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Aphron properties and application of surfactant drilling fluids in depleted reservoirs

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Abstract

Aphron drilling fluids (ADFs) are finding increasing application in science engineering fields because of their distinctive characteristic. As the interest in the application of aprons-based fluids continues to grow, there is a decisive need to advance a deeper understanding of the factors affecting their behavior and properties, especially for successful petroleum industries, such as drilling depleted reservoirs and production. This study delves into investigating the density, rheological behavior and properties, filtration properties, bubble size, and their distribution of Aphrons-drilling fluids utilizing two ionic surfactants. Sodium Dodecyl Benzene Sulfate (SDBS) as an anionic surfactant, Cetyl Trimethyl Ammonium Bromide (CTAB) as a cationic surfactant, described as environmentally friendly, in Iraqi depleted reservoirs drilling. With an emphasis on the concentrations balance between Aphron generator (SDBS) and Aphron stabilizer (CTAB), the study analyzes the behavior and characteristics of Aphron drilling fluid. The investigation demonstrates that adding SDBS and CTAB reduces system density by 28%, owing to microbubbles production which is utilized with near-balance drilling. Rheological testing reveals that shear-thinning behavior in all Aphron samples improved, and the presence of SDBS affects the fluid's internal friction, gel strength, and short-term gel structure. Filtering control characteristic study demonstrates that the presence of microbubbles significantly minimizes fluid loss by 33% with 0.20% SDBS during filtering. Bubble size and dispersion studies demonstrate that 0.20% SDBS concentration, along with 0.30% CTAB, gives the best microbubble size and distribution. These findings suggest that Aphron fluids will be a promising innovation in petroleum industries, during actual drilling operations in Iraqi depleted oilfields.

Keywords: Aphron; SDBS; CTAB; Balanced drilling; Aphron Microbubbles; Reservoir damage.

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1- Introduction

In the oil and gas sector, drilling fluids are essential for maintaining well pressure and stability, preserving the formation, lubricating the drill bit, and removing cuttings from the wellbore to the surface. Numerous drilling fluid types are employed based on the particular well conditions, especially in depleted zones where hydrocarbons have been extracted extensively over time from mature oil and gas sources, resulting in diminished formation pressure. Low-density drilling fluids are used to balance the drilling fluid pressure with the formation pressure in these depleted zones, preventing wellbore collapse or instability [1].

In order to lower the density of drilling mud while maintaining its necessary qualities, such as lubricating and cuttings removal, low-density drilling fluids are formulated by adding additives, microspheres, or foaming agents to the mud commonly used low-density foam drilling muds are produced by injecting nitrogen or compressed air, providing the necessary weight reduction without sacrificing good performance, similarly, in order to reduce wellbore instability, aerated drilling muds—which employ gases such as air, carbon dioxide, or natural gas—are favored in deep-water drilling [2].

Nun-return drilling mud (Loss circulation) is one of the most frequently discussed problems that has attracted oil industry-wide attention. It happens when drilling fluid that is circulated through the drill string and the annulus doesn't come back up to the surface, partially or completely. instead, it goes into the permeable layers that are being drilled, causing delays in the drilling plan (NPT) and increases in costs. Ali Al-Delfi with Faleh Almahdawi, added the polyacrylamide (PAM) granular gel to drilling mud and studied their effect to enhance the mud properties. Their outcomes indicated that the ability of PAM granular gel to reduce the mud lost circulation. Increased concentrations of the PAM reduced the mud loss significantly which is an excellent indicator to mitigate mud lost circulation [3].

Both Noor Amory with Faleh Almahdawi investigated the ability to promote improved mud properties by adding the powder of the grape seed and pomegranate peel to the drilling fluid. Their results showed that the effect of the

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added powder led to a reduction in mud loss which is a good indicator of mitigating lost circulation with increased local materials concentrations [4]. The reservoir and wellbore are under negative pressure while drilling, which assists the flow of formation fluids into the well, therefore should maintain the stability of drilling wells[5].

Amel Habeeb Assi, investigated the potential use of orange peel powder (OPP) and Sidr leaf powder (SLP) as green additives to drilling fluid. Laboratory experiments were conducted to identify the effect of Local material OPP, and SLP on the drilling fluid properties. The experimental results reveal the effect of both the filtration, viscosity, and alkalinity, with Side leaves proving to be more attractive mud properties [6].

