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Enhancing drilling mud efficiency and environmental safety with biodegradable materials

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Abstract

Using biodegradable chemicals such as potassium sorbate, potassium citrate, and potassium bicarbonate in drilling mud is pivotal for enhancing the rheological mud properties while addressing environmental concerns. Despite their proven success in various industries, their potential in drilling operations remains largely untapped. The presence of potassium ions in these chemicals can consider them as promising alternatives to the traditional shale inhibitors including KCl. In this study, different concentrations (1%-7%) of the selected chemicals were incorporated into the drilling mud, with varying weights (3.5g to 24.5g). These drilling muds were then subjected to different tests encompassing mud density, rheology, filtration volume, and pH. The results indicated that potassium sorbate at 7% concentration notably an increase in mud viscosity with a shear stress reading of 150 at 600 RPM. Conversely, potassium citrate exhibited similar rheological properties to KCl, with a shear stress reading of 50 at the same concentration. The results of Potassium bicarbonate are comparable to the results of KCl. Potassium sorbate significantly enhanced the mud filtration properties at 7% concentration, yielding approximately 5 ml filtrate in 7.5 minutes, while the other chemicals showed minimal impact on filtration volume even at higher concentrations. All materials maintained a pH of around 8 at elevated concentrations. This study underscores the potential of biodegradable materials in optimizing rheological mud properties for efficient and environmentally friendly drilling operations.

Keywords: Drilling fluid; environmentally friendly; Potassium sorbate; potassium citrate; potassium bicarbonate.

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1- Introduction

Drilling fluid is a major component in drilling operations. It has various functions, including wellbore stabilization, the removal of drill cuttings to the surface, and lubricating and cooling the drilling equipment [1]. Drilling mud also aids in controlling the formation pressure limiting wellbore influx and lowering the possibility of blowouts. Furthermore, it allows for the collection of formation data during drilling, which aids in the evaluation of geological features and informs decisions regarding well completion and production strategies. These functions can be achieved through constructing the rheological mud properties, mud density, filtration control, and pH However, more uncertainties in planning the drilling fluid's rheological properties and filtration capability meant that operators faced more drilling challenges with inexplicable differences between the used and the required mud properties.

Fluid additives are chemical substances that are added to the base drilling fluid to obtain specific drilling qualities and improve drilling efficiency [2]. They are essential in influencing the drilling fluid's rheological properties, such as viscosity and gel strength, which affect flow behavior and hole cleaning [3]. As well as it can achieve filtration management, limiting solids invasion and ensuring wellbore stability. The application of weighing agents achieves density control while also maintaining correct hydrostatic pressure and well control [4]. Concerning pH, water-based drilling fluids operate best at pH levels ranging from 8.0 to 10.5. However, mud with a pH below 7.0 becomes acidic, causing corrosion and pollution. To elevate the pH of drilling mud to 8.0 or 10.5, imported chemicals like NaOH and Na_2CO_3 are typically added [5]. Furthermore, environmental concerns can be addressed by the use of environmentally friendly additives. The effect of adding potassium sorbate on the properties of drilling mud and also as an alternative to KCL as a shale inhibitor has been studied by researchers, the results showed a clear effect of increasing the rheological properties and viscosity when starting with increasing the concentration of potassium sorbate. It can also provide good efficiency in solving the problem of shale swelling. But it gives lower density compared to KCL [6].

There is also a study that focused on the impact of potassium citrate as a swelling inhibitor on the filtration properties. They concluded that the addition of potassium citrate can reduce the filtrate volume (thus also reducing the cake thickness) of drilling mud when a high concentration of potassium citrate was used (greater than 25g for 350ml of water) [7].

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Potassium drilling mud produces hydrostatic pressure to avoid wellbore collapse, interacts with clay minerals to minimize swelling, can withstand high temperatures, and it is environmentally work well, resulting in more effective drilling operations. Overall, potassium drilling mud can significantly contribute to achieving efficient and safe drilling operations [8]. The most common potassium mud is potassium chloride. However, the existence of chloride, which has substantial detrimental impacts on the environment, has given rise to the need to discover alternative materials [9]. Excessive usage of chloride is capable of harming plants, causing soil and water pollution, as well as, it has a higher corrosion potential [10]. The greatest difference between this study and the literature is that several concentrations were used to compare the properties that the materials can support the drilling mud. In addition, the potassium bicarbonate is being tested for the first time as an additive to drilling mud.

