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Araştırma Makalesi / Research Article

Evaluation of Microcrystalline Cellulose as Viscosifier Agent in Water-Based Drilling Fluids

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Abstract

Developing an efficient flow for drilling fluid is important in drilling operations. For this purpose, a lot of organic and inorganic additive agents are used to regulate for flow properties in wellbore. However, cheaply, eco-friendly and efficiently agents are desired in well planning. Thus, new agents have been researching and developing in recent studies. In this study, a new viscosifier agent, which is microcrystalline cellulose (MCC), was evaluated for water-based drilling fluids (WBDFs). Characterizations were determined by X-ray diffraction (XRD) flourier transform infrared spectroscopy (FT-IR) methods and digital microscopy (DM) images. In the experiments, WBDFs were prepared by using different ratios of MCC. Rheology tests were performed by Apparent viscosity (AV), plastic viscosity (PV), yield point (YP) measurements. Thixotropy calculations (STI and TI) and filtration measurements were made. According to results of MCC added samples, maximum AV, PV and YP were measured as 43 cP, 16 cP and 54 lb/100ft^2, respectively. The best STI and TI values were calculated as 0.1 and 0.915. Minimum filtrate was obtained as 11.9 ml. Results showed that MCC is effective viscosifier agent on WBDFs.

Keywords: Microcrystalline cellulose, drilling fluids, viscosity, fluid loss.

Mikrokristalin Selülozun Su Bazlı Sondaj Sıvılarında Viskozlaştırıcı Katkı Maddesi Olarak Değerlendirilmesi

Öz

Sondaj operasyonlarında sondaj sıvısı için verimli bir akış geliştirmek oldukça önemlidir. Bu amaçla, kuyu içindeki akış özelliklerini düzenlemek için birçok organik ve inorganik katkı maddesi kullanılmaktadır. Ancak, kuyu planlamasında ekonomik, çevre dostu ve verimli katkı maddeleri kullanılmak istenmektedir. Bu nedenle son yıllarda yapılan çalışmalarda bu yeni maddeler araştırılmakta ve geliştirilmektedir. Bu çalışmada, yeni bir viskozite artırıcı katkı malzemesi olarak mikrokristalin selüloz (MCC) su bazlı sondaj sıvıları için değerlendirilmiştir. Karakterizasyonlar X-ışını kırınımı (XRD), flourier transform infrared spektroskopisi (FT-IR) yöntemleri ve dijital mikroskopi (DM) görüntüleri ile belirlenmiştir. Deneysel çalışmalarda, su bazlı sondaj çamurları farklı oranlarda MCC kullanılarak hazırlanmıştır. Reoloji testleri Görünür viskozite (AV), plastik viskozite (PV) ve kopma noktası (YP) ölçümleri yapılmıştır. Ayrıca tiksotropi hesaplamaları (STI ve TI) ve filtrasyon ölçümleri yapılmıştır. MCC eklenmiş numunelerin sonuçlarına göre, maksimum AV, PV ve YP sırasıyla 43 cP, 16 cP ve 54 lb/100ft^2 olarak ölçülmüştür. Optimal STI ve TI değerleri sırasıyla 0.1 ve 0.915 olarak hesaplanmıştır. Minimum filtrat 11,9 ml olarak elde edilmiştir. Sonuçlar, MCC'nin su bazlı sondaj çamurları üzerinde etkili bir viskozlaştırıcı katkı maddesi olduğunu göstermiştir.

Anahtar Kelimeler: Mikrokristalin selüloz, sondaj çamuru, viskozite, sıvı kaybı.

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1. Introduction

Oil and natural gas reserves are among the major energy sources. Nowadays, oil reserves are nearly 1,650 billion barrel and consumptions are 35 billion barrel per year. Natural gas reserves are nearly 1,153 billion BOE (barrels of oil equivalent) and consumptions are 22,048 billion BOE per year. These results shown that 47 years left for oil and 52 years left for natural gas in now (Wordometer, 2025). Considering the limited reserves of these energy resources, production efficiency and production/consumption ratio need to be increased. The main method of production of these energy resources in the past to today is drilling operations. Therefore, high yield drilling operations are an important component of the efficient production of these energy resources.

There are many factors that effect to success of drilling operations, such as well planning, drilling fluids, formation properties and mechanical effects. However, in general, the success of drilling depends on a stable well planning in which these factors are integrated (Kim and Dornfeld, 2001). Drilling fluid is one of the important component of well planning (Okoro et al., 2018; Orun et al., 2023). There is no drilling fluid suitable for all situations. Drilling fluids with different base liquids, different dominating cations in the aqueous phase, different chemical additives, or broadly diverse physical characteristics are offer different options. For this reason, a wide range of selection is provided according to conditions. Drilling fluid selection can be evaluated of many parameters such as safety of well, high temperatures and high pressures of formations, environment impact, shale problems, and cost. For the choice of optimum drilling fluids, these parameters must be considered as detailed (Guan et al., 2021; Bleier, 1990; Bloys et al., 1994).

Basically, various drilling fluids are used in drilling such as water-based, oil-based and air-based. Drilling fluids have important tasks such as kick fluid prevention, suspend cuttings in non-circulated conditions and transportation to surface in circulated, make non-permeable cake on formation wall, well stabilization, friction reducing, bit lubrication and cooling. These parameters are controlled and regulate in drilling operations as regularly. Thus, the impact on the total cost can be controlled, successful well planning can be made and the well cost can be minimized with high efficient drilling fluids (Abdou and El-Sayed Ahmed, 2011; Caenn and Chillingar, 1996; Erge et al., 2020).

