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The influence of mandarin peel powder on filtration properties and temperature stability of water-based drilling mud

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Abstract

The growing energy demand in the world, as well as the current geopolitical situation, require countries to make additional investments in the exploration and production of hydrocarbons from their own sources. This means that companies must develop new fields which have remained undeveloped until now, mostly because of the extremely harsh environment where they are located (deep sea, high temperature, high pressure, heavy oils, etc.). The development of these new fields requires the development and adoption of new technology, among other things, and the development of a temperature-stable drilling fluid system able to fulfil all tasks according to the new technical challenges. Except for the technological challenges, there are also growing concerns related to the influence of the drilling operation on the environment. All of the above encourage the industry to develop new, inexpensive, and environmentally friendly additives which will be able to satisfy all of the technical and technological requirements and challenges of modern drilling. In the last few years, there has been a growing trend of laboratory research that includes different types of biodegradable waste as a potential additive that can achieve useful properties in mud. In this paper, the influence of mandarin peel powder on the filtration properties of mud after the aging process at elevated temperatures is examined. This eco-friendly additive was added to water-based muds in concentrations of 1% and 2% by volume of water. Laboratory research has shown stable filtration properties of the water-based mud containing mandarin peel powder even after exposing the mud to temperatures higher than 130°C.

Keywords:
mandarin peel powder; mud; filtration; hot roll process

1. Introduction

The drilling fluid or drilling mud is probably the most important and most expensive component of the drilling process, and its main task is the removal of the drilling cuttings from the wellbore (**Valizadeh and Nasiri, 2012; Sarah et al., 2016; Gudarzifar et al., 2020**). Except carrying cuttings from the wellbore to surface, it must fulfil additional tasks, regardless of drilling mud type. Among others, the most important are balancing pore pressure and prevention of reservoir fluid overflow and possible blowout, cooling and lubrication of the drill string and drill bit, the prevention of mud losses by the creation of a filter cake on the wellbore wall and supporting the weight of the drilling string (**Neshat et al., 2015.; Olise et al., 2017; Ma et al., 2021; Chu and Lin, 2019; Wiśniowski et al., 2020; Wiśniowski et al., 2022; Long et al., 2022**). Also, in regular drilling conditions, drilling mud density should be high enough to prevent the intake of the reservoir fluid into the wellbore and below the level that would result in the fracturing of the reservoir rock at the same time. The demand for the new energy sources also requires drilling deep, high temperature or extended wells which entails further development of the drilling mud in order to satisfy the drilling process in these complex conditions (**Huang et al., 2019; Ismail et al., 2020; Chu et al. 2020a; Fayad et al., 2021**).

The drill cutting removal process also depends on the rate of penetration, and the pure wellbore cleaning from excessive drilling cuttings results in spending energy for additional crushing of the drilled cuttings. Unfortunately, a temperature increase with the depth results in thermal thinning for many types of drilling mud and causes inadequate wellbore cleaning and consequently a slowing down of the drilling process, the occurrence of unwanted drilling events (stuck pipe, blowouts or wellbore instability) and therefore questions drilling security as well as assurance of the wellbore isolation by cementation (**Echt and Plank, 2019; Liu et al, 2020; Hamad et al., 2020; Gudarzifar et al., 2020**).

All the above-mentioned tasks as well as the complex and the unique downhole conditions makes the drilling mud design process technical and its engineering demanding (**Yunita et al., 2016**). Moreover, it should be

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kept in mind that the drilling mud design process includes designing more than one drilling mud for a specific well. Although oil companies select water-based drilling mud rather than oil-based drilling, they are aware of the water-based drilling mud deficiencies at elevated temperatures. Moreover, numerous research studies clearly indicate that oil-based mud has a larger stability in high-temperature and high-pressure conditions as well as other advantages regarding water-based drilling mud (gives better lubricity, increases wellbore stability, decreases filtrate invasion and formation damage, etc.), but economic and environmental concerns have limited their wider application (**Ettehadi, 2021; Khan et al., 2018; Said and El-Sayed, 2018**). Synthetic-based drilling mud (Esters, Olefin, Ethers, Polyalphaolefins) has lower toxicity compared to oil-based drilling mud, it can be recycled and exhibits thermal stability. Although oil- and synthetic-based drilling muds are initially more expensive than water-based drilling mud, they can reduce overall drilling cost by decreasing some drilling problems, which cannot be solved by using water-based drilling mud (**Sajjadian et al., 2016**). In the deep offshore drilling range of the wellbore, temperature variation is especially emphasized, and the typical range is between 4°C and 80°C (**Xie et al., 2021**). According to **Xie et al. (2021)** common polymers and clays have a similar response to the temperature changes and do not fit temperature alteration in deep offshore drilling. According to **Wenjun et al. (2014)** high temperature influences the polymer stability in a drilling mud system in two ways. The high temperature can cause the removal of the hydrophilic group from the main chain of the polymer and breaking the carbon-carbon bond or crosslinking of the polymer because of an unsaturated bond and active group. Except high temperature conditions, salts (of specific type and concentration) have a great influence on polymer stability as well as the presence of dissolved oxygen (**Ma et al., 2021**). Some authors found that the addition of antioxidants, formate salts and polyglycols can increase the temperature stability of biopolymers within water-based drilling mud systems and prevent acid-catalysed hydrolysis and oxidation-reduction reactions as the main mechanisms responsible for the thermal degradation of biopolymers (**Valizadeh and Nasiri, 2012; Akpan, et al., 2018**). The elevating temperature can influence drilling mud viscosity through the process of high temperature thinning, thickening or solidification causing changes in mud fluidity (**Fuhua et al., 2012**). Better stability of the water-based drilling mud in high-temperatures and high-saline environments can be achieved using a synthetic polymer (**Hamad et al., 2020; Chu and Lin, 2019**). The molecular flexibility of the synthetic polymers used as additives for the regulation of the rheological and filtration properties of the water-based drilling mud, can assure thermal stability of the water-based drilling mud and sustainability of its properties (**Chu and Lin, 2019**).