"Aphron " is a novel kind of liquid foam used as promise drilling fluid, that was invented by Sebba-Freedom Aphrons are made up of an internal phase core encircled by a thin layer of aqueous material that contains molecules of surfactant, which serves as a barrier to prevent coalition with nearby Aphron s. The idea of Aphron s has been exploited in a number of industries, such as the oil and gas area, where thousands of depleted reserves have been successfully drilled using aphron-based drilling fluids [7].

Aphronized drilling fluids (ADFs) are a kind of drilling mud that contains tiny bubbles called "Aphrons" in their nature are enhance the drilling fluid's performance in drilling operations. These tiny Aphrons are microscopic gas-filled bubbles surrounded by the shell that are stabilized by surfactants, which prevent these bubbles from merging and coalescing with each other. This outcome in a drilling fluid with unique properties (physical and chemical properties), has the ability to improve the efficiency of drilling, particularly in depleted reservoirs [8].

On the other hand, Aphronized drilling fluids can also increase the drilling operations efficiency. For instance, it can contribute to a decrease in the drill string problems (torque and drag), enhance the penetration rate, and increase the mud's ability to transport drilled cutting to the surface. Moreover, it can reduce the number of waste generated during drilling processes and provide environmental improvements by reducing of toxic chemicals used [9].

In the field, the economic using of ADFs versus underbalanced drilling (UBD) fluids will depend on numerous factors, including the cost of the drilling mud preparation and equipment, the specific drilling application, and the savings of the costs associated with improved efficiency of drilling or mitigated reservoir damage. Ultimately, before making any decision on the choice of drilling fluid type, it's necessary to consult and discuss with drilling connoisseurs and evaluate the existing conditions [10, 11].

Brookey presented the first use of ADFs, which they future named "micro-bubbles," in West Texas (a re-entry well). He outlined the system's advantages, including how well it can improve suspension qualities, hole cleaning, filtrate control, microbiological control, and corrosion control. It has gained broad use in the industry and has been effectively used to drill thousands of depleted reservoirs without experiencing any loss of circulation problems [12].

Investigators (White et al., and Growcock et al.), reported on the creation and use of a drilling fluid based on microbubbles to limit mud loss in the North Sea depleted reservoir. They described the operating techniques, the field use of the drilling fluid, and the laboratory methodologies utilized to create suitable formulations. The pressure gradients needed to enable Aphron s to penetrate deeply into the linked microfracture/pore network of the permeable formation were also covered [11, 13].

Growcock et al., discovered that, in contrast to traditional bubbles, Aphron can tolerate high pressures for extended periods of time. They also discovered that Aphron s migrate more quickly than the base liquid, which enables them to concentrate at the fluid front and form an internal seal inside the rock's pore network. Also found that Aphron-bubbles are circulated easily by prepared fluids since it's showing little attraction among them or to mineral surfaces [10].

Bjorndalen and Kuru investigated the use of ADFs in order to reduce formation damage when penetrated in at-balance drilling. The bubble size of Aphrons was examined in relation to several parameters, including continuous phase quality (water quality), mixing period, surfactant type, and concentrations of both polymer and surfactants. Characteristics of these drilling fluids (ADFs), such as mud weight, viscosities, and API filtration loss, were also inspected. Furthermore, sizes of ADFs made with anionic surfactants had greater filtration volumes than those made with cationic surfactants, the researchers found. Also, Cationic surfactants were more successful than anionic surfactants in generating micro-bubbles[14].

Khamehchi. et al., investigated the stability and rheological properties of ADFs. After evaluating the fluid's flow behavior at different temperatures using three different models—Power law, Bingham Plastic, and Herschel-Bulkley—it was discovered that the Herschel-Bulkley model was the most accurate. The study came to the conclusion that the fluid's ability to release entrained gas may be connected to its stability and that the fluid's yield stress and gel strength were improved by the addition of surfactant. Furthermore, the fluid demonstrated superior shear thinning behavior, high viscosity, and improved wellbore cleaning capability after Aphron formation. The study's findings provide valuable insights into the behavior of Aphron-based drilling fluids, which can further the development of drilling technology [2].

