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TESTING OF DRILLING FLUIDS FORMULATED FROM TABUK FORMATION CLAYS

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ABSTRACT

There are huge drilling operations in most areas of the Kingdom of Saudi Arabia nowadays searching for potential hydrocarbon reservoirs. The increasing expense of importing drilling fluid components for oil and gas wells, drilling, especially clays, necessitates the testing of some local clays which are less expensive and are abundantly available. Therefore, representative Tabuk formation clay samples from the northern and central provinces of Saudi Arabia have been studied. The clays were mineralogically investigated using x-ray diffraction and scanning electron microscopy. The physicochemical properties of clay suspensions with and without common drilling fluid additives were measured. These properties include rheology, filtration loss, density and pH. The thermal stability of clay minerals and suspensions was studied. Since sample 2 of the Tabuk clay produced better results, its thermal stability was further studied by autoclaving its suspensions at temperatures between 25 and 121°C after the addition of high-viscosity carboxy methyl cellulose (HV-CMC) and XC-polymer. A concentration of 10% by weight of sample 2 of the Tabuk formation clay plus 1% NaOH and 0.5 XC-polymer produced the best rheological, filtration and thermal stability.

Corrosion in drilling operations is strongly related to the composition of drilling fluids. A concentration of 10% by weight of sample 2 of the Tabuk formation clay plus 0.5% NaOH and 0.5 XC-polymer developed minimum corrosion rates as revealed by corrosivity tests (static and dynamic) and surface morphology investigations

Key Words: Corrosivity, drilling fluids, thermal stability, rheology, Tabuk formation, clays

INTRODUCTION

Clays in Saudi Arabia are represented by numerous commercial stocks [1-2]. The mineralogical, chemical and mechanical analysis of these clays led to their use in different industrial applications. The use of these national clays in the drilling of oil, gas or water wells in the Kingdom as well in other Arabian Gulf countries will save millions of dollars that otherwise would be spent on purchasing these materials. In the Khurays and Qasim regions, many kinds of clays are found and can be studied [3]. Other unexplored areas for commercial utilization of clay and shale are abundant in the northern region of the Kingdom, especially in the Tabuk formation. The clay deposits of AsSarat in the southern region of the Kingdom represent another possible source of clay minerals [4]. The geological studies of the Ummer Radhuma and Dammam formations have indicated the presence of numerous types of clay minerals, especially palygorskite, in these formations [5,6,7]. In Saudi Arabia, the utilization of clays, especially in the drilling of oil and water wells, has been very limited. The intense exploration for oil and water in the Kingdom as well as other Gulf countries, necessitates the use of local raw materials in this important industry [8].

EXPERIMENTAL PROCEDURE

This study specifically aims to achieve the following objectives:

- Geological sampling of good clay occurrence in the northern province of Saudi Arabia,
- (Characterization of clay and non-clay minerals by mineralogical and mechanical analysis of clay samples, and
- Testing of the application of Tabuk formation clays in drilling fluids by:
    a) Measuring the rheological behavior of clay suspensions, and correlating the mineralogical analysis and rheological properties,
    b) Studying the stability of formulated drilling fluids at high temperatures and in chemically complex environments,
    c) Activating those clays shown to be of lower filtration, yield or rheological properties, and
    d) Study of the corrosivity of the formulated drilling fluids.

Figure 1 represents a flow diagram of tests and analysis conducted in this study.

METHODS OF CHARACTERIZATION

Oriented clay films were prepared on glass slides after having been dried at 40-50°C in an oven. The slides then were analyzed with a Philips x-ray diffractometer with a graphite monochromator and a Cu-target x-ray tube operated at 35 kV and 15 mA. The precise determination of the shape of the clay particles was made by the electron microscope. The samples were mounted on stubs to be coated with gold for 3 minutes at 15 on an EMSCOPE SC-500 sputter coater, and then examined with a JEOL-35 FC scanning electron microscope. All rheological properties, both at room and high temperatures, were investigated using the standard devices offered by courtesy of Baroid Petroleum Services. The corrosivity of the formulated drilling fluids was investigated using various laboratory test equipment including a dynamic flow loop (Fig. 2), a static test reservoir, a pH meter and a low power microscope with a camera.

