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Evaluation of using waste pinecones as an eco-friendly additive to water-based mud

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Abstract
This study is investigating the possibility of using pinecones as additive materials to develop a water-based drilling mud. Pinecones are environmentally friendly agricultural wastes and have no practical applications. Therefore, this study is of great importance in that it highlights the investment of these natural waste materials in practical fields. The study focused on the effectiveness of pinecone powder in a water-based drilling mud. To this end, an experimental study on five types of pinecones (Austrian pinecones, Black Hills Spruce, Sitka Spruce, Norway Spruce, and White pinecones) was performed and tested to determine their ability to reduce filter loss and also the effect of those eco-friendly materials on the rheological properties and density of the mud. In the study, 26 samples of water-based mud mixed with the different types of pinecones at different concentrations based on the weight of mud sample (1 wt%, 2 wt%, 3 wt%, 4 wt%, and 5 wt%) were used to perform the experiments. The results of the study showed that pinecones have a great ability to reduce filter loss, particularly Norway Spruce cones, which, based on this study, are considered the superior type with a concentration of 3 wt%.

Keywords:
pinecone powder; rheology; filter loss control; filter cake; environmentally friendly materials

1. Introduction

Wells are drilled in the oil and gas industry to reach the reservoir using safe procedures that cause no concerns. This requires protecting the excavated formations and preventing any damage inside them. This protection is achieved through the use of a mud cake that covers the wellbore, thus creating a low permeable boundary between the drilled formation and the inside of the well (**Feng et al., 2018**). A good mud cake must be thin and impermeable (**Khalid and Pao, 2014**). For this purpose, various water-based mud additives are used to reduce filter loss and also provide a mud cake with the proper specifications (**Fink, 2015**). There are several commercial additives, such as carboxymethyl cellulose (CMC), hydroxyethylcellulose (HEC), sodium polyacrylate, and polyanionic cellulose (PAC) that are used to control filter loss (**Houwen, 1993**). Mud cake formation means that the liquid phase of the drilling mud penetrates the drilled formations, leaving behind the solid phase to make a mud cake on the wellbore that limits further significant fluid filtration (**Ezeakacha et al., 2016**). One of the most significant characteristics of water-based mud is filter loss and through this property, the performance of water-based mud can be evaluated (**Agwu et al., 2019**). When the filtration liquid enters the formations, they contaminate the zones around the well, which leads to a negative impact on the productivity of these formations and reduces the strength of the wellbore (**Feng et al., 2018**). Commercial additives, such as (CMC) and (PAC) are costly materials that increase the total cost of drilling (**Okoro et al., 2018; Okon et al., 2020**). Therefore, researchers are looking for environmentally friendly natural materials with a lower cost compared to commercial additives that are used to reduce filter loss. Pinecones are highlighted in this research work as an additive to drilling mud to reduce the problem of filter loss and determine the effect of these materials on the rheological properties and density. The cone is the part of the pine tree that holds the seeds (**Sahin and Yalcin, 2017**). These cones are generally natural waste and have no practical use in human life. However, an attempt is made to use these cones in different fields (**Büyüksarı and Dundar, 2010; Gokdai et al., 2017; Ouafi et al., 2021**). The huge quantities of these abandoned cones in forests and greenery areas prove the fact that these cones are practically useless. Tons of pinecones are produced annually worldwide and remain environmentally neglected (**Ciesla and Nations, 1998; Sahin and Yalcin, 2017**). Pine forests are one of the largest and most widespread forests in the world (**The State of the World's Forests 2020**). Coniferous forests cover mountains in most areas of their spread in the world, especially in the northern

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hemisphere (**Plomion et al., 2007**). Most of the forests (more than half of the forests in the world) are concentrated in China, the United States of America, Russia, Canada, and Brazil (**The State of the World's Forests 2020**). Each pine tree produces an average of 50 pinecones per year. Pine nuts are a non-wood forest product and have nutritional uses (**Gonultas and Balaban Ucar, 2013**). Thus, these cones can be employed in the oil industry, especially as an additive to water-based mud, which may be profitable and environmentally safe. On the one hand, these natural wastes are treated beneficially, and on the other hand, they are used to solve the problem of filter loss, which protects the wellbore from contamination with these liquids. Pinecones can also be a natural source of cellulose, and carboxymethyl cellulose (CMC) can be prepared from pinecone powder (**Sahin and Yalcin, 2017**).

To the best of our knowledge, pinecones have not been used in any previous studies as an additive to water-based mud to control the rheological properties and reduce filter loss. Hence, the use of these different types of pinecones and their potential to reduce filter loss are the main novelties of this study. These experimental tests will be performed in the laboratory. There are many types of pinecones, and in this study, experiments were conducted on five types (Austrian Pinecones, Black Hills Spruce cones, Sitka Spruce cones, Norway Spruce cones, and White Pinecones).

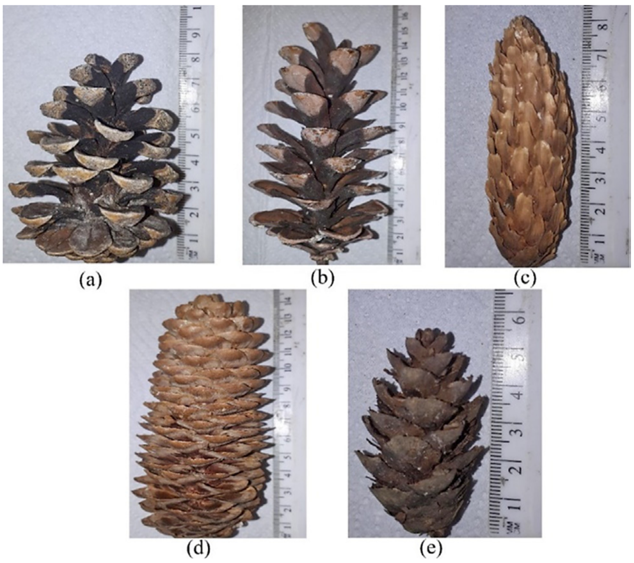

Figure 1: Waste pinecones: (a) Austrian pinecone, (b) White pinecone, (c) Sitka Spruce cone, (d) Norway Spruce cone, and (e) Black Hills Spruce cone.