Haideri et al. conducted a laboratory investigation concerning the generation, description, and evaluation of Aphron-microbubbles in the fields of chemical engineering, drilling engineering, and petroleum refining engineering. The effects of the different concentrations of surfactant and polymer on the physicochemical characteristics of Aphrons, including rheological characteristics, mud weight, bubble size, distribution, and filtration loss properties, were the foremost focus of the study. The results show that more microbubbles were formed while increasing the concentration of surfactant and decreasing mud weight, filtration volume, and average bubble size, it also enhances the rheological mud characteristics by increasing the concentration of polymer[15].

The use of natural plant surfactants in Aphron fluids was examined by Ali et al., the investigation focused on the physicochemical properties of these fluids, including stability testing, bubble size measurements, and rheological characterization. The outcomes showed that the two naturally occurring surfactants that were added might be used to produce drilling fluids based on Aphron with less of an impact on the environment and at a lesser cost than surfactants from the market. Additionally, increasing the concentration of surfactant reduced Aphron diameter and fluid density, while increasing the concentration of polymer enhanced rheological properties and fluid density. The findings of the tests showed that the Aphrons created from the two plant-based surfactants remained remarkably stable over time, with no evidence of volume shrinkage. These findings illuminate the utilization of natural surfactants in the processing of Aphron-based drilling fluids, potentially leading to more environmentally friendly and cost-effective drilling techniques[16- 18].

The aim of this study is to investigate the characteristics of apron microbubbles and their impacts on the efficiency of Iraqi drilling fluids and related performance parameters to reduce damage in depleted reservoirs. This was carried out by conducting a numeral of laboratory experimental tests using two types of surfactant, CTAB and SDBS. Maintaining mud rheological and best wellbore cleaning properties, identifying the rheological behavior, and reducing the fluid filtration of mud, hence less formation damage, as a result, Aphron drilling fluid can provide these benefits using low-drilling mud density. Economic limitations and formation lithology, however, can be restricted from being utilized.

2- Experimental work

The behavior and characteristics of Aphron drilling fluid were studied through a number of tests and experiments under laboratory conditions. Aphron with various SDBS concentrations was created and tested in order to assess the impact of the Aphron generator and stabilizer on the drilling fluid.

2.1. Preparation of the base fluid

The first stage entails adding soda ash to fresh water to eliminate any potential hardening ions. The components employed in the production of Aphron drilling fluid are listed in the following Table 1. Following the addition of caustic soda to get the base fluid's pH to 9.5, bentonite is added, the mixture is stirred for 20 minutes, and the mud is aged for 16 hours in laboratory condition. The base fluid was mixed for 20 minutes at 10000 r/min using a Hamilton Beach mixer, with the polymer mixture (Xanthan polymer (XC)) added.

Table 1. Drilling fluid components

Component	Concentration (wt%)	Function
Water	100	Continuous phase
Bentonite	6.67	Gel builder
Soda ash	0.1	Hardness buffer
Caustic soda	0.1	pH control
Xanthan Polymer (XC)	0.45	Viscosifier,filtration control

2.2. Preparation of the Aphron drilling fluid

In order to produce Aphron microbubbles, the viscous fluid is prepared and then the Aphron Generator Surfactant is applied to the system Table 2. To improve Aphron 's bubble stability, add the non-ionic surfactant Aphron stabilizer surfactant to the mixture. For optimal surfactant dispersion, stir the mixture for two minutes.

Table 2. Aphron drilling fluid components

Component	Concentration (wt%)	Function
Water	100	Continuous phase
Bentonite	6.67	Gel builder
Soda ash	0.1	Hardness buffer
Caustic soda	0.1	pH control
Xanthan Polymer (XC)	0.45	Viscosifier,filtration control
SDBS	0.05, 0.1, 0.15, 0.2 or 0.3	Aphron generator
CTAB	0.3	Aphron stabilizer; viscosities

2.3. Density testing

One important characteristic of Aphron drilling fluids is density, which is particularly important when drilling in depleted zones. Duration, temperature, pressure, mixing duration, mixing speed, concentration of the Aphron generator and stabilizer, and other parameters all impact the density of the Aphron. Analyzing this impact on density with various concentrations of SDBS has been occupied.