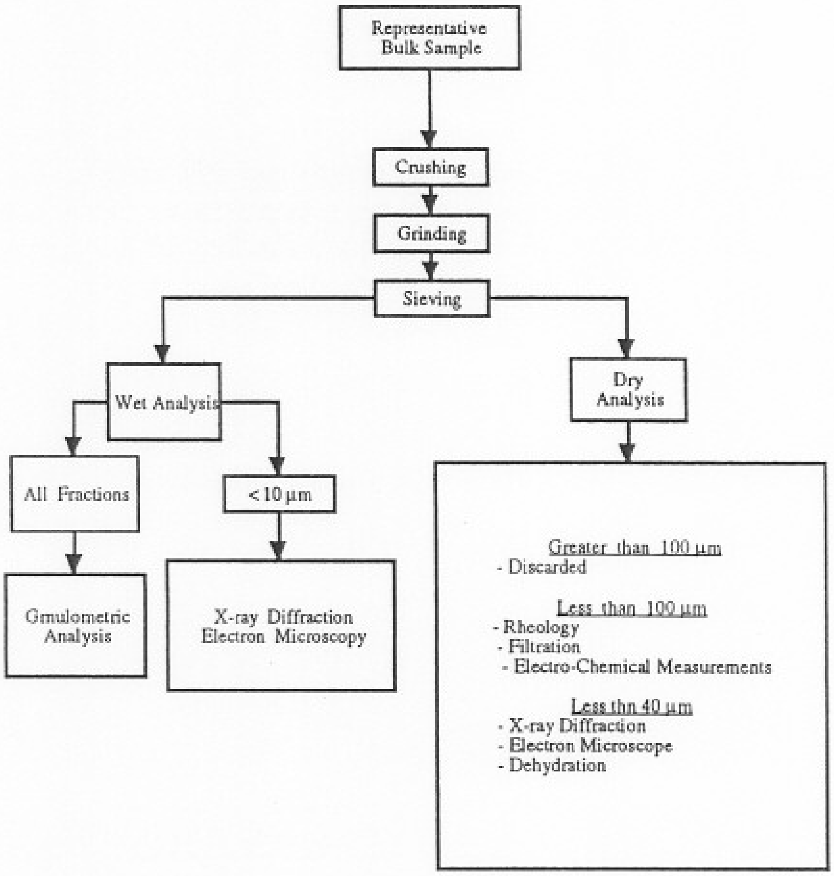


Figure 1. Schematic diagram of tests and analysis

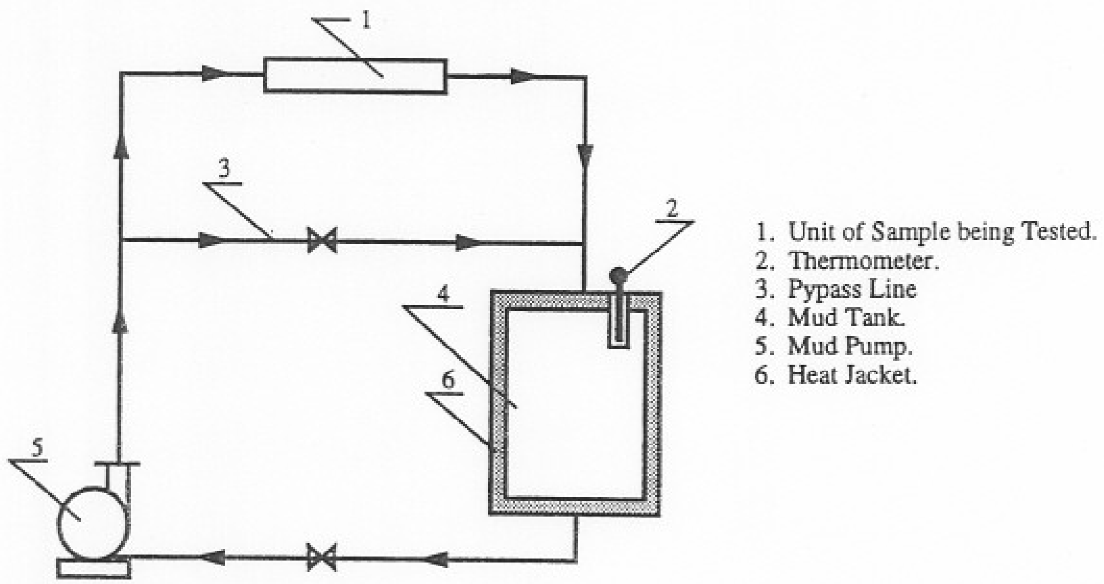


Figure 2. Schematic diagram of the closed dynamic loop

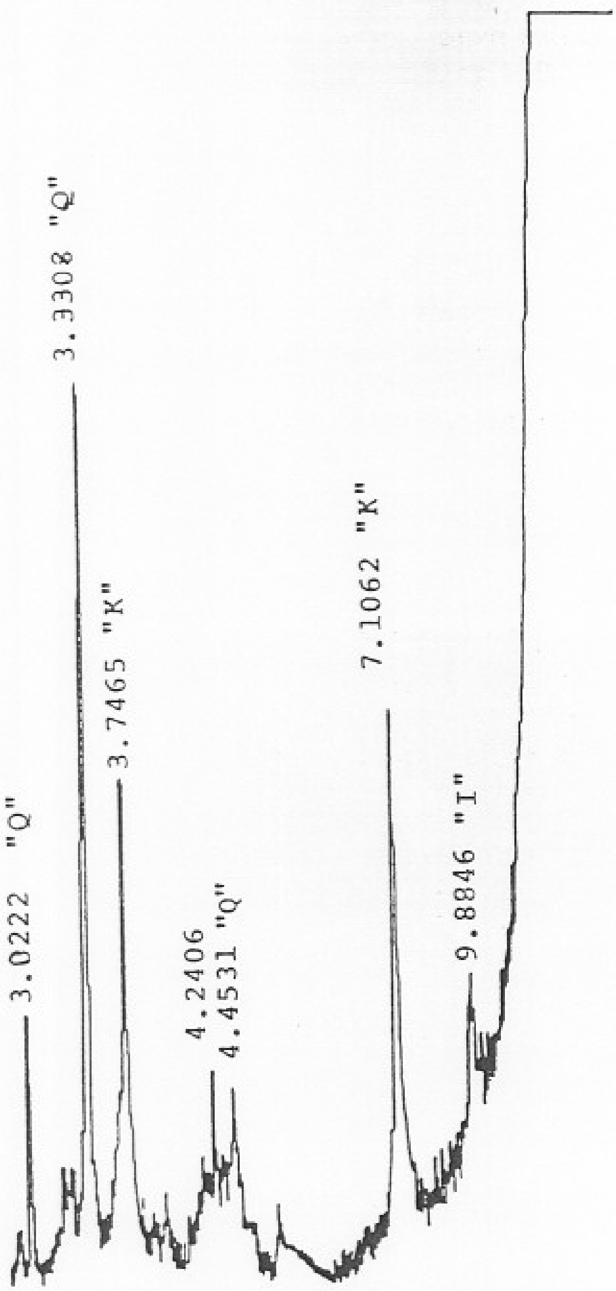
RESULTS AND DISCUSSION

Characterization

The importance of the granulometric analysis goes back to the fact that the clays which contain more than very small amounts of non-clay minerals, especially in the size of sand and silt, will not be suitable for drilling fluid applications. Sand can import undesirable properties to drilling fluids and have an erosive action on pumps and drill strings. The granulometric analysis of Tabuk formation clays showed that more than 95% of the samples had fineness fractions of < 37 mm as shown in Table 1. The good rheology of the suspensions prepared from Tabuk formation clays is caused in part by the fineness of the Tabuk formation clays. The results obtained from x-ray diffractograms (Fig. 3) showed that the samples consisted exclusively of illite and