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Enhancing Drilling Efficiency and Reducing Vibration Induced Failures with Mud Lubricants

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Abstract

In the context of hard rock drilling, it is observed that drill pipes utilized in oil well drilling operations may experience significant vibrations and exhibit torsional forces, leading to potential detachment or breakage. The phenomenon known as stick-slip has the potential to inflict damage onto drill strings and subterranean equipment. The management of vibrations is crucial in order to enhance operational efficiency and reduce expenses associated with drilling activities. This study focuses on the experimental investigation of mud drilling evaluation methods. The objective is to mitigate the friction factor by incorporating additives into the typical mud mixture, which serve as lubricating agents. Several laboratory experiments were carried out to investigate the impact of graphite alone and a combination of graphite and petrol oil as a mud lubricant on the rheology, filtration losses, and lubricity of drilling fluids when added to water-based mud. The objective was to evaluate and enhance the performance of the mud. A total of six samples were generated for each test, utilizing water-based mud and either additional graphite (with a particle size of 38 μm) or a combination of graphite and gasoil. The findings of this study indicate that the use of graphite, either alone or in combination with petrol oil, in water-based drilling fluids can effectively mitigate stick slide phenomena and improve the rheological characteristics of the fluids. Based on the findings of the experimental study, it was determined that the optimal quantity of graphite additive is 5 grammes, resulting in the lowest friction factor value of 0.33. Additionally, the minimum friction factor value of 0.18 can be achieved by incorporating a combination of 5 grammes of graphite and 5% gasoil.

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1. Introduction

Stick-slip vibration is a phenomenon that manifests in drilling systems whereby the drill string undergoes periodic slipping and sticking against the wall of the borehole. The aforementioned issues can give rise to a variety of challenges, encompassing premature equipment malfunctions, suboptimal drilling practices, and substandard wellbore conditions [1].

The phenomenon of stick-slip vibration arises due to the interaction of frictional forces between the drill string and the wall of the borehole. During the rotation of the drill string, the interaction between the two surfaces might result in the accumulation of frictional force, eventually leading to the occurrence of slippage of the drill string. Upon the occurrence of a slip in the drill string, the frictional force experienced is diminished, so enabling the drill string to resume its rotational motion. The aforementioned phenomenon recurs, leading to the distinctive stick-slip oscillation. Several factors can contribute to stick-slip vibration, such as the characteristics of the drilling fluid, the rock's hardness which is mean rock mechanical properties like frictional angle, [2], and the drill bit's design. The mitigation of stick-slip vibration can be achieved by the regulation of several parameters, in addition to the utilization of vibration-damping devices. The primary goal of this research is to investigate the sick slip effects and provide solutions for preventing the damage of expensive equipment. String components that can be damaged by stick-slip include drill bits, downhole motors or rotary steerable systems, measuring equipment, stabilizers, drill collars, and drill pipe. This study is attempted to mitigate stick slip motion by using a mud lubricator and investigation the effect of mud on fresh water drilling fluid by reducing the friction factor between the components of drilling string and formation to be drilled [3].

1.1. Stick-Slip Relating to Drilling

Stick-slip is a common vibration phenomenon in drilling that can cause premature tool failures, low drilling efficiency, and poor wellbore quality. Researchers have investigated the effects of mud properties, drill bit design, drilling parameters, drill string stiffness, wellbore inclination, and mud additives on stick-slip since the 1960s, and proposed various methods to mitigate it, such as using mud lubricators, optimizing drilling parameters, designing new drill bits, optimizing drill string stiffness, mitigating stick-slip in inclined wells, and using vibration-damping sleeves [4].

Stick-slip motion in drilling oil wells has garnered substantial attention in the scientific papers. A comprehensive review of the phenomenon is presented in several studies. In a survey of the literature, researchers have focused on both theoretical and experimental aspects of stick-slip vibration in oil well drillstrings. Tang L et al (2020) aims to understand and suppress stick-slip vibrations, which are detrimental to drilling operations [5]. Recent approaches, such as real-time prediction using machine learning, have been explored to enhance stick-slip vibration control by Elahifar, B., Hosseini (2023) [6]. Additionally, an up-to-date review outlines the phenomena and modeling methods of stick-slip behavior in drillstrings presented by Zhu et al (2014) [7]. These studies collectively contribute to the development of effective treatment strategies for mitigating stick-slip motion during oil well drilling operations.