2. Experimental procedures

2.1. Preparation of the pinecone powder

The five species of pinecones that were used in this study (Austrian Pinecones, Black Hills Spruce, Sitka Spruce, Norway Spruce, and White Pinecones, shown in **Figure 1**) were collected from the Tapolca Forest in Miskolc, Hungary. The cones were washed with clean water and then dried under the sun for one week. After drying, the cones were open and then all the seeds were removed from the cones. Next, the cones were ground by an electric grinding machine, see **Figure 2**. Finally, the powder was sieved by mesh with a size equal to or smaller than 450 μm. **Figure 3** displays the particle size distribution of the pinecone powder of different types, which were identified by using the HORIBA LA-950V2 laser diffraction particle size analyser. While the x-axis shows the particle diameter of the pinecones, the y-axis indicates cumulative undersize particles (%). The distribution of the microparticles range from 7 μm to 450 μm and the mean size of the Austrian pinecones was 100.62 μm, Black Hills Spruce was 97.17 μm, Sitka Spruce was 119.81 μm, Norway Spruce was 84.41 μm, and for the White pinecones, it was 94.12 μm. Then the cone powder was dried in an oven at 80°C for 4 hours to reduce the humidity of the cones. Approximately 350 g of pinecone powder were used for the experiments. The pinecone powder was added to the water-based mud as an additive with increasing concentrations based on the weight of mud sample (1 wt%, 2 wt%, 3 wt%, 4 wt%, and 5 wt%).

2.2. Preparation of water-based mud

In this study, the American Petroleum Institute standard (**API RP 13B-1, 2003**) was used to conduct all tests. The drilling mud in this research consists of water and bentonite in addition to calcium carbonate, which is usually used as a weighting agent to the drilling mud used to drill production zones. **Table 1** presents the mud compo-

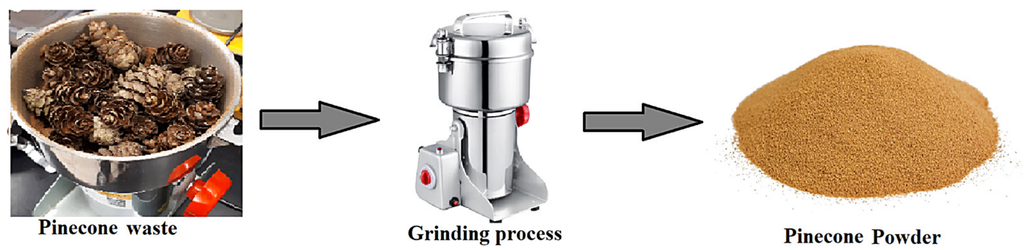

Figure 2: Grinding process

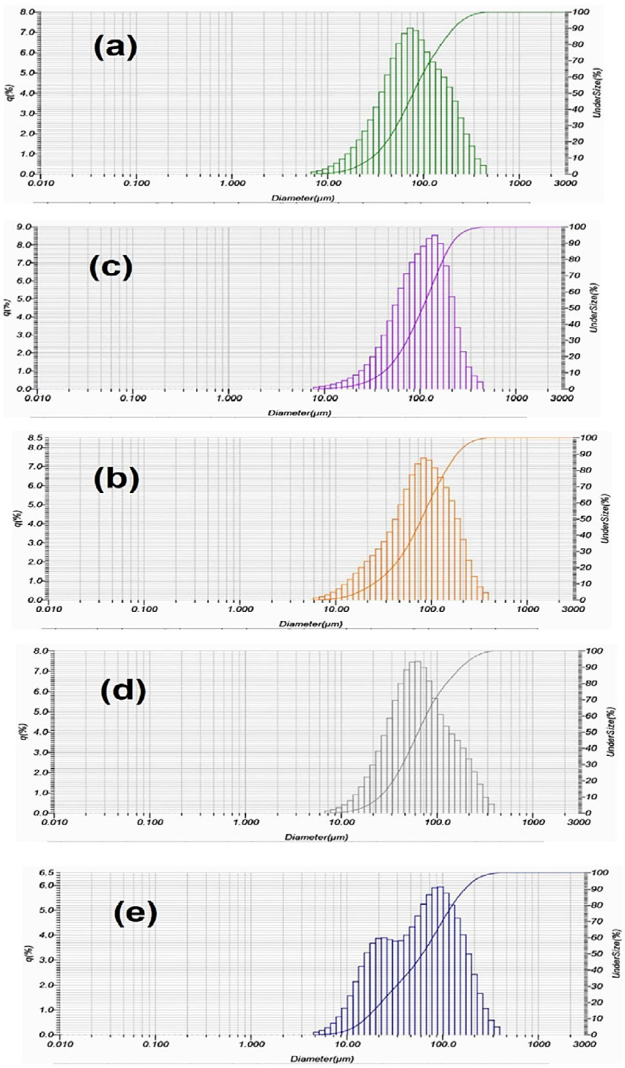

Figure 3: the particle size distribution of the (a) Austrian pinecone, (b) White pinecone, (c) Sitka Spruce cone, (d) Norway Spruce cone, and (e) Black Hills Spruce cone

Table 1: The materials and dosage used to formulate the water-based mud

Additives	Function(s)	Dosages
Water	Base fluid	350 [cm^3]
Bentonite	Viscosifier agent	22.5 [g]
Calcium carbonate	Weighting agent	45.8 [g]

sition and dosage used to formulate the water-based mud that was used in this work.