Yunita et al. (2016) tried to improve the stability and overall performance of water-based drilling mud at elevated temperatures by adding non-ionic and anionic surfactants. The results obtained from laboratory research clearly indicate that adding surfactants can stabilize and even improve rheological properties after 16 hours of the hot rolling process at elevated temperatures and decrease filtration up to 41.3%. Except additives for rheological and filtration properties, some other additives, such as shale inhibitors (KCl or NaCl) can also be affected by increased temperature but to a lesser extent (**Liu et al, 2020**). One of the shale inhibitors with a great potential, polyamine, have temperature stability on less than 120°C and an elevation in temperature causes the easy desorption of inhibitors from the clay surface (**Chu et al., 2020b**). In this situation, new polymers such as PGBA (P(AMPS-MBA)-g-P(Am-DEAm)) ensure temperature stability of drilling mud rheological properties over the whole range of the wellbore temperature. **Liu et al. (2020)** developed and tested new bentonite based drilling muds by adding poly(Sodium 4-Styrenesulfonate) to the base bentonite mud, and the new formulation exhibits superior rheological and filtration properties over regular bentonite drilling muds with hydroxyethyl cellulose (HEC) and carboxymethyl cellulose (CMC). They concluded that adding poly(Sodium 4-Styrenesulfonate) prevents aggregation of the bentonite particles and therefore drilling mud keeps good properties even after hot rolling at 200°C. **Akpan et al. (2018)** investigated the influence of the combination of additives on the stabilization of the biopolymers (konjac and xanthan gum) at high temperatures, and they found that best biopolymer stabilization can be achieved by a combination of potassium formate, sodium erythorbate and 0.7% polyethene glycol. To overcome water-based drilling mud problems caused by thermal degradation, **Hamad et al. (2020)** added a small amount of amphoteric polymer (PEX) to the drilling mud formulation which improves both, rheological and filtration properties of the tested water-based drilling mud. **Khan et al. (2018)** researched the influence of the carbon nanotubes and zinc oxide nanoparticles on thermal stabilization of the water-based drilling mud and conclude that carbon nanotubes can promote thermal stability as well as rheological and filtration properties of the tested water-based drilling mud, while this improvement was absent in the case of drilling mud with zinc oxide nanoparticles. A similar positive effect of nanoparticles, in this case bismuth ferrite nanoparticles on rheological and filtration properties of water-based drilling mud, were noticed by **Perween et al. (2018)** in their research. They believed that this positive effect is the result of the interaction between nanoparticles and clay particles. **Gudarzifar et al. (2020)** achieved significant improvement/stabilization of water-based drilling mud properties, especially at elevated temperatures by adding nanocomposite material (graphene oxide nanosheet, polyacrylamide and gra-