It starts when the energy (or torque) produced by the drill string to the bit is insufficient to overcome the formation being drilled. The bit slows or stops in the "stick" phase at this moment. Torque accumulates in the drill string, forcing it to twist. When the torque is high enough to tear the bit free from the formation, the bit accelerates fast in the "slip" phase. Until the operating settings or formations change, the drilling assembly will cycle between the "stick" and "slip" phases. This action is demonstrated in Figure (1). [8].

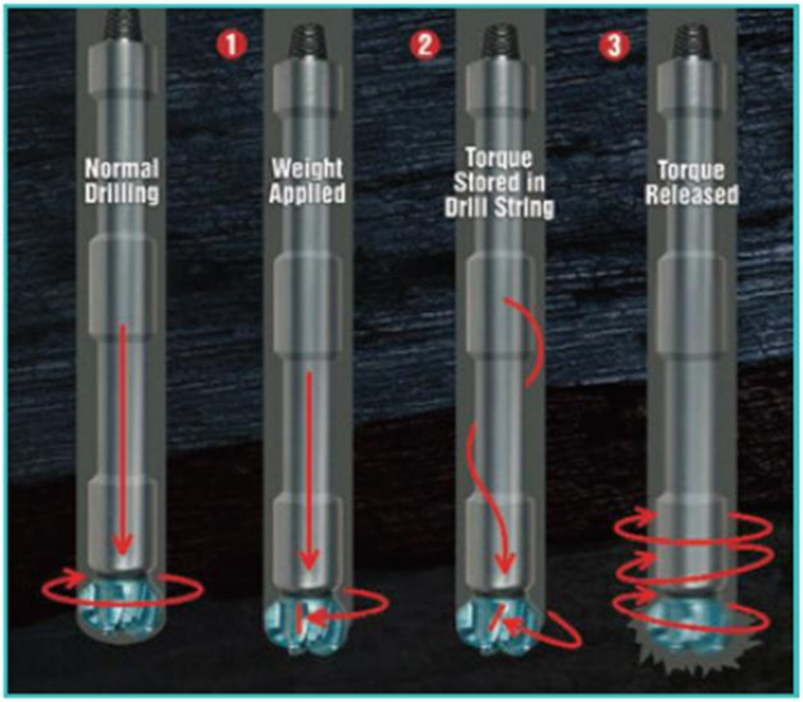

Figure 1: Stick-slip in a drilling environment, [8].

2. Experimental work and Apparatuses

Numerous laboratory investigations were undertaken to examine the impact of graphite and petrol oil as additives for enhancing the rheological properties, filter loss characteristics, and lubricating capabilities of drilling fluids, with the aim of evaluating and enhancing the overall performance of the mud system.