For the experiment measurements, 26 samples of water-based mud were prepared. Water-based bentonite mud, which is commonly used in well drilling, was used in the study. Fresh water and bentonite were used to prepare the mud in addition to Calcium carbonate, which was utilized as a weighting agent. Firstly, water was poured into a Hamilton Beach mixer, bentonite and calcium carbonate was added gradually during the mixing process, then the mixture was stirred for 20 minutes to get complete homogeneity. After that, the mixture was left for 24 hours to ensure the hydration of the bentonite before using it in the measurements. Experiments were then carried out to determine the rheology, density, filtration volume, and mud cake properties of the water-based mud sample without adding pinecone powder, and this was considered as the control mud in this study. Later, the designed concentrations of pinecone powder (1 wt%, 2 wt%, 3 wt%, 4 wt% and 5 wt%) in sequence from each type of pinecones were added to the 25 samples of water-based mud, then mixed for 10 minutes by a Hamilton mixer until homogeneity. Thereafter, a rheological test, density test under atmospheric pressure and ambient temperature (24°C), filtration volume test and mud cake thickness at 100 psi, and ambient temperature (24°C) were performed, and then the results of these tests were analysed.

3. Results and discussion

3.1. Rheological test results

Based on the data obtained with the Model 35A viscometer, the apparent viscosity, plastic viscosity, yield point, and gel strength were measured and calculated in this section. The rheological model which best describes flow characteristics of tested muds is Bingham plastic fluids. The equations of this model were used to perform all the calculations. The apparent viscosity is one of its most important properties, and it plays a critical part in the evaluation of water-based mud. The apparent viscosity of the water-based mud must be sufficiently high to properly suspend drilled cutting and perform well cleaning. Drilling fluid with insufficient apparent viscosity might cause major complications, leading to the well's abandonment. **Figure 4** depicts the apparent viscosity of water-based bentonite systems with and without increasing concentrations of pinecone powder. The inclusion of different types of pinecone powder in the water-based mud improves the apparent viscosity of the mud, as seen in **Figure 4.** When compared to base water-based mud without pinecone powder, the apparent viscosity of all samples incorporating different types of pinecone powder had a higher apparent viscosity. The apparent viscosity of the mud increased by 54%, 23%, 7%, 33% and 15% with a 5 wt% concentration composition of Austrian pinecone powder, Black Hills Spruce cone powder, Sitka Spruce cone powder, Norway Spruce cone powder, and White pinecone powder, respectively. Austrian pinecones showed a significant improvement in the apparent viscosity compared to the other types of cones.

Figure 5 demonstrates how the plastic viscosity of the mud changes when different types of pinecone powder are added. The plastic viscosity is proportional to the solid's concentration in the water-based mud and is caused by mechanical friction between particles in the mixture. In drilling operations, the plastic viscosity should be as low as feasible to reduce frictional pressure

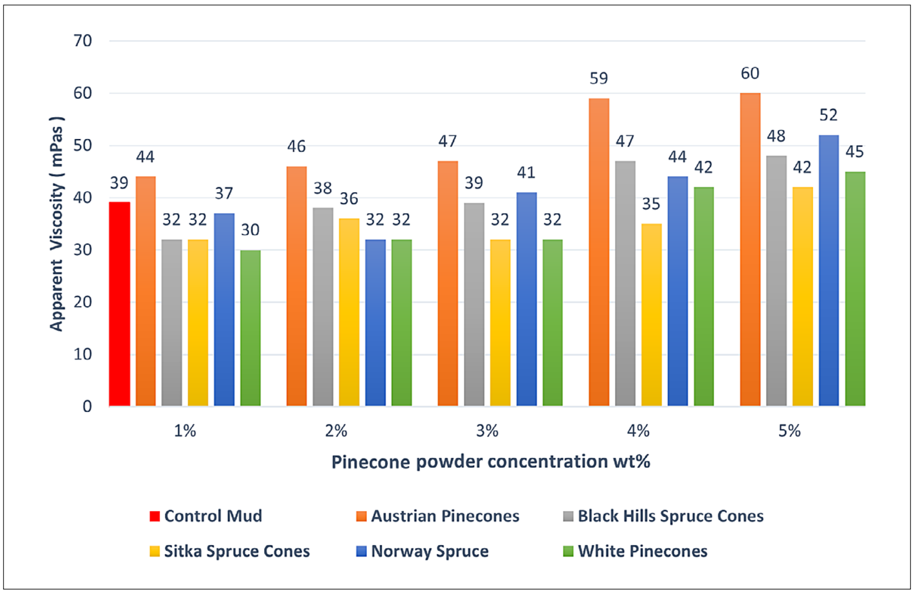

Figure 4: Apparent viscosity of water-based bentonite mud with additive at different pinecone concentrations

