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Investigation of Carboxymethyl Cellulose and Barite Additives on the Corrosion Characteristics of Water-Based Drilling Mud

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HIGHLIGHTS

- Adding additives important to regulate the rheological properties of drilling fluid.
- Substantial changes in the plastic viscosity, density, yield point, and gel strength are distinguished to link to changes in the concentration of the additive.
- Carboxymethyl Cellulose is a good inhibitor for mild carbon steel corrosion, especially in low concentrations in water base bentonite mud.
- Barite has little effect as a corrosion inhibitor on mild carbon steel corrosion in water base bentonite mud.

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ABSTRACT

Drilling fluids can be considered complex liquids containing several desired materials. These materials (small additives) are specialty products that serve a specific need, such as controlling the rheological properties of the drilling fluid and reducing corrosion for operational drilling of both oil and gas wells. Additives used to resist corrosion are called corrosion inhibitors. Previous research has shown that polymers such as Carboxymethyl Cellulose (CMC) have high characteristics of corrosion inhabitation in an aggressive environment. In this study, the effect of adding two samples of additives, CMC and Barite, on the corrosion of carbon steel in Iraqi bentonite water base mud solution has been evaluated using the weight loss technique. The study focuses on determining and comparing the corrosion characteristics of these mud additives. All the experiments were carried out in static flow and at room temperature. Results show that CMC works as a good inhibitor when added to bentonite/barite mud. The calculated corrosion rates of 0.95mpy, 0.75mpy, 0.53mpy and 0.49mpy were found for bentonite mud, bentonite/barite mud, bentonite/CMC mud, and bentonite/CMC/barite mud, respectively. This would result in an inhibitor efficiency of about 50%.

1. Introduction

The drilling fluid can be defined as a circulating liquid used in the rotary drilling process to accomplish several jobs vital in drilling procedures. It is the most crucial safe, efficient, and economic well drilling system. Drilling workers are continually confronted with increasing efficiency, low costs, and minimum environmental impact. The success of these outputs can produce sustainable solutions. This leads to better conditions and lengthy life of good equipment. The drilling fluid comprises various compounds used for diverse purposes. There are two main types of drilling fluid; water-based mud and oil-based mud. Water-based mud is the one in which the continuous phase of the system is water, and oil-based mud is that in which the continuous phase is oil. Water-based mud is the most commonly used in the world now. It is relatively cheap because it depends on inexpensive materials [1].

Water-based mud consists of three compounds; solids, liquids, and some chemicals. The clay additives (bentonite) and the polymers as a portion of solids can react with the water. On the other hand, the chemicals found in the mud are called active solids. They determine the viscosity of the mud and are known as viscosifiers. Alternatively, the solid materials that do not react within the mud are called inactive, such as Barite (Barium Sulphate). These solids increase the density of the mud without significantly affecting the viscosity. Commonly, freshwater can be used as the base for most of the mud. However, saltwater is the preferred liquid used in offshore drilling processes because it is more readily available [2].

The main drive of using drilling fluids was to remove cuttings constantly. Later, advancements in drilling technology necessitated more complexity from the drilling mud. Thus to improve the usage of such fluids, many additive materials were offered, and the modest fluid changed into an intricate mixture of materials. The drilling fluid properties are enhanced using

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several additives for the sole drilling process. This is done to match the requirements of different depth intervals. These comprise properties such as density, filtration, solid content, and rheology, besides chemical properties. These properties have to be properly measured, controlled, and preserved at their initial level during the progression of the drilling process. Substantial studies have been done in drilling fluid engineering to enhance its properties for an oil well's effective and economical completion. In fact, the cost of this mud itself is expensive, but the preservation of proper properties while the drilling process greatly affects the total well cost [3-6].

The purpose of adding bentonite clay to freshwater mud is to increase viscosity, thus increasing the hole cleaning ability, decreasing water filtration into penetrable formations, creating a filter cake of low permeability, indorsing hole stability in poorly cemented formations, and evading loss of circulation. In addition, the colloidal properties of organic polymers such as carboxymethyl-cellulose (CMS) are employed in drilling fluids to make filtration less, stabilize clays, and flocculate drilled solids, raising carrying capacity and serve as emulsifiers and lubricants [7].