Water-based drilling fluids (WBDFs) is mostly used type (about 50%) among the drilling fluids. Also, WBDFs divide three sub-type as non-inhibitive, inhibitive and polymer (Al-Shargabi et al., 2023). Many different additive materials compose to WBDFs compositions. Formation properties and well conditions are effects to determine of additive materials. These additive materials are mainly classified as viscosifiers, fluid loss inhibitors, weightening materials, shale inhibitors, bactericids, fluid loss control agents, flocculants and deflocculants. Aims of these additive materials are ensured optimum flow properties of WBDFs in drilling (Vivas and Salehi, 2021; Al-Shargabi et al., 2022; Oseh et al., 2023).

Viscosifiers enhance better hole cleaning, improve well stability and enable cutting transporting and suspending. Although there are many types, generally organic agents are used in WBDFs (Menezes et al., 2010; Villada et al., 2017; Dairanieh and Lahalih, 1988; Agwu et al., 2021). Mainly ones of these agents are carboxymethyl cellulose (CMC), polyanionic cellulose (PAC), hydroxyethyl cellulose (HEC), xanthan gum (XCD). However, eco-friendly and cost-effective materials are firstly preferred (Akpan, 2024; Khan et al., 2024). For this purpose, the usability of new additives that are cheap and easy to produce as viscosifiers such as cassava starch (Arinkoola et al., 2022), tragacanth gum (Almahdawi et al., 2018), panax notoginseng extract (Sun et al., 2022), dried potato powder (Sid et al., 2022; Suaib et al., 2022), grass powder (Hossain and Wajheeuddin, 2016; Ismail et al., 2021), aloe vera powder (Bagum et al., 2022), Terminalia mantaly leaves extract (Biwott et al., 2019; Dlama et al., 2016), hibiscus leaf extract (Hoai et al., 2019), mandarin peel powder (Bures et al., 2023), banana peel powder (Mamukuyomi, 2021), pomegranate peel powder (Ali et al., 2022) and basil seed powder (Gao et al., 2021) are being investigated nowadays.

Microcrystalline cellulose (MCC) is defined as a refined form of cellulose, the most common organic polymer found in plant cells and world (Levis and Deasy, 2001). MCC is formed when the polymer structure of cellulose is not too large (number of repeated units <200) (see Fig. 1) (Khorasani and Satvati, 2024). MCC is produced by controlled hydrolysis of highly purified a-cellulose obtained as pulp from fibrous plants. It is obtained by depolymerization, purification and mechanical disintegration of powdered cellulose. Due to the properties of its polymeric structure, it can generally be used as a thickener in situations requiring tight adhesion. It is an organic hydrocolloid that is dispersible in water and chemically stable (Wetterling et al., 2014; Chen et al., 2023; Rathod et al., 2023).

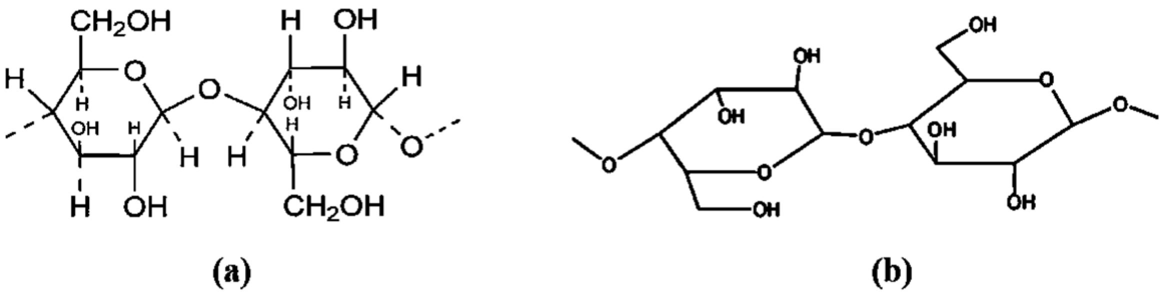

Figure 1. Structural formula of celluloses (a) and microcrystalline cellulose (b) (Awais et al., 2021; Kasperek et al., 2014)

In this study, a novel viscosifier agent named as microcrystalline cellulose (MCC) was evaluated in WBDFs. The aim of the study is developing to more economic, eco-friendly and high yield new additive materials for WBDFs. Although the widely used materials such as CMC, PAC, HEC or XCD are relatively eco-friendly, they are costly and limited producted in Turkey. In addition, polymer-containing or synthetic viscosifiers are quite costly and not eco-friendly. For these reasons, MCC was evaluated in this study as a new viscosity enhancing agent or an alternative to those commonly used in industry. The MCC obtained from commercial factory and product by depolymerization of highly purified fibrous plant. Characterizations were made by X-ray diffraction (XRD), flourier transform infrared spectroscopy (FT-IR) methods and digital microscopy (DM) images. In the experiments, MCC was added into WBDF samples at different amounts. Then, rheology tests were performed by Apparent viscosity (AV), plastic viscosity (PV), yield point (YP) measurements. Thixotropical properties were determined with shear thinning index (STI) and Thixotropy index (TI) calculations. Filtration measurements were applied for fluid loss determination.

2. Materials and Methods

2.1. Materials

2.1.1. Microcrystalline Cellulose (MCC)

The MCC sample used the experiments was taken as form of commercial product from ZAG Chemical. Its molecular formula is $C_{14}H_{26}O_{11}$ and its molecular mass is 370.35 g/mol. Its white color and micronized particle form.