2.1. Materials

Prior to commencing the trials, a concise summary of all the chemicals and additives employed in our research is presented. Bentonite is commonly regarded as the predominant ingredient utilised in drilling fluid within the oil sector. The term "bentonite" is a proprietary designation. The Ford Benton shale at Rock Creek, Wyoming has a clay-like substance. Bentonite consists primarily of finely-grained clays with a minimum of 85% Montmorillonite, which belongs to the smectites group of clay minerals [9]. Bentonite can be classified as either sodium bentonite or calcium bentonite, depending on the primary exchangeable cation. The categorization of bentonite as having a "high yield" (Sodium Bentonite) or "low yield" (Calcium Bentonite) performance is based on the relative reactivity of sodium bentonite in fresh water compared to calcium bentonite [9]. Figure 2 displays the characteristic atomic structure of clays. Barite, scientifically referred to as barium sulphate ($BaSO_4$), is a commonly employed substance for weight augmentation in the drilling sector. The range of specific gravity for barium sulphate is typically reported as 4.20 to 4.60. Barite is commonly employed when drilling fluids with densities over 10 pounds per gallon (ppg) are necessary. Barite has the potential to be employed in order to get densities of up to 22.0 pounds per gallon (ppg) in drilling fluids that are compatible with both water and oil [10]. In the process of clay beneficiation, soda ash or sodium carbonate (Na_2CO_3) is occasionally utilised to eliminate soluble calcium salts from makeup fluids and muds [11]. Sodium hydroxide (NaOH), commonly referred to as caustic soda, is a chemical compound. Water muds commonly utilise the application of certain substances to achieve various objectives. These substances serve to elevate the pH levels, saturate lignite, lignosulfonate, and tannin compounds, mitigate corrosion, and neutralise hydrogen sulphide. The clay particles have undergone adsorption of carboxymethyl cellulose (CMC), which is an anionic polymer. There exist three distinct levels of viscosity, namely low, medium, and high. Filtration is severely impeded by the presence of low quantities of CMC, especially in items with higher molecular weight and viscosity. The thermal breakdown of CMC is observed to accelerate when the temperature approaches 300 °F [11]. Gas oil was selected as the preferred formation oil above alternative petroleum products due to its suitability as a lubricant. This choice was made based on its user-friendly nature, non-volatility at ambient temperatures, and ready availability. The fundamental characteristics of petrol oil include its specific gravity (Sp.gr.) at a temperature of 24 °C, which is measured to be 0.825. Additionally, the viscosity of petrol oil at a temperature of 30 °C is determined to be 2.3 centipoise (c.p). Graphite, a crystalline manifestation of the element carbon, is classified as one of the allotropes of carbon and is also considered a semimetal. Given the prevailing conditions, graphite can be considered as the carbon allotrope with the highest level of stability. Due of its potential application as a lubricant for mining machinery and its utilisation in thermochemistry to quantify the heat of formation of carbon compounds. In the present investigation, graphite material was utilised subsequent to being crushed to a particle size of 38 μm. This crushed graphite was then incorporated as an additive to the usual drilling fluid.

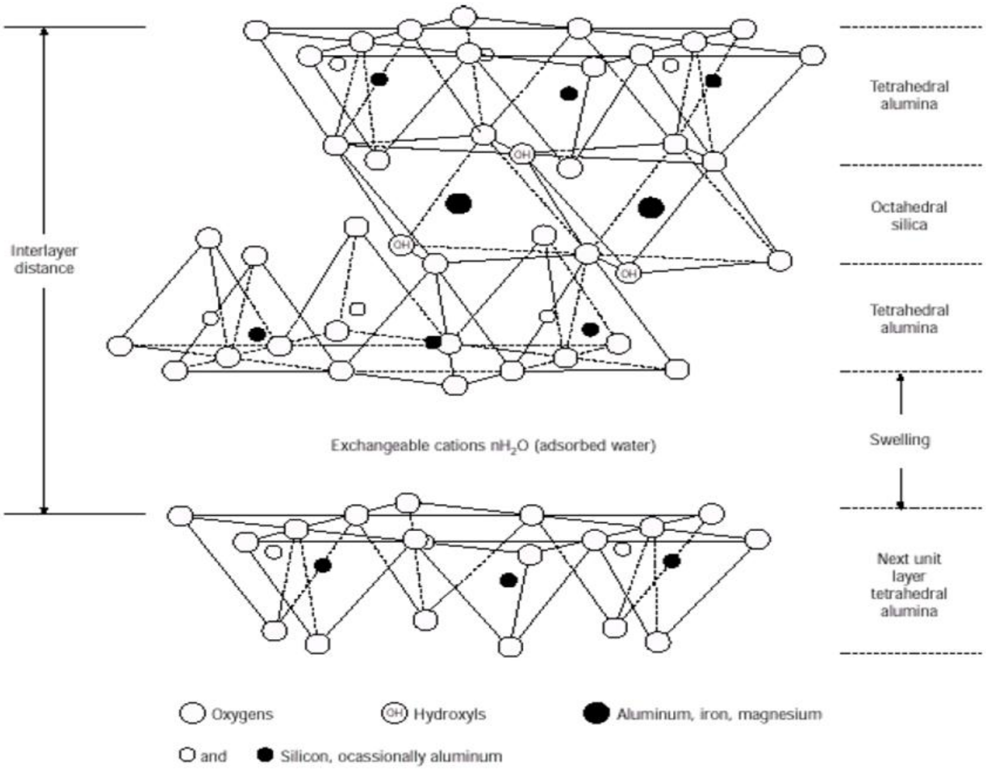

Figure 2: Characteristic Atomic Structure of Clays [10].

