of factors such as better pH control, water yield control, control of the clay crust thickness and rheological characteristics. In addition, it was found that biodegradable herbal powder (GP), compared to starch which is a widely used additive, is able to control the loss of fluid circulation. Although starch showed better rheological properties than grass powder, this indicates that grass can be used as an adjuvant in combination with starch to produce a more environmentally friendly additive.

Besides, henna leaf extracts and hibiscus leaf extract were found to improve the rheological and filtration properties of water-based drilling mud compared to the conventional additive used in the industry. Studies have also been carried out on henna leaf extract henna leaves extract in terms of its effectiveness in transporting cuttings during drilling operations. It was found that henna leaves are effective and have improved the rheological and filtration properties under thermal aging conditions [8].

There are many available drilling fluid additives. These mud additives are chemical substances added to the drilling mud to modify the properties and composition of the drilling mud. However, much effort has been devoted to drilling fluid formulation, mainly to improve the quality and functionality of drilling fluids and to comply with stricter environmental or marine pollution laws. Some of them are used to control pH, i.e. to control chemical reactions (inhibition or enhancement) and mitigate drill string corrosion. Since synthetic additives are now being used, several scientists have oriented their research towards the use of natural products as additives to these chemicals. The potential of cacao pods, plantain peels, rice husks and peanut shells as corrosion inhibitors has been investigated. Cocoa pod extracts had high corrosion inhibition potential compared to synthetic potassium hydroxide (SPH). It was also found that cocoa pod extract is more thermally stable and is very effective in reducing filtration losses at high temperatures. However, it showed a tendency to liquefy as the drilling mud required an additional viscosifier to improve its rheology. An experimental study on the use of burnt plantain and banana peel in local water-based drilling mud as corrosion control additives showed that although plantain peel was more effective than banana peel for increasing pH, both local additives increased the pH of the drilling mud to 9.5–12.5, which corresponds to imported sodium hydroxide [9].

The properties of a mixture prepared with different concentrations of cellulose processed from corn cobs were compared with those of a standard mixture prepared from polyanionic cellulose. The results showed that the pH, sludge density, specific gravity of sludge made from corn cob cellulose was higher than that of standard sludge, but the rheology of the prepared sludge was lower than that of standard sludge. The results show that cellulose derived from corn can significantly reduce fluid loss in water-based drilling fluid, suggesting that cellulose is a good means of controlling fluid loss [5]. The grass added to the bentonite drilling fluid improved rheological properties such as apparent and plastic viscosity, as well as the strength of the gel. The filtration characteristics of bentonite drilling fluid were also improved since lower filtration losses were observed for all samples. However, a pH test has shown that the addition of grass reduces the pH of the drilling fluid [10].

In the drilling industry, many additives are currently used to ensure satisfactory drilling fluid performance. However, these materials have been found to be hazardous to both the workforce working on the site and the environment. Extensive research has been conducted on possible alternative drilling fluid additives that meet two conditions: first, the additive provides the properties required of drilling fluids; and secondly, it is eco-friendly, biodegradable and sustainable. This review presents studies conducted using a variety of environmentally friendly waste additives in water-based drilling fluids. In particular, the effects of these additives on rheological properties such as plastic viscosity, yield strength, gel strength, filtrate loss, and clay crust thickness are evaluated.

Global scientific Achievements on the Chosen Topic of Scientific Research

The main functions of drilling fluids include removal of drill cuttings and wellbore cleaning, lubrication and cooling of the drill bit and drill string, wellbore formation maintenance and prevention of well blowout [11]. Thus, drilling fluid plays an important role in the oil and gas industry. As a major factor in the success of drilling processes, the properties of drilling fluids are continuously monitored and regulated in accordance with the American Petroleum Institute (API) Recommended Practice 13B-1 for WBDF and Recommended Practice 13B-2 for OBDF». Based on API 13B-1 Recommended Practice International Organisation for Standardisation (ISO) prepared and set out ISO 101 414 under the general title "Oil and gas industry – Field testing of drilling fluids" (API, 2009). ISO 10 414 sets out standard procedures for the regular determination and monitoring of drilling fluid properties to maximise drilling performance. These procedures are improved and periodically revised as new research and developments become available.

Density or Weight of the Drilling Fluid

Mud density or mud weight is an important property of drilling fluids which improves wellbore stability and maintains reservoir pressure. Low mud density can lead to rock shear failure, known as a wellbore blowout, which subsequently destroys the wellbore. However, there is a chance of possible loss of circulation, reduced rate of penetration and formation damage due to excessive mud density values. Thus, researchers have worked to develop a reliable route, i.e., PSO-ANN model, to estimate the most appropriate drilling fluid density under HTHP wellbore conditions [12].

Plastic Viscosity

Viscosity measures the internal resistance of drilling fluids, while plastic viscosity (PV) represents the specific resistance to flow caused by friction between solids in drilling fluids and fluid layers. PV depends on the viscosity of the base fluids, i.e., water and oil, and the concentration of solids. In short, an increase in mud weight or solids content in drilling fluids results in higher PV, which is undesirable because it reduces drilling speed. The side effects caused by PV have been reduced by the addition of water or diluent additive [13].

Yield Point

Yield point (YP) is defined as the measured degree of shear liquefaction of non-Newtonian drilling fluids. It is the ability to carry drill cuttings in suspension while circulating in the wellbore and out of the annulus. In this way, drilling problems such as differential sticking can be prevented. As the additive solids decrease in size, the YP increases. This is due to the increase in the attraction forces between the solid particles, which increase the carrying capacity of the drill cuttings and clean the wellbore [13].

Gel Strength

Gel strength (GS) measures the forces of attraction between particles under static conditions, as opposed to YP, which measures them under dynamic conditions. Thus, gel strength refers to the ability to hold the drill cuttings during joints or other static conditions. As it increases over time, more pressure is required to overcome the accumulated gel strength and initiate circulation [14].

Filtrate loss and Clay Cake Thickness

Filtration or water loss measures the amount of fluid that penetrates the solid clay cake. According to previous researchers, drilling fluids penetrate well formations in response to greater hydrostatic fluid pressure compared to pore pressure. This leads to the formation of clay cake as the pores are filled with suspended solids from the drilling mud. Consequently, the rate of filtrate loss and the thickness of the clay cake decreases as the solids concentration in the drilling fluids increases. Both filtration rate and clay cake thickness are controllable properties of drilling fluids. This is associated with the high filtrate loss, and clay cake thickness can potentially lead to seizure of the differential pipe. Exceptional clay cake has extremely low permeability, being equally thin, strong and compressible. Filtration control is expensive due to the need for many control factors such as mud concentration, size and type of suspended solids, concentration of FLC additives, and thermal stability of the system.

The world's population, currently 8 billion and growing at 1.1 % per year, depends on the consumption of the Earth's natural resources. Waste is unusable materials that have exceeded their useful life and have been discarded. Unfortunately, a consequence of this continued consumption is the proliferation of waste of all varieties.

Waste includes municipal solid waste (MSW), namely common items consumed and discarded by the population, and represents the fastest growing form of waste due to its prevalence in urban society. It has been estimated that by 2025, the volume of MSW will achieve about 1.42 kg per capita per day (2.2 billion tonnes per year), generated by 4.3 billion urban dwellers. The authors also calculated that 1.8 million tons of solid waste will be generated daily in Asia.

Other types of waste are generated from a variety of sources, including domestic and commercial; ashes; animals; biomedical and construction industries; and sewerage. This waste may include industrial solid waste, biodegradable and non-biodegradable waste, and hazardous waste.

Some of these types of waste pose a serious threat to the environment and human health. Clinical wastes that are generated by medical clinics, hospitals and laboratories carry a risk of contamination and can spread disease if not handled properly [15].

