J. King Saud Univ., Vol. 10, *Eng. Sci.* (2), pp. 141-299 Engl., 23-44 Ar., Riyadh (A.H. 1418/1998)

ISSN 1018-3639

Engineering Sciences (2)

A.H. 1418 (1998)

King Saud University

J. King Saud Univ., Vol. 10, *Eng. Sci.* (2), pp. 285-299 (A.H. 1418/1998)

TECHNICAL NOTE

Rheology and Corrosivity of Drilling Fluids Formulated from Al-Ghatt Saudi Clays

Musaed N. J. Al-Awad
Petroleum Engineering Department, College of Engineering
King Saud University, P.O. Box 800, Riyadh 11421, Saudi Arabia.

(Received 23 November 1996; accepted for publication 17 June 1997)

Abstract. An experimental investigation has been carried out to determine the rheological and corrosive properties of Al-Ghatt clay, when used as a basic constituent for drilling fluid, on mild steel and J-55 steel alloys normally used in oil and gas wells casing fabrication. The study was extended to investigate the effect of a sodium hydroxide (NaOH) addition on the corrosive properties. Corrosion rates were measured under both static and dynamic conditions at 15% by weight clay concentration and with the addition of various concentrations of sodium hydroxide (NaOH). Under the static conditions, the maximum corrosion rate was found to vary from zero to 73.25 mil-inch/year. Under dynamic conditions, however, a maximum corrosion rate of 155.3 mil-inch/year and a minimum of 0.125 mil-inch/year was detected. The results showed that the resistance to corrosion of the steel alloys is very good at high alkalinity drilling fluids in both static and dynamic conditions. Based on the rheological and corrosivity tests, drilling fluids formulated from Al-Ghatt clay are suitable for oil and gas wells drilling as long as the concentration of the NaOH is maintained at 1% by weight.

Introduction

Corrosion in drilling operations has been a problem in the petroleum industry for over 100 years. However, the significance of corrosion was brought to the attention of the industry in 1943 [1-2]. Drilling fluid components play a major part during the corrosion process. Numerous commercial deposits of clays are discovered in Saudi Arabia [3-6]. To understand the influence of drilling fluids on the rate of corrosion, certain factors should be studied thoroughly. These factors are: the drilling fluids components used, and their physical and chemical properties. In this work samples of clays were taken from Al-Ghatt area. Al-Ghatt lies in a large valley (wadi) surrounded by high hills. The area is superficially covered with silt, sand, and gravel underlained by olive-green plastic clays which are part of the predominant formation in the area called Dhruma formation [7, 8]. In this work physical and chemical properties (flow and filtration characteristics, density, hydrogen ion concentration and mud cake thickness) of Al-Ghatt clays have been investigated. Laboratory test procedures were developed to evaluate the rate of corrosion. These tests were carried out on water base drilling fluids similar to that commonly used by the drilling industries [9-11]. The effects of common drilling fluid additives on rheology and corrosion properties were also studied. This was done to obtain valuable insight into the potential use of such clay as a basic ingredient of drilling fluids. Corrosion rates within the drilling fluid was simulated by immersing the test specimens in the drilling fluid sample for a period of one week at room temperature (23°C) for both the static and the dynamic tests. However, during the dynamic corrosion tests, the temperature of the drilling fluid was gradually increased up to 50°C due to friction between the test fluid and the cell body caused by agitation (at 300 rpm). The loss in weight of the test specimen served to measure the rate of corrosion. The measured corrosion rates were then checked by studying the roughness and morphology of the corroded steel specimens.

Apparatus and Experimental Procedures

Standard API equipment were used to characterize the rheological, filtration and electrochemical properties including API filter press, HT-HP filter press, mud balance, pH meter, resistivity meter and Fann V.G. meter. A U.S. standard set of sieves were used in the wet sieving analysis. In performing these tests the recommended API procedures were followed. Steel specimens were cut from two types of casing steel, mild steel and J-55 grades. A hole was drilled at one end of each sample to allow easy suspension. Prior to testing, the specimens were first cut to a certain dimensions then abraded with wet silicon carbide abrasive papers, progressively from 80 to 1000 grits. The samples were then immersed in different formulated test fluids for a period of 7 days. Corrosion tests were performed using a specially designed cell as shown in Fig. 1. The cell is consists of a container with a cap and a motor to continuously mix (ranged from 100 to 600 rpm) the drilling fluid to simulate circulation in the rotary drilling process. A roughness measuring apparatus was used to characterize the roughness of the corroded steel specimens before and after corrosion tests. The surface morphology of the steel specimens was tested under a stereo microscope before and after the corrosion tests. The corrosion rate was calculated as follows [1]:

$$\mathrm{mpy} = \left[\frac{22272\,w}{\rho A\ t}\right] \tag{1}$$

where,

mpy = corrosion rate, mil-inch/year.
w = weight loss, gm.
ρ = metal density, gm/cm^3.
A = exposed surface area, in^2.
t = exposure time, days.