2.2. The Laboratory Apparatus

The Model 800 8-Speed Electronic Viscometer is extensively utilised on a global scale, in both field and laboratory environments, for the exact assessment of the rheological properties of fluids. The conventional 800 Viscometer is utilised to evaluate the flow characteristics of oils and drilling fluids by measuring shear rate and shear stress throughout different time and temperature intervals, particularly in high-pressure environments. The device provides a selection of eight test speeds, which are accurately measured in revolutions per minute (RPM). These rates include 3 RPM (Gel), 6 RPM, 30 RPM, 60 RPM, 100 RPM, 200 RPM, 300 RPM, and 600 RPM.

A low-pressure filter press is utilised for the assessment of the filtration and wall cake forming characteristics of muds. The design of the filter press comprises of several components, including a cell body that serves the purpose of containing the drilling fluid sample, a pressure chamber, and a base cap that is fitted with a screen and filter paper. The pressure cell is specifically engineered to fit a 3-inch (9 cm) sheet of filter paper positioned at the base of the chamber, with the purpose of effectively eliminating particles from the fluid. The filter area is consistently maintained at a value of 7.1 ± 0.1 square inches (equivalent to 4.580 ± 60 square millimetres). Pressure can be exerted by employing a non-volatile fluid medium, such as gases or liquids. Multi-element filter presses are very ideal for laboratory settings where there is a requirement to run many tests concurrently. The units are equipped with manifolds, air tubes, and bleed-off valves, as illustrated in Figure 3.

The EP (Extreme Pressure) and Lubricity tester is a high-quality instrument used to assess the lubricating properties of drilling fluids. It provides data for evaluating the type and quantity of lubricating additives needed and predicts wear rates of mechanical components in known fluid systems. The test involves measuring the torque applied to a steel block as it presses against a rotating steel ring, with a maximum torque limit of 600 inch-pounds as show in figure 4 below.

Figure 3: The device exhibits a pressure drop of 6 units due to water loss.

Figure 4: The device under consideration is an Extreme Pressure and Lubricity tester.

2.3. Experimental Methodology

2.3.1. Effect of Graphite as a Lubricator on Water Base Mud

In this test, 6 samples were prepared by using water base mud and additive graphite (with particle size 38 µm) without treatment to look at the effects of lubricating a water base fluid in a lab setting on the rheological, filter loss, and performance of graphite.

• Sample1(blank): Adding 22.5 gm bentonite+50gm barite+1gm NaOH+1gm CMC to an equivalent bbl of a mud (350 cc) water to prepare a conventional water-based fluid.

• Sample 2, 3,4, 5 and 6: Water based drilling fluid is formulated using 22.5gm bentonite+1gm soda ash+1gm NaOH with 350 ml distilled water. Mixing the mud at least for 20 min to prepare a unique fluid. Adding 50gm of barite to the mixture and mixing for 15 min. Adding 1gm of CMC to the mixture and mixing for 10 min. Adding various amounts of graphite, (1, 2, 3, 4 and 5) gm. respectively. Mixing all the samples produced at 6000 rpm for 10 min by using Hamilton beach mixer. Measurements made in the laboratory included mud weight, pH, viscosity, and routine API filter and lubricity tests.

2.3.2. Effect of Graphite& Gasoil as a Lubricator on Water Base Mud

In this experiment, six samples were prepared using water-based mud and an addition that was identical to the material used in the initial experiment. Additionally, 5% gasoil was added to investigate the impact of lubricating a water-based fluid on the rheological properties, filter loss, and performance of graphite in a laboratory setting.

3. Results and Discussion

Based on the analysis of the Rheogram figure, it can be observed that the tested samples and the similar model employed in this study conform to the Bingham plastic model, therefore serving as an appropriate rheological model, as depicted in figures 5 and 6.

