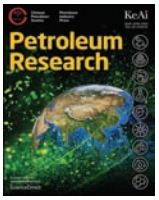
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Full Length Article

Influence of dually modified tapioca starch on drilling fluid filtration and filter cake development on rock samples



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ABSTRACT

Degradation of biomaterials under high temperatures and saline conditions leads to deterioration and loss of performance in deep well drilling applications. This research focuses on examining the impact of colloidal and dually modified tapioca starch (CMITS) on filtration characteristics. Mud filtration properties under various conditions of temperatures were evaluated through API and HPHT filter presses. Different rock samples, including sandstone and limestone, each characterized by unique pore size distributions, porosity, and permeability, are utilized to simulate filtration processes. The thermal stability of drilling fluid additives and the interactions between rocks and filtrate are investigated in hot roll oven and aging cells. The findings evaluate the interaction between temperature and starch additives on mud filtration properties. Notably, in sandstone samples, at 200 °F, Bandera Brown exhibits the lowest filtrate volume (6.2 mL) with DS 0.66 starch, while Boise sandstone produced a higher volume (38.6 mL) due to its inherent permeability. As the temperature rises to 250 °F, the effects become more pronounced. At 250 °F, Indiana limestone with DS 0.66 starch shows minimal filtrate loss (5.4 mL), while Boise sandstone faces pore plugging issues resulting in higher filtrate volumes. At 300 °F, temperature continues to exert change, with Indiana limestone and Bandera Brown displaying minimal filtrate volumes.

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1. Introduction

Drilling fluid plays a critical role in the oil and gas industry during the drilling process. One of its primary functions is to maintain wellbore stability and prevent formation damage (Agwu et al., 2021; Inemugha et al., 2019). Mud filtration characteristics are considered crucial, which impact their effectiveness in controlling fluid loss and maintaining wellbore integrity (Ali et al., 2024; Elrayah, 2024; Oseh et al., 2019). Drilling fluids are complex mixtures containing various additives (soluble and inert). These additives are added for various purposes, including enhancing rheological properties, controlling fluid loss, and stabilizing wellbore conditions (Vivas and Salehi, 2021).

Numerous materials including but not limited to bentonite, calcium carbonate, starches, lignins, cellulose, chitosan, and nanoparticles have been used for various functions in different muds (Ahasan et al., 2022; Al-Ziyadi and Verma, 2025; Ali et al., 2021a; Dong et al., 2024; Ghosh et al., 2020; Lei et al., 2020; Li, Wu, Han, et al., 2020; Li, Wu, Lei, et al., 2020; Pourmahdi et al., 2023). Considering their hazardous nature, oil and gas industry is searching for a green and economical material which can be used as an alternative of the chemically based materials that pose a negative impact on the ecosystem (Elgaddafi et al., 2023). Thus, various alternatives have recently been tested to fulfill the industry requirements. Starches are commonly used for their ability to modify drilling fluid properties and owing to their green nature (Zhong et al., 2021). Tapioca starch is a natural polysaccharide derived from cassava roots. It has gained attention in the oil and

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gas industry as a potential additive in drilling fluids due to its unique properties. Tapioca starch can improve fluid viscosity, reduce fluid loss, and enhance filtration control, making it an attractive choice for optimizing drilling fluid formulations (Aghdam et al., 2020; Ali et al., 2021b, 2024; You et al., 2024).

Recent research has shown that tapioca starch can be effective in controlling fluid loss particularly when added in water-based drilling fluids. Its ability to form a stable filter cake on the wellbore wall is key to preventing excessive fluid loss and maintaining wellbore integrity. Studies have explored the impact of tapioca starch concentration and particle size on filtration properties, revealing its potential to enhance drilling fluid performance (Ali et al., 2022; Balaga and Kulkarni, 2022).

The accurate evaluation of drilling fluid properties is crucial in the oil and gas industry to ensure efficient drilling operations and wellbore stability. Among these properties, filtration characteristics play a pivotal role in determining the drilling fluid's performance (Gautam and Guria, 2020). Most of the research has been carried out using a bentonite-based mud system, which poses various irreversible problems particularly while drilling a payzone section (Mech, 2023; Mech et al., 2020). In the recent literature, very limited research has been carried out to investigate the effects of modified starches in bentonite-free formulations. Thus, there is a need to examine the influence of modified tapioca starch in payzone section which is an acid soluble additive. In addition, the literature lacks the mud filtration behavior of bentonite-free formulations using rocks discs with varying properties. Although this research gap is of paramount significance as it serves as a critical prerequisite for comprehending the behavior of these formulations within specific environmental settings, particularly those characterized by filtration media such as sandstone and limestones.