1.1 Rheology of Drilling Fluid:

The term rheology is given to the investigation procedure of the alteration of fluids and flow of matter. The significance of this investigation is well-known in the analysis process of fluid viscosity, fluid flow velocity, friction pressure losses, and annular borehole cleaning, besides the yield point and gel strength. They are the foundation for all analysis of wellbore hydraulics to assess the job of the mud system. Factors such as density, viscosity, gel strength, etc., are verified throughout the drilling processes. The failure to control and uphold these properties may result in financial and loss of time. It could also result in the desertion of the well. In addition, many other rheological tests, such as pH, chemical analysis, and resistivity, were conducted during the drilling process [8].

1.2 Corrosion in Drilling:

Corrosion can be regarded as the deterioration of metal due to its interaction with its surrounding. Metal ruin is implied by the decline of the physical properties of the metal. This may be represented by corrosion fatigue, weight loss, or stress corrosion. In fact, corrosion can be the reason behind several forms of drill string failures. The corrosion fatigue can be caused by the mechanical cyclic loading resulting in major drill string early failure, which is a cause of alarm for the people in the drilling profession. The cost of corrosion consequences during the drilling procedure is substantial. Therefore, it is vital to understand the fundamentals of corrosion and control it [9-12].

Also, corrosion is a costly problem in the drilling industry. Because the tubular goods are mostly iron, and most drilling fluids are water-based. Consequently, corrosion is unavoidable. In general, four circumstances must be encountered to acquire corrosion:

1. An electrochemical cell must occur.
2. The environment has to be a conductive medium.
3. A potential difference exists in the electrochemical cell.
4. There must be an electrical circuit there.

It can be seen that the drill pipe itself can represent the anode and cathode, the drilling fluid symbolizes the electrolytic environment, and the drill pipe metal shapes the coupling. Finally, the potential difference is due to the rocks structure and dissimilar metals used in the drilling pipe alloy. In addition, dissolved gasses such as O_2, CO_2, H_2S, and Cl^- may contaminate drilling fluids, which will corrode not only well casing but also drilling equipment, pipelines, and mud handling equipment. Furthermore, other features with high flow rate, acidity, temperature, and the composition of the mud may contribute to drilling equipment corrosion [12].

1.3 Corrosion Prevention:

Several methods for corrosion deterrence are being engaged in drilling processes. Both field practice and available data have proposed that outspreading corrosion weariness life of metal is more valuable than stopping metal loss. Carbon steel or alloy steel with enhanced fatigue life can control corrosion. Yet, such improved material is restricted due to economic reasons. Conventional approaches such as coating, deactivating the corroding, and using inhibitors materials are widely employed to reduce corrosion. It is also protuberant in the industry to amend mud properties to favor drilling apparatus and reduce corrosion rates. pH values of the mud are also modified by adding alkaline material to the mud, usually NaOH [13-14].

Inhibitors are either organic or inorganic chemicals added in small amounts to a corrosive medium, thus decreasing the surface corrosion process to be protected. Because that apparatus made of materials resistant to corrosion usually is very expensive, it is mutual to use corrosion inhibitors as a practical, economical and simple alternative. Occasionally, adopting two ingredients in a specific formula may increase the efficiency compared to that obtained from the amount of efficiencies of corrosion inhibitors [15-22].

The corrosion inhibitors can be classified in different ways:

1. According to the specific application.
2. According to the type of material to be protected.
3. As anodic, cathodic, and mixed inhibitors.

The adsorption behavior usually describes the mechanisms of the inhibitors. This is explained by forming a thin film that may be adsorbed onto the metal surface. In addition, it may happen by encouraging the formation of corrosion products such as iron sulfide, a passivizing species. The mechanism can also be clarified by altering media characteristics, creating precipitates that would be behaved as protective and eliminating or inactivating a destructive constituent.

Many researchers used the compound carboxymethyl cellulose as a corrosion inhibitor for mild steel in various aqueous environments [19, 20, 23-27]. It has been reported that the use of corrosion inhibitors - chemicals added to the corrosive environment in small, in many cases, reduces the corrosion rate to approximately 5-10% of the corrosion rate with no inhibitors [28]. However, research using CMC as a corrosion inhibitor in bentonite environments has not been reported.

The aims of this study can be put in the following points:

1. Determining the effects of three additives (bentonite, CMC, and barite) on the drilling mud properties.
2. Determining the corrosion influence of these solids on the weight loss of the carbon steel samples.
3. Propose a suitable mechanism for the corrosion inhibition process.

The scope of this plan is only used for water-based muds.