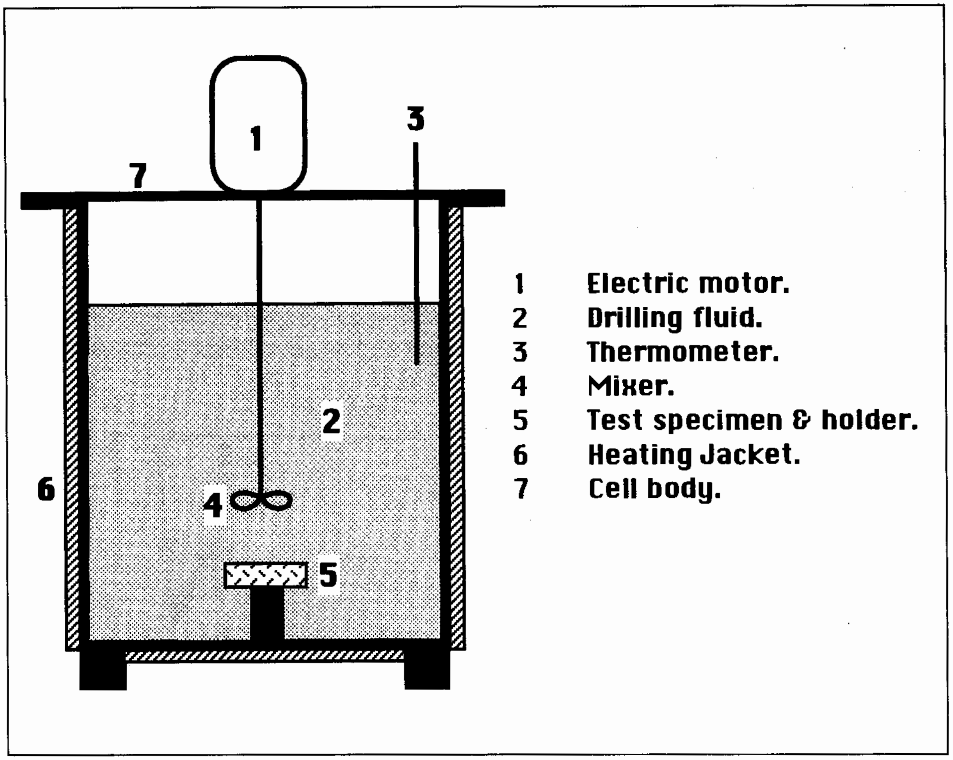


Fig. 1. Schematic diagram of the corrosion cell.

Results and Discussion

Mineralogical, garanulometrical and rheological analysis

Oriented clay films on glass slides were prepared by drying at 40-50 °C in an oven. The slides were then mounted into a Philips x-ray diffractometer. The result obtained from the x-ray diffractometer is shown in Fig. 2. The predominant clay minerals as shown by their peaks are kaolinite and attapulgite. The non-clay minerals characterized by the diffractogram are mainly quartz. The importance of granulometric analysis goes back to the fact that the minerals which contain more than very small amounts of non-clay minerals specially in the size of sand or silt will not be suitable for the drilling fluids applications due to its adverse effect on viscosity [6, 9-11]. The granulometric analysis of Al-Ghatt shale was done by means of wet sieving method. Fig. 3 shows that this shale contains more than 92% by weight of fine fractions (< 37 mm). The ability to use a specific material in the drilling fluids application depends on its flow, filtration and electro-chemical characteristics. Attapulgite possesses such suitable behavior which can be improved further by the addition of common drilling fluids additives. The filtration, rheological and some other properties of different samples are presented in Table 1. The filtration losses and the rheological properties of the suspensions prepared from pure Al-Ghatt clay lie below the expected range as shown in Fig. 4. To improve such properties of Al-Ghatt clay suspensions, common additives such as XC-polymer, high viscosity Carboxy Methyl Cellulose (HV-CMC) and Wyoming bentonite were added to its suspensions in fresh water. Large improvements in the rheological and filtration properties of Al-Ghatt clay suspension were obtained after the addition of the above mentioned common additives. XC-polymer and HV-CMC had a better effect when compared with bentonite. Therefore, a typical drilling fluid was formulated from 15% Al-Ghatt clay plus 1% XC-polymer and 1% HV-CMC. This composition has provided excellent rheological and filtration properties and was thermally stable up to 90°C as shown in Table 1. To overcome the low pH value of this mixture, 1%