2.1.2. WBDFs Additive Materials and Compositions

The additive materials were used for regulating to WBDF flow properties. Sodium carbonate (Na_2CO_3) and sodium hydroxide (NaOH) were taken from TEKKIM Chemical. Polyanionic cellulose with low viscosity (PAC-LV) and modified starch were taken from AKKIM Chemical. Limestone was taken as fine grained from NIGTAS. Each of them has a different function on WBDFs and the compositions that used experiments is given in Table 1.

Table 1. Additive Materials and Compositions

Material	Composition (g/L)	Function
Na_2CO_3	1.25	Ca^{2+} contamination control
NaOH	0.25	pH control
PAC LV	5	Low viscosity increase Fluid loss control
Limestone	700	Bridging of particles mud weight increase
Modified starch	15	Fluid loss control

WBDFs were prepared as 400 ml according to the compositions. The MCC was added into WBDFs as 2, 4, 6, 8 and 10 g/L amounts. These amounts were determined according to usage amounts in drilling applications of other viscosifier agents such as CMC, PAC, HEC and XCD that used in industrial and laboratory applications. The WBDFs were coded as DF-1, DF-2, DF-3, DF-4 and DF-5 according to increasing MCC ratio. The sample that not contained MCC was coded as DF-0.

2.2. Instruments

XRD patterns were obtained by using Malvern Panalytical EMPYREAN X-ray diffractometer with Cu-K radiation in 2θ angle and range 5-90°. FT-IR measurements were obtained by using JASCO FT/IR-6700 with range of 400-4000 cm^{-1}. DM images were obtained by using HiView portable digital microscopy.

2.3. Rheology Tests

Rheology tests are typically used as the chosen method to achieve potential of an additive material to improve the viscosity and gelation of WBDFs. The rheology tests were applied with apparent viscosity (AV), plastic viscosity (PV) and yield point (YP) were calculated from 300 and 600 rpm dial readings (θ_{300} and θ_{600}) by using OFITE Model 800 viscometer. The AV, PV and YP calculations were calculated according to American Petroleum Institute (API) standard (API, 2017) using with R1-B1 rotor-bob system with under atmospheric pressure and room temperature suitable as laboratory conditions. The R1-B1 system dimensions are 1.8415 cm for rotor diameter, 1.7245 cm for bob diameter and 3.8 cm for bob length. The equations are given in Eq. 1-3. The aim of the rheology tests is to show improving potential of MCC by measuring the parameters of these.

AV (cP) = $\theta_{600} / 2$ (1)

PV (cP) = $\theta_{600} - \theta_{300}$ (2)

YP (lb/100ft^2) = θ_{300} – PV (3)

2.4. Thixotropy Tests

Thixotropy tests are used to determine of shear thinning property of viscous fluids at time-dependent conditions. In the yield pseudoplastic fluids such as WBDFs, thixotropy tests are vital for determine to potential of an additive material. The thixotropy tests were applied with two main indicator as shear thinning index (STI) and thixotropy index (TI) in the experiments. The STI and TI calculations were calculated from 3, 300 and 600 rpm dial readings ($\theta_{3,}$ θ_{300} and θ_{600}) by using the viscometer that is used in rheology tests according to Eq. 4-5.

STI = θ_3 / θ_{300} (4)

TI = $\theta_{600\ \mathrm{min.}} / \theta_{600\ \mathrm{max.}}$ (5)

2.5. Filtration Tests

Fluid loss and filtration controlling are important for preventing to formation collapse and ensure wellbore stability. Viscosifiers can reduce fluid loss in WBDFs and wellbore stability can be controlled. In the experiments, filtration tests were applied to evaluate decrease potential of MCC to filtrate of prepared WBDFs. These tests were conducted using Fann model 300 filter press under the 100 psi pressure for 30 minutes and filtrate volumes were recorded.

3. Results and Discussion

3.1. Characterization of MCC

The XRD pattern of MCC is given Fig. 2. The pattern revealed that the prominent peaks at 6.27°, 14.98°, 22.14° and 34.37° indicating crystallinity of MCC. Also, the crystallinity index (Crl) was calculated as 64.7% by using Segal equation.