Electrical and electronic waste (E-waste) from electronic equipment such as cables, wires, cords and batteries emit hazardous substances and thus cause serious harm to those who come into contact with them, especially recycling workers. In addition, waste management requires the treatment of hazardous waste using a variety of approaches.

Food waste is a serious global problem caused by factors such as poor food handling and management, inadequate planning of food consumption in households and overcooking in the food and beverage industry. Nevertheless, the problem of food waste can be effectively addressed if the waste can be recycled and reused for various purposes. Accumulation of food waste in landfills leads to the generation of methane gas and further air pollution [16].

Waste in Drilling Fluids

A significant amount of research has been done on the use of food waste in the oil and gas drilling industry. For example, a number of scientists have investigated the use of tangerine peel powder in an eco-friendly liquid supplement as an alternative to non-biodegradable additives that are harmful to the environment. They used tangerine peel powder as an environmentally friendly alternative liquid additive compared to the reference polymer PAC-LV. The addition of mandarin peel powder gave better results as it was able to significantly reduce the pH and reduce fluid circulation losses at a low concentration of powder. Thus, tangerine peel powder has been shown to be a good additive for lowering pH, controlling viscosity, and reducing circulation loss. This research encouraged the use of food waste as a suitable alternative to the non-biodegradable chemicals currently used in the drilling industry [17].

In addition, grass, hay and palm leaves were also recognized as acceptable candidates. The study confirmed that food waste can be recycled to ensure the environmentally friendly operation of the oil and gas industry. The herb has been used as an additive to prepare an environmentally friendly drilling fluid with a variety of particle sizes and concentrations. The results obtained show that the grass added to the bentonite of drilling mud (all concentrations at different particle sizes) improved rheological properties such as apparent and plastic viscosity, as well as gel strength. The filtration performance of the bentonite drilling fluid also improved as lower filtration losses were observed in all samples. Tests conducted at pH have shown that the addition of grass reduces the pH of the drilling fluid.

Grass is offered as a rheology modifier, filtration control, and alkalinity control for drilling fluid. We also recommend that studies be conducted with this additive at elevated temperatures to analyze its characteristics so that an informed decision can be made in favor of the proposed herb, which may be the best choice to replace the current toxic chemicals.

In the oil and gas drilling industry, drilling fluid additives are used for various purposes, such as pH regulation and imparting rheological properties including plastic viscosity, gel strength, and yield strength. These additives must also address issues such as circulation loss control, wellbore integrity, wellbore completion, and corrosion inhibition to ensure smooth drilling. However, at present, chemicals used for these purposes are not biodegradable and can have a significant negative impact on the environment [18]. An environmentally friendly solution is to use biodegradable chemicals that do not harm the environment and at the same time provide the desired properties of a good drilling fluid.

Recent studies have shown the effect of various additives derived from waste on the effective rheological properties of drilling fluids. For example, the effect of using tamarind seed powder on the density of drilling fluid has been investigated. Drilling fluid density is one of the important properties of drilling fluids and helps to ensure and regulate the stability of the wellbore and control reservoir pressure. In the course of the study, it was found that the density of the drilling mud sample increases when tamarind seed powder and a combination of bentonite are added. Increasing the concentration of tamarind seed powder resulted in a thicker sample of drilling fluid and an increase in the density of drilling fluid. Density of drilling fluid in samples was in the range of 8.22–8.97 pounds per gallon, which is considered to be a suitable range for use as an additive in drilling fluids [19].

The use of environmentally friendly okra as a viable alternative mud additive has also been demonstrated as a viable alternative mud additive. The effectiveness of okra as an additive was evaluated in the absence and presence of clay in drilling fluids. In comparison, the introduction of okra into clay-based drilling muds showed a greater improvement in rheological properties compared to drilling muds without clay. In clay-based drilling fluids, the addition of 2 and 3 g of okra resulted in an increase in plastic viscosity (PV) of more than 100 % compared to the addition of 2 g of starch, which gave an increase of only 45.7 %. Increasing the concentration of okra also resulted in an increase in the yield point of the drilling fluids. However, it was observed that starch was more effective in increasing the yield point than okra. In addition, filter cake thickness decreased with the addition of okra, with further reduction evident at higher concentrations.

The effectiveness of okra powder as a fluid loss regulator was investigated by conducting fluid loss tests on okra-based drilling fluids. In addition, rheological tests were conducted to determine the effect of okra addition on drilling fluids. Different drilling fluids were prepared on the base of different concentrations of okra powder and tested [20].

Besides, saffron purple petals have been proposed as an environmentally friendly alternative to drilling mud additives. The addition of saffron petal powder to the drilling mud resulted in an effective increase in PV values. As the concentration of purple saffron petal powder increases, the PV value also increases. Moreover, the introduction of this powder in the drilling mud also significantly increases the yield point as compared to the base mud. The inclusion of saffron purple petal powder in the drilling mud showed excellent filtrate loss; herewith the volume of filtrate gradually decreases with the increase of powder concentration. Its addition to the drilling mud also resulted in a reduction in clay cake thickness compared to the base mud [21].

Nanomaterials are manufactured substances ranging in size from 1 to 100 nanometers (nm) and are therefore used in extremely small dosages. Nanomaterials are widely used in various fields, such as pharmaceuticals, automotive engineering, electronics, and above all in a number of areas of the chemical industry. An example of this is the drilling industry [22].

To facilitate well drilling, drilling fluids are a vital factor for successful drilling; That is, the fluids help to remove drill cuttings and fragments from the drilling area and wellbore.

Nanomaterials have an extremely high surface area-to-volume ratio due to their nanoscale particles. Therefore, WBDF containing the active agents of nanomaterials has improved physical and chemical sensitivity which improves its performance compared to OBDF. In addition to the advantages over OBDF improved nanotechnology-based WBDF is also cheaper and safer for the environment. For example, graphite nanomaterials are excellent binders and have been successfully used to create a dense, impermeable and thinner clay cake. This allows the nanopores to be physically connected, thereby reducing water loss during the formation of shale rocks. Therefore, the use of the graphene family increases the stability of the wellbore [23].

In addition, nanomaterials are also used as lubricants to reduce friction between the wellbore and the drill string, hence reducing the chances of pipe sticking. For example, adding traces of nanomaterials to drilling fluid has been found to promote its transformation into nanofluid, play an important role in improving the quality of the clay cake and reduce pipe adhesion to the formation, promote good wellbore stability and reservoir protection, and increase oil recovery of both oil and gas products. This was made possible by the modification of the liquid caused by nanoparticles and contributed to its excellent performance [24].

Another reflection of this finding was obtained in a number of studies, in which the authors found that nanomaterials helped improve the quality of the clay cake and reduce losses during the circulation. They also found that when nanomaterials were used as thickeners, emulsifiers, and lubricants, they improved the quality of wellbore cleanup, wellbore stability, and reservoir protection, as well as increased oil and gas recovery.

Other researchers have analyzed important parameters related to the use of nanomaterials. This study highlights the key factors which need to be considered to ensure good drilling fluid performance [26].

In addition to materials derived from waste, recent studies have presented nanomaterials as a promising alternative for use in the function of additives in drilling fluids. For example, the effect of Fe_3O_4-nanocomposite carboxymethylcellulose (CMC) as an additive to control fluid loss in drilling fluids was evaluated. In this study, the effect on the rheological properties of drilling fluid with and without the addition of salt was studied. The study showed that the use of a nanocomposite increases the viscosity of the drilling fluid in both conditions. According to the results of the study as a whole, the yield point of drilling fluid is further increased with an increase in the concentration of the nanocomposite. It has been observed that the addition of a nanocomposite to the drilling fluid makes it possible to obtain a thinner filter cake compared to the CMC drilling fluid system [27].