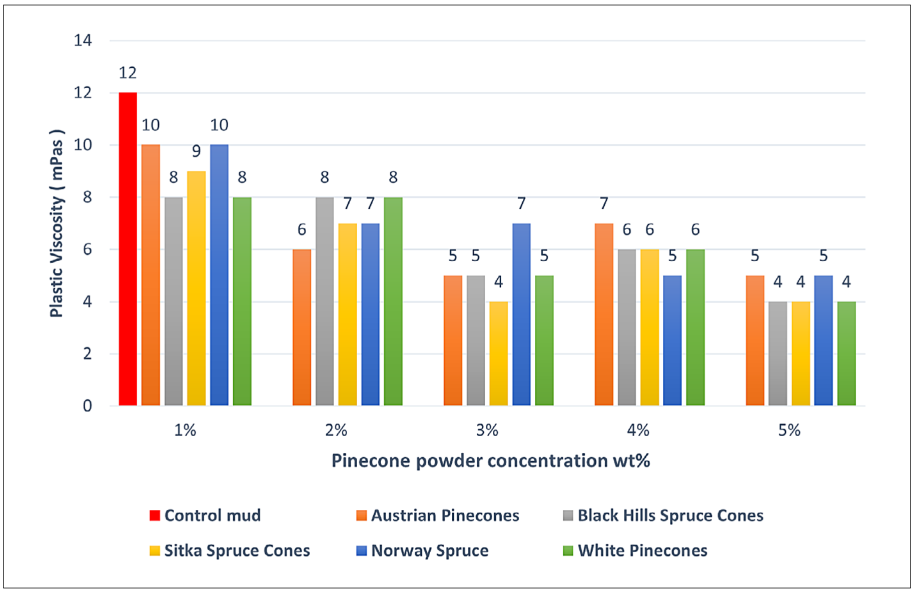

Figure 5: Plastic viscosity of water-based bentonite mud with additive at different pinecone concentrations

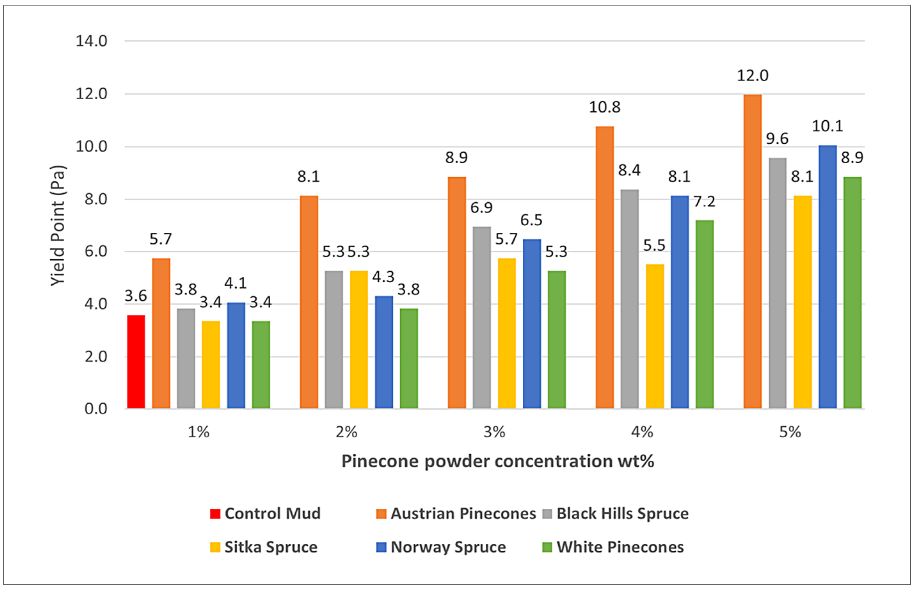

Figure 6: The yield point of water-based bentonite mud with an additive at different pinecone concentrations