The aim of the current work is to examine the influence of bentonite free mud composed of acid soluble materials on the mud filtration characteristics. In addition, the filtration characteristics at high temperature and pressure have been examined utilizing rock samples with varying properties (porosity and permeability). Finally, an investigation has been conducted into the filtercake morphology to gain insights into the bridging mechanisms involving the dually modified tapioca starch (CMITS).

2. Materials and methods

This research employs a dually modified starch (Carboxymethyl irradiated tapioca starch: CMITS), which was previously prepared in an earlier study (Ali et al., 2023), as an alternative of bentonite in the experimental formulations. Xanthan Gum, Polyanionic cellulose (PAC) were provided by Scomi Oiltools. Calcium carbonate, sodium hydroxide, and sodium chloride were precured from A&M.

2.1. Mud samples preparation

In accordance with API standards, the mud preparation process began by taking 350 mL of deionized water, placed into a clean and calibrated mixing cup. Xanthan gum was then added into the water, and thorough mixing ensued for a duration of 20 min, allowing for optimal hydration and consistency. Later, PAC (Polyanionic Cellulose) was added to the mixture and was subjected to an additional 10 min of mixing to confirm proper integration. Subsequently, CMITS (Carboxymethyl irradiated tapioca starch) with various degree of substitution (0.56, 0.64, and 0.66) was added and mixed for another 10 min, maintaining consistent agitation. The addition of salt followed, and the mud was mixed further to achieve the desired properties. Lastly, calcium carbonate was added and mixed for 15 min. To uphold the pH within the recommended range, sodium hydroxide (NaOH) was gradually added as needed.

To assess mud filtration characteristics, the industry standard involves the use of filter presses, both API (American Petroleum Institute) and HPHT (High-Pressure High-Temperature) were used to measure parameters including filtrate volume and filter cake thickness under various conditions.

2.2. API and HPHT filter press

The standard procedure to determine a drilling fluid's filtration properties (in static conditions) is to use a filter press. Filter press was used to examine the effect of colloidal and polymers on the filtration characteristics of the formulated drilling muds. It provided the filtrate volume and filter cake thickness in static conditions. Two categories of filter presses were used, including API and HPHT filter presses. API was used in ambient conditions where the pressure source delivered nitrogen gas with a pressure of 100 psi. However, the Ofite 4-unit HTHP filter press that accommodates 175 mL filtration cell with separate regulators and temperature controller was used for HPHT filtration. The cell was pressurized to the 650 psi pressure with a back pressure of 150 psi using a nitrogen (N_2) source. API standard filter paper (2.5 in diameter) and five different rock discs were used as filter media.

Following the standard API procedures (SPEC, 2010), the filtrate volume was measured after 1, 2, 3, 5, 7.5, 10, 15, 20, and 30 min. After 30 min, the drilling fluid was discarded, and finally, the filter cake thickness was measured with a digital vernier caliper. Each experiment was conducted three times and an average of the three was recorded and documented to get representative results.

2.3. Rock samples filtration

The rock samples (discs) with different characteristics were used to simulate filter cake development in the filtration process at an appropriate temperature and pressure. The rocks had different pore size distributions, porosity, and permeability. The porosity of rock discs was determined using the saturation method with deionized water and KCl (3 wt%). The porosity of the studied discs was calculated using Eq (1).

$$\phi = \frac{V_p}{V_b} \times 100 \tag{1}$$

$$V_p = \frac{Weight\ of\ wet\ disk - Weight\ of\ dry\ disk}{Density\ of\ deionized\ water} \tag{2}$$

$$V_b = \pi r^2 h \tag{3}$$

Where ϕ is the porosity in percentage, Vp is the pore volume, and Vb is the bulk volume of the rock disc calculated using Eqs (2) and (3). r and h represent the radius and thickness of the disc, respectively. Fig. 1 shows the filtration setup containing a rock sample disc.

2.4. Hot roll oven and aging cells

A hot roll oven is primarily used to simulate down-hole conditions of the wellbore and to determine the chemical reactions taking place in a drilling mud at the applied conditions of temperature and pressure. Fann hot roll oven (Fann Model: 705 ES) was utilized in the current work, which provided an excellent method of simulating the heating and agitating that the drilling fluid experiences when circulated through the borehole. The mud samples were contained in an HPHT aging cell. The main aim of

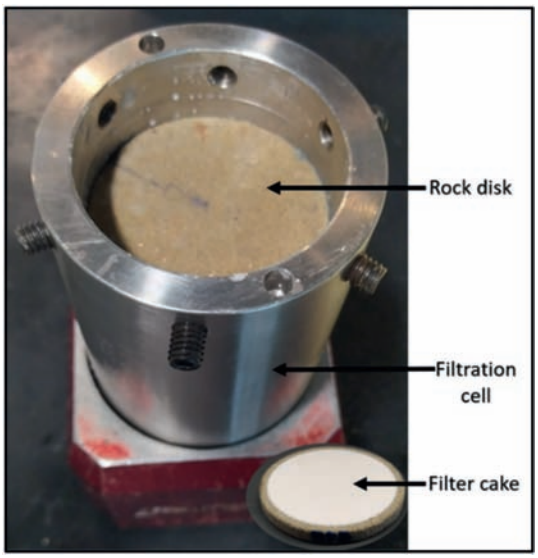


Fig. 1. Ofite filter press cell.

this hot roll was to determine the thermal stability of drilling fluids additives, especially biopolymers (xanthan gum and modified starch) when exposed for a longer time.