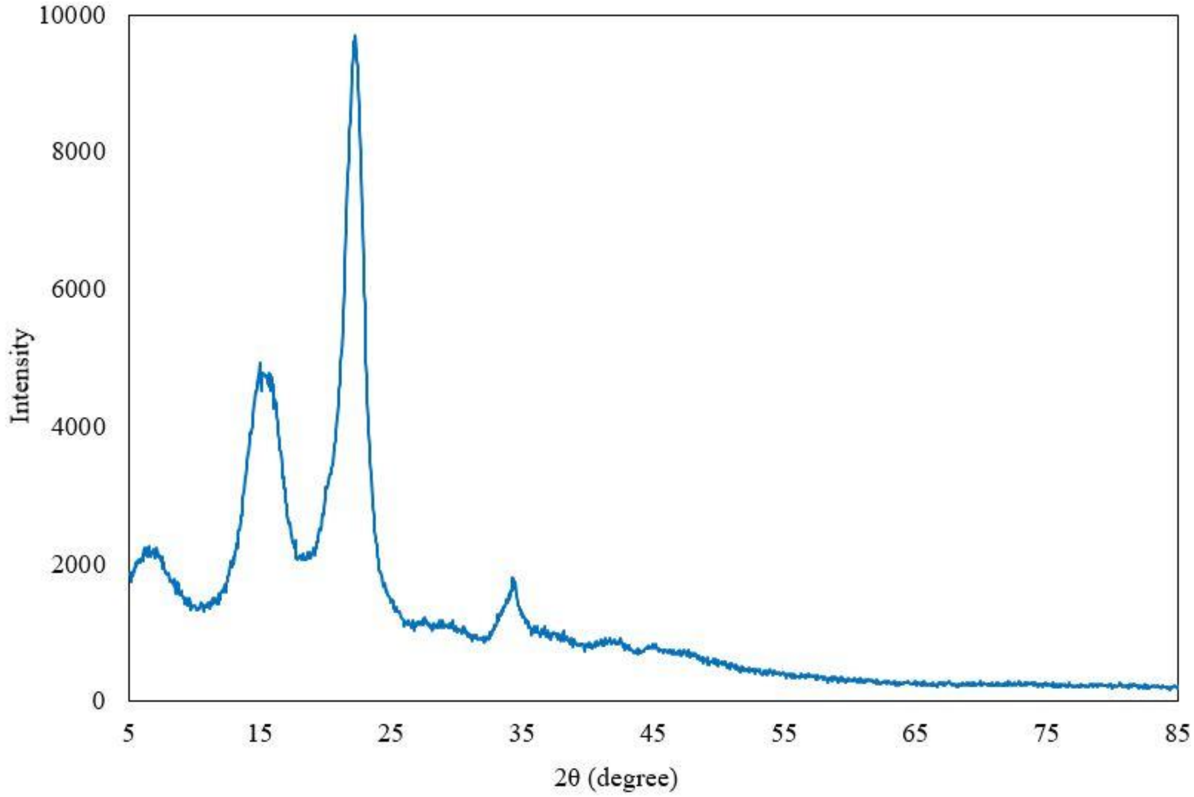

Figure 2. XRD pattern of the MCC

The FT-IR spectrum of MCC is given in Fig. 3. The spectrum showed a strong peak at 3328 cm^{-1} due to surface hydroxyl (O-H) stretching. The band at 2894 cm^{-1} was occured due to the stretching and bending modes of C-H. The peak at 1634 cm^{-1} was occured due to adsorbed water molecules. The bands at 1427 cm^{-1} and 1368 cm^{-1} were due to the deformation of CH_2 and CH_3, respectively. The absorption peaks at 1323 cm^{-1} and 1314 cm^{-1} were occurred due to C-H and C-OH deformations, respectively. The band at 1104 cm^{-1} was due to the stretching of C-O and ß-glycosidic bonds between the sugar units. The peak at 1027 cm^{-1} was occured due to C-O-C stretching and the peak at 556 cm^{-1} was due to O-H out of plane bending in COH alcoholic groups.

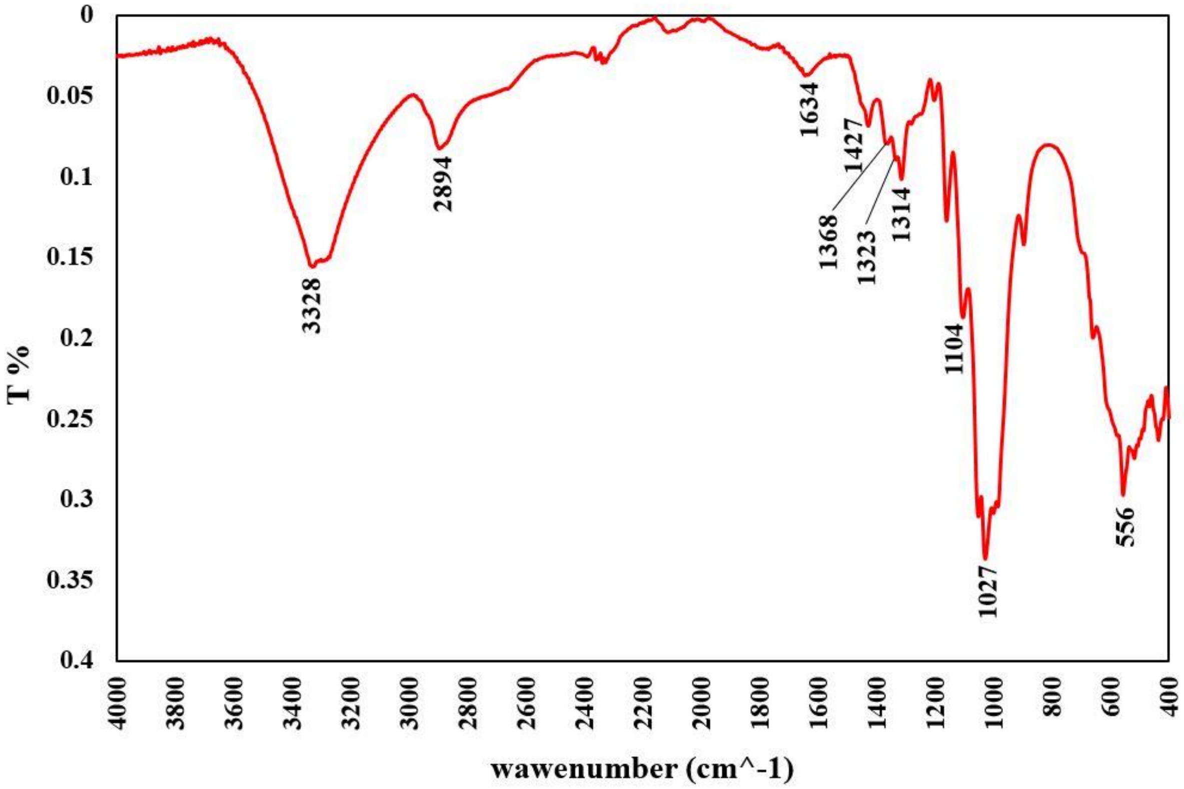

Figure 3. FT-IR spectrum of the MCC

The DM images was obtained as different magnification, angle and modes. Full area scanning (a), shadow scanning (b), surface roughness scanning (c), colored scanning of impurities (d) were evaluated (see Fig. 4).