2. Experimental Work

The methodologies used to determine the effect of mud additives on the rheology of drilling mud and corrosion of carbon steel are outlined here. The experimental work for this project includes many parts. The first part focuses on the CMC effect on the drilling mud properties. The motivation of the second part will be on the outcome of CMC on the corrosion of carbon steel, and the third part emphasizes the effect of barite on the corrosion of steel. Lastly, we practice the idea of mixing all these ingredients and studying their corrosion effects.

2.1 Rheological Experimental setup:

Drilling mud samples were made by mixing (300 ml) of water and different concentration of commercial Bentonite (3%, 5%, 6%, and 7%), and the rheological properties of each mud sample were measured. Drilling mud samples were also prepared by mixing (300 ml) of water and (6%) concentration of commercial Bentonite with adding different concentrations of CMC (1%, 1.5%, and 3%). Then, the rheological properties of each mud sample were measured. Several 45 samples were tested in this part of the study.

2.2 Corrosion Experimental Setup:

The weight loss technique is the simplest and longest-established procedure for approximating corrosion losses. This test method is under the jurisdiction of ASTM Committee D19. A coupon weighed sample of the metal under study is presented in the process and later detached after a realistic time interval. This coupon is then cautiously cleaned of all corrosion products and re-weighed. Finally, the weight loss is converted to a corrosion rate. All chemical materials were used as received from the source. The corrosion rates of the coupons were evaluated at 298K. The test specimens used were commercially available mild carbon steel coupons with dimensions (Ø25 mm Diameter and 3mm thickness). The initial weights of the coupons were taken to the nearest 0.0001 g by a digital balance (KERN German made). Before use, the surface of the specimens was polished carefully with successively smaller grit soft fine emery paper to a mirror finish, rinsed with distilled water, then degreased with acetone, and dried in air at room temperature before total immersion in 100ml of the test solutions with and without the additives. After that, the coupon was taken out of each container and washed with tap water, then in acetone using an ultrasonic bath (SilverCrest- 46kHz, 50W) to remove the corrosion products, and finally rinsed with deionized water. Finally, the coupons were dried with nitrogen and weighted to obtain the new weight. The weight loss within the immersion period was calculated as the difference between the initial weight prior to immersion and the final weight after immersion. The corresponding metal loss and corrosion rate were then calculated (using standard equations).

2.3 Preparation of Bentonite Drilling Fluid:

Bentonite is considered the most commonly used drilling fluid additive containing finely ground sodium bentonite clay. Mixing bentonite with water will result in a slurry with a viscosity greater than water. It possesses the ability to suspend relatively coarse and heavy particles. It also inclines to form a thin cake with very low permeability on the borehole walls [1].

We used commercial Iraqi bentonite supplied by (the South Oil company) as a base to prepare the drilling fluid for this study. First, a drilling mud consisting of 3 -7 % by weight of local bentonite was prepared. The resulted muds were tested for viscosity, density, yield point, plastic viscosity, and pH. Then a comparison was performed between these types of mud. Various properties of drilling fluid are monitored and adjusted to achieve desired performance. Procedures for measuring fluid properties can be found in API Recommended Practice 13B-1 for water-based drilling fluids. In addition, the mixture of drilling fluid systems is prepared by adding the tested additive in low volumetric fractions to the base fluid. In this case, 300 ml of fresh tap water was added to 20 g of bentonite and stirred in the bucket until no more lumps were observed with the assistance of an electric mixer. Then, it was left to stay overnight (16 hours) to swell. Next, bentonite drilling fluid with CMC and Barite was prepared by adding 1% of Barite to 1.5% of CMC and 6% of bentonite and 91.5% of water. After that, the fluid was left overnight, stirred vigorously, and homogenized with an electronic mixer for about 15 minutes. These mud mixtures were used later for various experiments. Upon the additive's addition, the bentonite mud's corrosion properties, bentonite/CMC mud, bentonite/barite mud, bentonite/barite/CMC mud were investigated with exposure time (24-600 hrs) at 298K. The weight loss values were obtained and converted to Corrosion Rate (CR) using standard equations [29].

3. Results and Discussion

The properties of the drilling fluids are related to most drilling problems. Therefore, a minor discrepancy in drilling fluid properties may cause unlikely problems. In this study, corrosion characteristics and rheological of drilling fluid additives were examined and compared.

Bentonite and mild carbon steel coupons were tested by X-ray to determine their compositions. These results are shown in Tables (1 and 2). The unique physical and chemical characteristics of sodium montmorillonite clay allow its use as the base material for drilling fluids. It provides rheological properties and filtration control to water-based fluid systems. In addition, its superior swelling features and low permeability offer exceptional sealing capabilities when used as a sealing product.