The importance of increasing the appropriate concentration of additives in the drilling fluid to improve the properties was investigated by increasing the concentration of copper oxide (CuO), also called polyacrylamide nanocomposite, in the water-based drilling fluid. It was found that the increased concentration significantly minimized fluid loss and filter cake thickness compared to the absence of nanocomposites. Higher viscosity, thermal conductivity, and favorable porosity of the filter cake have been observed [28].

Another important distinction was made by comparing the characteristics of the drilling fluid in salt and non-saline water. It was found that both types showed the best performance under certain conditions, and that a certain concentration of salt can provide the best performance for both salt and unsalted water. This study again showed that additives play a vital role in the performance of drilling fluid [29].

Other nanomaterials, such as graphene and magnesium oxide (MgO), were also studied in various concentrations and separately in combination with commercial nanobentonite to observe the work of the liquid. The addition of MgO with nanomaterials resulted in improved filter losses and yield point. This suggests that a wide range of additives in appropriate concentration can improve the performance of drilling fluids [30].

Graphene materials are widely used in drilling fluids because they improve the rheological properties of these fluids. The use of grapheme oxide additive in water-based drilling fluids was found to improve their filtrate absorption characteristics, significantly reducing filter cake thickness and fluid loss, and optimizing shear thinning and thermal stability. It has also been observed that graphene, both in the form of flakes and in powder form, contributes to improved performance. This study demonstrates that the presence of an additive affects drilling fluid properties and shows how the form of the additive can contribute to value-added properties [31].

It has also been observed that conventional water-based drilling fluids exposed to water-sensitive oil shale cause the oil shale to absorb water from the drilling fluid, leading to problems during operation. Consequently, water-based drilling fluids must contain additives to effectively inhibit shale. Salt compounds have been used to inhibit shale. However, high concentration of salt compounds affected the surrounding ecosystems. The concentration was changed and the shale was successfully inhibited. This study demonstrates the importance of optimal additive concentration in drilling fluids to achieve superior drilling fluid performance without side effects [32].

Similarly, polyoxyalkyleneamine (POAM) has been investigated as a potential additive. POAM was found to improve shale inhibition properties in water-based drilling fluids. Additional advantages of POAM are water solubility, good compatibility with other drilling fluid additives and non-toxicity. Further, nanomaterials have been investigated as potential additives for use in drilling fluids [33].

In the drilling industry, many researchers have studied nanomaterials and found a wide range of chemicals that can improve the properties of drilling fluids. A clear advantage of using nanomaterials is that their required quantity is very small. Consequently, the use of nanomaterials can conserve resources. The drilling industry spends millions of dollars to eliminate wellbore instability. The use of nanomaterials as additives to drilling fluids must be economically feasible so that resources can be conserved. For example, nanomaterials which are used to reduce filtration, such as thickeners, emulsions, and clays, can reduce the rate of water penetration into shale because these nanomaterials are small enough to insulate shale, thereby strengthening the wellbore. The researchers found that SiO_2 nanoparticles added to water-based drilling fluids enhanced inhibition as well as filtrate loss and rheological properties.

An additional advantage is that obtaining SiO_2 nanoparticles has low cost due to common methods of their production. It was found that the optimum concentration of SiO_2 nanoparticles is less than 1 % wt./vol. in oil shale inhibition, which amounts to a very small and therefore economical concentration [34].

Other studies have proposed SiO_2 nanoparticles as an additive to water-based drilling fluids. They found that SiO_2 nanoparticles increase the viscosity of the fluid, allowing it to carry drill cuttings away from the wellbore more efficiently. This keeps the wellbore clean and therefore does not create problems when the drill has to be removed or maintenance is required [35].

In addition, the use of SiO_2 nanoparticles with xanthan gum as a base in water-based drilling fluids was investigated and found to have increased yield point, superior well cleaning ability, reduced filtrate loss and more effective lubrication of the drill bit during operation compared to drilling fluid without SiO_2 [36].

Bayat et al. studied four types of nanoparticles, namely aluminum oxide (Al_2O_3), titanium dioxide (TiO_2), SiO_2, and CuO in bentonite, and their effects on water-based drilling fluids. They found that the combination additives improved the overall rheological properties and strength of the gel at low concentration compared to a base liquid without nanoparticles. This shows that additives effectively improve rheology at low concentration and thus save resources during the drilling process [37].

In the other recent studies it has been evaluated the effect of zinc oxide (ZnO) nanoparticles on the rheological properties of non-damaging drilling fluid (NDDF). Compared to the base NDDF, NDDF with the addition of ZnO nanoparticles exhibited higher shear stress and viscosity. The addition of ZnO nanoparticles to NDDF helped solve the problem of NDDF degradation by stabilizing viscosity at higher temperatures. Temperature sweep measurements have shown that a good operating temperature range of basic NDDF is between 70 and 80 °C. NDDF containing ZnO nanoparticles has demonstrated improved fluid loss control. However, it was observed that an increase in pressure led to a decrease in fluid loss [38].

The above-mentioned studies have demonstrated the efficacy of food waste in drilling fluid additives as a substitute for environmentally hazardous materials currently used in industry. In this regard, it is necessary to promote the concept of "waste to wealth" by studying the possibility of applying unused derived waste as additives to drilling fluids, as well as to solve the problem by studying the rheological properties of additives providing their viability and economic efficiency [39].

One of the important characteristics of drilling fluids is lubricity. Lubricity is required to reduce friction due to the constant contact between the wellbore and the drill string in horizontal and directional wells. There are two main aspects regarding the lubricity of drilling fluids, which are called torque and resistance. Torque refers to the frictional resistance to the rotation of the drill string, whereas resistance is described as the frictional resistance to the lowering and lifting of the drill string. Compared with water-based drilling fluids, it is evident that oil-based drilling fluids have better lubricating properties. However, water-based drilling fluid is preferable to petroleum-based drilling fluid due to the use of environmentally friendly additives in the first one. As a result, lubricant additives are used in water-based drilling fluids to reduce friction between the wellbore and the drill string, reduce the likelihood of differential stick and increase drilling speed [40].

It was presented the research of thermophysical properties of drilling fluid containing nanoparticles aimed at studiyng the ability of drilling fluid to transfer heat. The use of nanoparticles, including titanium dioxide nanoparticles and hydrocarbon nanotubes (HCNT), has been proposed due to the fact that nanoparticles have a high specific surface area, which can increase the heat transfer rate. The study found that drilling fluids integrated with HCNT exhibit a higher percentage of convective heat to conducted heat ratio compared to solutions that use titanium dioxide nanoparticles. Thus, HCNT are not recommended for improving the coefficient or level of convective heat transfer. In addition, the study observed an increase in heat transfer rate and convective heat transfer coefficient while decreasing the average size of titanium dioxide and HCNT, respectively. This indicates that the size of nanoparticles is an important parameter which should be considered while using nanoparticles in drilling fluids [41].

In drilling fluids, lubricity reduces torque and drag force. As a rule, the lubricity of drilling fluids is measured by the reduction in torque, which can be determined by the coefficient of friction (CoF). CoF is defined as the ratio of the frictional force between two bodies to the force that presses them together. Ideally, a good lubricant should have favorable properties, including high viscosity, high lubricant film strength, low flammability, low corrosion, and high solubility, and must also be nontoxic. The addition of a minimum amount of lubricants is sufficient to ensure adequate lubricity of drilling fluids [42].

Studies have reported on various types of additives used as a lubricant for drilling fluids, including modified vegetable oils and purified polyols. The combination of polyols and drilling fluid alters the wetting characteristics of the drilling fluid, causing it to behave similarly to petroleum drilling fluid [43]. Therefore, the lubricity and stability of the drilling fluid have greatly been improved. However, polyols can also change the wettability of reservoir rocks, leading to the formation of water blocks [44]. Currently, polyalkylene glycols (PAGs) and polyalphaolefins (PAOs) are the most common types of lubricants used in drilling fluids [45]. PAOs are preferred in synthetic drilling fluids due to their remarkable lubricating properties, and they are used for wellbore cleaning, shale stabilization, and bit cooling and lubrication [46]. However, PAOs have disadvantages, including a small viscosity range and low polarity [47].