The full area and shadow scanning images showed that distribution is homogenized and particle size equal. Also, the impurities, which are seen brown color in (a) and deep sea blue in (b), were low amounts. The surface roughness scanning was showed that the particles are non-clumping and moisture free in generally. The impurities in the MCC were seen by colorness scanning. The black areas were illustrated the impurities. According to the image, the rate of impurities is between about 5-8 percent. These results indicated that the MCC can be use as additive material in disperse systems.

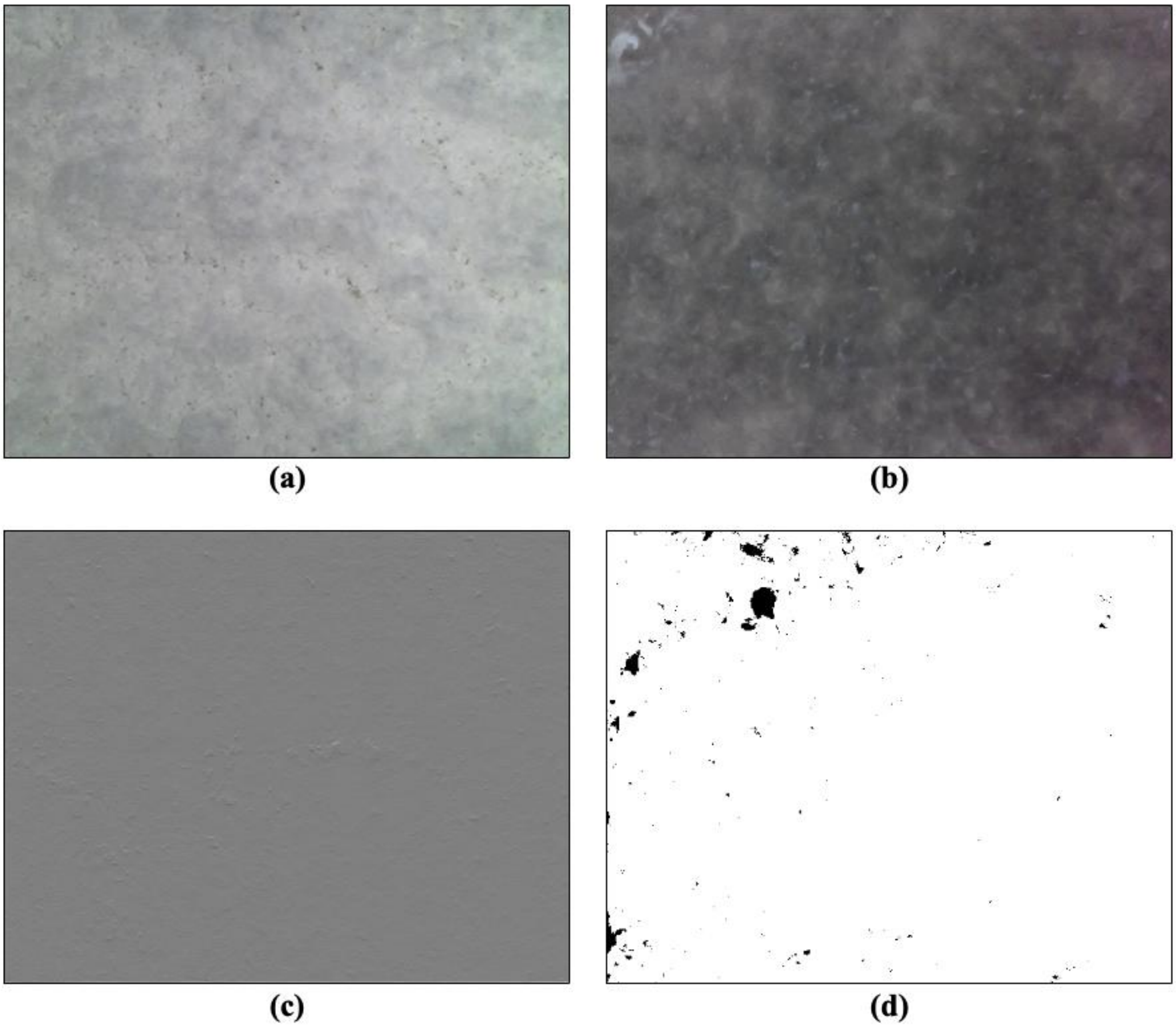
(a) (b) (c) (d)

Figure 4. DM images of the MCC
(a: full area scanning, b: shadow scanning, c: surface roughness scanning, d: colored impurity scanning)

3.2. Rheology Test Results

The rheogram curves and AV, PV, YP results of the WBDFs are given in Fig. 5 and Fig. 6. It was seen that the rheogram curves have decreasing slopes with increasing shear rate, which is similar to the yield pseudoplastic flow among non-Newtonian flow models. The flow properties of drilling muds must be yield pseudoplastic. For this reason, it was determined that the compositions determined for rheology tests were compatible with drilling muds. In addition, there was an increase in shear stresses due to the increase in the MCC additive ratio at constant shear speeds. This indicated that MCC was successful as a viscosity increasing additive material on drilling mud. According to the results, the highest shear stress value was measured as 86 cP from the DF-5 coded sample. There was an increase of 36 cP compared to the drilling mud without the MCC (DF-0).