2.4. Rheological and filtration measurement

Rheological characterization of Aphron was tested automatically programmable using Viscometer model 45 APV that measures viscosity, yield point, and gel strength of Aphron drilling mud. It also provides a reading of shear stress against a wide range of shear rates from (Φ6-Φ600). In addition, the major filtration properties of the drilling fluid, such as the filtration rate and the thickness of the filter cake were measured using the API filter press.

3- Results and discussions

It has been discovered that the existence of microbubbles promotes the system's density to decline with the inclusion of the Aphron generator and stabilizer. The density testing results displayed in Fig. 1 clearly demonstrated the impact of the Aphron additive on base mud. From Fig. 1, it can be observed that the density of the 0.05% SDBS Aphron is higher compared to other 0.10 %, 0.15%, 0,20%, and 0.30% SDBS Aphron samples respectively. This result indicates that the lower addition of SDBS failed to generate a significant number of microbubbles, resulting in a less noticeable reduction in density. Conversely, the inclusion of 0.20% SDBS resulted in a more substantial decrease in density compared to the addition of 0.1%, and 0.15 % SDBS, despite the lower concentration of the Aphron generator. Moreover, increasing the ratio of the additive SDBS to 0.30 % illustrates a rise in density because CTAB couldn't keep microbubbles in a stable situation. This finding can be explained by considering the balance between the Aphron generator (SDBS) and the Aphron stabilizer (CTAB). It should be noted that the concentration of stabilizer (CTAB) was kept constant across all Aphron samples. Consequently, the combination of 0.20 % SDBS and 0.30% CTAB exhibited a favorable balance that led to the generation of a greater number of microbubbles with a well-distributed spatial arrangement. The results emphasize how crucial it is to properly choose and balance the components in order to produce microbubbles and achieve the intended density decrease.

In summary, the reduction of fluid density is primarily attributed to the presence of Aphron-microbubbles generated after adding the Aphron generator and stabilizer has a noticeable impact directly on the density of drilling fluid. The appropriate selection and balance of these components are essential to achieve optimal results in practical applications, where controlling density can be of significant importance.

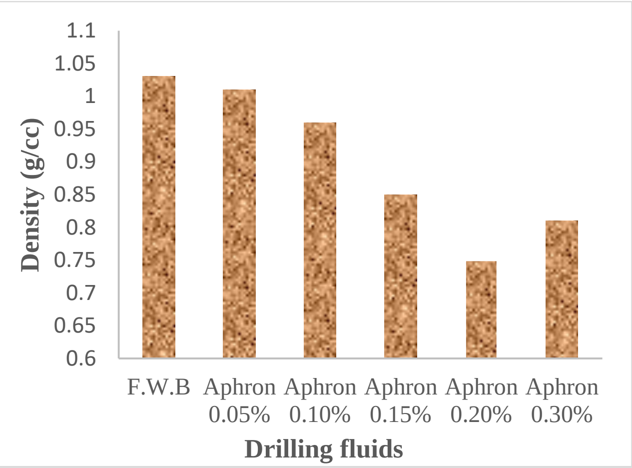

Fig. 1. Density of F.W.B and Aphron drilling fluids at different concentrations of SDBS

3.1. Aphron bubble size and distribution

Fig. 2 illustrates microscopic images of five Aphron prepared samples with various ratios of SDBS. Moreover, the following table demonstrates the results regarding bubble size, film thickness, and distribution in Aphron drilling fluids.

The results showed that the concentration changing of SDBS significantly affected bubble size, film thickness, and bubble dispersion as shown in Fig. 3. In order to clarify the above results, we have to consider the continued existence of HTAB as an apron stabilizer. 0.30% SDBS concentration resulted in a substantial increase in average bubble size (400 µm) compared to the other concentrations. This shows that adding more SDBS may result in greater bubble size. However, at 0.20 % SDBS concentration in Aphron fluid shows higher bubble distribution with better film thickness and more stability (Fig. 3). In conclusion, the results illustrate that the concentration of the Aphron generator SDBS has an enormous effect on the size, film thickness, and distribution of bubbles in the Aphron drilling fluids. Lower SDBS concentrations produce larger bubbles with thicker films, whereas higher concentrations produce smaller bubbles and thinner films. The ideal concentration of 0.20% SDBS, along with 0.3% CTAB, appears to give the best circumstances for producing smaller and more frequent bubbles with thinner sheets.