In recent decades, there has been a growing interest in the use of nanomaterials as lubricant additives. This interest has been motivated by the industry's move towards the use of water-based drilling fluids owing to the environmental concerns associated with the use of petroleum-based drilling fluids and synthetic drilling fluids [48, 49]. The new properties of nanoparticles offer many potential applications, especially in the oil and gas industry. Recently, the potential use of environmentally friendly nanoparticles in drilling fluids has been demonstrated. This approach significantly improved the lubricating and rheological properties of the drilling fluid at the expense of the asymmetric morphology of nanoparticles, which facilitated the rotation of metalto-metal surfaces [50].

Existing Unsolved Scientific Problems on the Topic of Research

According to the results of the latest research, the use of environmentally friendly additives, such as biowaste, has greatly improved the performance and functionality of drilling fluids..

However, several challenges need to be addressed before these biowastes can be applied and commercialised on a large scale in the oil and gas industry. One of the key challenges is that the feedstock waste and waste-derived nanomaterials can contain large amounts of impurities, which requires an additional purification process. Therefore, it is necessary to carry out further research aimed at the improvement of the waste-derived nanomaterials characteristics and optimization of their production. Schematic representation of the problems associated with the waste collection and recycling and the interrelated role of consumers in society are given in [10].

Besides, it is also important to investigate new waste derivatives by conducting ageing tests and experimental research under HPHT conditions to study the decomposition of environmentally friendly additive [12].

Moreover, the environmental impact of waste-derived nanomaterials should be addressed. These waste additives can be used and optimized in OBDF and SBDF formulations in addition to WBDF ones [11].

In addition, a thorough comprehensive quantitative analysis of the different types of green additives and their characteristics can be carried out to determine the best rheological improvements.

In the future, the role of environmentally friendly additives derived from waste will play an important role in the preparation of new environmentally friendly additives for drilling fluids. It is recommended that future studies should be focused on the identification of a green additive optimally improving the essential rheological and filtration properties of drilling fluids. Therefore, a breakthrough is possible by increasing the efficiency of drilling operations while reducing any harmful risks to the environment and personnel health [15].

Methods for solving existing Scientific Problems

In order to implement the use of materials derived from waste, more research focused on their application in the oil and gas industry is needed. Waste, such as food waste, can be used as an alternative to harmful and toxic additives that are commonly used in drilling. To date, many materials derived from waste have been researched due to their potential use as additives. These materials include food waste, such as durian peel, and plant waste such as black sunflower seeds. The role of nanomaterials derived from waste and the key characteristics that can increase the efficiency of drilling are set out in [8].

The recommendations of the authors of this study are as follows:

- A comprehensive study of the interactions between materials derived from waste and the content of drilling fluids, such as bentonite, should be carried out;
- The cost-effectiveness of waste management requires more attention prior to commercialization n order to ensure consistency in the production of drilling fluids with improved rheological properties;
- In-depth analysis is required to develop extensive methodologies for manufacturing additives based on waste-derived materials;
- Future studies should consider the analysis of the lubricity of drilling fluids with the use of waste-derived materials. Careful examination is needed to study the morphological properties of drilling fluids;
- The possibility of converting waste into nanomaterials and the reproducibility of the conversion should be considered for different applications;
- A comprehensive quantitative analysis of nanomaterials used in drilling operations is needed. Particular attention is required to determine optimal concentrations to improve resource conservation;
- Additional research should focus on the mechanisms of interaction between nanomaterials and other additives present in drilling fluids;

• A comparison of drilling fluid optimisation should be made between water-based drilling fluids using nanomaterials and synthetic and petroleum-based drilling fluids. The comparison should be made in relation to conventional base fluids subjected to high temperatures and pressures [11].

Conclusion

The increase in waste production is a major concern due to its impact on public health and the environment. In particular, the mishandling of food waste has become a serious global problem, creating a need for more efficient solutions that utilise these materials for a variety of purposes.

Based on the performed analysis the following conclusions were made:

1. Chemical additives to drilling fluids are necessary components to facilitate drilling operations by improving the properties of the fluids, including rheological properties and filtrate loss.
2. Food waste can be considered as a sustainable alternative to drilling fluid additives used in the oil and gas drilling industry.
3. Studies have shown that materials derived from waste, including food waste, can be an environmentally friendly alternative to the toxic conventional chemical additives used in water-based drilling fluids.
4. The materials summarized in this review article include food waste and waste from plants.
5. The potencial of these materials was evaluated in terms of their effect on yield strength, plastic viscosity, filtrate loss, and clay cake thickness.
6. Nanomaterials are viable alternative additives for drilling fluid applications.
7. Nanomaterials can be used economically due to the low concentrations required for their effective use in drilling fluids.
8. The lubricity of drilling fluids is a property which is considered necessary to ensure smooth drilling.
9. On the basis of generalized studies it was revealed that the amount of less than 1 g is sufficient to change the lubricity of drilling fluids.
10. Water-based drilling fluids require lubricating additives to provide better lubrication and thus reduce friction during drilling.