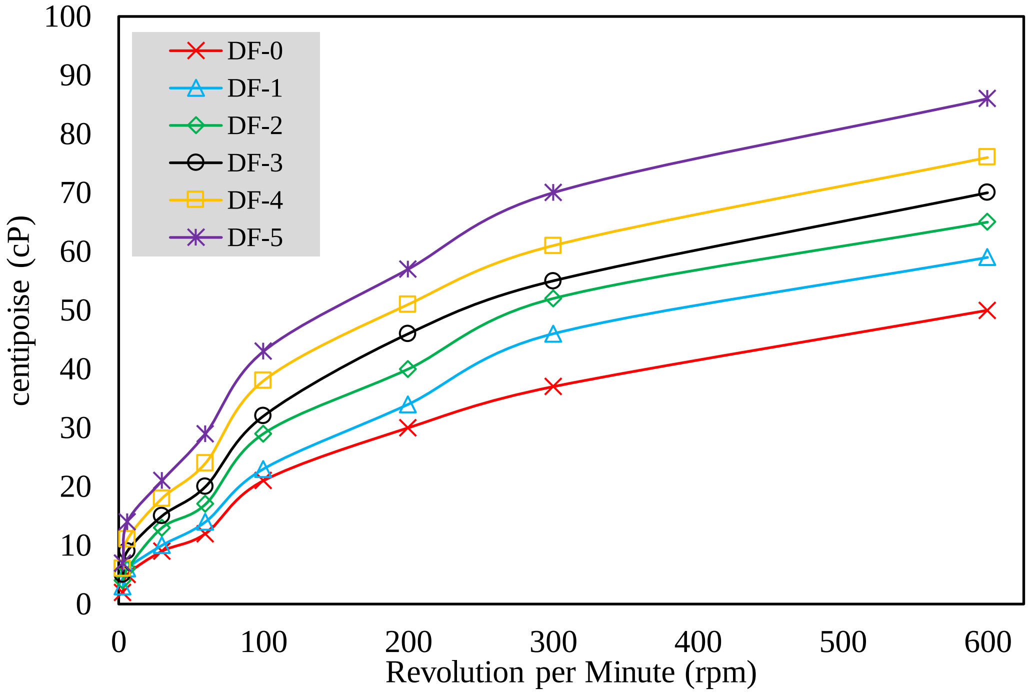

Figure 5. Rheogram curves of the WBDFs

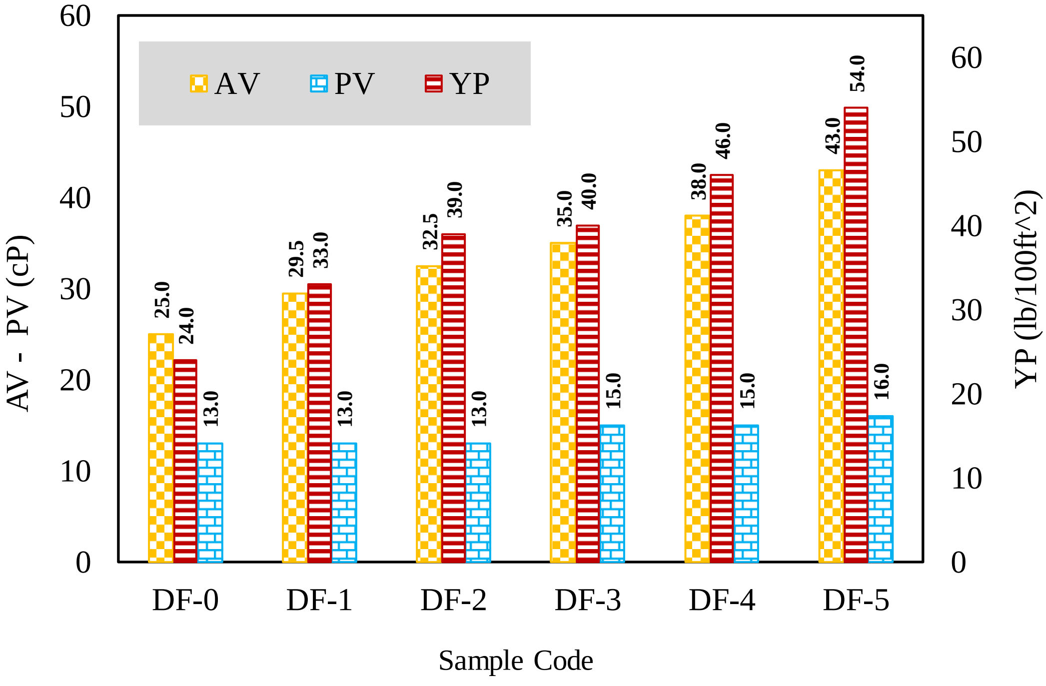

Figure 6. Rheological results of the WBDFs

The basis of rheology tests is AV, PV and YP measurements. These measurements were conducted with different parameters. In the experiments, AV was measured for real time viscosity determination; PV was measured for solid content effect on viscosity of the WBDFs; and YP was measured for transition initial shear stress from static to dynamic phase and capability of suspend solids in WBDFs.

AV is one of the testing parameter that showed non-newtonian flow, especially showed yield pseudoplastic flow. Among the viscosifiers, polymers are important to aim of AV increasing. According to results, MCC increased the AV values and improved the viscosity of the WBDFs. The highest value was measured from DF-5 as 43 cP and there was an increase of 18 cP compared to DF-0 with MCC addition. In addition, AV should be measured as minimum 15 cP for drilling fluids according to American Petroleum Institute (API) standard. Results showed that MCC improved to viscosity of the WBDFs and all samples are suitable for usability in drilling operations.