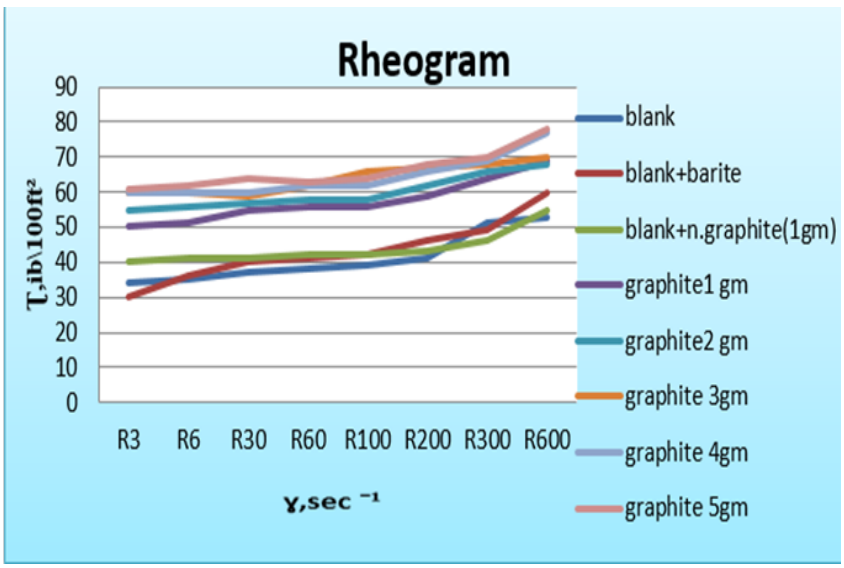

Figure 5: The findings indicated that employing the identical model approach to the Bingham plastic model yielded consistent outcomes when applied to the evaluated samples.

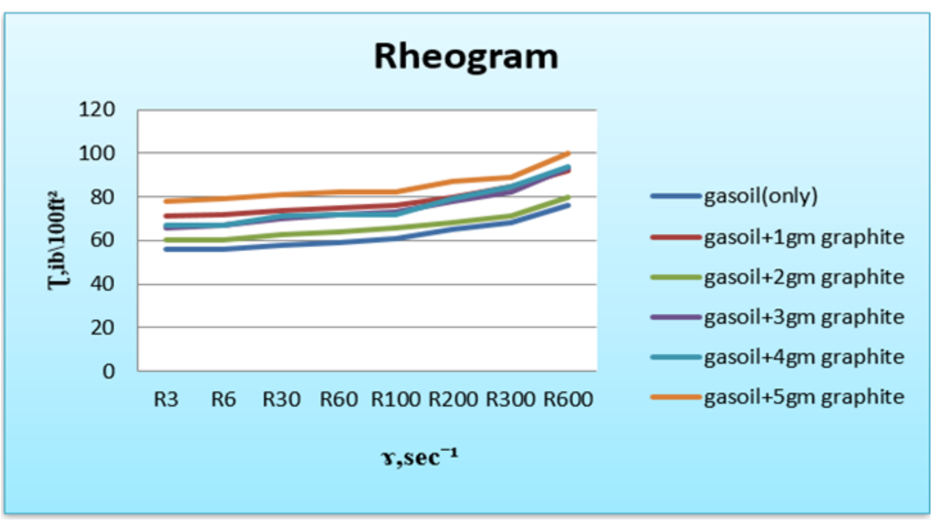

Figure 6: the results showed that the identical model approach to Bingham plastic model with the tested samples.

3.1. Effect of graphite as a lubricant on water base mud

After undergoing sample preparation and a hydration period of 16 hours, the samples were subjected to laboratory settings for the measurement of several properties including viscosity, density, pH, filtration, and lubricity. The findings are presented in Table 4-1, illustrating the following results. The plastic viscosity, apparent viscosity (AV), yield point (Yp), and gel strength of water-based drilling fluid containing graphite were shown to be comparatively elevated when compared to conventional drilling fluids, as depicted in Figure 7 (a, b,c, d, e, f, g, h).

Table 1: the measurements of viscosity, density, pH, filtration and lubricity test at laboratory condition and before and after adding graphite.