The aim of study is to investigate the effect of three biodegradable materials (potassium sorbate, potassium citrate, and potassium bicarbonate) on the drilling mud to understand how its properties (density, viscosity, filtration volume, and pH) are changed, then compare the results with the properties that given by KCL drilling mud.

2- Materials and overview

Potassium Bicarbonate: $KHCO_3$ is a white, odorless, crystalline powder and soluble in water. Potassium bicarbonate has numerous applications in various industries. It is used in the food industry to regulate pH, leaven, and buffer. It has a density of 2.17 g/cc. It is safe to consume and well-recognized as a food ingredient. It also works as a potassium supplement for deficiency and a potassium source in agriculture, aiding in the prevention of fungal diseases, as well as it works as a fire suppressant in extinguishers for a variety of fires [11].

Potassium Citrate: It is a potassium salt of citric acid with the chemical formula $K_3C_6H_5O_7$. It is a white, odorless, hygroscopic crystalline powder that dissolves in water. It has a density of approximately 1.98 g/cc. Potassium citrate is used to treat a kidney stone problem known as renal tubular acidosis, it is commonly used as a wet chemical fire suppression in aqueous solutions with other potassium salts. It serves as a buffering ingredient in a variety of soft drinks [12].

Potassium Sorbate: This synthetic salt is normally made from sorbic acid and potassium hydroxide; it has no odor or flavor. Potassium sorbate increases the shelf life of foods by inhibiting the formation of mold, yeast, and fungi. The chemical formula is $C_6H_7KO_2$. The white crystals have a density of 1.363 g/cc and a solubility of 58.5 g/100 mL in water at 100°C [13].

Potassium Chloride (KCL). It is a white crystalline solid that is highly soluble in water. It has a density of 1.98 g/cm³. It has a salty taste, used as a food additive to enhance flavor and as a preservative. It is used in medical settings as a source of potassium supplementation and as a salt substitute. However, excessive intake should be avoided [9].

These materials offer cost-effective solutions by enhancing food preservation, aiding agriculture in disease prevention, and serving diverse industrial needs, such as fire suppression. Their multiple applications underscore their economic value and importance across various sectors.

3- Drilling mud tests

The drilling mud was prepared based on API 13A, which includes adding 22.5 g of bentonite to 350 ml of water (the density of the Blank Mud was 8.55 ppg). The materials were added in different volumetric concentrations (1%-7%). The mud was left 24 hr before testing, then the effect of the materials concentrations on the properties of drilling mud was tested as follows:

3.1. Mud density

Mud weight, which is sometimes expressed in pounds per gallon (lb/gal) (ppg) or pound cubic feet (PCF), is the density of the drilling fluid that is required to control the formation pressure by the pressure exerted by the weight of mud column, known as hydrostatic pressure. Mud weight reduction could lead to formation collapse. In contrast, if the mud weight is greater than the fracture gradient of the interested zone it may fracture the formation [14].

After preparing different samples of drilling mud containing different volumetric concentrations of the selected materials the mud balance was used to conduct the density test, as it contains a cup in which drilling mud is placed, and through a weight on an arm, the weight is balanced, and the density value can be read in different units. The density of drilling mud without any addition is 8.55 ppg. As presented in Fig. 1, the results showed a difference in the density incremental of the drilling mud due to the difference in the density of each additive. It can be noted that potassium sorbate gave the lowest density compared to the rest of the materials, KCL and potassium citrate have the same density (each one has density of 1.98 g/cc), while Potassium Bicarbonate ($KHCO_3$) gave the highest density among other materials.