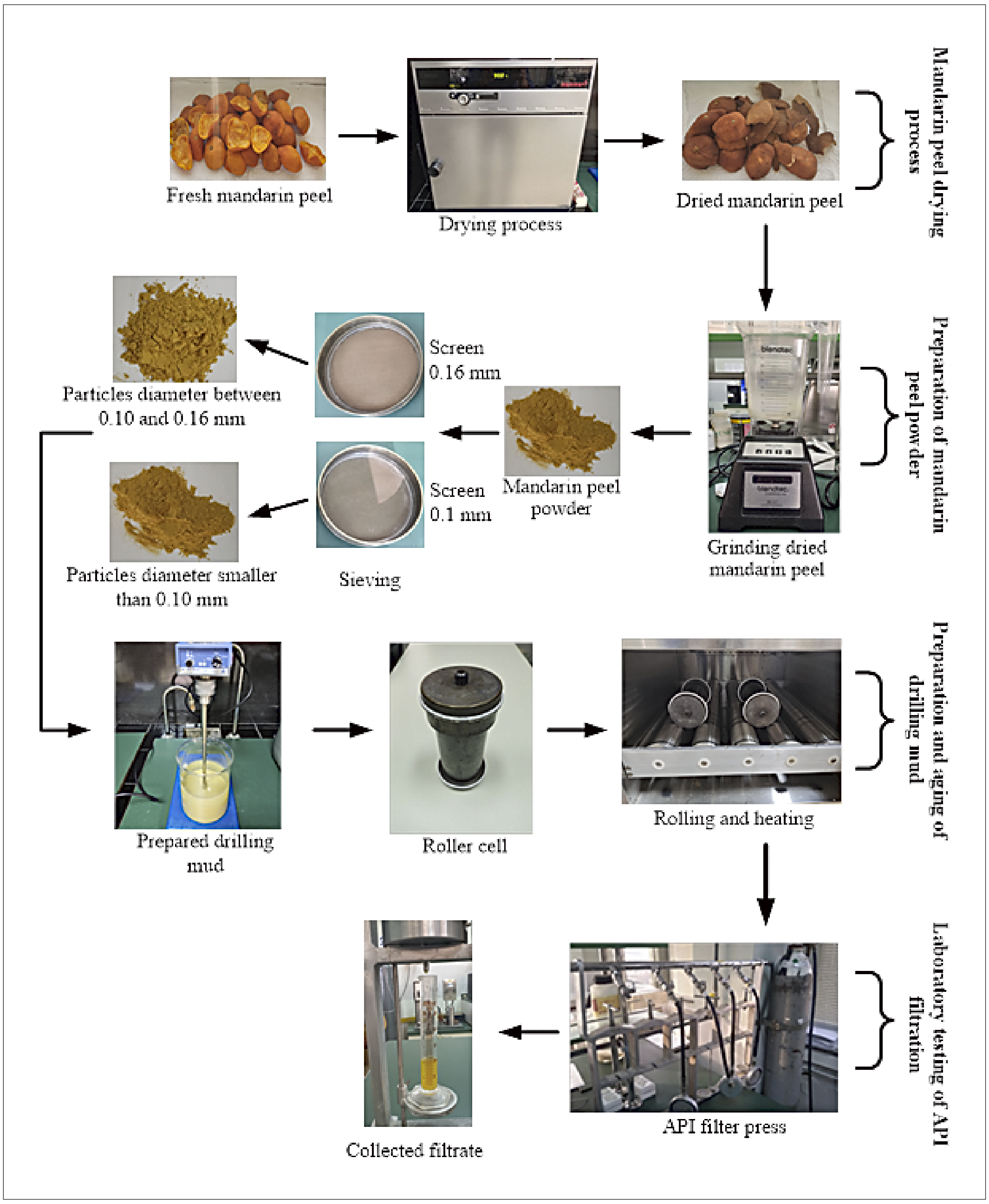

Figure 1: The process of preparing mandarin peel powder and performing API filtration after mud aging

phene oxide nanosheet/polyacrylamide nanocomposite) in drilling mud formulation.

The proper drilling mud design process includes the conduction of the laboratory test at simulated downhole conditions. Some authors are questioning conventional methods for researching the influence of temperature on the drilling mud properties, especially for rheological properties measurements. In their research, **Echt and Plank (2019)** point to a fact that hot rolling of the drilling mud, with the aim of determining the drilling mud thermal stability and consequently carrying capacity, can lead researchers to wrong conclusions. For better determination of the in situ rheological properties of the drilling muds, some authors such as **Ettehadi (2021)** suggest using Discovery Hybrid Rheometer (DHR-II) instead of Fann VG viscometer, and extension of the routine laboratory test according to API standards with additional tests such as the Freeze-Thaw Cycle test. Although these new recommendations undoubtedly contribute to a better simulation of the downhole hole conditions and give more precise results, most researchers adhere to common testing procedures according to the API standards.

In order to satisfy the increasingly rigorous standards in environmental protection, the oil and gas industry is trying to develop new environmentally friendly drilling mud formulations and additives as well. In the last few years, there has been a growing trend of testing different types of biodegradable waste as a potential additive that can achieve useful properties in mud. The advantage of this type of additive is primarily in reducing the negative impact on the environment, considering that many commercially available additives for water-based mud fall into the category of non-degradable and environmentally hazardous materials (**Zheng et al., 2020**). One of the possible solutions is using cellulosic agricultural waste material (for example Plant press slag) as an additive for the preparation of environmentally friendly drilling mud (**Long et al., 2022**). Despite the great potential of this idea, additional comprehensive laboratory and filed research are needed to fully understand the effect of this waste material as a new drilling mud additive at complex downhole conditions.

Research presented in this paper is a continuation and upgrade of the previous tests on the use of mandarin peel powder, in which the positive properties of this additive on the filtration properties of the mud with a change in the rheological properties within acceptable limits (**Medved et al., 2022a**) and a reduction in the swelling of the clay component were proven (**Medved et al., 2022b**), which positively affects the stability of the wellbore. The aim of this paper is to prove the resistance of mandarin peel powder in basic and more complex mud compositions to elevated temperatures, that are common in well conditions.

2. Laboratory Research

In order to investigate the influence of this additive under elevated pressure conditions, different mud compositions were subjected to the hot roll aging process. Prepared mud samples were sealed in a separate cell and placed inside a roller, over an equal period of time. The observed samples are continuously rolled on rotating shafts which simulates the circulation of drilling mud in the well.

2.1. Mandarin Peel Powder Preparation and Laboratory Tests

After collecting the mandarin peel, the first stage in the preparation of this eco-friendly additive is drying in an oven at 90°C for two days. The dried mandarin peels are then ground and sieved through screens with different openings – 0.16 mm opening on the sieve and 0.10 mm opening on the sieve. In this way, the distribution of particle sizes in two groups is obtained (particles smaller than 0.10 mm and from 0.10 mm to 0.16 mm). Through laboratory measurements, it can be determined whether this has any influence on the results of filtration, in addition to the influence of the concentration of this additive in the mud. This is followed by the mud preparation, in accordance with API Specifications 13A and API 13B-1 **(American Petroleum Institute, 2003)**, of a certain composition and pouring into cells that are placed in a roller and heated at an elevated temperature for 16 hours. After the mud aging process is completed, mud is poured into the API filter press cell and the API filtration is measured during 30 minutes. A pressure of 0.6895 MPa (100 psi) was utilized during that period, and the volume of collected filtrate in a laboratory beaker was extracted from the water-based drilling mud through Whatman No. 50 filter paper with a filtration area of 45.8 cm^2 (7.1 in^2) located on the bottom of API filter press cell.