Adding graphite to the water base mud						
Rheological Properties	Water base mud	1gm	2gm	3gm	4gm	5gm
R600/R300	59/52	69/60	74/64	77/67	79/68	79/68
R200/R100	46/42	59/56	62/58	67/66	66/62	68/64
R60/R30	41/40	56/55	58/57	62/59	62/62	63/64
R6/R3	36/30	51/50	56/55	60/60	60/60	62/61
AV,cp	29.5	34.5	37	38.5	39.5	39.5
PV,cp	7	9	10	10	11	11
YP,lb/ft^2	45	51	54	57	57	57
YP/PV	6.4	5.6	5.4	5.7	5.1	5.1
Gel10sec/1min lb/100ft2	41/47	50/53	52/54	52/53	53/60	59/66
Mud weight	1.13	1.13	1.13	1.135	1.14	1.14
Filter loss,ml	12	12.2	12	12	12	12
pH	9.3	10.3	10	10	9	9.7
Lubricity test	0.4	0.37	0.37	0.35	0.34	0.33

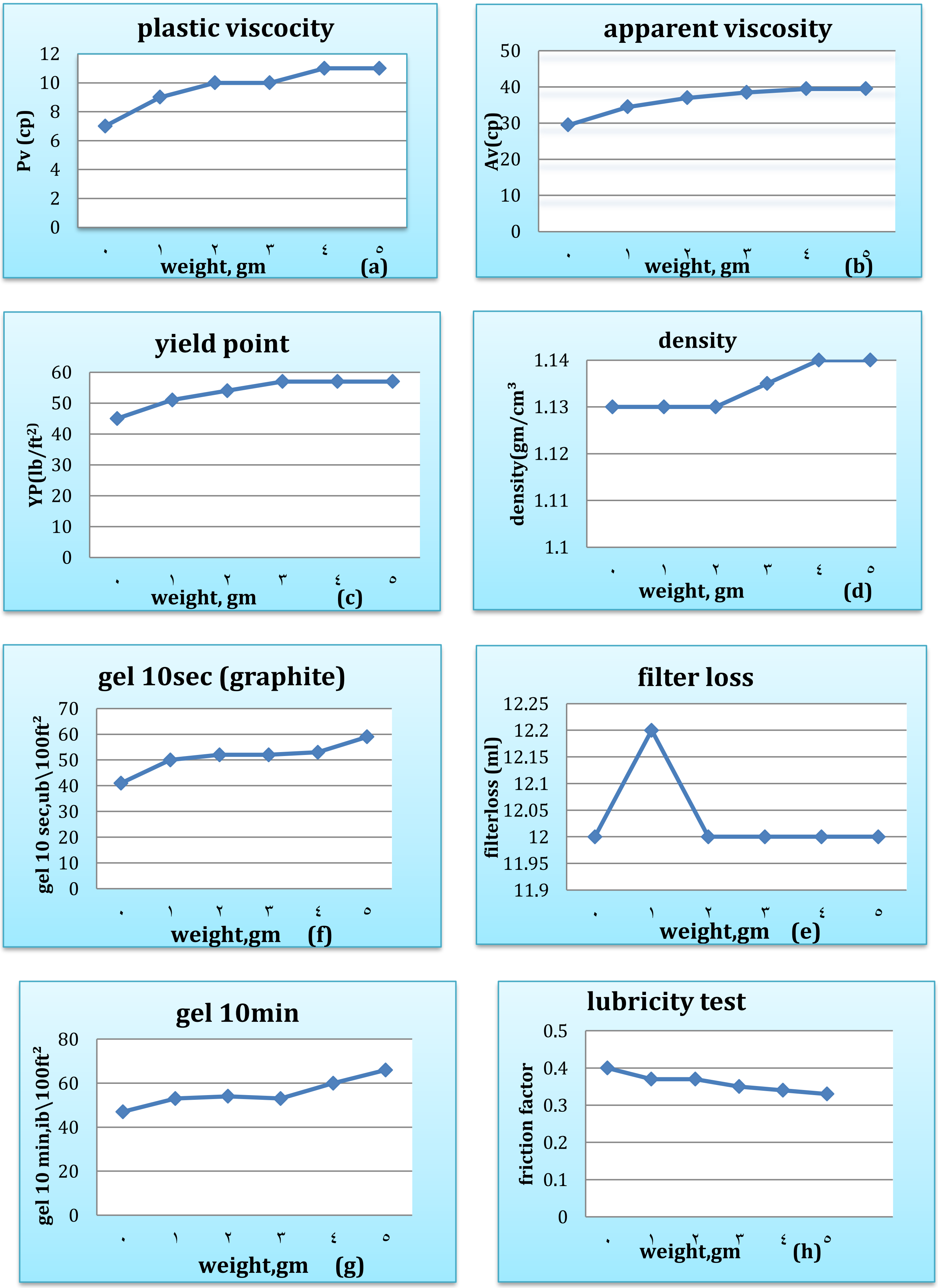

Figure 7: The impact of graphite as a lubricant on water-based mud.

The figure (7-h) clearly demonstrates the potential of graphite in reducing torque and drag during drilling operations. Additionally, graphite can effectively address the stick slip phenomenon by acting as a mud lubricator. This is achieved through the formation of a protective film that enhances lubricity, prevents bit balling, prolongs the lifespan of the bottom hole assembly (BHA), increases the rate of penetration (ROP), and notably, enhances the thermal stability of the drilling fluid.

3.2. Effect of graphite& gasoil as a lubricator on water base mud.

After undergoing sample preparation and a hydration period of 16 hours, the samples were subjected to measurements of viscosity, density, pH, filtration, and lubricity within controlled laboratory circumstances. The findings are presented in Table 4-2.