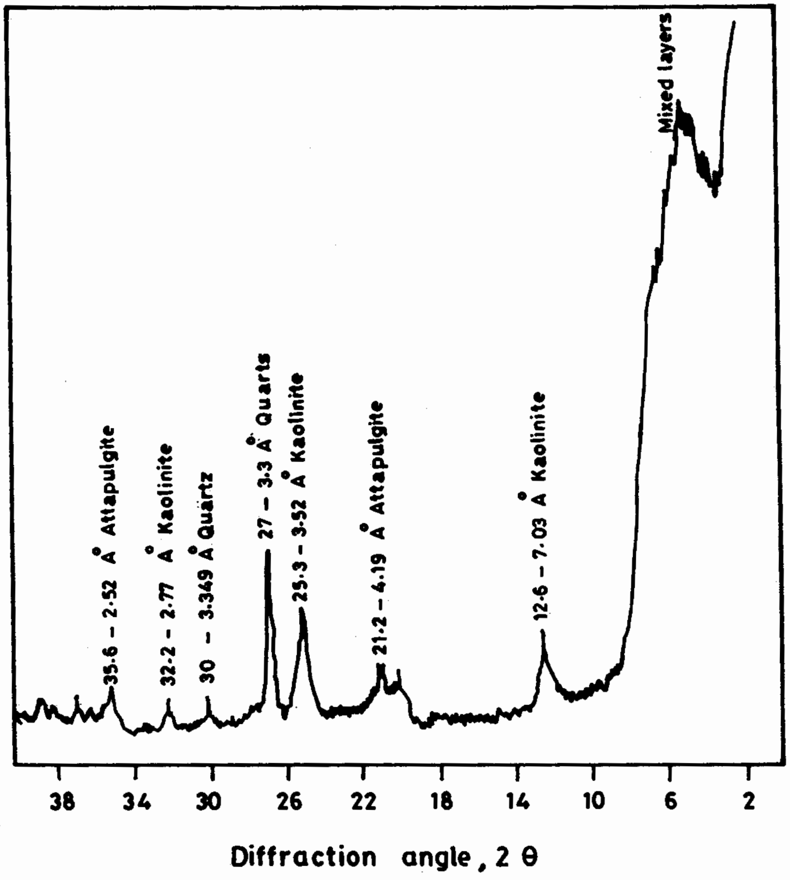


Fig.2. X-ray diffractogram of Al-Ghatt Saudi shale.

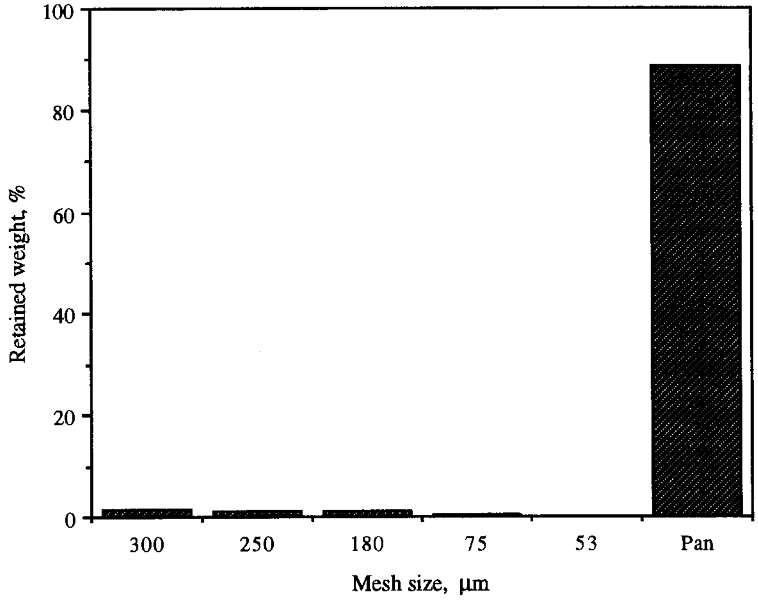


Fig. 3. Granulometric analysis of Al-Ghatt clay.

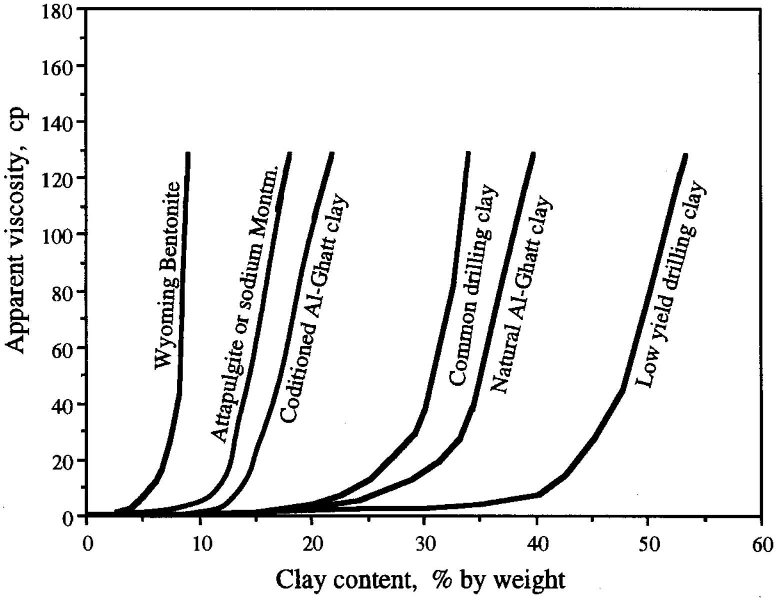


Fig. 4. Natural and conditioned suspentions of Al-Ghatt clay in fresh water (15% Al-Ghatt clay + 1% XC-Polymer + 1% HV-CMC + 1% NaOH).