3.2. Rheological mud properties

Rheological properties of drilling mud refer to its flow and deformation characteristics, which influence its ability to carry cuttings, manage pressure, and maintain well stability during drilling operations [15]. These characteristics are apparent viscosity, gel strength, yield point, and plastic viscosity. A viscometer is mostly used in the laboratory to assess the rheological properties of mud [16]. A variety of factors can influence the drilling mud's rheological properties, including the mud's composition, Temperature, pressure, shear rate, age, salinity, pH levels, and solids concentration. Understanding these aspects and their impacts is essential for improving the mud compositions, modifying parameters, and sustaining efficient drilling operations while preserving wellbore stability [17].

By adding different volumetric concentrations of the selected materials, it was tested with a viscometer model 35, which has 7 speeds through which the rotational speeds are 6, 30, 60, 100, 200, 300, and 600 RPM. At each speed, the shear stress is read, which is an indicator of the mud's viscosity.

Fig. 2 illustrates the results of adding $KHCO_3$, which causes a slight increase in the viscosity of the drilling fluid. This increase appears at high concentrations (i.e., at the weight of 24.5 g). Adding potassium citrate provides outcomes similar to that obtained by adding $KHCO_3$ and KCL. This can be attributed to the increase the viscosity of drilling mud at 7% concentration (Fig. 3). Also, the results showed that potassium sorbate increases the rheological properties of drilling mud, as the results began to increase at a concentration of 3%. The shear stress is reached to be 150 at 600 RPM at a concentration of 7% (Fig. 4), which makes it useful for improving the properties of drilling mud. When compared to KCL (Fig. 5), potassium sorbate provides a viscosity that differs significantly from KCL, whereas KCL produces results similar to $KHCO_3$ and potassium citrate. Adding all the previous materials to drilling mud has been observed to have an impact on its viscosity. However, the extent of this impact is contingent upon the concentration of each material. Consequently, it is important to note that the properties contributed by these materials may vary when considering the same concentration levels.

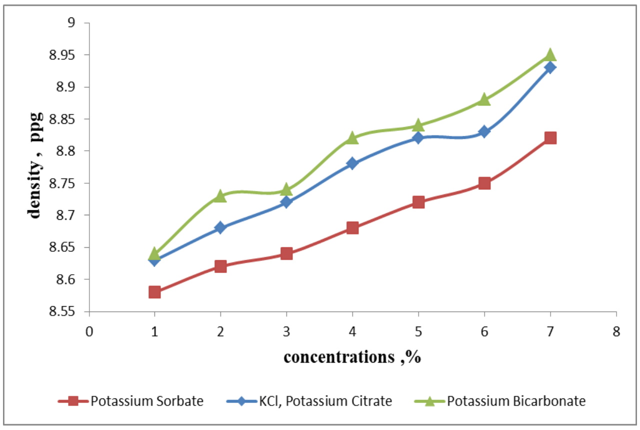

Fig. 1. Density of drilling mud with various concentrations of materials

3.3. pH

The pH scale represents the hydrogen ion concentration in a liquid, which is used to determine how acidic or alkaline drilling mud is. The pH scale, which ranges from 0 to 14, represents the inverse measurement of the hydrogen concentration in the fluid. A pH of 7 is generally considered neutral. A fluid is deemed alkaline if its pH is greater than 7. Conversely, liquids having a pH of less than 7 are referred to as acidic [18]. pH is one of the most important mud qualities to monitor in drilling mud since it affects the solubility of specific compounds, corrosion processes, and clay interactions [19]. pH paper or a pH meter can be used to measure the pH of drilling mud. A row of pH-sensitive indicators on pH paper changes color in response to the fluid's pH. By comparing the color changes on the pH paper with the color chart that comes with the sticks, the pH can be found. they are simple to use and highly convenient [20].