3.2. Rheology

3.2.1. Rheological behavior

For evaluating the rheological behavior of the freshwater bentonite and Aphron samples, shear stress has been recorded using a Viscometer as illustrated in Fig. 4. As is obvious, it clearly illustrates that the overall pattern of decreasing viscosity rate as the shear rate rises, a feature typical of shear-thinning fluids, commonly referred to a pseudoplastic fluid. Furthermore, the figure reveals the occurrence of yield stress, which is defined as the lowest shear stress required for the fluid to begin flowing. This attribute is consistent with Herschel-Bulkley drilling fluids. Herschel-Bulkley model is ideal for applications requiring high rates of shear, especially drilling activities in deep drilling (Fig. 4). These kinds of fluids can also be useful in conditions requiring a high yield stress, such as drilling wells in unstable formations. Such fluids have a yield stress that prohibits cuttings from settling in the bottom of the wellbore, and its shear-thinning tendency makes pumping and circulation less complicated. As a result, Herschel-Bulkley model drilling fluids are versatile enough for a wide range of applications, which makes them an effective option in a variety of operating scenarios. Their particular blend of qualities makes them adept at controlling various obstacles faced during actual drilling activities.

3.2.2. Rheological properties

Fig. 5 and Fig. 6 demonstrate the rheological parameters of Aphron drilling fluids, including plastic viscosity (PV), yield point (YP), cleaning capacity, and gel strengths tested at 10 seconds and 10 minutes. The observed alterations in rheological parameters are influenced by the concentration of SDBS. The variations can be due to the interaction of SDBS and base fluid in the drilling mud system. It can be seen clearly that the plastic viscosity (PV) has improved due to the rise of the percentage of SDBS in the drilling mud system due to the existence of friction force between bubbles. Whereas, 0.20% SDBS of Aphron shows tranquil cleaning efficiency compared to another rate of SDBS. A clear trend of increasing the plastic viscosity is obtained by increasing the concentration of Aphron. However, the value of the yield point is highly increased by adding 0.05 wt.% SDBS into the base drilling fluid from 22 to 116 lb/100ft^2 and decreased with increasing the concentration to 0.1 wt.%. Afterward, the inverse behavior of the yield point was achieved with the concentration of SDBS as shown in Fig. 5. Furthermore, Fig. 6 presents the features of the initial and final gel strength along with the cleaning capacity measured under the influence of Aphron agent at different concentrations. As is clear, the values of these parameters were increased when the first dosage of SDBS was added to the base drilling fluid and then started to decline with increasing its concentration.