PV is associated with solid material amount and interaction of solid particles. In generally, increase of solid particles can increase to PV. However, interaction of solid particles is more important to PV increasing. Thus, high gellability materials such as cellulosic polymers can be used for this aim. The best PV value was measured from DF-5 as 16 cP. Also, no PV changes were observed in non-added and low added WBDFs (DF-0, DF-1 and DF-2). This situation occurred due to two reasons: low solid content and inadequate bond interaction of cellulose particles. It was determined that with the increasing of MCC particles, PV of the WBDFs improved due to gellation and bond establishment.

YP is a point that the elastic limit is exceeded by an applied stress and occurs deformation in fluids. A high YP implies more solid carrying and suspending ability in WBDFs. According to results, he highest YP value was measured from DF-5 as 54 lb/100ft^2 and there was an increase of 30 lb/100ft^2 compared to DF-0. Also, it was seen that YP increased according to additive amount. The results showed that more MCC addition caused higher YP in the WBDFs. This showed that high concentration MCC provided YP enhancing properties due to greater gelation and interparticle bonds and can be used as YP increasing agent in WBDFs.

3.3. Thixotropy Test Results

STI and TI results are given in Figure 7. According to the results, it was determined that STI values increased, and TI values decreased depending on the MCC concentration. The highest STI was determined as 0.1 from DF-5 and was almost twice as much as that of the non-MCC added sample (DF-0). Also, the lowest TI value was obtained from DF-5 as 0.915. The MCC improved the gelation of the WBDFs by creating interparticle bonding and the results showed that MCC had positive effect on thixotropy of the WBDFs. Especially, in the shear thinning flow conditions such as circulation of drilling fluids in wellbore, these indicators showed that MCC can be used as additive material for WBDFs.

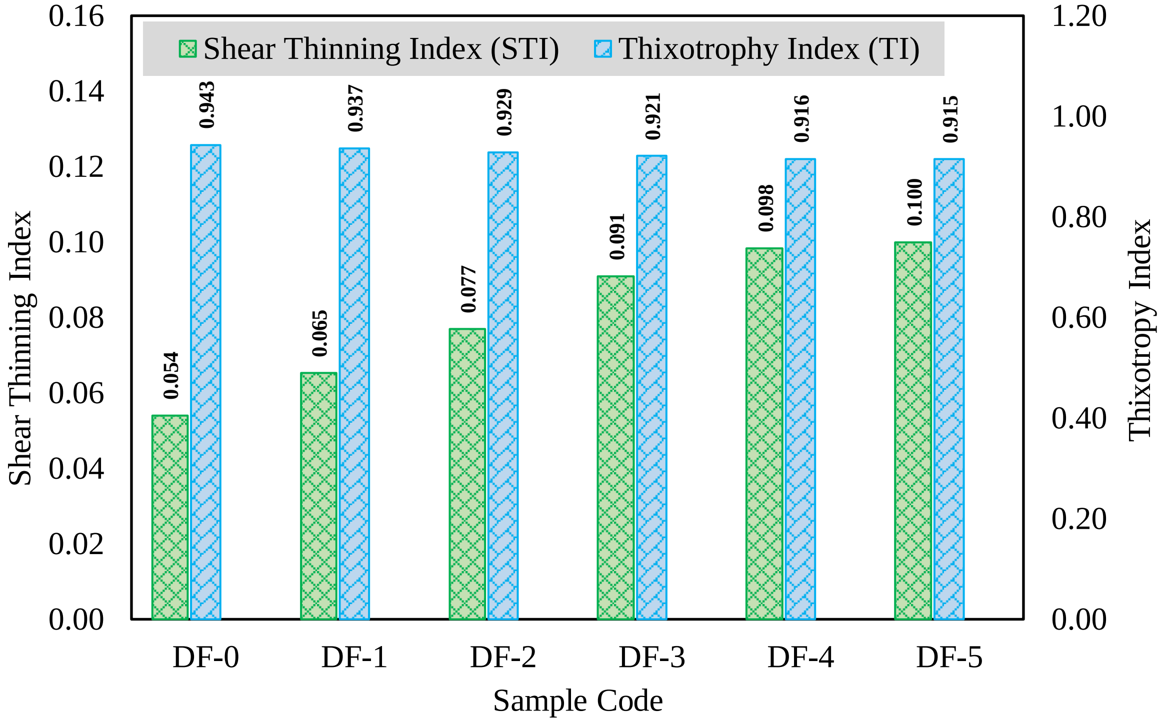

Figure 7. STI and TI results of the WBDFs

3.4. Filtration Test Results

Filtration control is one of the most important parameter of WBDFs for flow and wellbore stability. In some cases, there is fluid transfer from the drilling mud to the formation, and this situation occurs in formations that exhibit swelling properties, causing many drilling problems. The effect of the MCC used in experimental studies to prevent these problems on filtration are given in Fig. 8.