By immersing the pH paper into drilling fluid that containing different volumetric concentrations of the selected materials and observing its color change, the results showed that the drilling fluid has 6 as a pH value when additives have not existed. With the addition of low concentrations of materials (from 1% to 3%), the result of pH is still equal to 6. With increasing concentrations from 4% to 7%, the value of pH increases to be 8. The presence of potassium ions in chemicals added to drilling mud significantly influences the pH of the mud, act as buffering agents. Potassium ions absorbing hydrogen or hydroxide ions that subsequently forming potassium hydroxide, an alkaline substance. This process increases the pH value of the drilling mud. Additionally, the concentration of potassium ions is directly correlated with the pH value; higher concentrations of potassium ions lead to a higher pH value.

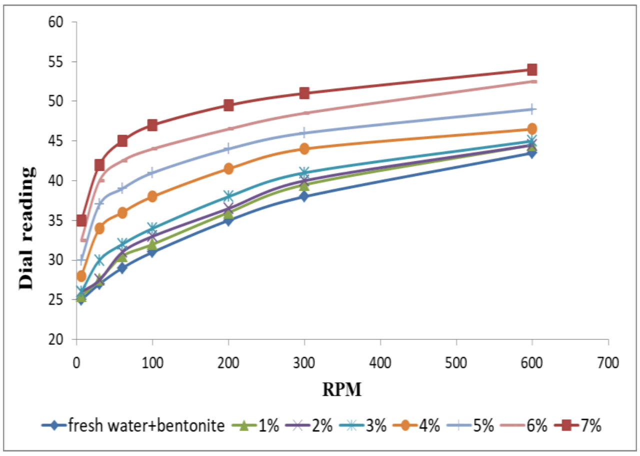

Fig. 2. Dial reading of $KHCO_3$

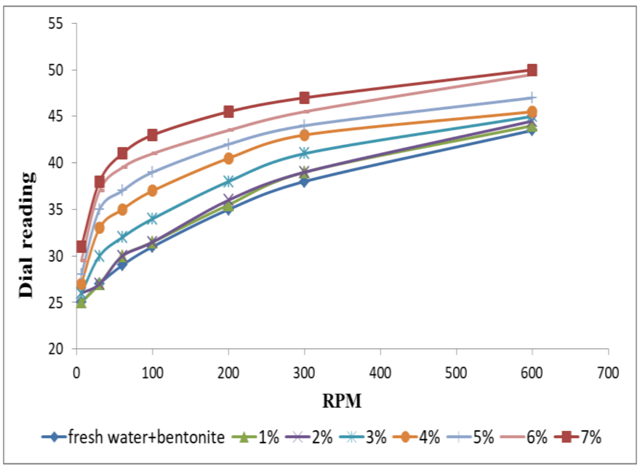

Fig. 3. Dial reading of potassium citrate

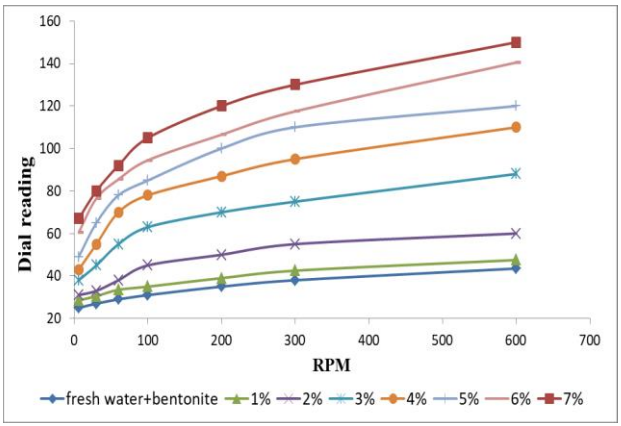

Fig. 4. Dial reading of potassium sorbate

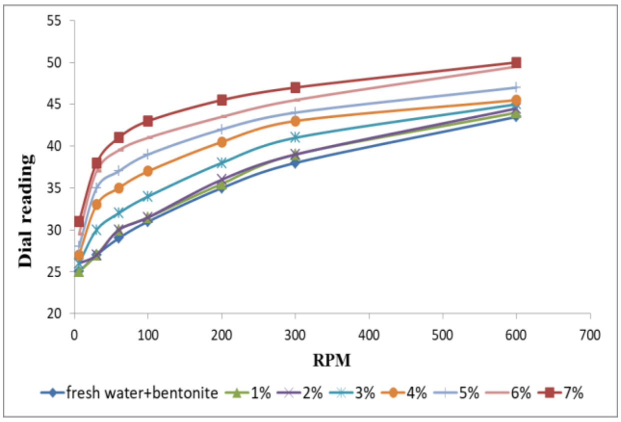

Fig. 5. Dial reading of KCL

3.4. Filtration volume test

The filtration property of drilling mud is crucial for preserving wellbore stability, reducing formation damage, and assuring efficient drilling operations by effectively eliminating solid particles and contaminants from the drilling fluid [21]. In general, the filtering phenomenon happens when a porous medium is compressed against a drilling fluid that contains suspended particulates. Mud cake is produced when the solid components of the mixture settle and connect to the surface of the porous formation that is in contact with the liquid. Over time, the cake thickens, causing the filtration rate to gradually decrease [22]. To maintain good filtration properties, various additives, such as filtration control agents, are often added to drilling mud formulations. These additives