References

1. Nutskova M.V., Rudiaeva E.Iu. Obosnovanie i razrabotka tekhniko-tekhnologicheskikh reshenii dlia povysheniia effektivnosti bureniia skvazhin v usloviiakh pogloshcheniia promyvochnoi zhidkosti [The effect of water-swellable polymer on well drilling with mud loss]. *Nedropol'zovanie*, 2018, vol. 17, no. 2, pp. 104-114. DOI: 10.15593/2224-9923/2018.2.1
2. Litvinenko V.S., Nikolaev N.I. Tekhnologicheskie zhidkosti dlia povysheniia effektivnosti stroitel'stva i ekspluatatsii neftianykh i gazovykh skvazhin [Technological fluids for increasing effectivity of construction and exploitation oil and gas wells]. *Zapiski Gornogo instituta*, 2011, vol. 194, 84 p.
3. Malyshkin M.M. Ekologizatsiia tekhnologii burenii skvazhin [Well drilling technologies ecologization]. *Zapiski Gornogo instituta*, 2013, vol. 203, 63 p.
4. Malyshkin M.M. Snizhenie ekologicheskoi opasnosti pri vedenii burovykh rabot [Reducing environmental hazard drilling works]. *Zapiski Gornogo instituta*, 2014, vol. 207, 186 p.
5. Nikolaev N.I., Leusheva E.L. Razrabotka sostavov promyvochnykh zhidkostei dlia povysheniia effektivnosti bureniia tverdykh gornykh porod [Development of drilling fluids composition for efficiency increase of hard rocks drilling]. *Zapiski Gornogo instituta*, 2016, vol. 219, 412 p. DOI: 10.18454/pmi.2016.3.412
6. Iakovlev A.M. Znachenie smazyvaiushchikh dobavok pri almaznom burenii [The importance of lubricants in diamond drilling]. *Zapiski Gornogo instituta*, 1976, vol. 71(2), 80 p.
7. Chen C., Li C., Reniers G., Yang F. Safety and security of oil and gas pipeline transportation: A systematic analysis of research trends and future needs using WoS. *J. Clean. Prod.*, 2021, vol. 279, 123583 p. DOI: 10.1016/j.jclepro.2020.123583
8. Cheraghian G., Wu Q., Mostofi M., Li M.-C., Afrand M., Sangwai J.S. Effect of a novel clay/silica nanocomposite on water-based drilling fluids: Improvements in rheological and filtration properties. *Colloids Surf. A*, 2018, vol. 555, pp. 339-350. DOI: 10.1016/j.colsurfa.2018.06.072
9. Medhi S., Chowdhury S., Gupta D.K., Mazumdar A. An investigation on the effects of silica and copper oxide nanoparticles on rheological and fluid loss property of drilling fluids. *J. Pet. Explor. Prod. Technol.*, 2020, vol. 10, pp. 91-101. DOI: 10.1007/s13202-019-0721-y
10. Zheng Y., Amiri A., Polycarpou A.A. Enhancements in the tribological performance of environmentally friendly water-based drilling fluids using additives. *Appl. Surf. Sci.*, 2020, vol. 527, 146822 p. DOI: 10.1007/s13202-019-0721-y
11. Meng X., Zhang Y., Zhou F., Chu P.K. Effects of carbon ash on rheological properties of water-based drilling fluids. *J. Pet. Sci. Eng.*, 2012, vol. 100, pp. 1-8. DOI: 10.1016/j.petrol.2012.11.011
12. Chang X., Sun J., Xu Z., Lv K., Dai Z., Zhang F., Huang X., Liu J. Synthesis of a novel environment-friendly filtration reducer and its application in water-based drilling fluids. *Colloids Surf. A*, 2019, vol. 568, pp. 284-293. DOI: 10.1016/j.colsurfa.2019.01.055
13. Ismail A.R., Mohd N.M., Basir N.F., Oseh J.O., Ismail I., Blkoor S.O. Improvement of rheological and filtration characteristics of water-based drilling fluids using naturally derived henna leaf and hibiscus leaf extracts. *J. Pet. Explor. Prod. Technol.*, 2020, vol. 10, pp. 3541-3556. DOI: 10.1007/s13202-020-01007-y
14. V. de Oliveira, K. dos Santos Alves, A. da Silva-Junior, R. Araújo, R. Balaban Testing carrageenans with different chemical structures for water-based drilling fluid application /, L. Hilliou. *J. Mol. Liq.*, 2020, vol. 299, 112139 p. DOI: 10.1016/j.molliq.2019.112139
15. Yang M., Luo D., Chen Y., Li G., Tang D., Meng Y. Establishing a practical method to accurately determine and manage wellbore thermal behavior in high-temperature drilling. *Appl. Energy*, 2019, vol. 238, pp. 1471-1483. DOI: 10.1016/j.apenergy.2019.01.164
16. Ahmad H.M., Kamal M.S., Al-Harthi M.A. High molecular weight copolymers as rheology modifier and fluid loss additive for water-based drilling fluids. *J. Mol. Liq*, 2018, vol. 252, pp. 133-143. DOI: 10.1016/j.molliq.2017.12.135
17. Ahmadi M.A., Shadizadeh S.R., Shah K., Bahadori A. An accurate model to predict drilling fluid density at wellbore conditions. *Egypt. J. Pet.*, 2018, vol. 27, pp. 1-10. DOI: 10.1016/j.ejpe.2016.12.002
18. Elkatatny S. Enhancing the rheological properties of water-based drilling fluid using micronized starch. *Arab. J. Sci. Eng.*, 2019, vol. 44, pp. 5433-5442. DOI: 10.1007/s13369-019-03720-1
19. Basfar S., Mohamed A., Elkatatny S., Al-Majed A. A Combined Barite-Ilmenite Weighting Material to Prevent Barite Sag in Water-Based Drilling Fluid. *Materials*, 2019, vol. 12, 1945 p. DOI: 10.3390/ma12121945
20. Oseh J.O., Norrdin M.M., Farooqi F., Ismail R.A., Ismail I., Gbadamosi A.O., Agi A.J. Experimental investigation of the effect of henna leaf extracts on cuttings transportation in highly deviated and horizontal wells. *J. Pet. Explor. Prod. Technol.*, 2019, vol. 9, pp. 2387-2404. DOI: 10.1007/s13202-019-0631-z
21. Alakbari F., Elkatatny S., Kamal M.S., Mahmoud M. Optimizing the gel strength of water-based drilling fluid using clays for drilling horizontal and multi-lateral wells. *SPE Kingdom of Saudi Arabia Annual Technical Symposium and Exhibition; OnePetro: Kuala Lumpur, Malaysia*, 2018. DOI: 10.3933/applrheol-28-43606
22. Mohamed A., Al-Afnan S., Elkatatny S., Hussein I. Prevention of barite sag in water-based drilling fluids by a urea-based additive for drilling deep formations. *Sustainability*, 2020, vol. 12, 2719 p. DOI: 10.3390/su12072719