2.5. Filtercake morphology and texture

The optimized filter cakes developed in the studied filtration experiments have been characterized using SEM (Model: ZEISS - EVO LS 15, Carl Zeiss, Germany) to examine the morphological structure of the mud additives at ambient and at higher temperature conditions. SEM analysis can produce high-quality images of the studied porous media (Blunt et al., 2013; Rezaeizadeh et al., 2021). The texture of the mud filter cake is one of the elements to be considered when assessing the drilling mud's performance. The type of additive used in the mud formulation controls the features of the mud filter cake, such as smoothness or coarseness, as well as the number of spaces and cracks.

3. Results and discussion

3.1. Filter cake evolution

The effect of mud additives on pore throat clogging was investigated using the rock samples listed in Table 1, which had different porosity, permeability, and strength (UCS) values. The ideal packing theory was used to select an appropriate plugging material (calcium carbonate) for the rock samples. The rock samples were exposed to optimized mud samples with different degrees of substitution values. The effect was examined at 8 ppb CMITS concentration, 2.8 M NaCl concentration, and 200, 250, and 300 °F temperatures. The obtained results are presented in Table 2.

Fig. 2 (a) illustrates the filtrate volume obtained after filtration

Table 1
Rock samples properties before filtration.

Rock type	Porosity, %	Permeability, mD	UCS, kN
Bandera Brown	22.13	30.65	47.01
Berea Buff	21.06	320.44	27.08
Boise	28.77	722.52	19.46
Michigan	17.94	685.66	37.33
Indiana LS	16.45	19.41	30.18

Table 2
Filtration characteristics with DS 0.66, 0.64, and 0.56 at 200, 250 and 300 °F

DS 0.66						
Rock type	200 °F		250 °F		300 °F	
	FLV, mL	FCT, mm	FLV, mL	FCT, mm	FLV, mL	FCT, mm
Bandera Brown	6.2	1.19	7.1	1.33	7.9	1.39
Berea Buff	8.8	1.42	11.5	1.68	16.9	1.72
Boise	38.6	0.76	68.8	0.62	96	0.55
Michigan	14.2	1.73	15.6	1.76	18.8	1.8
Indiana LS	5.1	0.98	5.4	1.08	6.8	1.21
DS 0.64						
Bandera Brown	7.5	1.34	8.3	1.62	8.8	1.97
Berea Buff	9.9	1.6	14.1	1.93	18.3	2.13
Boise	36.5	0.63	63	0.56	101	0.49
Michigan	16.8	1.88	19.5	2.04	24.6	2.26
Indiana LS	7.1	1.09	7.9	1.33	8.4	1.52
DS 0.56						
Bandera Brown	7.8	1.63	9.8	1.87	15.6	2.16
Berea Buff	10.2	1.97	19	2.09	26.7	2.37
Boise	37.8	0.7	67.7	0.68	100	0.34
Michigan	21.3	2.41	28.4	2.39	36.8	2.78
Indiana LS	8.5	1.19	11.6	1.41	16.3	1.66

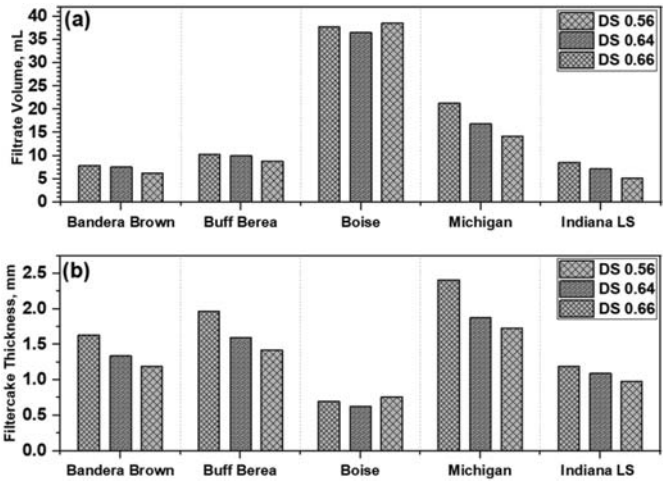


Fig. 2. Filtrate volume (a) and filter cake thickness (b) of rock samples with various degrees of substitution at 200 °F.