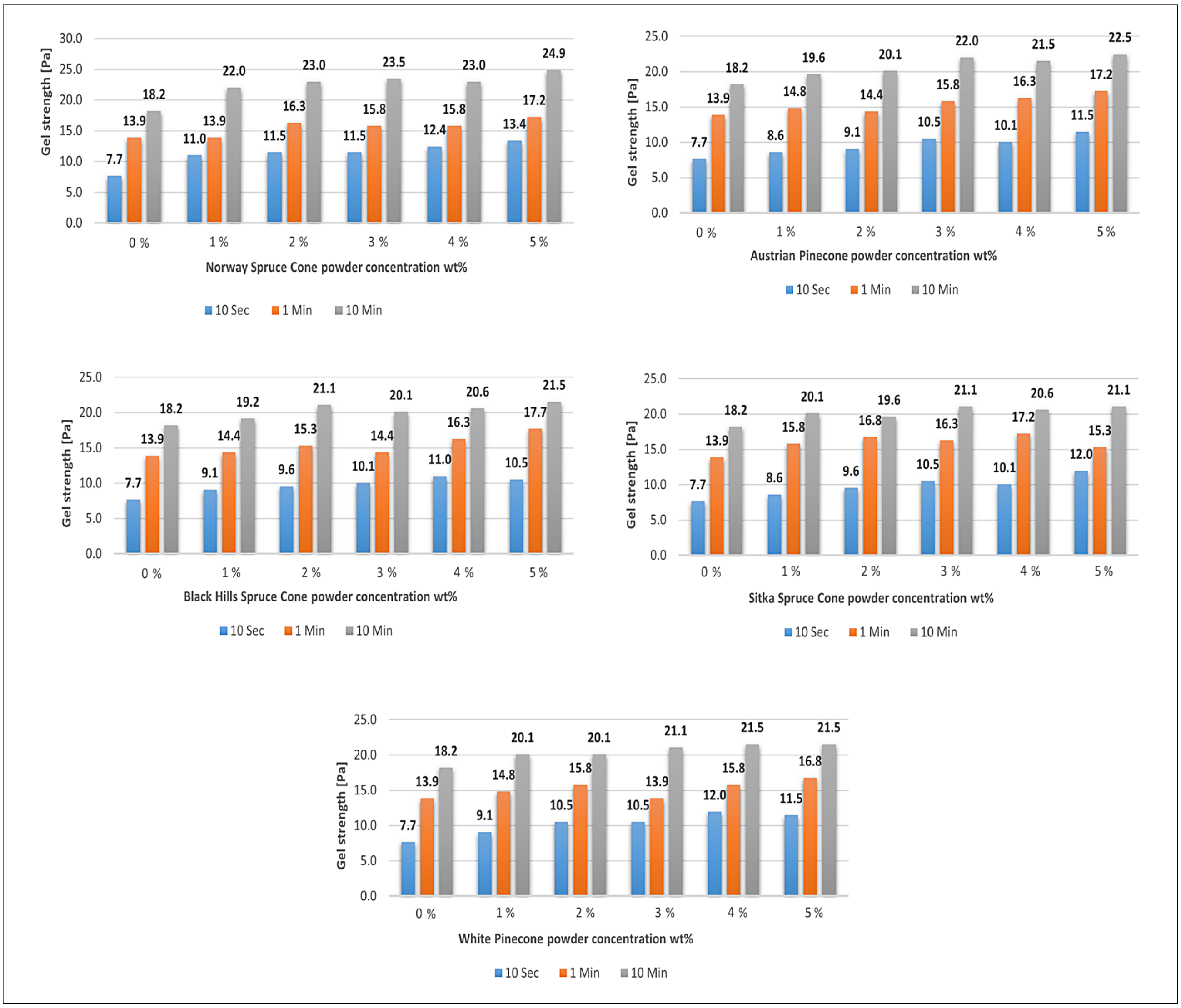

Figure 7: The gel strength of water-based bentonite mud with additive at different pinecone concentrations after (10 seconds, one minute, and 10 minutes)

loss in the drilling system. Higher equivalent circulation density (ECD) and pump pressure result from increased pressure losses. The greater (ECD) may be unacceptably high, causing a fracture in the formations, resulting in a significant rise in mud cost and negatively impact drilling costs. The plastic viscosity was consistently reduced when the concentration of pinecone powders was increased up to 5 wt%, which means that the pinecone particles dissolved in water.

The yield point of a water-based mud system is a very important property that indicates the degree of attraction between particles, and also determines the carrying capacity of the fluid. The yield point should be high enough to provide a higher carrying capacity, improve hole cleaning and decrease the hole problems. **Figure 6** shows the effects of adding different concentrations and types of pinecone powder to the mud on the yield point. The use of pinecone powder in the water-based mud increased the yield point of the mud, according to the results. With the addition of pinecone powder, the mud yield point increased. The yield point climbed steadily as the pinecone powder concentration increased, with the highest production point achieved with a water-based mud system containing 5 wt% Austrian pinecone powders, which boosted the yield point by 233%.

Gel strength is an important property of the water-based mud during periods of discontinuation of mud circulation. Water-based mud must have sufficient gel strength to hold the rock cutting and prevent their deposition at the bottom, which increases the difficulty of circulating the water-based mud again and increases the chances of pipe sticking. In this study, gel strength was measured after ten seconds (initial gel strength) and ten minutes (final gel strength). **Figure 7** demonstrates that the gel strength of 10 seconds, 1 minute, and 10 minutes grew steadily as the concentration of different types of pinecone powder increased. The gel strength value re-

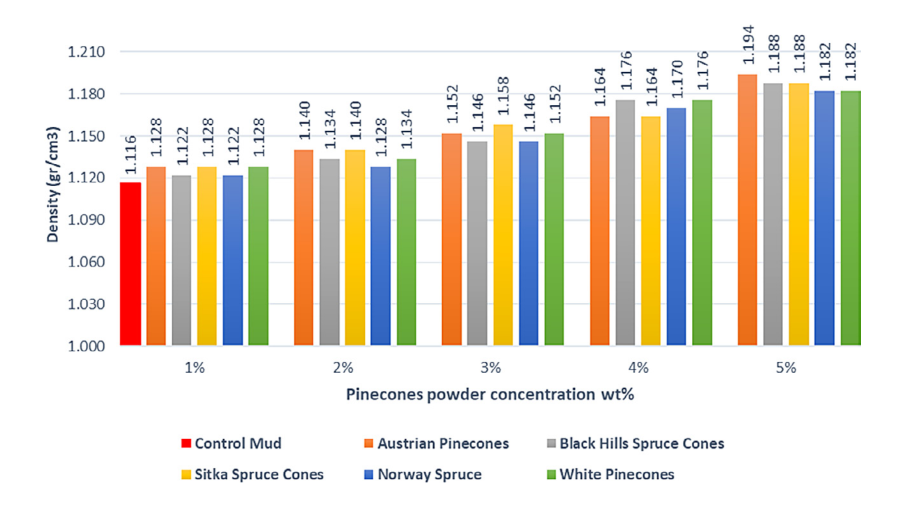

Figure 8: Density of water-based bentonite drilling fluid at different pinecone concentrations