23. Novriansyah A. Experimental analysis of cassava starch as a fluid loss control agent on drilling mud. *Mater. Today Proc.*, 2021, vol. 39, pp. 1094-1098. DOI: 10.1016/j.matpr.2020.07.189
24. Dejtaradon P., Hamidi H., Chuks M.H., Wilkinson D., Rafati R. Impact of ZnO and CuO nanoparticles on the rheological and filtration properties of water-based drilling fluid. *Colloids Surf. A*, 2019, vol. 570, pp. 354-367. DOI: 10.3390/en13133417
25. Ali M., Jarni H.H., Aftab A., Ismail A.R., Saady N.M.C., Sahito M.F., Keshavarz A., Iglauer S., Sarmadivaleh M. Nanomaterial-based drilling fluids for exploitation of unconventional reservoirs: A review. *Energies*, 2020, vol. 13, 3417 p. DOI: 10.3390/en13133417
26. Bologna M., Aquino G. Deforestation and world population sustainability: A quantitative analysis. *Sci. Rep.*, 2020, vol. 10, 7631 p. DOI: 10.1038/s41598-020-63657-6
27. Rautela R., Arya S., Vishwakarma S., Lee J., Kim K.-H., Kumar S. E-waste management and its effects on the environment and human health. *Sci. Total Environ.*, 2021, vol. 773, 145623 p. DOI: 10.1016/j.scitotenv.2021.145623
28. Castillo-Giménez J., Montañés A., Picazo-Tadeo A.J. Performance and convergence in municipal waste treatment in the European Union. *Waste Manag.*, 2019, vol. 85, pp. 222-231. DOI: 10.1016/j.wasman.2018.12.025
29. Demirbas A. Waste management, waste resource facilities and waste conversion processes. *Energy Convers. Manag.*, 2011, vol. 52, pp. 1280-1287. DOI: 10.1016/j.enconman.2010.09.025
30. Al-Hameedi A.T.T., Alkinani H.H., Dunn-Norman S., Alashwak N.A., Alshammari A.F., Alkhamis M.M., Albazzaz H.W., Mutar R.A., Alsaba M.T. Environmental friendly drilling fluid additives: Can food waste products be used as thinners and fluid loss control agents for drilling fluid? *SPE Symposium: Asia Pacific Health, Safety, Security, Environment and Social Responsibility; OnePetro: Kuala Lumpur, Malaysia*, 2019. DOI: 10.2118/195410-MS
31. Majid N.F.F., Katende A., Ismail I., Sagala F., Sharif N.M., Yunus M.A.C. A comprehensive investigation on the performance of durian rind as a lost circulation material in water-based drilling mud. *Petroleum*, 2019, vol. 5, pp. 285-294. DOI: 10.1016/j.petlm.2018.10.004
32. Ghayedi A., Khosravi A. Laboratory investigation of the effect of GO-ZnO nanocomposite on drilling fluid properties and its potential on H2S removal in oil reservoirs. *J. Pet. Sci. Eng.*, 2020, vol. 184, 106684 p. DOI: 10.1016/j.petrol.2019.106684
33. Davoodi S., SA A.R., Jamshidi S., Jahromi A.F. A novel field applicable mud formula with enhanced fluid loss properties in high pressure-high temperature well condition containing pistachio shell powder. *J. Pet. Sci. Eng.*, 2018, vol. 162, pp. 378-385. DOI: 10.1016/j.petrol.2017.12.059
34. Hossain M.E., Wajheeuddin M. The use of grass as an environmentally friendly additive in water-based drilling fluids. *Pet. Sci.*, 2016, vol. 13, pp. 292-303. DOI: 10.1007/s12182-016-0083-8
35. Azizi A., Ibrahim M.S.N., Hamid K.H.K., Sauki A., Ghazali N.A., Mohd T.A.T. Agarwood waste as a new fluid loss control agent in water-based drilling fluid. *Int. J. Sci. Eng.*, 2013, vol. 5, pp. 101–105. DOI: 10.12777/ijse.5.2.101-105
36. Iscan A., Kok M. Effects of walnut shells on the rheological properties of water-based drilling fluids. *Energy Sources Part A*, 2007, vol. 29, pp. 1061-1068. DOI: 10.1080/00908310600713982
37. Alcheikh I., Ghosh B. A comprehensive review on the advancement of non-damaging drilling fluids. *Int. J. Petrochem. Res.*, 2017, vol. 1, pp. 61-72. DOI: 10.18689/ijpr-1000111
38. Li M.-C., Wu Q., Lei T., Mei C., Xu X., Lee S., Gwon J. Thermothickening Drilling Fluids Containing Bentonite and Dual-Functionalized Cellulose Nanocrystals. *Energy Fuels*, 2020, vol. 34, pp. 8206-8215. DOI: 10.1021/acs.energyfuels.0c01192
39. Câmara da P.C., Madruga L.Y., Marques N.d.N., Balaban R.C. Evaluation of polymer/bentonite synergy on the properties of aqueous drilling fluids for high-temperature and high-pressure oil wells. *J. Mol. Liq.*, 2021, vol. 327, 114808 p. DOI: 10.1016/j.molliq.2020.114808
40. Dong W., Pu X., Ren Y., Zhai Y., Gao F., Xie W. Thermoresponsive bentonite for water-based drilling fluids. *Materials*, 2019, vol. 12, 2115 p. DOI: 10.3390/ma12132115
41. Abdou M., Al-Sabagh A., Ahmed H.E.-S., Fadl A. Impact of barite and ilmenite mixture on enhancing the drilling mud weight. *Egypt. J. Pet.*, 2018, vol. 27, pp. 955-967. DOI: 10.1016/j.ejpe.2018.02.004
42. Magzoub M., Mahmoud M., Nasser M., Hussein I., Elkatatny S., Sultan A. Thermochemical upgrading of calcium bentonite for drilling fluid applications. *J. Energy Res. Technol.*, 2019, vol. 141, 042902 p. DOI: 10.1115/1.4041843
43. Karagüzel C., Çetinel T., Boylu F., Cinku K., Çelik M. Activation of (Na, Ca)-bentonites with soda and MgO and their utilization as drilling mud. *Appl. Clay Sci.*, 2010. vol. 48, pp. 398-404. DOI: 10.1016/j.clay.2010.01.013
44. Li M.-C., Wu Q., Han J., Mei C., Lei T., Lee S.-Y., Gwon J. Overcoming Salt Contamination of Bentonite Water-Based Drilling Fluids with Blended Dual-Functionalized Cellulose Nanocrystals. *ACS Sustain. Chem. Eng.*, 2020, vol. 8, pp. 11569-11578. DOI: 10.1021/acssuschemeng.0c02774
45. Xie B., Tchameni A.P., Luo M., Wen J. A novel thermo-associating polymer as rheological control additive for bentonite drilling fluid in deep offshore drilling. *Mater. Lett.*, 2021, vol. 284, 128914 p. DOI: 10.1016/j.matlet.2020.128914
46. Ikram R., Jan B.M., Ahmad W. An overview of industrial scalable production of graphene oxide and analytical approaches for synthesis and characterization. *J. Mater. Res. Technol.*, 2020, vol. 9, pp. 11587-11610. DOI: 10.1016/j.jmrt.2020.08.050
47. Wang K., Jiang G., Li X., Luckham P.F. Study of graphene oxide to stabilize shale in water-based drilling fluids. *Colloids Surf. A,* 2020, vol. 606, 125457 p. DOI: 10.1016/j.colsurfa.2020.125457
48. Aramendiz J., Imqam A. Water-based drilling fluid formulation using silica and graphene nanoparticles for unconventional shale applications. *J. Pet. Sci. Eng.*, 2019, vol. 179, pp. 742-749. DOI: 10.1016/j.petrol.2019.04.085
49. Gbadamosi A.O., Junin R., Abdalla Y., Agi A., Oseh J.O. Experimental investigation of the effects of silica nanoparticle on hole cleaning efficiency of water-based drilling mud. *J. Pet. Sci. Eng.*, 2019, vol. 172, pp. 1226-1234. DOI: 10.1016/j.petrol.2018.09.097
50. Al-Yasiri M., Awad A., Pervaiz S., Wen D. Influence of silica nanoparticles on the functionality of water-based drilling fluids. *Journal of Petroleum Science and Engineering*, 2019, vol. 179, pp. 504-512. DOI: 10.1016/j.petrol.2019.04.081
51. Medhi S., Gupta D., Sangwai J.S. Impact of zinc oxide nanoparticles on the rheological and fluid-loss properties, and the hydraulic performance of non-damaging drilling fluid. *J. Nat. Gas Sci. Eng.*, 2021, vol. 88, 103834 p. DOI: 10.1016/j.jngse.2021.103834
52. Barry M.M., Jung Y., Lee J.-K., Phuoc T.X., Chyu M.K. Fluid filtration and rheological properties of nanoparticle additive and intercalated clay hybrid bentonite drilling fluids. *J. Pet. Sci. Eng.*, 2015, vol. 127, pp. 338-346. DOI: 10.1016/j.petrol.2015.01.012
53. Elochukwu H., Sia L.K.S., Gholami R., Hamid M.A. Data on experimental investigation of Methyl Ester Sulphonate and nanopolystyrene for rheology improvement and filtration loss control of water-based drilling fluid. Data Brief. 2018. vol. 21, pp. 972-979. DOI: 10.1016/j.dib.2018.10.055
54. Abdo J., AL-Sharji H., Hassan E. Effects of nano-sepiolite on rheological properties and filtration loss of water-based drilling fluids. *Surf. Interface Anal.*, 2016, vol. 48, pp. 522-526. DOI: 10.1016/j.powtec.2020.08.053
55. Medhi S., Chowdhury S., Bhatt N., Gupta D.K., Rana S., Sangwai J.S. Analysis of high performing graphene oxide nanosheets based non-damaging drilling fluids through rheological measurements and CFD studies. *Powder Technol.*, 2021, vol. 377, pp. 379-395. DOI: 10.1016/j.powtec.2020.08.053

Библиографический список

1. Нуцкова М.В., Рудяева Е.Ю. Обоснование и разработка технико-технологических решений для повышения эффективности бурения скважин в условиях поглощения промывочной жидкости // Недропользование. – 2018. – Т. 17, № 2. – С. 104–114. DOI: 10.15593/2224-9923/2018.2.1
2. Литвиненко В.С., Николаев Н.И. Технологические жидкости для повышения эффективности строительства и эксплуатации нефтяных и газовых скважин // Записки Горного института. – 2011. – Т. 194. – С. 84.
3. Малышкин М.М. Экологизация технологии бурении скважин // Записки Горного института. – 2013. – Т. 203. – С. 63.
4. Малышкин М.М. Снижение экологической опасности при ведении буровых работ // Записки Горного института. – 2014. – Т. 207. – С. 186.
5. Николаев Н.И., Леушева Е.Л. Разработка составов промывочных жидкостей для повышения эффективности бурения твердых горных пород // Записки Горного института. – 2016. – Т. 219. – С. 412. DOI: 10.18454/pmi.2016.3.412
6. Яковлев А.М. Значение смазывающих добавок при алмазном бурении // Записки Горного института. – 1976. – Т. 71(2). – С. 80.
7. Safety and security of oil and gas pipeline transportation: A systematic analysis of research trends and future needs using WoS / C. Chen, C. Li, G. Reniers, F. Yang // J. Clean. Prod. – 2021. – Vol. 279. – P. 123583. DOI: 10.1016/j.jclepro.2020.123583
8. Effect of a novel clay/silica nanocomposite on water-based drilling fluids: Improvements in rheological and filtration properties / G. Cheraghian, Q. Wu, M. Mostofi, M.-C. Li, M. Afrand, J.S. Sangwai // Colloids Surf. A. – 2018. – Vol. 555. – P. 339–350. DOI: 10.1016/j.colsurfa.2018.06.072