at HPHT conditions. The lowest filtrate volume (5.1 mL) was found for the least permeable rock (Indiana limestone), which shows that the opening pores of the rock samples were plugged by the bridging materials and starch (DS 0.66), which stopped further filtrate loss. However, at higher temperature (250 °F), the loss also rose and showed a higher fluid loss (5.4 mL). This is due to the disintegration of the starch molecules at higher temperatures. Additionally, the effect of the degree of substitution is also very dominant and shows a negative trend with the filtrate volume because of its better solubility that results in more uniform dispersion in the mud, further leading to a thin, compact, and less permeable filter cake. By comparing the filtrate volume obtained from various DS starches on rock samples, it was found that the lowest filtrate volume for all the studied samples was found by using DS 0.66 starch sample, which significantly affected the filtration characteristics. As a general rule, the filtration rate is influenced by structuring agents, including clay, polymers, and other solid phases present in the drilling fluid (Morenov and Leusheva, 2019). A significant reduction in fluid loss volume was observed for the studied samples except for Boise sandstone. The reason for the higher volume is its higher permeability and loosely

structured morphology. The filtrate loss for Boise sandstone at 200 °F was found 38.6, 36.5, and 37.8 mL for DS 0.66, 0.64, and 0.56, respectively. The bridging particles were passed through the bigger pore throats, which resulted in higher filtrate loss.

Likewise, Fig. 2 (b) demonstrates the modified starch's effectiveness in developing a thin and impermeable filter cake on the exposed rock surface. The mud sample containing DS 0.66 resulted a filtercake of 0.98 1.08 and 1.21 mm for 200, 250, and 300 °F temperatures respectively. This indicates that an increase in temperature also increases the thickness of the filter cake. Comparing all the sample filter cakes reveals that they all fall within the API recommended range (Kania et al., 2015). The studied samples showed a significant reduction in filter cake thickness for the studied samples except for Boise sandstone. The Boise sandstone showed an unusual behavior, and the modified starch failed to control the fluid loss at the mentioned temperature conditions. The reason could be its higher permeability, and the pores could not be plugged using the formulated mud. The Boise sandstone's pore throat size was larger than the other rocks, which allowed the bridging materials to pass through the channels and completely contaminated the exposed rock.

Similarly, Fig. 3 (a) shows the response of starch at 250 °F. It is revealed that the Indiana limestone sample showed the least filtrate loss (5.4 mL) at the studied temperature when the DS 0.66 was used. However, DS 0.56 and 0.64 resulted in 11.6 and 7.9 mL, respectively. Moreover, the Bandera brown samples showed better results yielding the least filtrate volume for all the starch samples. The Bandera brown sample resulted in a 9.8, 8.3, and 7.1 mL filtrate volume for DS 0.56, 0.64, and 0.66, respectively. This shows that a better plugging capability was observed when the DS 0.66 was added to the mud. On the other hand, the Berea Buff samples resulted in 19, 14.1, and 11.5 mL, while Michigan produced 28.4, 19.5, and 15.6 mL filtrate loss for DS 0.56, 0.64, and 0.66, respectively. Although an increase in filtrate volume from 5.1 to 5.4 mL (Indiana limestone) and 6.2–7.1 mL (Bandera brown) resulted from the rise in the system temperature, this increase is still acceptable because the obtained value is lower than the suggested values by API. On the other hand, the Boise sandstone completely failed to plug the pores, resulting in the filtrate volume of 67.7, 63, and 68.8 mL for the studied starches. It shows that none of the starch samples resulted in plugging the Boise sandstone's pore channels.

Fig. 3 (b) shows the filter cake thickness obtained from the rock samples at 250 °F. It is evident that a thin filter cake (1.08 mm) was developed on the surface of Indiana limestone samples, while a thicker cake (1.76 mm) was obtained when the mud was filtered using the Michigan samples. Both the porosity and permeability of Michigan were higher than the Indiana limestone, which increased the cake thickness on the surface.

The effect of starches on the filtrate volume and filter cake thickness on rock samples at 300 °F is shown in Fig. 4. Fig. 4 (a) shows that Indiana limestone produced a filtrate volume of 6.8 mL at 300 °F. In contrast, Bandera brown resulted in 7.9 mL when DS 0.66 was added into the mud. At the same temperature, the DS 0.56 and 0.64 resulted in 16.3 and 8.4 mL filtrate for Indiana limestone, while 15.6 and 8.8 mL for Bandera brown sandstone discs. Here, the DS 0.56 showed better plugging for Bandera brown as compared to Indiana limestone. Similar to the other studied temperature conditions, the Boise sandstone did not develop an external filter cake while contaminating the rocks' internal pore system. Fig. 4 (b) shows the filter cake thickness at 300 °F. It is evident that the lowest filter cake (1.21 mm) was obtained on the surface of Indiana limestone, while the Michigan sandstone showed a thickness of 1.8 mm. All the obtained thickness range lies in the API acceptable range. Similar to other temperature conditions, at 300 °F, Boise sandstone completely passed the mud, which contaminated the internal pores of the studied rock. The entire mud passed through the pores at this temperature once the pressure (650 psi) was applied to the filtration cell.