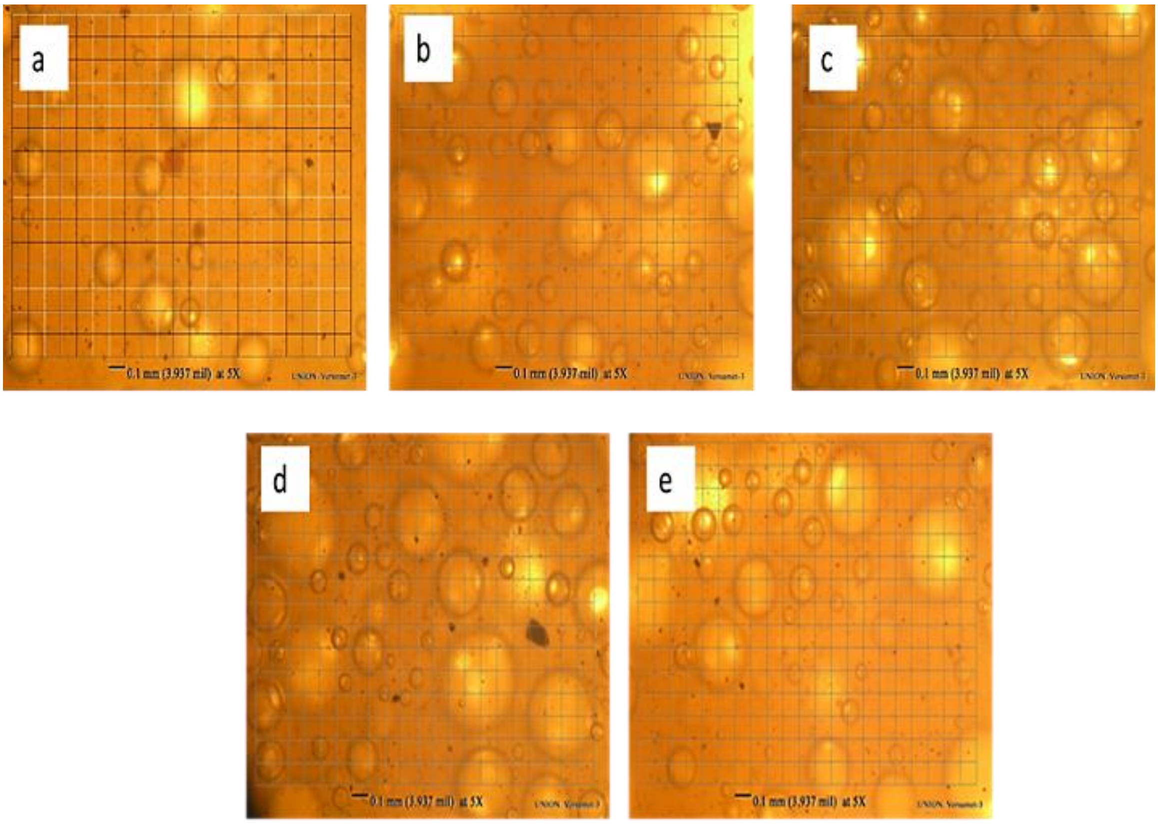

Fig. 2. Bubble size and distribution of aphron drilling fluid with (a) 0.05% SDBS (b) 0.10% SDBS (c) 0.15% SDBS (d) 0.20% SDBS (e) 0.30% SDBS

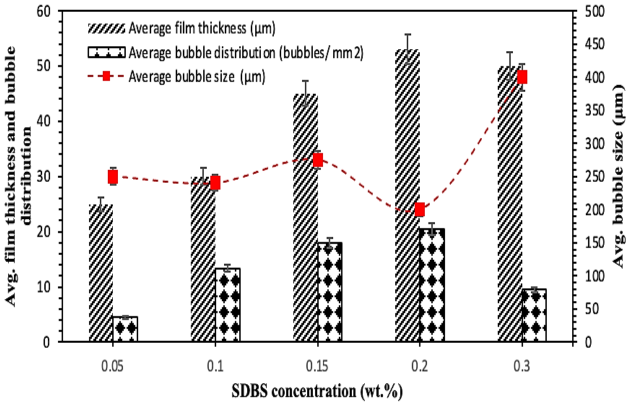

Fig. 3. Characteristics of the micro-bubbles created from the presence of SDBS within the drilling fluid at different concentrations

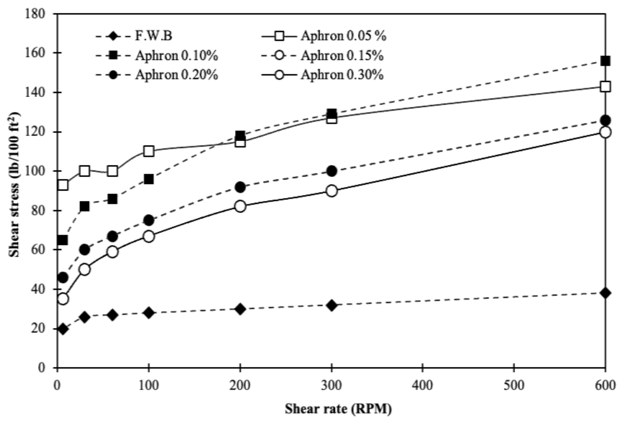

Fig. 4. Rheological behavior of the developed drilling fluids with and without the presence of aphron by shear rate vs. shear stress