9. An investigation on the effects of silica and copper oxide nanoparticles on rheological and fluid loss property of drilling fluids / S. Medhi, S. Chowdhury, D.K. Gupta, A. Mazumdar // J. Pet. Explor. Prod. Technol. – 2020. – Vol. 10. – P. 91–101. DOI: 10.1007/s13202-019-0721-y
10. Zheng Y., Amiri A., Polycarpou A.A. Enhancements in the tribological performance of environmentally friendly water-based drilling fluids using additives // Appl. Surf. Sci. – 2020. – Vol. 527. – P. 146822. DOI: 10.1007/s13202-019-0721-y
11. Effects of carbon ash on rheological properties of water-based drilling fluids / X. Meng, Y. Zhang, F. Zhou, P.K. Chu // J. Pet. Sci. Eng. – 2012. – Vol. 100. – P. 1–8. DOI: 10.1016/j.petrol.2012.11.011
12. Synthesis of a novel environment-friendly filtration reducer and its application in water-based drilling fluids / X. Chang, J. Sun, Z. Xu, K. Lv, Z. Dai, F. Zhang, X. Huang, J. Liu // Colloids Surf. A. – 2019. – Vol. 568. – P. 284–293. DOI: 10.1016/j.colsurfa.2019.01.055
13. Improvement of rheological and filtration characteristics of water-based drilling fluids using naturally derived henna leaf and hibiscus leaf extracts / A.R. Ismail, N.M. Mohd, N.F. Basir, J.O. Oseh, I. Ismail, S.O. Blkoor // J. Pet. Explor. Prod. Technol. – 2020. – Vol. 10. – P.l 3541–3556. DOI: 10.1007/s13202-020-01007-y
14. Testing carrageenans with different chemical structures for water-based drilling fluid application / V. de Oliveira, K. dos Santos Alves, A. da Silva-Junior, R. Araújo, R. Balaban, L. Hilliou // J. Mol. Liq. – 2020. – Vol. 299. – P. 112139. DOI: 10.1016/j.molliq.2019.112139
15. Establishing a practical method to accurately determine and manage wellbore thermal behavior in high-temperature drilling / M. Yang, D. Luo, Y. Chen, G. Li, D. Tang, Y. Meng // Appl. Energy. – 2019. – Vol. 238. – P. 1471–1483. DOI: 10.1016/j.apenergy.2019.01.164
16. Ahmad H.M., Kamal M.S., Al-Harthi M.A. High molecular weight copolymers as rheology modifier and fluid loss additive for water-based drilling fluids // J. Mol. Liq. – 2018. – Vol. 252. – P. 133–143. DOI: 10.1016/j.molliq.2017.12.135
17. An accurate model to predict drilling fluid density at wellbore conditions / M.A. Ahmadi, S.R. Shadizadeh, K. Shah, A. Bahadori // Egypt. J. Pet. – 2018. – Vol. 27. – P. 1–10. DOI: 10.1016/j.ejpe.2016.12.002
18. Elkatatny S. Enhancing the rheological properties of water-based drilling fluid using micronized starch // Arab. J. Sci. Eng. – 2019. – Vol. 44. – P. 5433–5442. DOI: 10.1007/s13369-019-03720-1
19. A Combined Barite–Ilmenite Weighting Material to Prevent Barite Sag in Water-Based Drilling Fluid / S. Basfar, A. Mohamed, S. Elkatatny, A. Al-Majed // Materials. – 2019. – Vol. 12. – P. 1945. DOI: 10.3390/ma12121945
20. Experimental investigation of the effect of henna leaf extracts on cuttings transportation in highly deviated and horizontal wells / J.O. Oseh, M.M. Norrdin, F. Farooqi, R.A. Ismail, I. Ismail, A.O. Gbadamosi, A.J. Agi // J. Pet. Explor. Prod. Technol. – 2019. – Vol. 9. – P. 2387–2404. DOI: 10.1007/s13202-019-0631-z
21. Optimizing the gel strength of water-based drilling fluid using clays for drilling horizontal and multi-lateral wells / F. Alakbari, S. Elkatatny, M.S. Kamal, M. Mahmoud // SPE Kingdom of Saudi Arabia Annual Technical Symposium and Exhibition; OnePetro: Kuala Lumpur, Malaysia. – 2018. DOI: 10.3933/applrheol-28-43606
22. Prevention of barite sag in water-based drilling fluids by a urea-based additive for drilling deep formations / A. Mohamed, S. Al-Afnan, S. Elkatatny, I. Hussein // Sustainability. – 2020. – Vol. 12. – P. 2719. DOI: 10.3390/su12072719
23. Novriansyah A. Experimental analysis of cassava starch as a fluid loss control agent on drilling mud // Mater. Today Proc. – 2021. – Vol. 39. – P. 1094–1098. DOI: 10.1016/j.matpr.2020.07.189
24. Impact of ZnO and CuO nanoparticles on the rheological and filtration properties of water-based drilling fluid / P. Dejtaradon, H. Hamidi, M.H. Chuks, D. Wilkinson, R. Rafati // Colloids Surf. A. – 2019. – Vol. 570. – P. 354–367. DOI: 10.3390/en13133417
25. Nanomaterial-based drilling fluids for exploitation of unconventional reservoirs: A review / M. Ali, H.H. Jarni, A. Aftab, A.R. Ismail, N.M.C. Saady, M.F. Sahito, A. Keshavarz, S. Iglauer, M. Sarmadivaleh // Energies. – 2020. – Vol. 13. – P. 3417. DOI: 10.3390/en13133417
26. Bologna M., Aquino G. Deforestation and world population sustainability: A quantitative analysis // Sci. Rep. – 2020. – Vol. 10. – P. 7631. DOI: 10.1038/s41598-020-63657-6
27. E-waste management and its effects on the environment and human health / R. Rautela, S. Arya, S. Vishwakarma, J. Lee, K.-H. Kim, S. Kumar // Sci. Total Environ. – 2021. – Vol. 773. – P. 145623. DOI: 10.1016/j.scitotenv.2021.145623
28. Castillo-Giménez J., Montañés A., Picazo-Tadeo A.J. Performance and convergence in municipal waste treatment in the European Union // Waste Manag. – 2019. – Vol. 85. – P. 222–231. DOI: 10.1016/j.wasman.2018.12.025
29. Demirbas A. Waste management, waste resource facilities and waste conversion processes // Energy Convers. Manag. – 2011. – Vol. 52. – P. 1280–1287. DOI: 10.1016/j.enconman.2010.09.025
30. Environmental friendly drilling fluid additives: Can food waste products be used as thinners and fluid loss control agents for drilling fluid? / A.T.T. Al-Hameedi, H.H. Alkinani, S. Dunn-Norman, N.A. Alashwak, A.F. Alshammari, M.M. Alkhamis, H.W. Albazzaz, R.A. Mutar, M.T. Alsaba // SPE Symposium: Asia Pacific Health, Safety, Security, Environment and Social Responsibility; OnePetro: Kuala Lumpur, Malaysia, 2019. DOI: 10.2118/195410-MS
31. A comprehensive investigation on the performance of durian rind as a lost circulation material in water-based drilling mud / N.F.F. Majid, A. Katende, I. Ismail, F. Sagala, N.M. Sharif, M.A.C. Yunus // Petroleum. – 2019. – Vol. 5. – P. 285–294. DOI: 10.1016/j.petlm.2018.10.004
32. Ghayedi A., Khosravi A. Laboratory investigation of the effect of GO-ZnO nanocomposite on drilling fluid properties and its potential on H2S removal in oil reservoirs // J. Pet. Sci. Eng. – 2020. – Vol. 184. – P. 106684. DOI: 10.1016/j.petrol.2019.106684
33. A novel field applicable mud formula with enhanced fluid loss properties in high pressure-high temperature well condition containing pistachio shell powder / S. Davoodi, A.R. SA, S. Jamshidi, A.F. Jahromi // J. Pet. Sci. Eng. – 2018. – Vol. 162. – P. 378–385. DOI: 10.1016/j.petrol.2017.12.059
34. Hossain M.E., Wajheeuddin M. The use of grass as an environmentally friendly additive in water-based drilling fluids // Pet. Sci. – 2016. – Vol. 13. – P. 292–303. DOI: 10.1007/s12182-016-0083-8
35. Agarwood waste as a new fluid loss control agent in water-based drilling fluid / A. Azizi, M.S.N. Ibrahim, K.H.K. Hamid, A. Sauki, N.A. Ghazali, T.A.T. Mohd // Int. J. Sci. Eng. – 2013. – Vol. 5. – P. 101–105. DOI: 10.12777/ijse.5.2.101-105
36. Iscan A., Kok M. Effects of walnut shells on the rheological properties of water-based drilling fluids // Energy Sources Part A. – 2007. – Vol. 29. – P. 1061–1068. DOI: 10.1080/00908310600713982
37. Alcheikh I., Ghosh B. A comprehensive review on the advancement of non-damaging drilling fluids // Int. J. Petrochem. Res. – 2017. – Vol. 1. – P. 61–72. DOI: 10.18689/ijpr-1000111
38. Thermothickening Drilling Fluids Containing Bentonite and Dual-Functionalized Cellulose Nanocrystals / M.-C. Li, Q. Wu, T. Lei, C. Mei, X. Xu, S. Lee, J. Gwon // Energy Fuels. – 2020. – Vol. 34. – P. 8206–8215. DOI: 10.1021/acs.energyfuels.0c01192
39. Evaluation of polymer/bentonite synergy on the properties of aqueous drilling fluids for high-temperature and high-pressure oil wells / P.C. da Câmara, L.Y. Madruga, N.d.N. Marques, R.C. Balaban // J. Mol. Liq. – 2021. – Vol. 327. – P. 114808. DOI: 10.1016/j.molliq.2020.114808
40. Thermoresponsive bentonite for water-based drilling fluids / W. Dong, X. Pu, Y. Ren, Y. Zhai, F. Gao, W. Xie // Materials. – 2019. – Vol. 12. – P. 2115. DOI: 10.3390/ma12132115
41. Impact of barite and ilmenite mixture on enhancing the drilling mud weight / M. Abdou, A. Al-Sabagh, H.E.-S. Ahmed, A. Fadl // Egypt. J. Pet. – 2018. – Vol. 27. – P. 955–967. DOI: 10.1016/j.ejpe.2018.02.004
42. Thermochemical upgrading of calcium bentonite for drilling fluid applications / M. Magzoub, M. Mahmoud, M. Nasser, I. Hussein, S. Elkatatny, A. Sultan // J. Energy Res. Technol. – 2019. – Vol. 141. – P. 042902. DOI: 10.1115/1.4041843
43. Activation of (Na, Ca)-bentonites with soda and MgO and their utilization as drilling mud / C. Karagüzel, T. Çetinel, F. Boylu, K. Cinku, M. Çelik // Appl. Clay Sci. – 2010. – Vol. 48. – P. 398–404. DOI: 10.1016/j.clay.2010.01.013
44. Overcoming Salt Contamination of Bentonite Water-Based Drilling Fluids with Blended Dual-Functionalized Cellulose Nanocrystals / M.-C. Li, Q. Wu, J. Han, C. Mei, T. Lei, S.-Y. Lee, J. Gwon // ACS Sustain. Chem. Eng. – 2020. – Vol. 8. – P. 11569–11578. DOI: 10.1021/acssuschemeng.0c02774
45. A novel thermo-associating polymer as rheological control additive for bentonite drilling fluid in deep offshore drilling / B. Xie, A.P. Tchameni, M. Luo, J. Wen // Mater. Lett. – 2021. – Vol. 284. – P. 128914. DOI: 10.1016/j.matlet.2020.128914
46. Ikram R., Jan B.M., Ahmad W. An overview of industrial scalable production of graphene oxide and analytical approaches for synthesis and characterization // J. Mater. Res. Technol. – 2020. – Vol. 9. – P. 11587–11610. DOI: 10.1016/j.jmrt.2020.08.050
47. Study of graphene oxide to stabilize shale in water-based drilling fluids / K. Wang, G. Jiang, X. Li, P.F. Luckham // Colloids Surf. A. – 2020. – Vol. 606. – P. 125457. DOI: 10.1016/j.colsurfa.2020.125457
48. Aramendiz J., Imqam A. Water-based drilling fluid formulation using silica and graphene nanoparticles for unconventional shale applications // J. Pet. Sci. Eng. – 2019. – Vol. 179. – P. 742–749. DOI: 10.1016/j.petrol.2019.04.085