Table 1. Composition and properties of various drilling fluids prepared using Al-Ghatt Saudi clay

Mud composition	7.5 min. API filtration loss, cc at 100 psi and 23°C	Plastic viscosity, cp	Apparent viscocity, cp	Yield point, lb/100 ft^2	pH	Density, ppg	Mud cake thickness, 32nd of inch	7.5 min HT-HP filtration loss, cc at 500 psi and 90°C
5% Al-Ghatt clay + fresh water	93.5	1	1.75	2.5	8.5	8.8	0.21	139.5
10% Al-Ghatt clay + fresh water	46	2	2.5	3	8.5	8.85	0.18	70.5
15% Al-Ghatt clay + fresh water	41	2	3.25	3.25	8.5	9.1	0.22	63
20% Al-Ghatt clay + fresh water	35	3	4.5	4.5	8.5	9.35	0.23	53
25% Al-Ghatt clay + fresh water	29	3	5	7	8.5	9.7	0.26	40.5
15% Al-Ghatt clay + 0.5 XC-Polymer + fresh water	7	9	24	30	6.5	9	0.04	14
15% Al-Ghatt clay + 1.0 XC-Polymer + fresh water	4.5	15	49	68	6.4	9.1	0.04	9.5
15% Al-Ghatt clay + 1.5 XC-Polymer + fresh water	4	21	80	118	6.4	8.95	0.06	7.5
15% Al-Ghatt clay + 0.5% HV-CMC + fresh water	6.5	5	5.5	1	7.5	9.1	0.069	11.5
15% Al-Ghatt clay + 1.0% HV-CMC + fresh water	4.5	11	12.5	3	7.2	9.1	0.10	8.5
15% Al-Ghatt clay + 1.5% HV-CMC + fresh water	4	21	24.5	7	7	9.1	0.10	7
15% Al-Ghatt clay + 2.5% Bentonite + fresh water	33	3	4.5	3	10	9.3	0.12	51
15% Al-Ghatt clay + 5.0% Bentonite + fresh water	30	3	5.25	4.5	10	9.3	0.12	44
15% Al-Ghatt clay + 10.% Bentonite + fresh water	16	7	20	26	10	9.3	0.12	23.5
15% Al-Ghatt clay + 1% XC-Polymer + 1% HV-CMC + fresh water	2.5	25	72	94	10	9	0.043	5.5
15% Al-Ghatt clay + 1% XC-Polymer + 1% HV-CMC + 1% NaOH + fresh water	3	26 at 23°C 22.5 at 90°C	72.5 at 23°C 66 at 90°C	93 at 23°C 87 at 90°C	13.5	9.1	0.043	5.5

NaOH was added. By comparing the formulated drilling fluids with the common commercial clays used in the preparation of the drilling fluids it was found that the formulated drilling fluids had similar behavior as the drilling fluids formulated from commercial attapulgite or sodium-montmorillonite (see Fig. 4). This behavior was achieved after the addition of some of the common drilling fluid additives.

Corrosivity analysis

Figures 5 and 6 show the corrosion rates as obtained by the static and dynamic (at 300 rpm) tests at various sodium hydroxide concentrations after seven days of exposure. It can be seen that the J-55 has a higher resistance to corrosion compared to the mild steel. Corrosion rates generated by the dynamic tests were two folds greater than those generated during static tests. This difference could be due to the high shear stresses affecting the steel surface caused by the drilling fluid flow (zero shear stresses in the case of static test) as well as the better circulation of the corrodant (drilling fluid) which would bring more undepleted corrosive fluids in contact with the specimen. Also with increased agitation, more oxygen would also be available at the surface of the corroding specimen leading to larger corrosion rates. This high shear stress if combined with non-clay particles can cause sever surface erosion. A 1% NaOH by weight possessed a minimal corrosion effect on the tested steel specimens in both static and dynamic tests. This was due to the increase in the pH of the test fluid caused by the addition of sodium hydroxide (pH=8.5 at 0% NaOH, and pH=13 at 1% NaOH). The addition of sodium hydroxide did not affect the rheological and the filtration properties of the formulated drilling fluids as shown in Table 1.