The complete process is shown in **Figure 1**. Given that the mud has undergone an aging process at several different temperatures, after measuring the API filtration it can be concluded from the filtrate volume whether the useful properties of this additive are lost at elevated temperatures and what is the temperature limit of mandarin peel powder in basic mud and muds with a more complex composition.

2.2. Drilling Mud Composition

For this research, a mandarin peel powder concentration of 1% and 2% by volume of water was selected in order to determine the filtration of the mud after the aging process, given that in previous research it was determined that a concentration of less than 1% does not give completely satisfactory results (**Medved et al., 2022a**), while a concentration above 2% is too high, given that the mud gels too much and it becomes impossible to mix it during preparation. For every temperature that was determined for hot roll aging of mud samples, five different basic mud compositions were prepared (see **Table 1**), as well as five more complex drilling mud compositions (see **Table 2**). Aging of all prepared drilling muds was conducted at four different temperature values: 75°C, 100°C, 125°C and 150°C. After the filtration results were analyzed, it was determined that a significant drop in the properties of the mud with added mandarin peel powder occurred at temperatures between 125°C and 150°C. In order to obtain more accurate results of the effect of temperature to positive properties of mandarin peel powder in drilling mud, two additional temperature values were added at which the aging of the mud was carried out, at 133°C and 142°C.

2.2.1. Basic Mud Composition

In order to better study the impact of mandarin peel powder on the filtration of water-based mud, the basic bentonite-based mud was compared with four other mud compositions in which mandarin peel powder of different particle sizes and concentrations was added. Laboratory research was conducted on two groups of particle sizes - less than 0.10 mm and between 0.10 mm and 0.16 mm, and in two concentrations of added mandarin peel powder, 1% and 2% by volume of water. The mud compositions are listed in **Table 1**. Base mud (Bentonite-based mud) is marked as BM, two drilling muds that contain mandarin peel powder with particles smaller than 0.1 mm are marked as A, and other two drilling

Table 1: Basic water-based drilling mud composition prepared for aging and filtration laboratory tests

Drilling mud mark	Water-Based Drilling Mud Composition			
	Bentonite (g/L)	NaOH (g/L)	Mandarin peel powder concentration (% by volume of water)	Mandarin peel powder particle size (mm)
BM	60	1	-	-
A1	60	1	1	smaller than 0.10
A2	60	1	2	smaller than 0.10
B1	60	1	1	between 0.10 and 0.16
B2	60	1	2	between 0.10 and 0.16

muds that contain mandarin peel powder with particles between 0.1 mm and 0.16 mm are marked as B. Each laboratory tested water-based mud was prepared in accordance with the American Petroleum Institute Standards, API Specifications 13A and API 13B-1 (**American Petroleum Institute, 2003**).

2.2.2. Complex Mud Composition

Although the direct influence of mandarin peel powder on the mud filtration properties can be seen in more detail in the basic mud, one of the aims of this paper is to determine if this eco-friendly additive has any effect on the said property in more complex muds. In this case, PAC R and barite have been added to basic water-based drilling mud. PAC R is a modified natural polyanionic cellulosic polymer and barite is a barium sulfate material. Barite is a heavyweight additive, and its function is to increase the density of mud in order to increase the hydrostatic pressure, given that the mud is the primary barrier to formation pressure. PAC R is an additive that has a positive effect on the filtration properties of mud and in this laboratory research it was added in its recommended concentration, so it is interesting to study whether mandarin peel powder can further improve filtration in the composition of mud that already has an additive for this property. It is also known that bentonite is also used to control filtration, so in this type of more complex mud composition it is much more difficult to improve this property compared to basic mud. The detailed composition of the more complex mud with the indicated markings is shown in **Table 2**. More complex base mud is marked as BMc and it consisted of bentonite, barite, NaOH and PAC R. Two drilling mud samples that contain all the listed additives with added mandarin peel powder with particles smaller than 0.1 mm are marked as C, and the other two drilling muds that contain base mud composition with added mandarin peel powder with particles between 0.1 mm and 0.16 mm are marked as D.

3. Results

3.1. API Filtration Results for Basic Water-Based Drilling Mud with Added Mandarin Peel Powder

Mud aging was done at six different temperatures, and all samples of basic water-based drilling muds were first aged at 75°C, and a final temperature was set at 150°C. **Figure 2** shows the results of API filtration laboratory tests for the five mud samples after 16 hours of hot roll mud aging at temperatures of 75°C, 100°C, 125°C and 133°C.

From the results presented in **Figure 2**, it can be concluded that values of API filtration decreased for every mud sample with the addition of mandarin peel powder in regard to base mud. It is also evident for muds which have concluded the aging process up to 100°C that there is no significant difference between muds into which 1% and 2% of mandarin peel powder was added, i.e. slightly better results were obtained with 2% of added mandarin peel powder. As for the differences in results between the two groups of different particle sizes, insignificant differences were recorded at the same concentration.