help in reducing the fluid loss and improving the filter cake quality, thereby enhancing the filtration efficiency [23]. The filtration property is typically measured by parameters such as the mud's filtration rate, filter cake thickness, and permeability. A good filtration property means that the mud forms a suitable filter cake on the wellbore walls, effectively preventing the invasion of formation solids into the wellbore and maintaining wellbore stability. It also ensures that the drilling fluid maintains its desired properties and functions optimally throughout the drilling process [24]. The filtration test involves placing the drilling mud in a mud cup that is installed by assembling the base cup with filter tube, filter paper, cell body, and rubber gasket (Fig. 6). It is closed using a top cup through which a pressure of 100 psia is applied. The pressure is adjusted while recording the time, collecting the amount of filtrate volume, and recording the filtrate volume at (0, 2, 4, 6, 7.5 min).

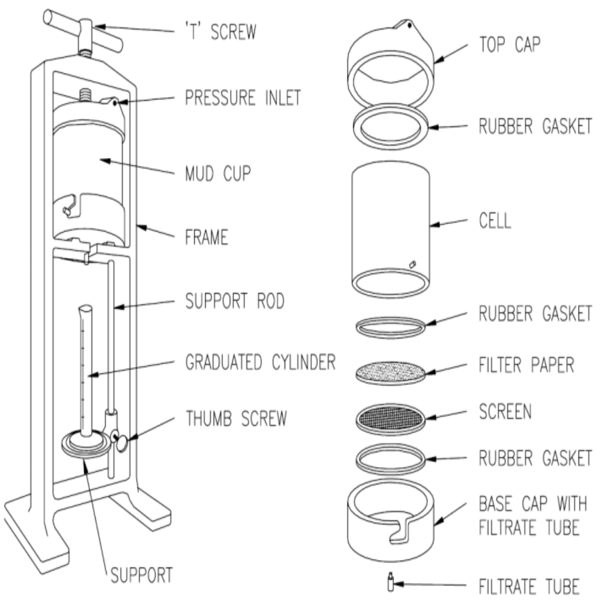

Fig. 6. Filtration test equipment

Through the use of different chemicals and conducting a filtration test, it was observed that $KHCO_3$ (Fig. 7) led to a slight reduction in filtration, as this reduction was observed at a concentration of 4%, where the filtration volume was 45ml at 7.5min. Potassium citrate, it can lead to a slight increase in the rheological properties; it reduced the filtration volume slightly, as at a concentration of 7%, the filtration volume was 46 ml at 7.5 min (Fig. 8). Additionally, potassium sorbate greatly improves the filtration properties, as the filtration volume decreases clearly when starting with a volumetric concentration of 3% upwards. The results showed a reduction of filter volume at 7% about 45 ml (Fig. 9). Compared to KCL (Fig. 10), potassium sorbate is the only substance that reduced the filtration volume significantly compared to the rest of the additives. Even at low concentrations, it shows a clear effect on the filtration volume.