The surface morphology of the steel specimens were examined under a stereo microscope and the results are shown in Figs. 7 and 8. As seen in Figs. 7 and 8, the surface of the test specimen before corrosion tests has no obvious corrosion pits. While microcavities (corrosion pits) appeared in the specimen surface after static and dynamic tests. When the alkalinity (pH) of the test fluid is increased, the corrosion pits were disappeared indicating lower corrosion rates. Surface roughness is a direct indication for corrosion pits. The average surface roughness of uncorroded specimen is 0.0799 μm indicating that there is no pits. After corrosion tests, the average surface roughness is highly increased. The average surface roughness for mild steel specimens tested under static conditions is 0.35 μm and 0.456 μm under dynamic test indicating the existence of corrosion pits. J-55 steel specimens showed lower surface roughness indicating its high corrosion resistance compared to the mild steel specimens. The measured surface roughness data of the same specimen are reported in Table 2 and plotted in Figs. 9 and 10. It is clear that the weight loss, surface morphology and surface roughness tests provided the similar findings. By comparison it is clear that a drilling fluid formulation from 15% Al-Ghatt clay plus 1% XC-polymer and 1% HV-CMC + 1% NaOH in fresh water has a minimal corrosion effect on the tested steel specimens and developed excellent rheological and filtration properties in comparison to the commercially available drilling fluids.

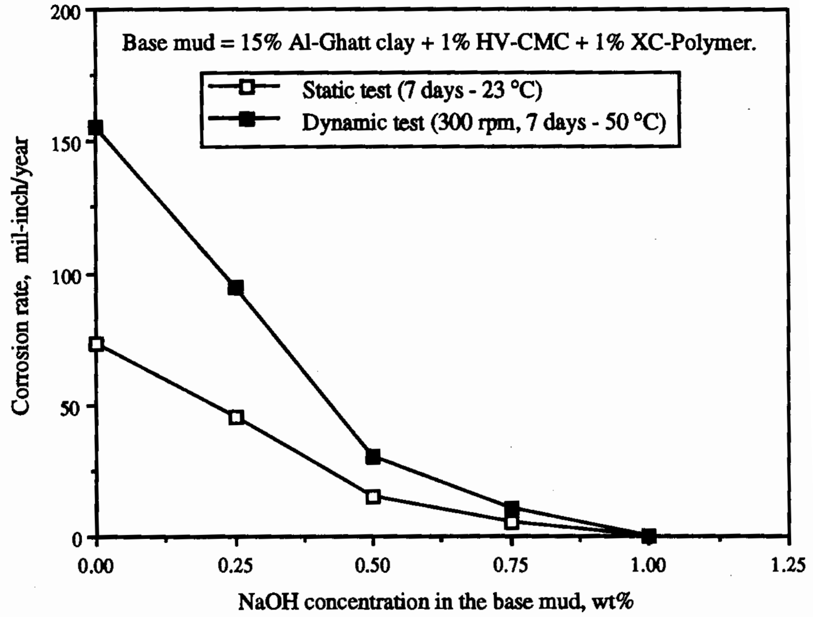


Fig. 5. Corrosivity of Al-Ghatt clay suspensions on mild steel casing.

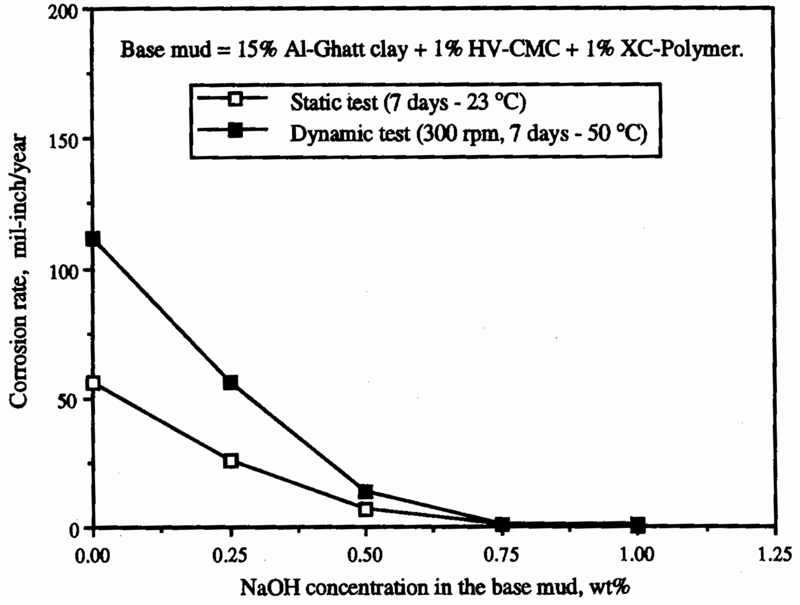
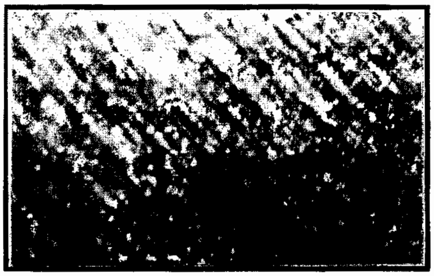


Fig. 6. Corrosivity of Al-Ghatt clay suspension on J-55 steel casing.