For higher temperatures of the mud aging process (125°C and 133°C), API filtration also decreased for every mud sample with added mandarin peel powder in regard to base mud. The positive influence of this addi-

Table 2: More complex water-based drilling mud composition prepared for aging and filtration laboratory tests

Drilling mud mark	Drilling Mud Composition					
	Bentonite (g/L)	NaOH (g/L)	PAC R (g/L)	Barite (g/L)	Mandarin peel powder concentration (% by volume of water)	Mandarin peel powder particle size (mm)
BMc	60	1	1	40	-	-
C1	60	1	1	40	1	smaller than 0.10
C2	60	1	1	40	2	smaller than 0.10
D1	60	1	1	40	1	between 0.10 and 0.16
D2	60	1	1	40	2	between 0.10 and 0.16

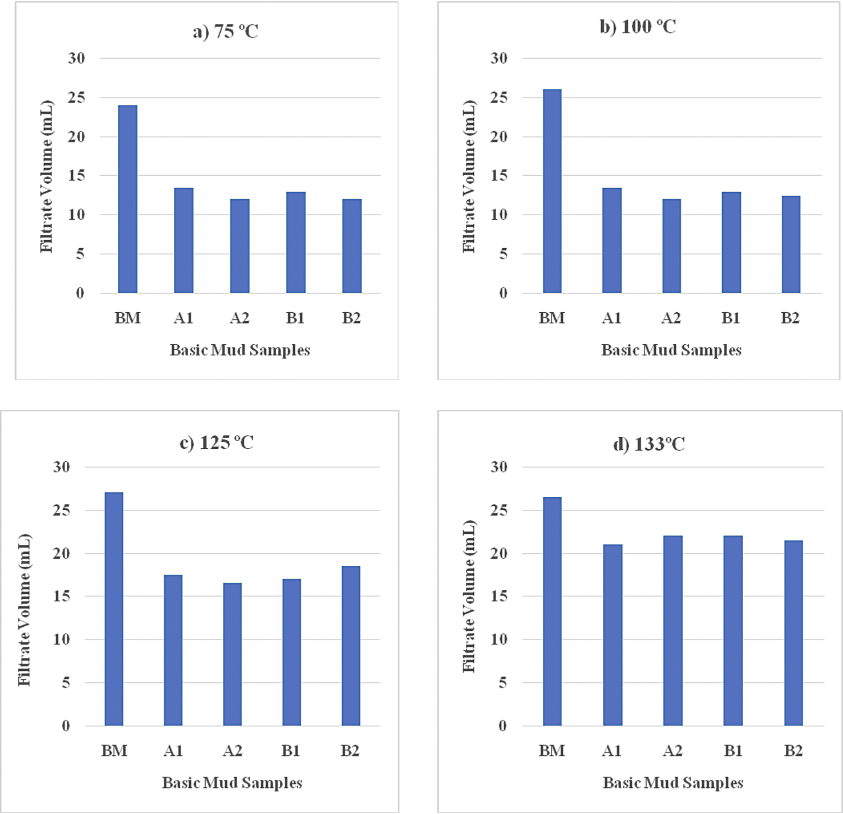

Figure 2: API Filtration results after the mud aging process at 75°C, 100°C, 125°C and 133°C for basic water-based drilling mud

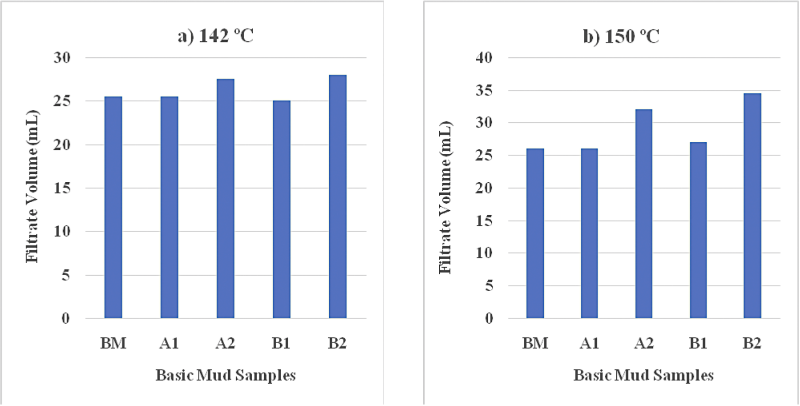

Figure 3: API filtration results after mud aging process at 142°C and 150°C for basic water-based drilling mud

tive on filtration is less pronounced (this especially applies to mud samples that completed the mud aging process at 133°C) than in the case of muds that have undergone the mud aging process up to a temperature of 100°C, and there is no significant difference in results between muds into which 1% and 2% of mandarin peel powder was added, and the same applies for differences in results between the two groups of different particle sizes.

Figure 3 shows the results of API filtration laboratory tests for the five mud samples after 16 hours of hot roll mud aging at temperatures of 142°C and 150°C.