The external filter cakes developed at 300 °F on the rock samples are given in Fig. 5. Generally, the solid particles in drilling fluids are divided into three types: large-sized, medium-sized, and small-sized. A fraction of the solid particles in drilling fluids will enter the rock during the filtration process. Large particles cannot penetrate through the narrow openings between the rock particles, and consequently, they settle in the pores of the rock. As large-sized particles bond to the exposed surface and bridge, medium-sized particles are consistently bridging, filling, and inlaying, and small particles are consistently filling the microscopic spaces between the large and medium-sized particles. Over time, these processes operate together to progressively build the filter cake and reduce its permeability, resulting in an effective external filter cake development.

3.2. Filter cake texture and morphology

From the current work, it was noticed that the mud filter cake developed due to the addition of modified starch was

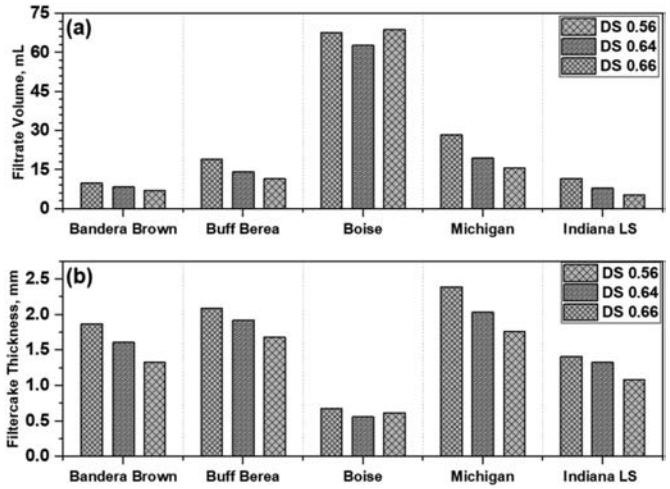


Fig. 3. Filtrate volume (a) and filter cake thickness (b) of rock samples with various degrees of substitution at 250 °F.

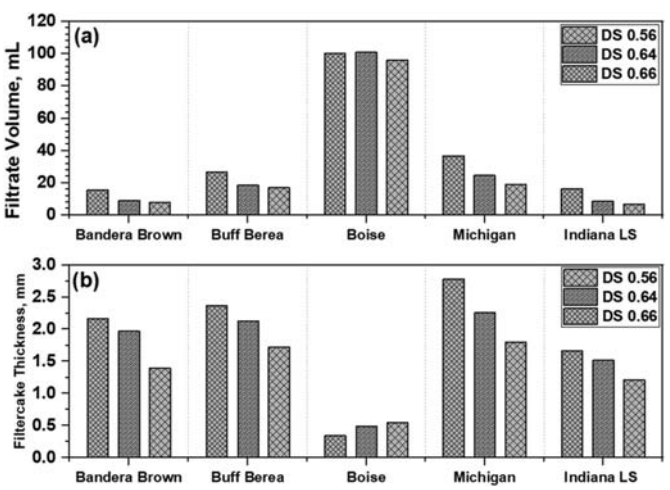


Fig. 4. Filtrate volume (a) and filter cake thickness (b) of rock samples with various degrees of substitution at 300 °F.