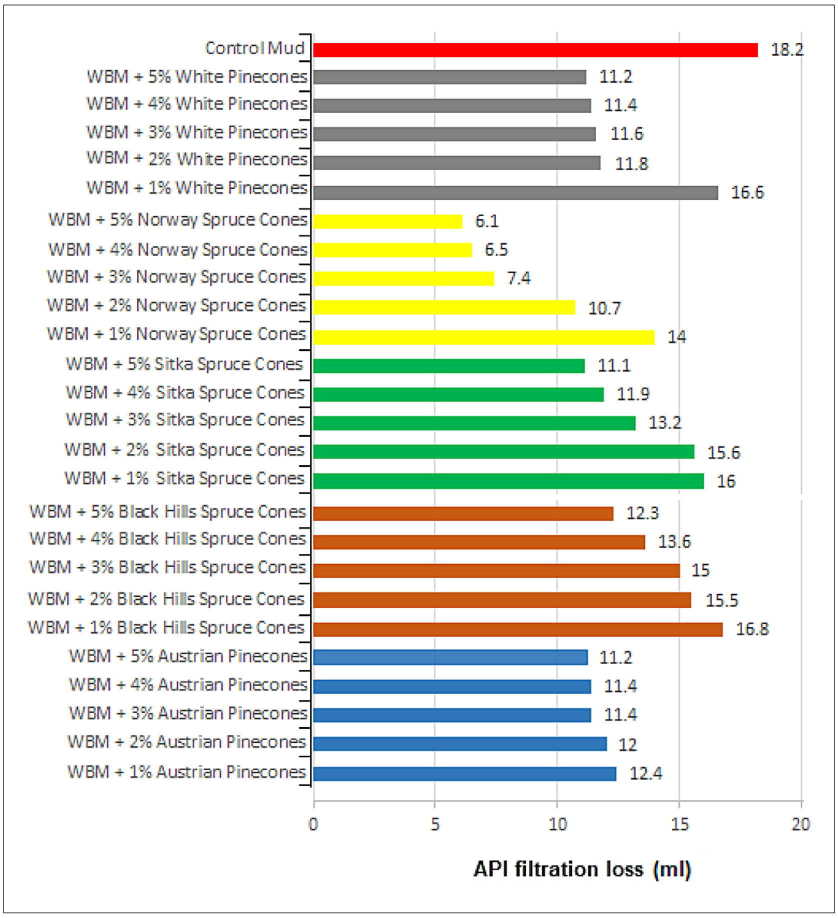

Figure 9: API filtration loss after 30 minutes for the water-based muds after adding different types and concentrations of pinecone powder

sulting from adding increasing concentrations of Norway Spruce cones powder was greater than the gel strength values after adding other types using the same concentrations, as can be seen in **Figure 7.** It can be noted that the strength of the gel has increased by 36% after Norway Spruce cones at 5 wt% was added to the water-based mud. It increased by 23%, 18%, 16% and 18% after Austrian pinecones, Black Hills Spruce Cones, Sitka Spruce Cones, White Pinecones respectively, were added at 5 wt% to the water-based mud.

When comparing the rheological results to the control mud, it can be seen that adding increasing concentrations of different pinecone powders improves the rheological properties significantly, with reservations about

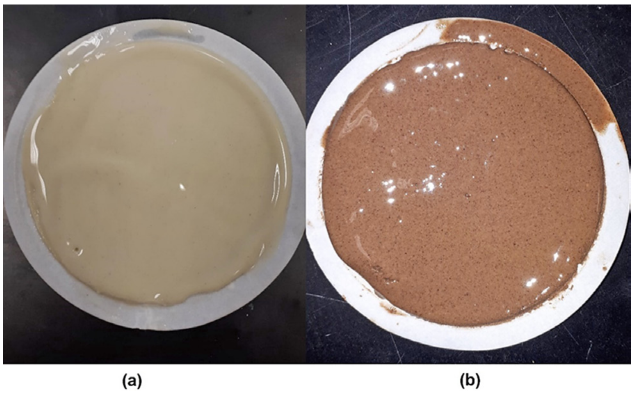

Figure 10: (a) a mud cake of the control mud (b) a mud cake of the mud after adding Austrian pinecone powder

the superiority of some types of cones over others in this degree of improvement.

3.2. Density test results

Mud density is a very important factor for applying hydrostatic pressure of a mud column greater than the pore pressure, which prevents the flow of formation fluids into the well. **Figure 8** shows the density of mud with and without the presence of increasing concentrations of the five types of pinecones. An increase in the density of mud can be observed with an increase in the concentration of pinecone powder. The explanation for the rise in density is because the solid mass in the mud has increased as the concentration of pinecone powder has increased. Nevertheless, the increase in mud density after adding pinecone powders was within the acceptable limits and did not significantly affect the density.

3.3. Filtration test results

The performance of different types of pinecone powder as a filter loss control after being added to the mud was evaluated. The result of the filtration test is shown in **Figure 9.** It is observable from **Figure 9** that the volume of filter loss decreased as the concentration of the pinecone powder added to the mud increased. It was also noted that when 3 wt% of Norway Spruce cones were added to the mud, it had a higher ability to reduce a filter loss compared with the control mud as, shown in **Figure 9.** The reason for this can be the fine size of the particles used from this type (mean size of Norway Spruce cones was 84.41 μm). Besides, other types of pinecones have shown high performance in reducing filter loss when the concentration of the pinecone powder in the mud is increased. Thus, it can be said that pinecone powder has succeeded as a filter loss control material when added to drilling mud in certain concentrations. This is likely due