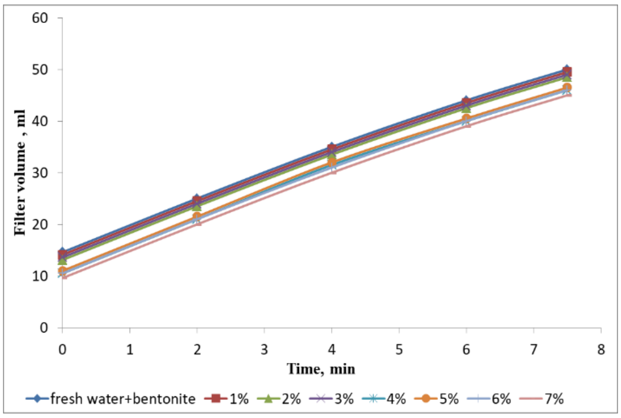

Fig. 7. Filter volume of $KHCO_3$

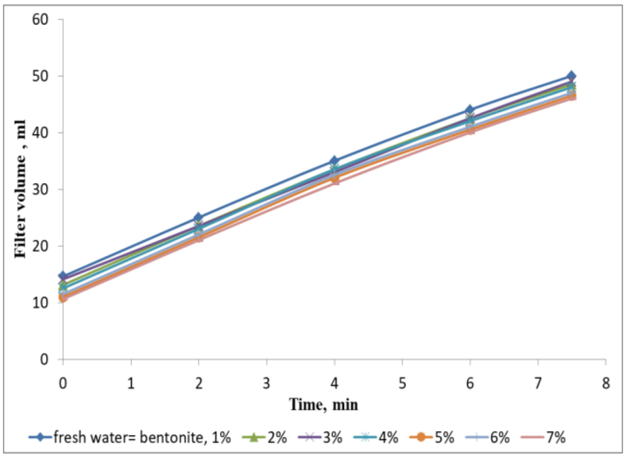

Fig. 8. Filter volume of potassium citrate

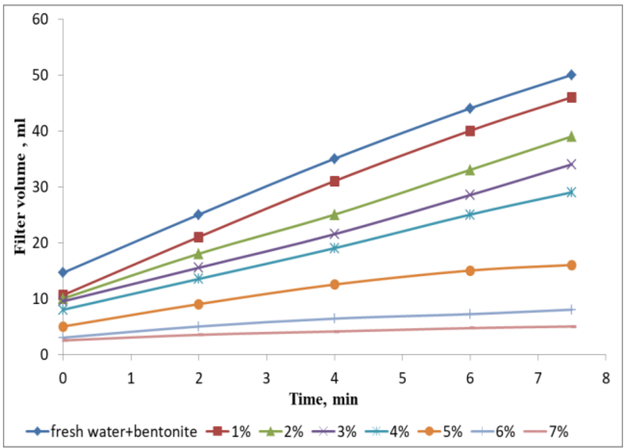

Fig. 9. Filter volume of potassium sorbate

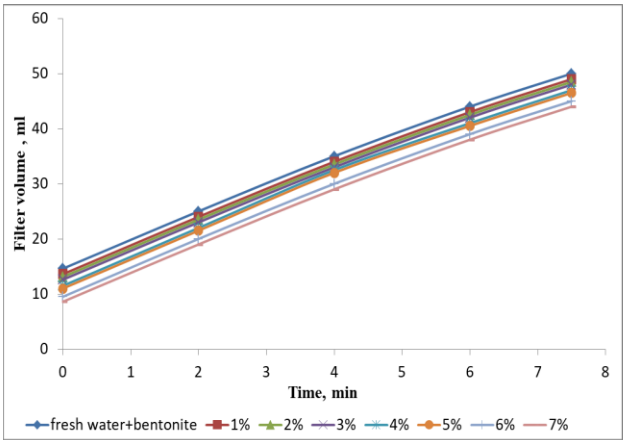

Fig. 10. Filter volume of KCL

4- Conclusion

This study presents three friendly-environmental biodegradable chemicals to evaluate their effects on the drilling mud's rheological properties. The obtained key points can be summarized as follow:

1. The proposed environmentally friendly and biodegradable materials (potassium bicarbonate, potassium citrate and potassium sorbate) have been firstly tested in this study to figure out their effects on the drilling mud properties. It can be used as an alternative to KCL.
2. Four tests were conducted to determine the properties of the drilling mud after adding environmentally friendly and biodegradable materials (density, viscosity, filtrate volume and pH). The results were also compared with the addition of KCL.
3. Using a mud balance, it was determined that $KHCO_3$ exhibited the highest density among the tested materials. Potassium citrate displayed the same density as KCL, as both materials possess similar densities to the base material. In contrast, potassium sorbate yielded a lower density compared to the other materials when incorporated into the drilling mud.
4. The VG-meter results showed that $KHCO_3$ and potassium citrate has rheological properties close to those given by KCL, with slight increase in the viscosity of the drilling mud, which appears at 7% concentration. Finally, Potassium sorbate is the only substance that gave a much higher viscosity than KCL, as even at low concentrations.
5. It has been observed that $KHCO_3$ and Potassium citrate does not decrease the volume of the filtrate significantly when added to drilling mud, as in the filtrate provided by KCL. The volume of the filtrate decreases significantly when potassium sorbate is added to the drilling mud. Even at low concentrations, potassium sorbate demonstrated improved filtration properties.
6. The thickness of the mud cake was large when $KHCO_3$ and potassium citrate were added, whereas it was close to the thickness when KCL was added. As for potassium sorbate, the mud cake decreased as the concentration of the substance increased.
7. The pH test showed that all materials at high concentrations give a pH of 8, but at concentrations less than 3% they give a pH close to 6.

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استخدام مواد قابلة للتحلل وصديقة للبيئة للحصول على خصائص طين حفر فعّالة

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[١] قسم هندسة النفط، كلية الهندسة، جامعة بغداد، بغداد، العراق

الخلاصة

يقدم هذا البحث استخدام ثلاث مواد صديقة للبيئة وقابلة للتحلل لإضافتها لطين الحفر وهي (potassiumbicarbonate , potassium citrate , potassium sorbate). حيث ان هذه المواد يمكن استخدامها كبديل للKCL بسبب ان ايون الكلور يسبب ضرر للبيئة حيث انه غير قابل للتحلل والنسب العالية منه تسبب ضرر للكائنات الحية. على الرغم من استخدام هذه المواد على نطاق واسع وناجح في العديد من الفروع الصناعية، إلا أنها لا تزال غير مستغلة بالقدر الكافي في صناعة الحفر لتطبيقات مستقبلية رائعة. يعد وجود أيون البوتاسيوم في جميع المواد المختارة فائدة أخرى مما يجعله مادة بديلة لـ KCL كمثبط للصخر الزيتي. تم في هذه الدراسة إجراء عدة اختبارات تشمل كثافة الطين، و ريولوجية الطين، وحجم الترشيح، ودرجة الحموضة للتحقق من خواص الطين الريولوجية. وقد أجريت هذه الاختبارات على طين الحفر الذي يحتوي على تراكيز حجمية مختلفة من المواد الكيميائية المختارة (١%–٧%)، والتي تشمل أوزان مختلفة (٣,٥ جرام، ٧ جرام، ١٠,٥ جرام، ١٤ جرام، ١٧,٥ جرام، ٢١ جرام، ٢٤,٥ جرام). اظهرت النتائج ان potassium sorbate يعمل على زيادة لزوجة سائل الحفر ويقلل من حجم الترشيح بصورة كبيرة مقارنة مع KCL. اما potassium citrate و potassium bicarbonate فإنها تعطي خواص لزوجة وحجم ترشيح قريب من تلك التي تعطيها KCL. بالنسبة لدرجة الحموضة فإنها كلما زاد تركيز ايون البوتاسيوم في طين الحفر يؤدي الى زيادة قاعدية الطين.

الكلمات الدالة: سائل الحفر، صديق للبيئة، سوربات البوتاسيوم، بوتاسيوم سترات، بيكربونات البوتاسيوم.