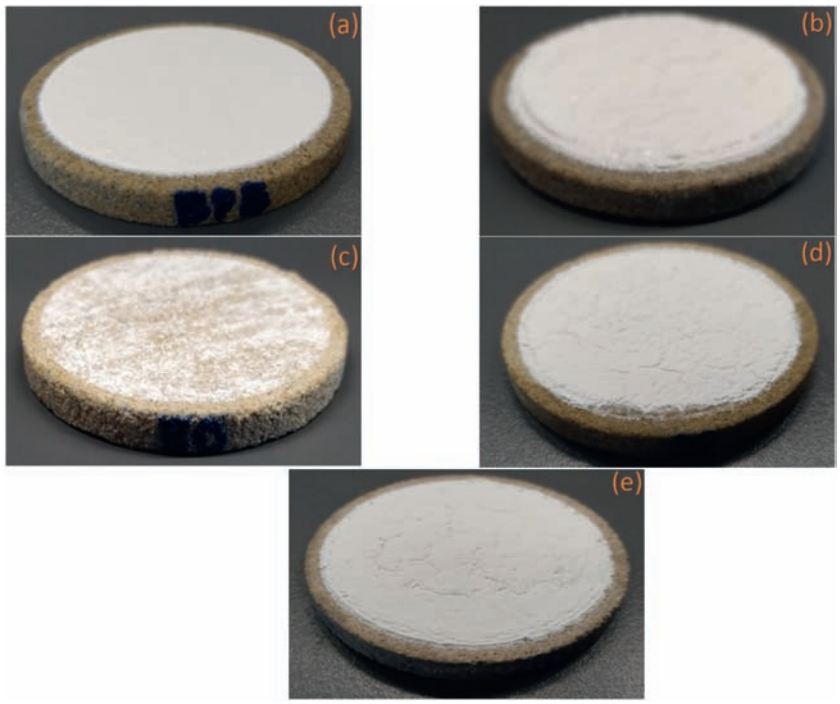


Fig. 5. External filter cake evolution on (a) Bandera brown, (b) Berea buff, (c) Boise, (d) Michigan, and (e) Indiana limestone.

comparatively smooth textured. Likewise, the filter cake formed after HPHT tests displayed a coarser filter cake of the base mud compared to the starch-based mud blends. This could be due to the disintegration of mud particles (xanthan gum), resulting in a lumped structure and generating voids between the particles. The increase in the temperature weakened the intermolecular interactions, causing inefficient packing of microstructures. This resulted in comparatively rough and permeable filter cake deposition during filtration experiments. The smoothness increased with the introduction of modified starch because it covered the pore spaces among the other particles. This plugging is attributed to the gelled nature of the starch and the variable-sized calcium carbonate that penetrated the micro-pores of the filter medium and filter cake. Furthermore, the modified starch's gelling properties aided in reducing filtrate volume by developing a complex network among the particles.

Fig. 6 (a) illustrates the surface morphology of filter cake generated from the mud sample at 70 °F. The filter cake had a smooth and reduced thickness, showing minimum pores for the passage of filtrate. The yellow encircled spots are the open spaces/fractures among the mud particles. However, most of the filter cake showed a packed pattern, which prevented the mud filtrate from passing through the filter media. The filter cakes produced with the DS 0.56 showed significant open channels, which provided a pathway to the fluid flow. While the DS 0.66 developed a stronger bond (Fig. 6 (b)) among the other particles, which restricted the fluid flow.

At 200 °F, the response of optimum starch concentration on the filter cake is shown in Fig. 7(a and b). It is evident that the open channels in the filter cake are raised, but the bridging mechanism is still acceptable because most of the portion has been plugged with the developed network structure. When compared with the ambient temperature conditions, the filter cake was more stable because the increase in temperature caused a decrease in the viscosity, which further penetrated the pores and caused better plugging. The plugging agents are surrounded by starch molecules which restrict the fluid from passing through the filter media.

The same samples were tested with a further increase in the system temperature to 250 °F, and filter cake morphology is presented in Fig. 8. From the SEM micrograms, it is observed that the pore channels become narrow with the increase in temperature, and more small pores are found on the surface of the filter cakes. As the filtrate volume increased with the increase in the temperature, but the volume was still acceptable. This shows that the modified starch can perform better even in the presence of salts and higher temperatures.

Similarly, the filter cakes developed at 300 °F are given in Fig. 9. In Fig. 9(a), the DS 0.56 starch showed some openings which can permit the filtrate through the filter media, while in Fig. 9 (b), only a few openings were observed when DS 0.66 starch was added into the mud. The images show that the modified starch can be used in high-temperature conditions in the presence of salts. Although the biopolymers were degraded at this temperature, and starch molecules were found responsible for maintaining the mud's integrity and providing significant rheological and filtration characteristics.

It was observed that the CMITS granules are linked with each other and other mud additives, as shown in Fig. 6. The high hydration feature of starch granules was associated with considerable water molecules and had blocked filtration channels, restricting drilling fluid filtration at normal temperature conditions. Furthermore, the polymer molecules passed through the pores like fingers, bridging them and attaching some amounts of water around, restricting filtration. Consequently, the filter cake permeability and filtrate volume were significantly reduced. The mentioned micrograms confirmed that the presence of the modified starch developed a strong filter cake by forming a physical network structure in the filter cake and covering the open spaces, cracks, and inconsistencies.