Table 2: The laboratory conditions were utilized to conduct tests on several parameters including viscosity, density, pH, filtration, and lubricity after adding gasoil and graphite.

Adding graphite to the water base mud						
Rheological Properties	**adding** gasoil	1gm	2gm	3gm	4gm	5gm
R600/R300	77/68	80/70	82/71	93/82	97/84	100/86
R200/R100	65/61	64/64	68/66	78/73	79/72	87/82
R60/R30	59/58	63/62	64/63	72/70	72/71	82/81
R6/R3	56/56	61/61	60/60	67/66	67/67	79/78
AV,cp	38.5	40	41	46.5	48.5	50
PV,cp	9	10	11	11	13	14
YP,lb/ft^2	59	60	60	71	71	72
YP/PV	6.5	6	5.4	6.4	5.4	5.1
Gel10sec/1minlb/100ft^2	53/54	65/64	68/71	68/72	70/72	74/75
Mud weight		1.11	1.11	1.09	1.08	1.07
Filter loss,ml	10	10.4	9.6	8.4	8	8
pH	9.8	9.65	9.75	9.76	9.98	9.95
Lubricity test	0.3	0.27	0.22	0.21	0.2	0.18

The plastic viscosity, apparent viscosity, yield point, and gel strength of a water-based drilling fluid containing a mixture of graphite and gasoil were observed to be slightly elevated compared to a conventional base fluid. This is depicted in figures 8 (a, b, c, e, f, g, and h). The increase in plastic viscosity is sometimes necessary to enhance the mud's ability to clean the hole. The combination of graphite and gasoil results in the formation of a cohesive and uniform film that envelops the drill-pipe. This film serves as an effective lubricant, hence mitigating the occurrence of stick slip phenomena.