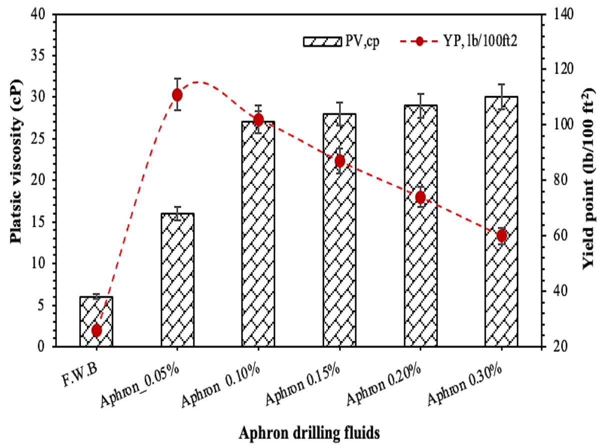

Fig. 5. Measured values of the plastic viscosity and yield point for the developed drilling fluids at different concentrations of Aphron

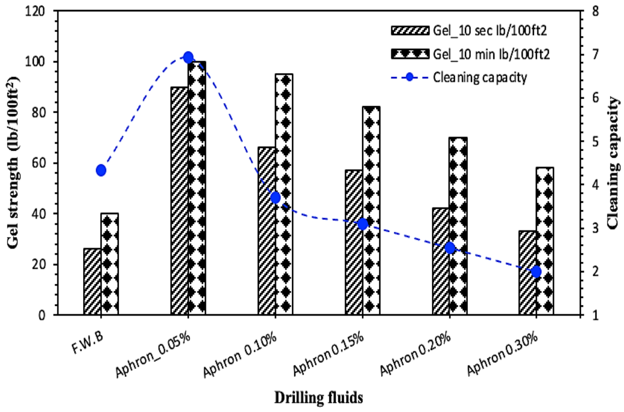

Fig. 6. Measured values of the gel strength and cleaning capacity for the developed drilling fluids at different concentrations of Aphron

3.3. API filtration loss

API filtration loss has been examined at laboratory conditions for both F.W.B and Aphron drilling fluid with varying rates of SDBS additive, in order to clarify the effect of microbubbles on filter control. The results of the test are summarized in Fig. 7. It can be clearly seen the effect of microbubbles caused by SDBS additive with various ratios in the Aphron drilling fluid which explains the trends in API filtration loss values. These microbubbles play a crucial role in filter control, influencing the fluid's filtering behavior during testing. The API filtration loss of F.W.B is 12 ml. which reflects the mud's natural filtering properties in the apron-microbubbles absence. Conventional muds, or bentonite-based systems, have filtration rates described as moderate to high, as a result, it depends on solids movement and growth of filter cake throughout tests.

The Aphron-based drilling fluids API filtration test demonstrated that the volume of filtrate loss reduced as the SDBS concentration increased in the Aphron mud sample. This is attributed to numerous microbubbles generated into the Aphron system forming a three-dimensional network inside the drilling fluid. This network works to prevent mud solids from migrating to the filter media, hence increasing the mud's resistance to filtration. The Aphron-microbubbles bridge the holes in the filtrating area by building a solid filter cake, limiting the cake's permeability and fluid loss.

Moreover, the microbubbles enhance the effective surface area of fluid, giving higher interaction with solid particles and enhancing solids suspension. These circumstances will persevere until the microbubbles starting burst, at which point the property that exists with 0.30% SDBS added to Aphron-based drilling fluid is lost.

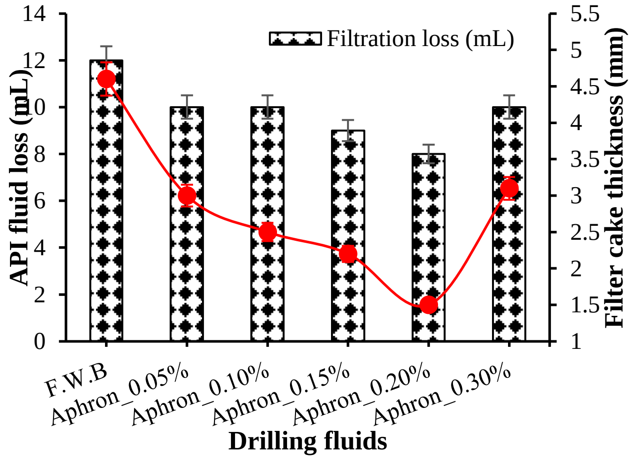

Fig. 7. Measured values of the fluid loss and filter cake thickness for the developed drilling fluids at different concentrations of Aphron

4- Conclusions

The results of this study accentuate the crucial role of the concentration balance between Aphron generator SDBS and Aphron stabilizer CTAB to determine Aphron-bubble size and distribution in the Aphron mud system. Achieving this balance is critical to optimizing the necessary drilling fluid characteristics and performance during drilling operations.