However, due to the starch particles' gelation at higher temperatures, a permeable cake with large pores was observed, resulting in high filtrate volume compared to the ambient conditions. Starch solubilized after HPHT filtration because of thermal

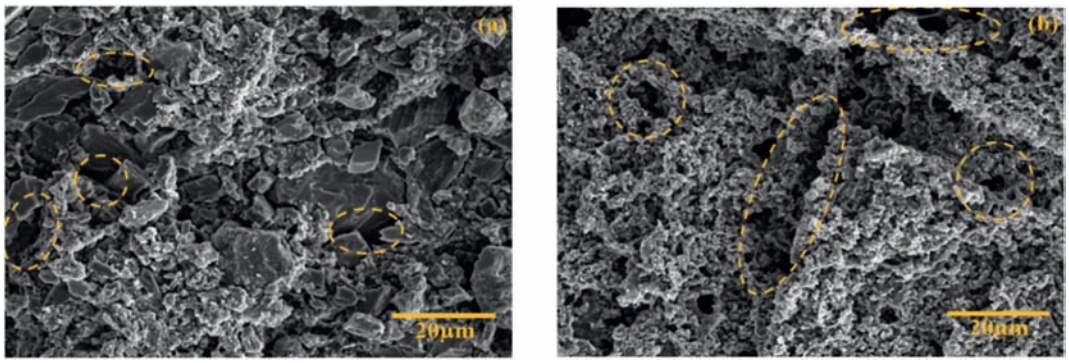


Fig. 6. Filter cake morphology of mud samples containing (a) modified starch (DS 0.56) at 70 °F and (b) modified starch (DS 0.66) at 70 °F

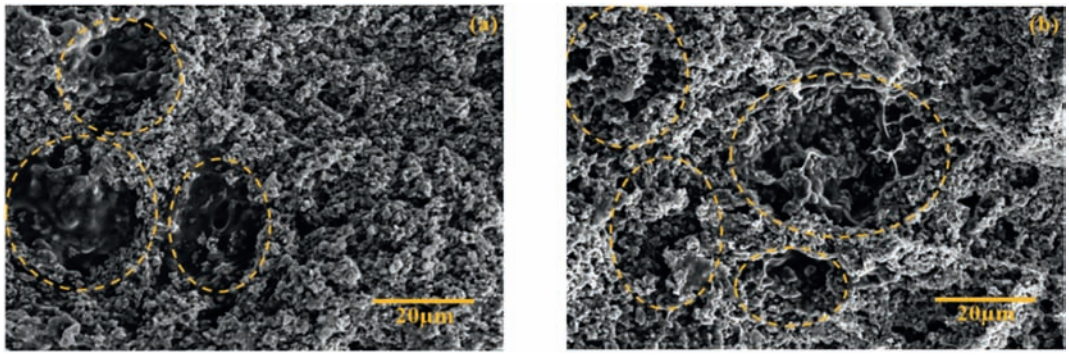


Fig. 7. Filter cake morphology of mud samples containing (a) modified starch (DS 0.56) at 200 °F and (b) modified starch (DS 0.66) at 200 °F

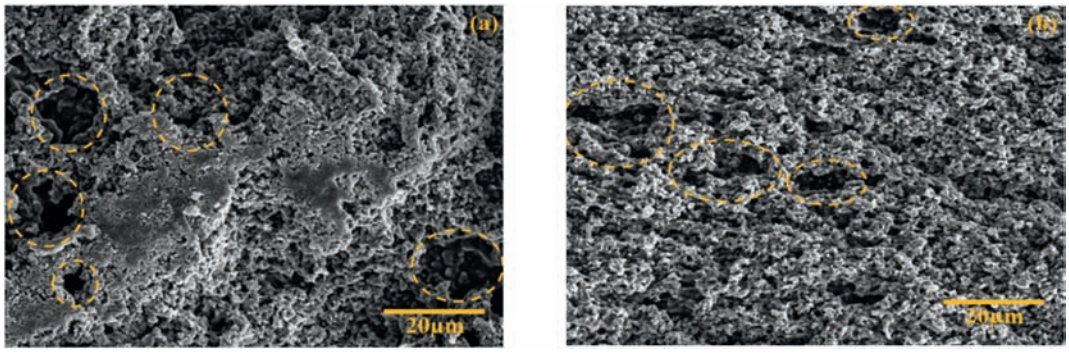


Fig. 8. Filter cake morphology of mud samples containing (a) modified starch (DS 0.56) at 250 °F and (b) modified starch (DS 0.66) at 250 °F

degradation and the lack of protective colloids, as seen in Figs. 7–9. Moreover, the fingers-like structure intensity also reduces and minimizes the sealing action due to the higher temperature. As a result, the effective flow cross-section inside the filter cake expanded significantly.

Based on the analysis of the SEM images of the developed filter cakes, it appeared that the structure of the filter cake changed according to the additive and its dosage in the mud. In the case of CMITS, the particles were oriented in a direction almost normal to the flow direction, resulting in a complex network structure that yielded a very low permeability of the filter cake, thus giving reduced fluid loss volume.