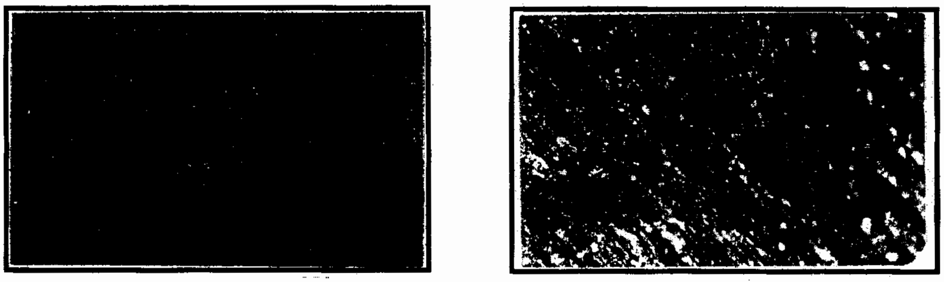


Original state (before testing)

Conditions	Test type	
	Static	Dynamic
Time, days	7	7
Temperature, ^{o}C	23	50
Speed, rpm	0	300

Tests conditions

Static corrosion test



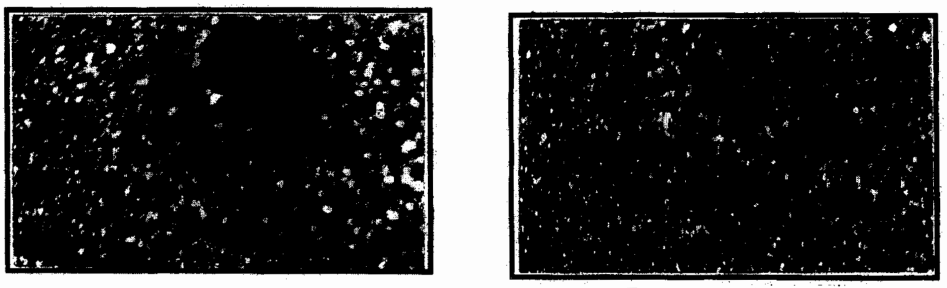
Maximum corrosion rate

Base mud + 0% NaOH
pH = 8.5

Minimum corrosion rate

Base mud + 1% NaOH
pH = 13

Dynamic corrosion test



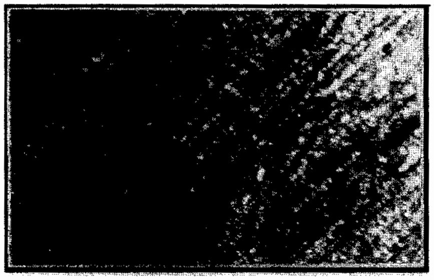
Maximum corrosion rate

Base mud + 0% NaOH
pH = 8.5

Minimum corrosion rate

Base mud + 1% NaOH
pH = 13

Fig. 7. Surface morphology of mild steel specimens before and after corrosion tests.

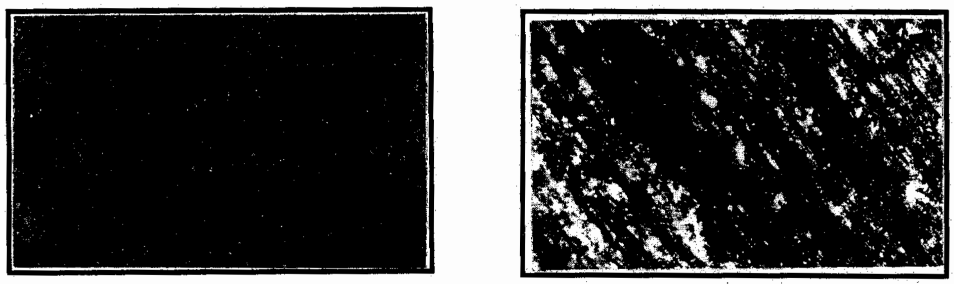


Original state (before testing)

Conditions	Test type	
	Static	Dynamic
Time, days	7	7
Temperature, ^{0}C	23	50
Speed, rpm	0	300