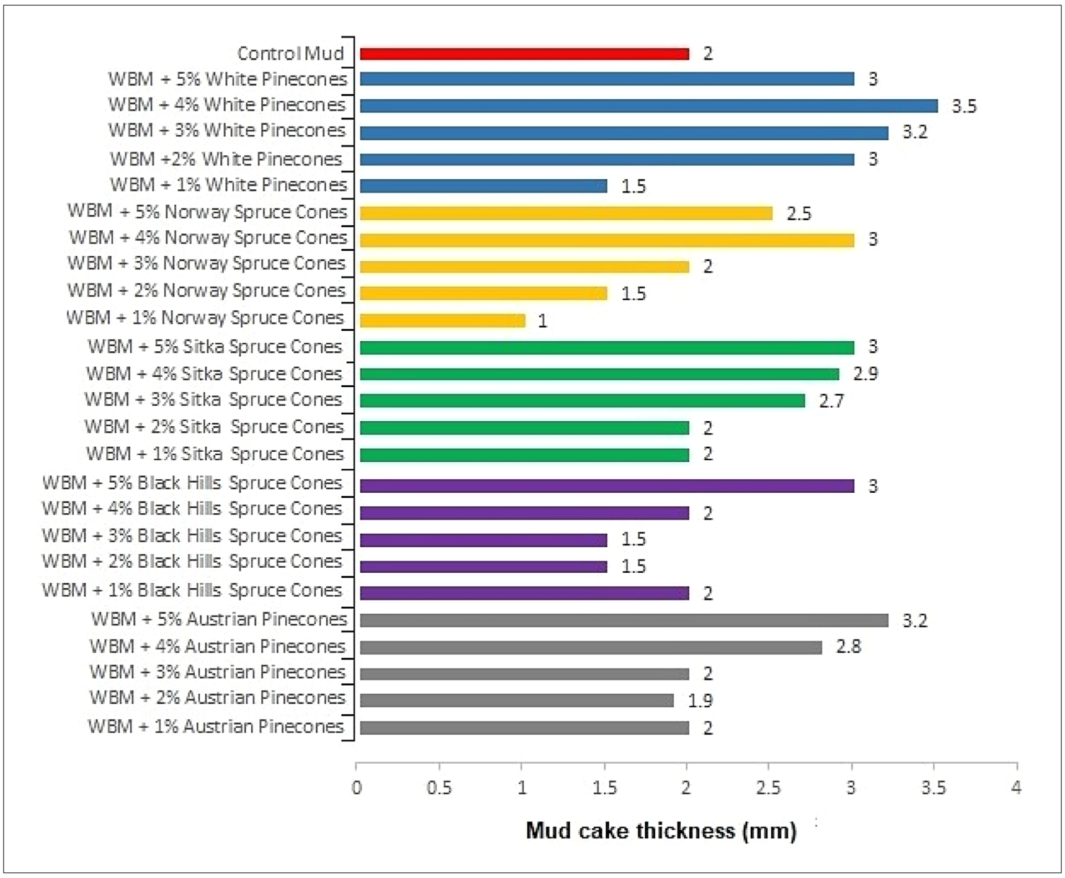

Figure 11: Mud cake thickness of the water-based muds after adding different types and concentrations of pinecone powder

Table 2: Discussing the results of the study

Mud property	Discussion	Best type of cones with optimum concentration
Apparent viscosity	The inclusion of different types of pinecone powder in the water-based mud improve the apparent viscosity of the mud, which enable the proper suspension of a drilled cutting and high performance well cleaning.	Austrian pinecone powder at 5 wt%.
Plastic viscosity	The inclusion of different types of pinecone powder in the water-based mud reduce the plastic viscosity of the mud, which led to a reduction of frictional pressure loss in the drilling system.	Black Hills Spruce cones at 5 wt%, Sitka, Spruce cones at 3 wt%, and White pinecones at 5 wt%.
Yield point	The inclusion of different types of pinecone powder in the water-based mud increase the yield point of the mud, which provide higher carrying capacity, improve hole cleaning and decrease the hole problems.	Austrian pinecone powder at 5 wt%.
Gel strength	The inclusion of different types of pinecone powder in the water-based mud increase the gel strength of the mud, which help to hold the rock cutting and prevent their deposition at the bottom.	Increased by 36% after adding Norway Spruce cones at 5 wt%.
Mud density	The inclusion of different types of pinecone powder in the water-based mud reduce the density of the mud, which help to create hydrostatic pressure of the mud column greater than the pore pressure with an acceptable value, which prevents the flow of formation fluids into the well.	Austrian pinecone powder at 5 wt%.
Filtration volume	The volume of filtrate decreased as the concentration of the pinecone powder added to the mud increased.	Norway Spruce cones at 5 wt%.
Mud cake thickness	After pinecone powder was added, the thickness of the mud cake differed according to the type of pinecones.	Based on API standards the acceptable mud cake thickness was obtained by adding: White pinecones at 1 wt%, Norway Spruce cones at 1, 2 and 3 wt%, Sitka Spruce cones at 1, and 2 wt%, Black Hills Spruce Cones at 1, 2, 3 and 4 wt%, and Austrian pinecone powder at 1, 2 and 3 wt%.
General overview and recommendations	After studying all the important properties of the water-based mud, it is clear that the addition of pinecones has improved the rheological properties of the water-based drilling mud and led to an increase in its density within the acceptable limits. It has also been successful as a material to reduce filtration mud cake thickness. Thus, there is a high possibility of applying pinecones as drilling mud additives to control the different properties.	Through this study, it is recommended to use all the previous types of pinecones as additives to water-based mud, especially Norway Spruce cones with a certain concentration (3 wt%), as it showed a high ability to reduce filtration volume compared to other types, as well as improving the rheological properties and density of water-based mud.

to an increase in the cellulose content in the mud by increasing the concentration of pinecone powder (**Agwu and Akpabio, 2018**). The results also indicated that when using Norway Spruce cones at a concentration of 3 wt%, 4 wt% and 5 wt%, the mud shows the lowest filter loss volumes compared to other pinecones types which were 40%, 35% and 33.5%, respectively compared to the control mud filter loss volume. Whereas the Austrian pinecone and White pinecone powders gave a volume of the filter loss of about 61% when they were separately added to the water-based mud at 5 wt%. The Black Hills Spruce cones gave a volume of filter loss of about 67% when added to the mud at 5 wt%. Finally, Sitka Spruce cone powder gave the mud a volume of filter loss of about 39% after being added at 5 wt%.

3.4. *Mud cake results*

3.4.1. Specification of mud cake

The **Figure 10** shows (a) a mud cake of the control mud and (b) a mud cake of the mud after Austrian pinecone powder was added. Same case for the other types of pinecones. It can be seen from the shape of the mud cake after adding the pinecone powder that it becomes slippery and smooth. This helps to reduce the problem of differential sticking of the drill pipes, which gives the pinecone powder a new advantage. The same situation was observed when adding the other types of pinecones.