3.1 Rheological Tests:

The Rheology results have been divided into four sections: mud density, plastic viscosity, yield point, and gel strength. Each of them was measured at different bentonite concentrations. The first set of rheological tests was done on bentonite additive. Graphical representations of these experiments are shown in Figure 1.

Figure 1 shows that an increase in the concentration of bentonite led to an increase in the rheological properties of the mud. That is because bentonite clay is a natural absorbent that can swell and gel, making them perfect viscosity enhancers. When exposing Bentonite to water, it appeals to water to its negative face. This exceptional property permits bentonite to absorb 10 times its weight in water and swell 18 times its dry volume. Thus, the rheological properties would increase [30]. The second set of rheological tests includes studying the effect of varying CMC additive concentrations on rheological properties, as presented in Figure 2. It is observed that the plastic viscosity, yield point, and gel strength increased with an increase in the concentration of CMC. The amount of the increase was about 50-75%. The reason for that is that the presence of the carboxy group in CMC causes water dispersibility. As a result, friction between particles increased. In addition, the shearing stress required induces a unit rate of shear increase, and hence plastic viscosity, yield point, and gel strength are also increased [31]. Figures 1 and 2 show a big difference in the viscosity between the two muds, especially at high concentrations. This is apart from the density, which is kept favorably low at about 1.04 g/cm^3 as the desired density of mud is usually less than 1.08 g/cm^3.

Table 1: shows the composition of Bentonite clay

Constituent	SiO_2	Al_2O_3	CaO	Na_2O	MgO	K_2O
Bentonite	64.97	12.59	1.03	2.75	2.49	1.12

Table 2: shows the chemical composition of mild carbon steel

Constituent	C	Si	Mn	P	S	Fe	Remainder
Carbon Steel	0.38	0.14	0.44	0.03	0.02	98.98	0.01