From the results presented in this figure, it can be concluded that values of API filtration for mud samples with added mandarin peel powder in concentration of 1% by volume of water remained at the same level as for the base mud, and that concentration of 2% of mandarin peel powder by volume of water even increased filtrate volume in

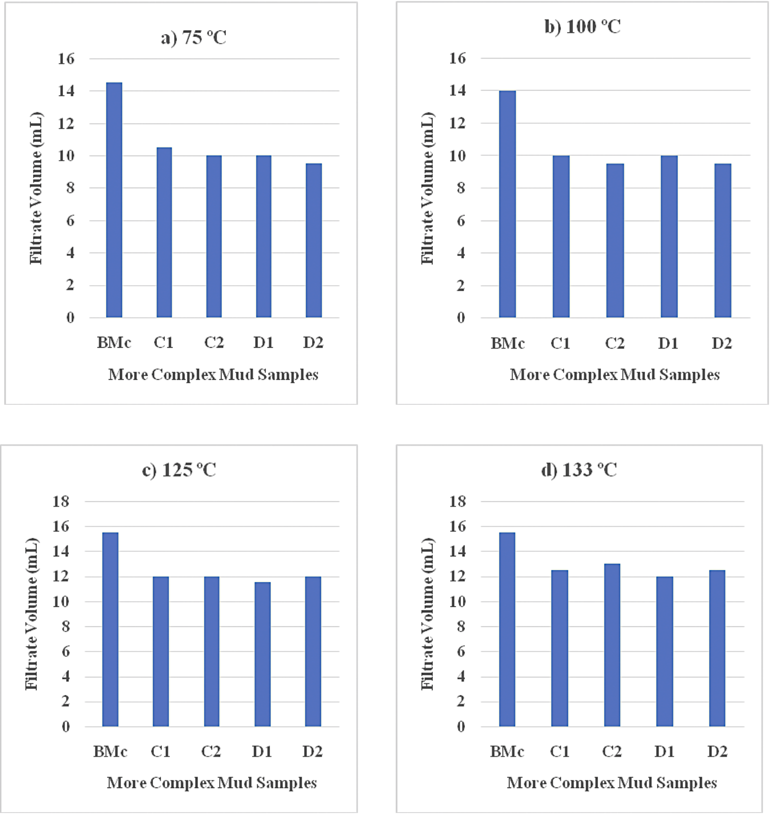

Figure 4: API filtration results after the mud aging process at 75°C, 100°C, 125°C and 133°C for more complex water-based drilling mud

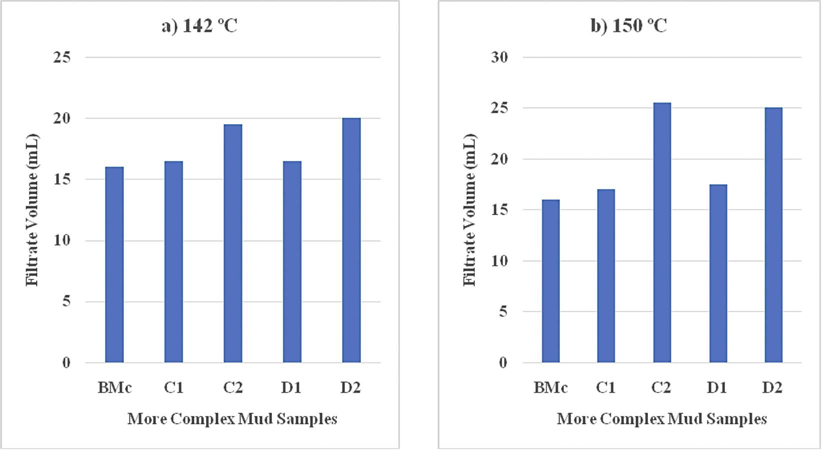

Figure 5: API filtration results after the mud aging process at 142°C and 150°C for more complex water-based drilling mud

regard to base mud. Again, insignificant differences in the results were observed between the two groups of different particle sizes, at the same concentration.

3.2. API Filtration Results for More Complex Water-Based Drilling Mud with Added Mandarin Peel Powder

The mud aging process was completed at six different temperatures at the same values as for the Basic Water-Based Drilling Mud. **Figure 4** shows the positive effect of added mandarin peel powder on API filtration results for the five mud samples after 16 hours of hot roll mud aging at temperatures of 75°C, 100°C, 125°C and 133°C.

From the results of laboratory tests presented in this figure, it can be concluded that the values of API filtration decreased for every mud sample with added mandarin peel powder in regard to base mud, and that this eco-friendly additive has a positive effect on the filtration

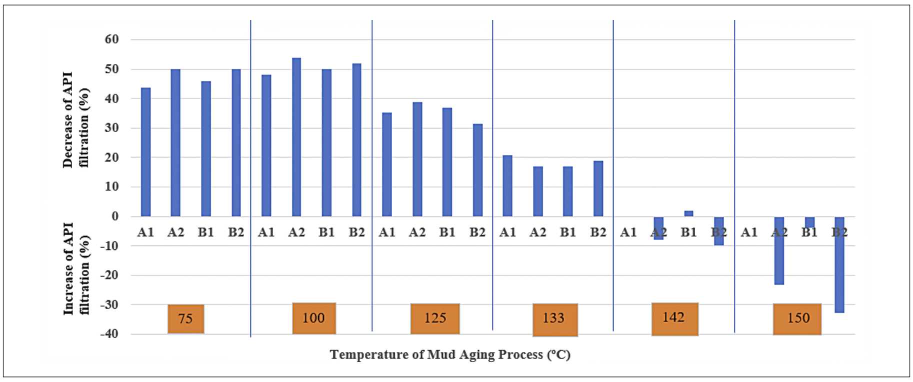

Figure 6: Effect of mandarin peel powder on API filtration in basic water-based drilling mud after the mud aging process