Tests conditions

Static corrosion test



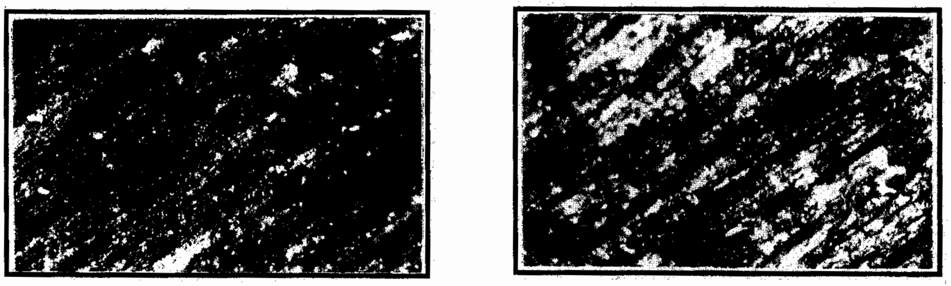
Maximum corrosion rate

Base mud + 0% NaOH
pH = 8.5

Minimum corrosion rate

Base mud + 1% NaOH
pH = 13

Dynamic corrosion test



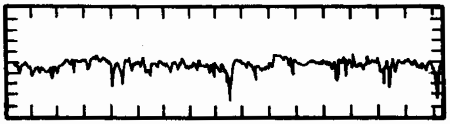
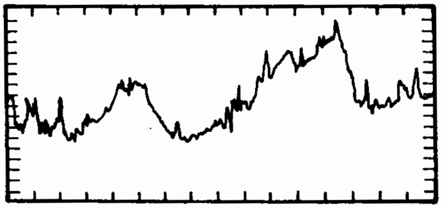
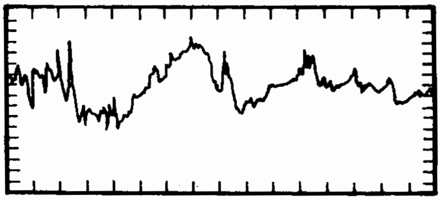
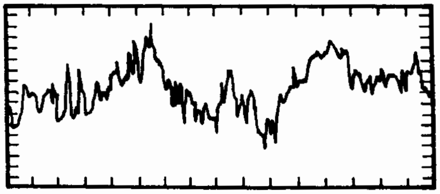
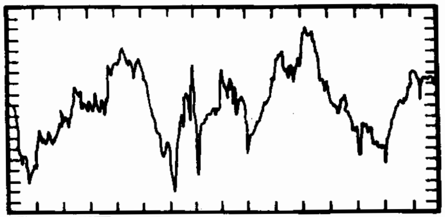
Maximum corrosion rate

Base mud + 0% NaOH
pH = 8.5

Minimum corrosion rate

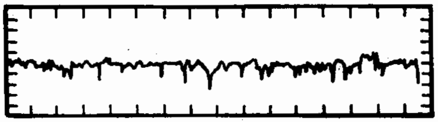
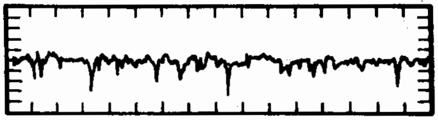
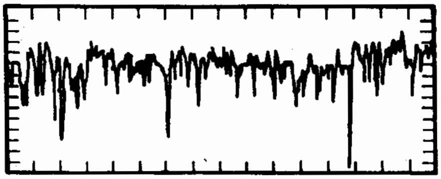
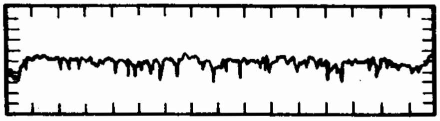
Base mud + 1% NaOH
pH = 13

Fig. 8. Surface morphology of J-55 specimens before and after corrosion tests.

Original state (before testing)		Ra = 0.24 Rmax = 2.91 V. Scale= 1mm= 0.333 μm H. Scale = 40:1
Static test Maximum Corrosion rate = 73.25 mil-inch/year Base mud + 0% NaOH pH= 8.5		Ra = 1.4 Rmax = 7.45 V. Scale= 1mm= 0.333 μm H. Scale = 40:1
Static test Minimum Corrosion rate = 0 mil-inch/year Base mud + 1% NaOH pH= 13		Ra = 0.75 Rmax = 5.5 V. Scale= 1mm= 0.333 μm H. Scale = 40:1
Dynamic test Maximum Corrosion rate = 155.3 mil-inch/year Base mud + 0% NaOH pH= 8.5		Ra = 1.28 Rmax = 9.05 V. Scale= 1mm= 0.333 μm H. Scale = 40:1
Dynamic test Minimum Corrosion rate = 0.125 mil-inch/year Base mud + 1% NaOH pH= 13		Ra = 1.5 Rmax = 8.7 V. Scale= 1mm= 0.333 μm H. Scale = 40:1

Ra= Average roughness Rmax= Maximum roughness V.= Vertical H.= Horizontal

Fig. 9. Surface roughness of mild steel specimens before and after corrosion tests.

Original state (before testing)		Ra = 0.22 Rmax = 2.89 V. Scale= 1mm= 0.333 μm H. Scale = 40:1
Static test Maximum Corrosion rate = 55.5 mil-inch/year Base mud + 0% NaOH pH= 8.5		Ra = 0.25 Rmax = 3.2 V. Scale= 1mm= 0.333 μm H. Scale = 40:1
Static test Minimum Corrosion rate = 0 mil-inch/year Base mud + 1% NaOH pH= 13		Ra = 0.74 Rmax = 3.1 V. Scale= 1mm= 0.333 μm H. Scale = 40:1
Dynamic test Maximum Corrosion rate = 112 mil-inch/year Base mud + 0% NaOH pH= 8.5		Ra = 0.23 Rmax = 5.2 V. Scale= 1mm= 0.333 μm H. Scale = 40:1
Dynamic test Minimum Corrosion rate = 0.45 mil-inch/year Base mud + 1% NaOH pH= 13		Ra = 0.84 Rmax = 3.18 V. Scale= 1mm= 0.333 μm H. Scale = 40:1

Ra= Average roughness Rmax= Maximum roughness V.= Vertical H.= Horizontal

Fig. 10. Surface roughness of J-55 steel specimens before and after corrosion tests.