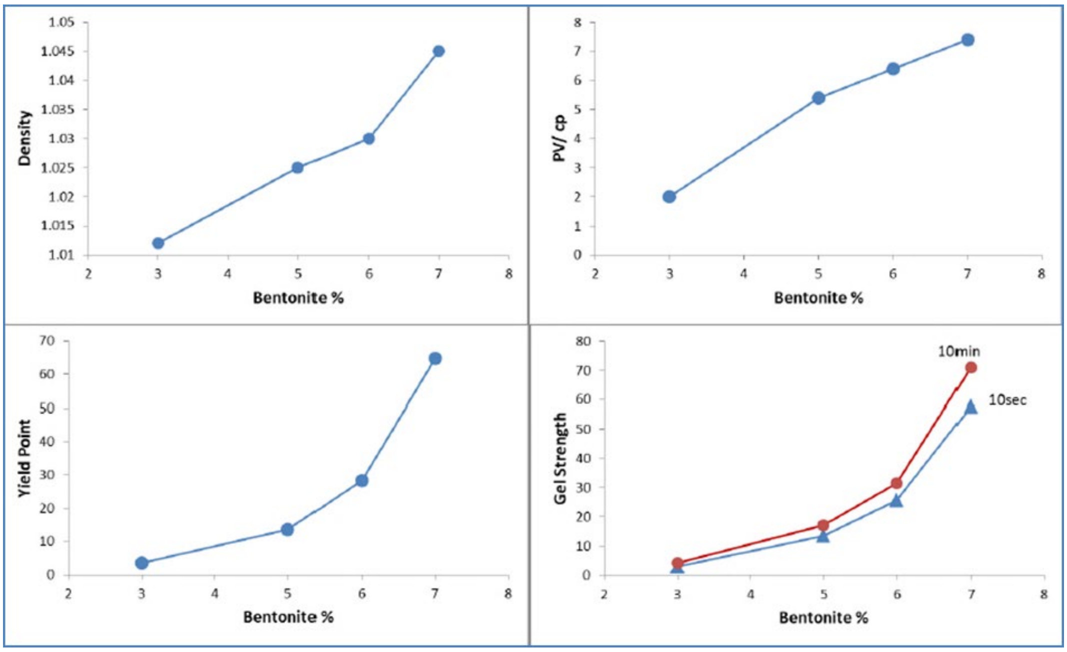

Figure 1: Rheological properties of Bentonite based mud

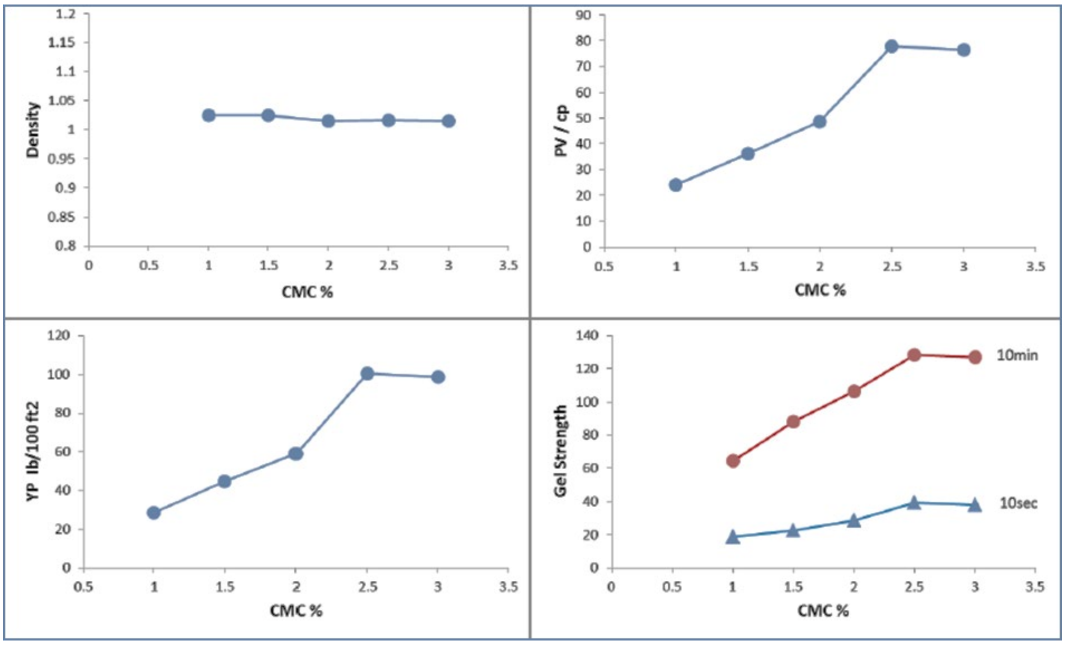

Figure 2: Rheological properties of Bentonite and CMC mud

3.2 Corrosion Tests:

The carbon steel investigated in this work was found to undergo uniform corrosion in all the experiments. Thus the corrosion rates were calculated using the following standard expression [29]:

$$CR\ (mpy) = \frac{W(g)\ 3.45\times10^7}{\rho(g/cm^3)\ A(cm^2)\ \ t(hrs)} \quad (1)$$

Where: CR: is the corrosion rate (mile per year), W: is the weight loss (g), A I: the area of coupon (cm^2), ρ: is the metal density of coupon (g/cm^3), t: is the time of exposure in a corrosive environment (hours). 3.45×10^7 is a conversion factor.

Graphical representations of the weight loss corrosion results are shown in figures (3,4, and 5). The results of the corrosion test specify that the bentonite base mud samples demonstrated the highest average corrosion rate. Data also show that the weight loss of carbon steel decreased when CMC was added, indicating CMC functioned as a good inhibitor isolating the metal from attack by the aggressive anions present in the mud. Comparing the results to the barite test data showed that the differences in corrosion were very small. However, the effect of adding barite to the Bentonite/CMC mixture has improved further the corrosion inhabitance, although not very much. From visual tests, no proof of any pitting corrosion was initiated.

In addition, figure 4 presents the corrosion behavior of each mud mixture as curves over a long time (24-650 hrs). Bentonite base mud (without any other additives) shows high corrosion at the start of the exposure. Then, later on, a reduction in corrosion rate has occurred. This behavior can be explained by forming a passive layer on the carbon steel's surface, limiting the corrosion later on. This has not been found with other mixtures. That could be attributed to the proposed mechanism put forward by many researchers showing adsorption of carboxylic groups adsorption on the surface of the steel, reducing corrosion [26-31]. Again, this can be explained by forming a barrier at the beginning of the process, limiting the corrosion rate.

Figure 5 shows the relation between corrosion rate and exposure time for the four sets of mixture muds. This was carried out by taking the average values of corrosion rates over the total exposure period.

The following calculated corrosion rates of 0.95mpy, 0.75mpy, 0.53mpy, 0.49mpy were found for bentonite mud, bentonite/barite mud, bentonite/CMC mud, and bentonite/CMC/barite mud, respectively. Thus, these calculated values indicate the ability of CMC to be a good corrosion inhibitor. Furthermore, the inhibitor efficiency was enhanced in the presence of barite, with total inhibitor efficiency of about 50%.