Increasing the surfactant content in Aphron drilling fluid has been demonstrated to be helpful since it reduces filtration loss and increases viscosity. These enhancements can lead to more efficient drilling operations and wellbore stability. Comprehensive testing revealed that an Aphron drilling fluid concentration of 0.2% SDBS provided the best results because it achieved the lowest fluid filtration with accepted other properties. This concentration should be investigated and confirmed under actual drilling conditions.

The rheological behavior of Aphron fluids demonstrated shear-thinning with a yield stress, corresponding with the Herschel-Bulkley model. This unique behavior makes Aphron fluids well-suited to certain drilling issues and broadens its possible occupies in the drilling field.

Nomenclatures and abbreviations

ADF	Aphron Drilling Fluid
API	American Petroleum Institute

AV	Apparent Viscosity
CTAB	City-Termidyl Ammonium Bromide
F.W.B	Fresh Water Bentonite
IDC	Iraqi Drilling Company
NPT	Nun-Productive Time
PAM	Polyacrylamide
PV	Plastic Viscosity
SDBS	Sodium Dodecyl Benzene Sulfate
UBD	Underbalance Drilling
XC	Xanthan
YP	Yield Point

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خصائص تقنيات الأفرون: سوائل الحفر المائية المعالجة بالمواد الخافضة للتوتر السطحي لتقليل الضرر في الخزانات المستنفذة

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الخلاصة

تجد سوائل الحفر أفرون (ADFs) تطبيقًا متزايدًا في مجالات الهندسة العلمية بسبب خصائصها المميزة. مع استمرار تزايد الاهتمام بتطبيق السوائل المعتمدة على الأفرون، هناك حاجة حاسمة لتعزيز فهم أعمق للعوامل التي تؤثر على سلوكها وخصائصها، خاصة بالنسبة للصناعات البترولية الناجحة، مثل حفر الخزان المستنزف والإنتاج. تتعمق هذه الدراسة في دراسة الكثافة والسلوك والخصائص الريولوجية وخصائص الترشيح وحجم الفقاعات وتوزيعها لسوائل الحفر الأفرونية باستخدام اثنين من المواد الخافضة للتوتر السطحي الأيونية. كبريتات دوديسيل بنزين الصوديوم (SDBS) كمادة خافضة للتوتر السطحي أنيونية، وسيتيل ثلاثي ميثيل بروميد الأمونيوم (CTAB) كمادة خافضة للتوتر السطحي الكاتيونية، توصف بأنها صديقة للبيئة، في مكامن الحفر العراقية المستنفدة. مع التركيز على توازن التراكيز بين مولد أفرون (SDBS) ومثبت أفرون (CTAB)، قامت الدراسة بتحليل سلوك وخصائص مائع الحفر أفرون. يوضح البحث أن إضافة SDBS وCTAB يقلل من كثافة النظام بنسبة ٢٨%، وذلك بسبب إنتاج الفقاعات الأفرونية الدقيقة. يكشف الاختبار الريولوجي عن تحسن سلوك ترقق القص في جميع عينات أفرون، ويؤثر وجود SDBS على الاحتكاك الداخلي للسائل، وقوة الجل، وبنية الجل على المدى القصير. توضح دراسة خصائص التحكم في الترشيح أن وجود الفقاعات الدقيقة يقلل بشكل كبير من فقدان السوائل بنسبة ٣٣% مع ٠,٢٠ % SDBS أثناء عملية الترشيح. تثبت دراسات حجم الفقاعة والتشتت أن تركيز SDBS بنسبة ٠,٢٠%، إلى جانب ٠,٣٠ % CTAB، يعطي أفضل حجم للفقاعات الأفرونية الصغيرة وتوزيعها. وتشير هذه النتائج إلى أن سوائل افرون ستكون ابتكارا واعدا في الصناعات النفطية خلال عمليات الحفر الفعلية في حقول النفط العراقية المستنزفة.

الكلمات الدالة: أفرون، مولد أفرون، مثبت أفرون، الحفر المتوازن، فقاعات أفرون، تضرر الخزان.