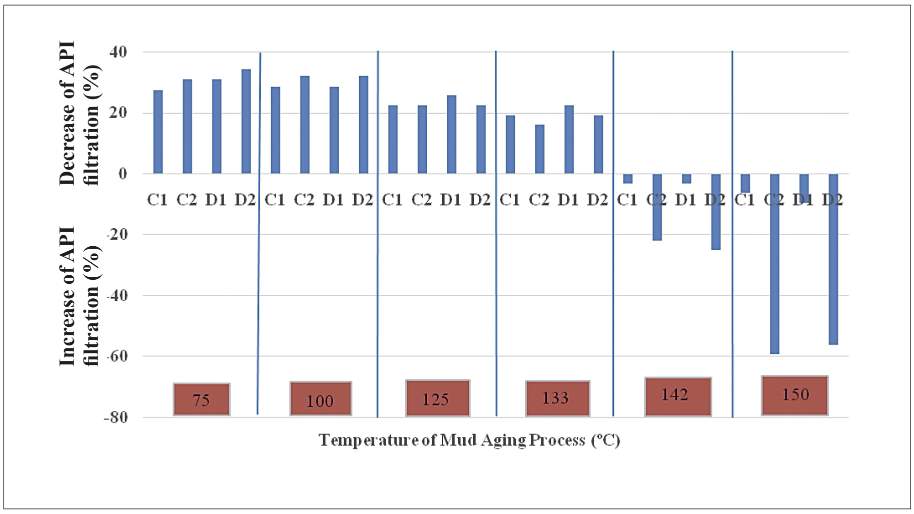

Figure 7: Effect of mandarin peel powder on API filtration in more complex water-based drilling mud after the mud aging process

properties of the mud. It is also evident for muds which have concluded that for the aging process up to 100°C, there is no significant difference between muds to which 1% and 2% of mandarin peel powder was added, i.e. slightly better results were obtained with 2% of added mandarin peel powder. This trend is identical to the basic water-based drilling mud with added mandarin peel powder. As for the differences in results between the two groups of different particle sizes, insignificant differences were recorded at the same concentration, which also matches the results for basic water-based drilling mud with added mandarin peel powder.

For higher temperatures of the mud aging process (125°C and 133°C), API filtration also decreased for every mud sample with added mandarin peel powder in regard to base mud, so mandarin peel powder still kept its positive effect on the filtration properties of the mud. By raising the temperature of the mud aging process to 133°C, the positive influence of this additive on filtration is less pronounced than in the case of muds that have undergone the mud aging process up to a temperature of 100°C. The presented results do not show a significant difference in results between muds to which 1% and 2% of mandarin peel powder was added in mud samples that completed the mud aging process at temperatures of 125°C and 133°C, and the same applies for differences in results between the two groups of different particle sizes.

Figure 5 shows the results of API filtration laboratory tests for the five mud samples after 16 hours of hot roll mud aging at temperatures of 142°C and 150°C.

From the results presented in this figure, it can be seen that the values of API filtration increased for every mud sample with added mandarin peel powder in regard to base mud, which indicates that at these temperatures, the positive effect of this additive on the filtration properties of the mud was completely lost. After the mud aging process at these temperatures, muds to which 1% of mandarin peel powder was added showed better results compared to muds to which 2% of mandarin peel powder was added but considering that the filtration results are worse compared to the base mud, these data are not so important. As well as for all previously shown sets of laboratory results, insignificant differences in results were observed between the two groups of different particle sizes, at the same concentration.

4. Discussion

All the obtained results of laboratory research were compared for basic and more complex mud in order to more accurately determine the impact of mandarin peel powder after the mud aging process. The research carried out on the basic (bentonite-based) drilling mud provides a detailed insight into the effect of mandarin peel powder on the filtration properties of the mud subjected to the aging process from a temperature of 75°C to 150°C. **Figure 6** shows all the filtration results for this type of drilling mud, presented to indicate the impact of mandarin peel powder on basic mud, compared to base mud without this additive.

This figure shows that the positive influence of mandarin peel powder is most significantly pronounced up to a temperature of 100°C, while after that temperature, this additive gradually loses its ability to reduce mud filtration. The temperature limit for a positive effect on the filtration properties of basic drilling mud with added mandarin peel powder is 133°C. Basic drilling mud with added mandarin peel powder that completed aging process on temperatures higher than 133°C shows a rapid decline of filtration control and complete loss of the positive influence that this additive provided at lower temperatures. Also, it can be noted that the filtration control is more pronounced up to a temperature of 125°C, since a decrease in the volume of filtrate for muds containing mandarin peel powder is over 30% compared to the base mud.

Figure 7 shows all filtration results for more complex composition of water-based drilling mud, presented to indicate the impact of mandarin peel powder in this type of mud, compared to base mud without this additive.

Since PAC R is a component of the base mud, the positive influence of mandarin peel powder in this drilling mud composition is much more difficult to obtain compared to the previous set of tests performed on basic (bentonite-based) mud. The influence of PAC R is best seen in **Table 3**, where it is shown how much the filtration of the more complex base mud has decreased, which contains this additive, compared to the basic base mud in which it is not included. Filtration of more complex base mud decreased from 37.3% to 46.2% compared to basic mud, when comparing the values for the entire temperature range of the mud aging process. These values show how difficult it is to achieve further reductions in filtration when PAC R is present in the base mud composition.