Chemical additives are added to the drilling mud to promote required functions and protect the surface of the equipment's metals either by merging with them or reacting with the impurities in the environment that may cause pollution. For example, the mechanism of the inhabitation effect can be described by the adsorption process of CMC, which has been generally accepted to be the mechanism responsible for inhibitory action. Corrosion inhibitors can affect the corrosion rate in two ways; by decreasing the available reaction area, the so-called geometric blocking effect, and by modifying the activation energy of the cathodic and/or anodic reactions occurring in the inhibitor-free metal in the course of the inhibited corrosion process and also reducing the movement or diffusion of ions to the metallic surface [31]. SEM studies confirmed the formation of protective film on the metal surface, and hence the corrosion process is inhibited by CMC presence [26].

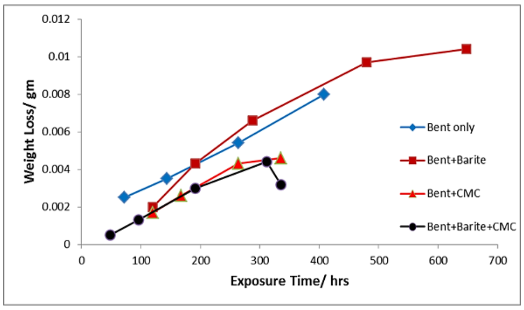

Figure 3: shows comparison results of weight losses behavior for four mud mixtures

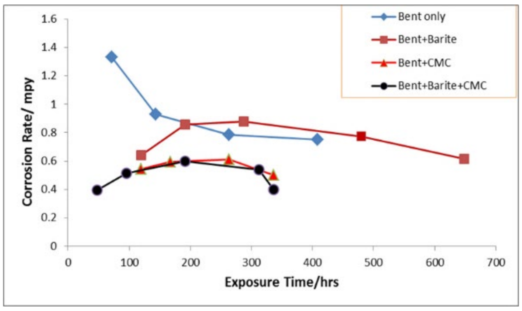

Figure 4: shows comparison results of corrosion rates behavior for four mud mixtures

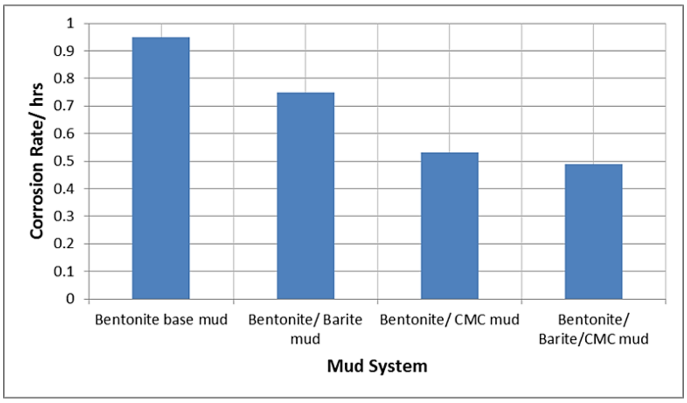

Figure 5: shows comparison results of average corrosion rates for four mud mixtures

4. Conclusions

The weight-loss method studied the corrosion inhibition of mild carbon steel by CMC and Barite in bentonite mud. The main conclusions of this study are described below:

The additives concentration is important to regulate the rheological properties of drilling fluid. Substantial changes in the plastic viscosity, density, yield point, and gel strength were distinguished to link to changes in the concentration of the additive (this includes 1% of Barite to 1.5% of CMC and 6% of bentonite and 91.5% of water).

Carboxymethyl cellulose (CMC) was a good inhibitor for mild carbon steel corrosion, especially in (0.5 %) low concentrations in water base bentonite mud.

Barite has a very small effect as a corrosion inhibitor on mild carbon steel corrosion in water base bentonite mud.

- The following corrosion rates were estimated of mild carbon steel at RT: 0.95mpy> 0.75mpy> 0.53mpy> 0.49mpy for the following drilling mud: Bentonite only> Bentonite/Barite > Bentonite/CMC> Bentonite/CMC/Barite

Total inhibitor efficiency of about 50% was obtained.

Lastly, the following recommendations are proposed for future work:

- Using actual drilling steel grade coupons.
- Determining the effects of temperature and pH of drilling mud.
- Determining the effect of dissolved gases in the drilling mud.

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Author contribution

All authors contributed equally to this work.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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