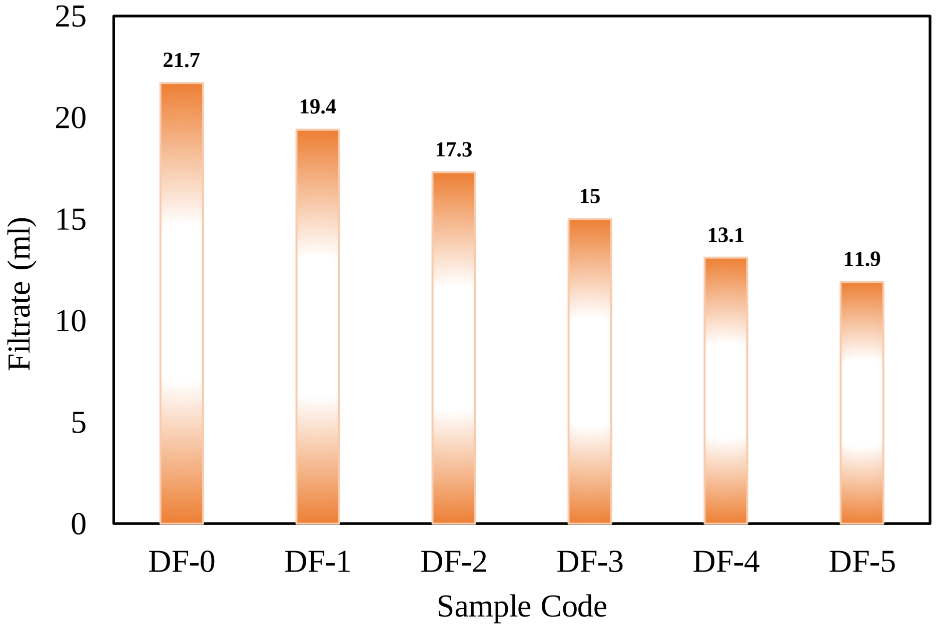

Figure 8. Filtrate volumes of the WBDFs

According to API, filtrate volume must lower than 15 ml. For this reason, it was determined that the DF-3, DF-4 and DF-5 coded samples were suitable for drilling operations. Also, the lowest filtrate volume was measured from DF-5 as 11.9 ml and highest filtrate volume was measured from the non-MCC added (DF-0) sample as 21.7 ml. The results indicated that the MCC had filtration decreasing effect on the WBDFs.

3.5. Evaluation of MCC Effect on WBDFs

In the studies examining WBDFs prepared with similar additives in the literature, it was determined that cellulosic additives have a positive effect on rheology, thixotropy and filtration properties.

In studies with CMC, Kelessidis et al. (2011) measured the maximum AV value as 90 cP at 1000 s^{-1}. Okon et al. (2014) measured the minimum filtrate amount of drilling muds with 2.5-10 g CMC as 17.5 ml and reported that a decrease occurred. Saboori et al. (2018) reported the max AV value as 110 cP, max YP value as 170 dyne/cm^2 and minimum filtrate as 15 ml in CMC was used as 1-10 g/350 ml.

In studies with PAC, Liu et al. (2022) measured the max AV and PV values as 62 cP and 38 cP, respectively. In addition, the max YP value was measured as 23 lb/$100ft^2$, and the minimum filtrate was measured as 2.5 ml. Al-Hameedi et al. (2020) examined the PAC contribution rate in the range of 1-4% and measured the max PV and YP values as 69 cP and 109 lb/$100ft^2$, respectively. They also determined that the filtrate amount was in the range of 5.1-5.3 ml.

In studies with HEC, Ouaer and Gareche (2018) measured the AV value as 75 cP at a shear rate of 1000 s^{-1} in WBDFs with additives in the range of 0.02-2.0% and reported that HEC-added fluids have high viscosity values. Wang et al. (2020) measured the max AV, PV and YP values as 34.5 cP, 28 cP and 6.5 lb/$100ft^2$ in WBDFs with HEC additives in the range of 0-2%, respectively. They also determined the minimum filtrate amount as 6.4 ml.

In studies with XCD, Jain et al. (2014) measured the maximum AV, PV and YP values as 26.5 cP, 17 cP and 19 lb/$100ft^2$, respectively at additive rate of wt. 0.4%. They also determined the minimum filtrate as 20.5 ml. Zhu et al. (2021) reported the AV as 150 cP and the filtrate as 11.5 ml in the measurements in the 0.5-3.0% additive range.

According to the results obtained from the experimental studies of this study, AV values in MCC-added WBDFs were measured in the range of 29.5-43 cP, PV values in the range of 13-16 cP, and YP values in the range of 33-54 lb/$100ft^2$. STI and TI values were calculated in the range of 0.054-0.1 and 0.915-0.943, respectively. Filtrate amounts were determined as 11.9-19.4 ml. According to these results, it was determined that MCC had a positive effect on rheology, thixotropy, and filtration properties in compared with the base sample (DF-0) and had similar positive effects to other cellulosic additives in the literature.

4. Conclusions and Recommendations

The main objective of this study is to investigate the usability of MCC as an alternative viscosity enhancing additive in WBDFs. In order to do so, a series of tests were carried out in both industrial and laboratory environments and the results were compared with viscosity improvers from the literature and commonly used in WBDFs. The results obtained within the scope of the study show that MCC generally improves the flow properties and is suitable for use in WBDFs. It was determined that MCC, a short-chain organic polymer, can be used as a viscosity enhancer and filtration control additive as an alternative to long-chain cellulosic polymers such as CMC, PAC, HEC and XCD, which are widely used for viscosity enhancement in industrial applications.

However, this study limited the positive effects of MCC to laboratory tests. In field applications, the effect on WBDFs may vary with the effect of factors such as pressure and temperature. As a result of the tests, it was determined that it can be used in shallow drilling conditions where the depth, temperature and pressure factors are not very high due to its low chain structure. It should be evaluated that chain structures may deteriorate due to temperature increase and may interact with other additives in WBDFs.

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Authors’ Contributions

All the paper is designed and created by one author.

Competing of Interest

The author declared no competing interests.

Statement of Research and Publication Ethics

The author declares that this study complies with Research and Publication Ethics.

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