49. Experimental investigation of the effects of silica nanoparticle on hole cleaning efficiency of water-based drilling mud / A.O. Gbadamosi, R. Junin, Y. Abdalla, A. Agi, J.O. Oseh // J. Pet. Sci. Eng. – 2019. – Vol. 172. – P. 1226–1234. DOI: 10.1016/j.petrol.2018.09.097
50. Influence of silica nanoparticles on the functionality of water-based drilling fluids / M. Al-Yasiri, A. Awad, S. Pervaiz, D. Wen // Journal of Petroleum Science and Engineering. – 2019. – Vol. 179. – P. 504-512. DOI: https://doi.org/10.1016/j.petrol.2019.04.081
51. Medhi S., Gupta D., Sangwai J.S. Impact of zinc oxide nanoparticles on the rheological and fluid-loss properties, and the hydraulic performance of non-damaging drilling fluid // J. Nat. Gas Sci. Eng. – 2021. – Vol. 88. – P. 103834. DOI: 10.1016/j.jngse.2021.103834
52. Fluid filtration and rheological properties of nanoparticle additive and intercalated clay hybrid bentonite drilling fluids / M.M. Barry, Y. Jung, J.-K. Lee, T.X. Phuoc, M.K. Chyu // J. Pet. Sci. Eng. – 2015. – Vol. 127. – P. 338–346. DOI: 10.1016/j.petrol.2015.01.012
53. Data on experimental investigation of Methyl Ester Sulphonate and nanopolystyrene for rheology improvement and filtration loss control of water-based drilling fluid / H. Elochukwu, L.K.S. Sia, R. Gholami, M.A. Hamid // Data Brief. – 2018. – Vol. 21. – P. 972–979. DOI: 10.1016/j.dib.2018.10.055
54. Abdo J., AL-Sharji H., Hassan E. Effects of nano-sepiolite on rheological properties and filtration loss of water-based drilling fluids // Surf. Interface Anal. – 2016. – Vol. 48. – P. 522–526. DOI: 10.1016/j.powtec.2020.08.053
55. Analysis of high performing graphene oxide nanosheets based non-damaging drilling fluids through rheological measurements and CFD studies / S. Medhi, S. Chowdhury, N. Bhatt, D.K. Gupta, S. Rana, J.S. Sangwai // Powder Technol. – 2021. – Vol. 377. – P. 379–395. DOI: 10.1016/j.powtec.2020.08.053

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