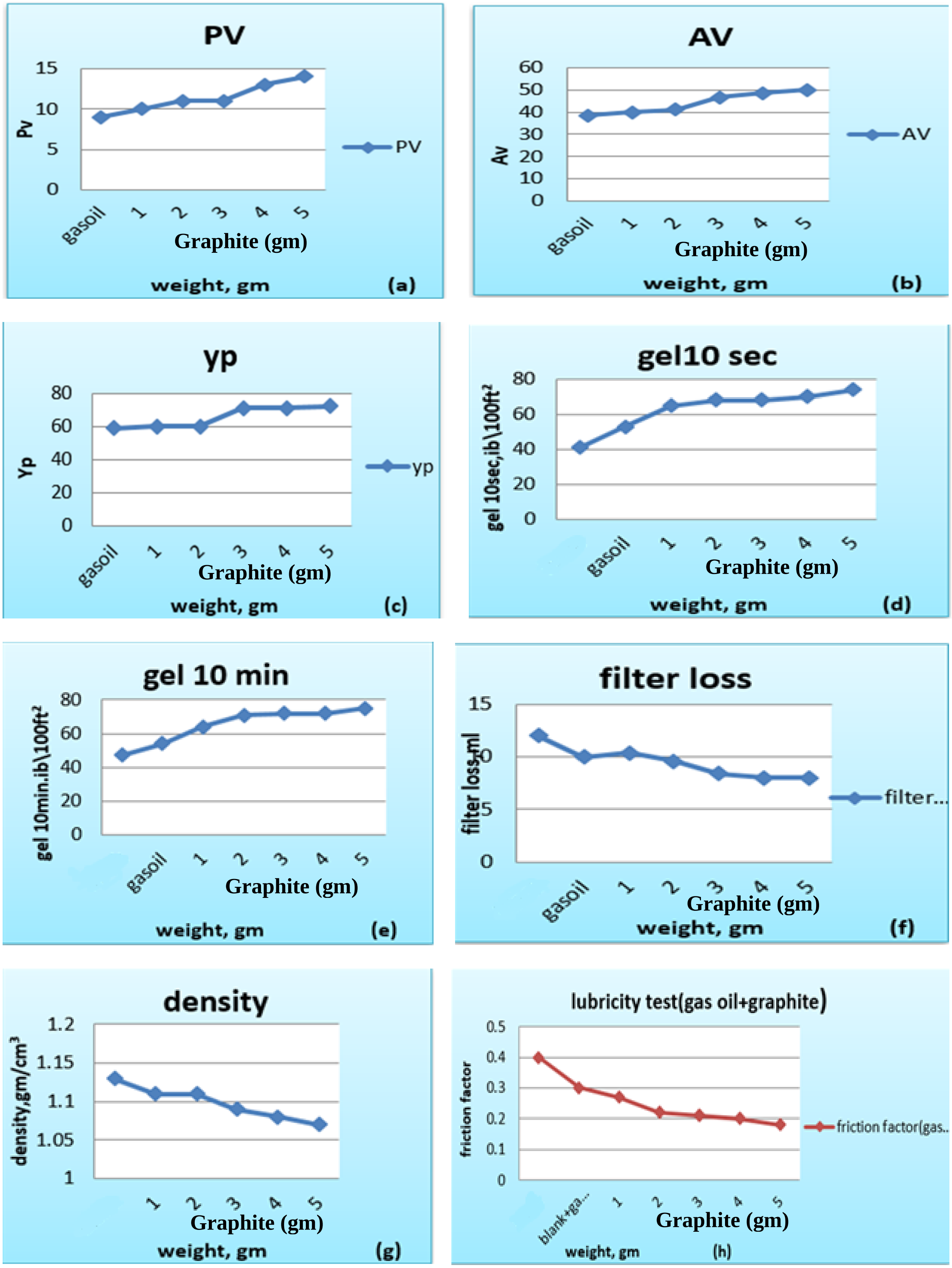

Figure 8: The impact of using graphite in gasoil as a lubricant on water-based mud.

4. Conclusion

The experimental findings demonstrated that the incorporation of graphite particles with a diameter of 38 μm, or a combination of graphite and gas oil in a controlled quantity, into a water-based drilling fluid resulted in :

- Decrease in the friction factor of the fluid because of graphite's lamellar structure makes it the perfect material for reducing friction. Solid graphite lubricant can be applied on the counterpart's surface during the friction process to stop adhesion and scuffing from occurring when the metals come into direct contact. The optimal quantity of graphite to be added is 5 grammes, resulting in a reduction of the friction factor to 0.33. The attainment of the minimal friction factor value (0.18) can be achieved with the inclusion of 5 grammes of graphite and a 5% concentration of gasoil.
- The findings additionally demonstrated that the use of graphite, either alone or in combination with gas oil, can effectively improve the rheological characteristics of drilling fluids. These improvements encompass plastic viscosity (Pv), yield point (yp), gel strength, and a reduction in filter cake thickness.

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