Table 3: Comparison of basic and more complex base mud filtrate volume after 30 minutes of the API filtration test

Temperature of mud aging process (°C)	Filtrate volume (mL)		Filtration decrease of more complex base mud related to basic base mud (%)
	Basic base mud	More complex base mud	
75	24	14,5	39.6
100	26	14	46.2
125	27	15.5	42.6
133	26.5	15.5	41.5
142	25.5	16	37.3
150	26	16	38.5

Still, mandarin peel powder proved to have a positive effect on the filtration property of more complex mud composition, and the trend is quite similar to the results for basic mud. This figure shows that the positive influence of mandarin peel powder is maintained up to a temperature of 133°C, so this temperature value can be defined as the temperature limit for the use of this eco-friendly organic additive. Like in the previous case for basic mud, at temperatures higher than 133°C, this additive rapidly loses its ability to reduce drilling mud filtration.

5. Conclusions

After conducting laboratory tests of API filtration on different samples of water-based drilling mud, it can be concluded that the positive influence of mandarin peel powder is present up to a temperature of 133°C, at which the mud was heated during the mud aging process. This temperature limit, up to which the positive influence of this eco-friendly additive has been observed, applies to both basic mud and more complex mud. The positive influence of mandarin peel powder is most pronounced when the mud is subjected to an aging process up to a temperature of 100°C, and in this case a filtration reduction of up to 53.9% was achieved in basic mud where 2% of mandarin peel powder (particles smaller than 0.1 mm) was added. For more complex mud samples that completed the aging process up to a temperature of 100°C, a filtration reduction of up to 34.5% was achieved where 2% of mandarin peel powder (particles between 0.1 mm and 0.16 mm) was added. In the temperature range from 100°C to 133°C, the positive influence of this additive is still present, but it becomes less pronounced. After the aging of the mud at a temperature of 133°C, the filtration reduction for the basic mud containing mandarin peel powder is in the range of 17.0% to 20.8%, which varies depending on the concentration and particle size of the added mandarin peel powder, and for the more complex mud, a decrease in filtrate volume from 16.1% to 22.6% was measured. It can be concluded that 133°C is the temperature limit for the use of this additive, since at higher temperatures the influence of mandarin peel powder is completely lost. As was assumed considering the composition of the basic mud, mandarin peel powder significantly influenced the control of the filtration properties of the basic mud compared to the more complex mud up to a temperature of 125°C, and at a temperature of 133°C the results are quite similar for both mud compositions. Regarding the concentration of added mandarin peel powder in base mud, the results are almost equal for both concentrations. Slightly better results were recorded when 2% of mandarin peel powder by volume of water was added to the mud compared to 1% by volume of water, after the mud aging process up to 100°C. For the temperature range from 100°C to 133°C the results are quite similar for both concentrations. By comparing the filtration results of different particle sizes for the same concentration of added mandarin peel powder in the mud, it can be concluded that there is almost no difference due to this factor, which means that the concentration of added mandarin peel powder is more important than different groups of particle sizes.

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SAŽETAK

Utjecaj praha kore mandarine na filtracijska svojstva i temperaturnu stabilnost isplaka na bazi vode

Sve veća potražnja za energijom u svijetu, kao i trenutna geopolitička situacija, zahtijevaju od zemalja dodatna ulaganja u istraživanje i proizvodnju ugljikovodika iz vlastitih izvora. To znači da tvrtke moraju razviti nova polja koja su do sada ostala nerazrađena uglavnom zbog izuzetno zahtjevnih uvjeta u podzemlju gdje se ona nalaze (duboko more, visoka temperatura, visoki tlak, teška nafta, itd.). Razvoj ovih novih polja zahtijeva razvoj i usvajanje novih tehnologija, između ostalog, i razvoj temperaturno stabilnog bušotinskih fluida koji mogu ispuniti sve zadatke sukladno tehničkim izazovima koji se pred njih stavljaju. Osim tehnoloških izazova, raste i zabrinutost vezana uz utjecaj bušaćih operacija na okoliš. Sve navedeno potiče industriju na razvoj novih, cjenovno povoljnijih i ekološki prihvatljivih aditiva koji će moći zadovoljiti sve tehničko-tehnološke zahtjeve i izazove suvremenog bušenja. Posljednjih nekoliko godina sve je veći trend laboratorijskih istraživanja koja uključuju različite vrste biorazgradivog otpada kao potencijalnih aditiva kojima se u isplaci mogu postići korisna svojstva. U ovom radu ispituje se utjecaj praha kore mandarine na filtracijska svojstva isplake nakon procesa starenja pri povišenim temperaturama. Ovaj ekološki prihvatljivi aditiva dodavan je u isplake na bazi vode u koncentracijama od 1% i 2% na volumen vode. Ispitivanja su pokazala stabilna filtracijska svojstva isplake na bazi vode koja sadrži prah kore mandarine i nakon izlaganja isplake temperaturama višim od 130 °C.

Ključne riječi:
prah kore mandarine, isplaka, filtracija, starenje isplake

Author’s contribution

This paper is a part of the PhD research of the author **Igor Medved** (PhD student, graduate engineer of petroleum engineering) who initialized the idea, led the laboratory research, participated in the interpretation of the laboratory results, discussion and wrote the whole paper. The supervisor of the PhD thesis, **Borivoje Pašić** (PhD, Associated Professor) provided the evaluation of the overall laboratory testing results and made a critical revision of the paper. **Petar Mijić** (PhD, Postdoctoral researcher) participated in the laboratory research and prepared one part of the introduction section. All authors participated in writing the conclusion of this paper.