Table 2. Surface roughness data for mild steel and J-55 steel alloys

Specimen type	Test type	Test fluid type	pH	Average roughness (Ra), μ m	Maximum roughness (Rmax), μ m
Mild steel	before test	—	—	0.0799	0.9690
Mild steel	static	Base mud + 0 % NaOH	8.5	0.4662	2.4809
Mild steel	static	Base mud + 1 % NaOH	13	0.2498	1.8315
Mild steel	dynamic	Base mud + 0 % NaOH	8.5	0.4262	3.0137
Mild steel	dynamic	Base mud + 1 % NaOH	13	0.4995	2.8971
J-55 steel	before test	—	—	0.0733	0.9624
J-55 steel	static	Base mud + 0 % NaOH	8.5	0.0833	3.5330
J-55 steel	static	Base mud + 1 % NaOH	13	0.2464	1.0323
J-55 steel	dynamic	Base mud + 0 % NaOH	8.5	0.0766	1.7316
J-55 steel	dynamic	Base mud + 1 % NaOH	13	0.2797	1.0590

Base mud = 15% Al-Ghatt clay + 1% HV-CMC + 1% XC-Polymer

Conclusions

On the basis of the analysis performed in this study, the following conclusions are obtained:

[1] Al-Ghatt clay contains appreciable amounts of clay minerals kaolinite and attapulgite and more than 92% by weight of fine materials.

[2] The viscosity developed by 15% Al-Ghatt clay in fresh water is ideal for use as a drilling fluid, especially when a low solids drilling fluids are required.

[3] The addition of XC-polymer and HV-CMC have improved the overall properties of Al-Ghatt clay suspensions in fresh water.

[4] The addition of NaOH has increased the pH of the suspension which in turn has reduced the corrosivity action of Al-Ghatt clay suspensions in fresh water.

[5] The measured rheological properties of Al-Ghatt clay suspensions in fresh water indicate that they lie in the range of typical native clays. After the addition of 1% XC-polymer, 1% HV-CMC and 1% NaOH the suspensions had similar flow behavior as the commercial attapulgite or sodium montmorillonite.

[6] Al-Ghatt clay plus 1% XC-polymer + 1% HV-CMC and 1% NaOH in fresh water was thermally stable up to 90 °C, and possessed a minimal corrosion effect on the tested steel as revealed by weight loss, surface morphology, and surface roughness tests.

[7] Corrosion under static conditions was found to be much lower than that under dynamic conditions which is attributed to erosional effects, and better circulation of the corrodant fluid.

[8] The use of Al-Ghatt clays as a basic constituent in oil and gas wells drilling fluids is recommended, provided that the NaOH concentration in the fluid is maintained at 1% by weight.

[9] Utilization of Al-Ghatt clay in drilling fluids is recommended especially after testing their effect on formation productivity (i.e. measuring the magnitude of decrease in formation permeability which may occur when this local drilling fluid is applied) and after performing economical feasibility studies. Further investigation is required to test their dynamic fluid loss properties.

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خواص السريان والتآكلية لسوائل الحفر السعودية المحضرة من طفلة الغاط في المملكة العربية السعودية

مساعد ناصر جاسم العواد

قسم هندسة النفط، كلية الهندسة، جامعة الملك سعود، ص ب ٨٠٠،

الرياض ١١٤٢١، المملكة العربية السعودية

(أستلم في ١٩٩٦/١١/٢٣م؛ وقُبل للنشر في ١٩٩٧/٦/١٧م)

ملخص البحث. تم إجراء تجارب معملية لقياس خواص السريان والتآكل لطفلة الغاط السعودية على كل من الحديد المطاوع و J-55 والتي تستخدم في تصنيع أنابيب التبطين وذلك من أجل استخدامها كمادة أساسية في سوائل الحفر.

تم دراسة تأثير إضافة هيدروكسيد الصوديوم على الخواص التآكلية لطفلة الغاط وقيس معدل التآكل في حالتي السكون والسريان لخليط مكون من ١٥٪طفلة الغاط بالوزن بالإضافة إلى نسب مختلفة من هيدروكسيد الصوديوم (ص ا يد).

ولقد وجد أن أكبر معدل للتآكل تحت الظروف الساكنة يتغير من صفر إلى ٧٣,٢٠مل- بوصة/ سنة وتحت ظروف السريان يتغير من ٠,١٢٥ إلى ١٥٥,٣٠ مل - بوصة/ سنة. وأظهرت الدراسة أن مقاومة أنابيب التبطين تزداد كلما زادت قلوية سائل الحفر في كلتا الحالتين السكون والسريان.

وبناءً على نتائج هذه الدراسة فإن طفلة الغاط يمكن أن تستخدم في تحضير سوائل الحفر بشرط أن لا تقل نسبة هيدوركسيد الصوديوم عن ١٪بالوزن.