3.4.2. Mud cake thickness

Figure 11 depicts the thickness of the mud cake after different types of pinecones have been added with increasing concentrations to the drilling mud and compared with the mud cake thickness of the control mud, as well as with the API standard that specifies the mud cake thickness as less than 2 mm. The thickness of the control mud was 2 mm. After pinecone powder was added, the thickness of the mud cake differed according to the type of pinecones. In the case of White pinecone powder, the mud cake thickness ranged from 1.5 mm to 3 mm. As for the Norway Spruce cone powder, the thickness of the mud cake ranged from 1 mm to 3 mm. Also, after adding Sitka Spruce cone powder at different concentrations, the thickness of the mud cake ranged from 2mm to 3mm. Adding the Austrian pinecone powder produced a mud cake with thickness ranges from 1.9 mm to 3 mm. As it is mentioned earlier that the lowest filtrate volume was achieved by the Norway Spruce cone which had the finest particle sizes, as well as for the mud cake, it can be notice from the **Figure 11** that the thickness of the mud cake was the least compared to the rest of the types, which indicates that the size of the particles has an effect on the properties of the thickness of the mud cake. Finally, after Black Hills Spruce cone powder was added to the water-based mud, the thickness of the mud cake ranged from 1.5 mm to 3.2 mm. In general, an increase in the concentration of pinecone powder in the drilling mud was associated with a thickening of the mud cake. Therefore, it can be stated that the pinecones in this study have achieved the API standard (thickness of the mud cake is less than 2 mm) if added at certain concentrations to the water-based mud. The minimum mud cake thickness obtained in this study is 1 mm after 1 wt% of Norway Spruce cone powder was added to the water-based mud.

Based on the previous results, an overview of the effect of the five types of pinecones on the different properties (rheological, filtration and density) of the water-based mud can be summarized, and the best type that improves these properties is suggested, while determining the optimum concentration as shown in **Table 2**.

4. Conclusions

The aims of this study have been to holistically evaluate the water-based mud after using five types of pinecones as filter loss control agents and their effect on other properties. Based on the results, the following conclusions were drawn:

1. In general, adding different types of pinecones to the drilling mud led to a significant improvement in its rheological properties as it led to an increase in the apparent viscosity and a decrease in the plastic viscosity, which reduces the loss of frictional pressure in the drilling system.
2. Using pinecone powder led to an increase the yield point of the mud which means a higher carrying capacity, improved hole cleaning and decreased hole problems.
3. Pinecone powders increased the gel strength of water-based drilling mud, which means that adding these cones to drilling mud will increase their ability to suspend cuttings when drilling mud circulation is stopped and prevents their deposition.
4. The results showed increases in water-based mud density after adding pinecone powders with increasing concentration and it was within acceptable limits.
5. It can be said that pinecones have succeeded in significantly reducing filtrate volume. Therefore, pinecones can be declared to be promising materials for reducing filtrate volume.
6. The addition of pinecones to the water-based mud led to the formation of a mud cake with an acceptable thickness and this mud cake looks slippery and smooth. This helps to reduce the problem of differential sticking of the drill pipes, which gives the pinecone powder a new advantage.

For future research, it is recommended to study the formation damage, the rheological properties at high temperatures-high pressure and applying dynamic filtration. It is also useful to study the effectiveness of the pinecones in inhibitive mud.

Acknowledgement

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Note

This study was produced from the first author's PhD thesis.

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SAŽETAK

Ispitivanje mogućnosti korištenja češera kao ekološki prihvatljivih aditiva u isplakama na bazi vode

Ovo istraživanje obuhvaća ispitivanje mogućnosti upotrebe češera kao aditiva u isplakama na bazi vode. Češeri su ekološki poljoprivredni otpad i kao takav nemaju praktičnu primjenu. Stoga ovo istraživanje ima veliku ulogu u isticanju potrebe investiranja u upotrebu prirodnoga otpada u praktične svrhe. Fokus je ovoga istraživanja na poboljšanju reoloških svojstava i gustoće isplake na bazi vode dodavanjem praškastoga materijala dobivenoga mljevenjem češera. Također, primjena navedenoga praha kao aditiva za sprečavanje gubitka cirkulacije smanjuje zagađenje okoliša te znatno smanjuje troškove isplake na bazi vode. U ovome su radu provedena ispitivanja pet tipova češera (austrijski šišar, smreka Black Hills, sitkanska smreka, norveška smreka i bijeli bor) i njihove sposobnosti smanjenja gubitka fluida, kao i utjecaj toga ekološki prihvatljivoga materijala na reološka svojstva i gustoću isplake. Ispitivanje je provedeno na 26 uzoraka isplake na bazi vode koje su sadržavale različite tipove češera dodane pri različitim koncentracijama (težinski udio 1 %, 2 %, 3 %, 4 % i 5 %). Rezultati istraživanja pokazuju da češeri imaju znatnu sposobnost sprečavanja gubitka fluida, posebice češeri norveške smreke, koji su se tijekom ovoga istraživanja, u usporedbi s ostalim češerima, pokazali kao najučinkovitiji, i to pri koncentraciji 3 % težinskoga udjela.

Ključne riječi:
prah češera, reologija, sprečavanje gubitka fluida, isplačna obloga, ekološki prihvatljivi materijali

Author’s contribution

Hani Al Khalaf (1) (PhD student, Petroleum Engineer), and **Nagham Al Haj Mohammed (2)** (MSc student, Petroleum Engineer) performed the laboratory test and presented the results. **Gabriella Federer Kovacsne (3)** (Assoc. Prof. Dr., Petroleum Engineer) provided analyses of the results.