The comparison of the filter cake deposited at 70 °F (Fig. 6) with the cake at higher temperatures (Figs. 7–9) confirmed the significant changes in the filter cake microstructure that resulted from the presence of CMITS. Looking thoroughly at the filter cakes, it can be observed that the modified starch behaved as a plaster covering the open spaces in the cake, resulting in a reduction in filter cake permeability and, as a result, a significant improvement in filtration performance. In the presence of modified starch, the xanthan gum developed a more compact morphology when it was mixed with cellulose (polyanionic cellulose). It is because the starch contains native waxes and mucilage that pack the free volume between the xanthan gum, PAC, and bridging materials. Furthermore, the addition of starch to mud blends enhances the mud system's cohesiveness and consistency. Consequently, the filtration process produces minimal fractures, voids, and inconsistencies in the filter cake.

The microporous structure created by the cluster and filling of starch particles acted as an invasion channel for filtrate, resulting in a higher filtrate volume. The high temperature intensified the thermal movement of water molecules and lowered the hydration

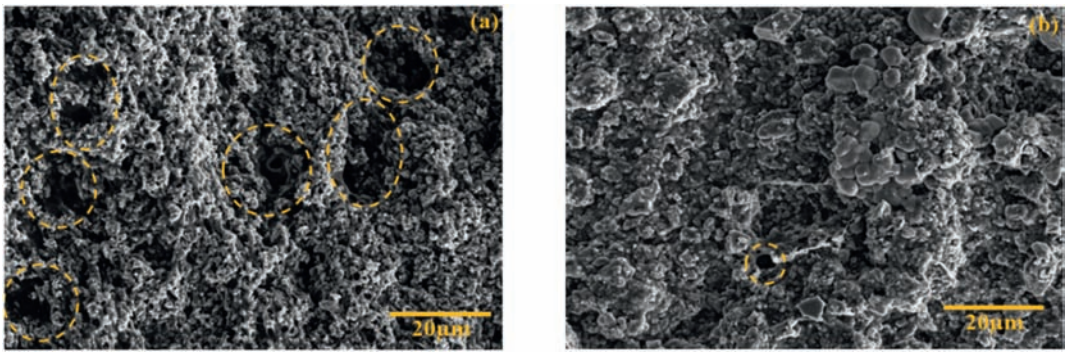


Fig. 9. Filter cake morphology of mud samples containing (a) modified starch (DS 0.56) at 300 °F and (b) modified starch (DS 0.66) at 300 °F

capacity of starch molecules, causing the hydration film to become thin and repulsive forces between mud particles to reduce, resulting in an enhanced tendency for mud particles to aggregate. Increased micropores and cracks on the filter cake surface increased fluid invasion channels into the formation, leading to increased filtrate volumes. However, when the amount of CMITS was gradually increased, the filter cake surface became denser and smoother, limiting the fluid loss channels and resulted in a reduced filtrate volume. Secondly, the higher repulsive forces between the mud particles support in decreasing aggregation between the particles, resulting in the formation of a compact filter cake that reduces the amount of filtrate.

4. Conclusions

This study unraveled critical insights into drilling fluid filtration properties, emphasizing the pivotal roles of temperature and starch additives in governing fluid loss and filter cake development. These findings are invaluable for optimizing drilling fluid formulations and enhancing drilling operations in diverse geological conditions and temperature regimes. The filtration properties of drilling fluids were examined, using a dually modified tapioca starch (CMITS). The investigation employed both API and HPHT filter presses, providing comprehensive insights into filtration characteristics by using various rock samples. The results highlighted the significance of modified tapioca starch (CMITS) utilization for improving mud filtration performance. At 200 °F, the choice of starch and rock type played pivotal roles, with Bandera Brown demonstrating remarkable resistance to filtrate loss when DS 0.66 starch was applied, whereas Boise sandstone exhibited higher permeability. This trend persisted at 250 °F, as the temperature effect became more pronounced, and starch additives continued to influence filter cake development. Despite the challenges posed by Boise sandstone, the study revealed a range of scenarios, with some rock types demonstrating effective plugging mechanisms even at elevated temperatures. The filtration at 300 °F further highlighted the interplay between temperature, rock type, and starch additives. Indiana limestone and Bandera Brown emerged as suitable candidates for maintaining low filtrate volumes, while Boise sandstone remained a remarkable challenge. Scanning electron microscopy offered a deeper understanding of filter cake morphology, elucidating the role of starch additives in enhancing stability. Modified starch created a plaster-like matrix that reduced filter cake permeability, showing its potential to mitigate fluid loss.

CRediT authorship contribution statement

Imtiaz Ali: Writing – original draft, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Maqsood Ahmad:** Writing – review & editing, Supervision. **Shiraz Ahmad:** Writing – review & editing. **Muhammad Yasir:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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