kaolinite, interpreted by the presence of the principal peaks characterizing both clays. The non-clay minerals characterized by the diffractograms were mainly quartz. For further investigation, the samples were examined by the scanning electron microscope to study the texture of the clay minerals present. The electron micrographs of the Tabuk formation clays indicated the presence of disordered illite between kaolinite particles, as shown in Fig. 4. Dehydration curves of the Tabuk formation clays are shown in Fig. 5. These clays lost their absorbed water at 100°C, whereas the interlayer water was lost between 100 and 400°C. The hydroxyle water was lost in the range of 400-600°C. It was very difficult to distinguish the clay minerals from such curves because mixtures of different minerals occur in the samples.

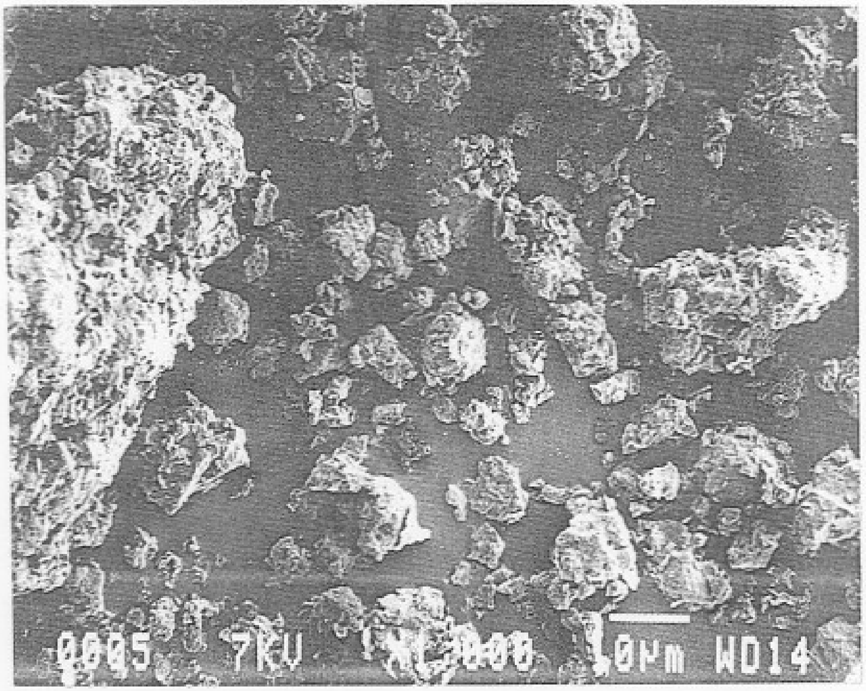
Table 1. Granulometric Analysis of Tabuk Formation Clays

Sieve Size (mm)	Weight (%) Sample 1	Weight (%) Sample 2
500	0	0
300	0.2	0
150	0.3	0
100	0.3	0
63	1.6	0.3
40	2.6	0.5
Fines	95	99.2

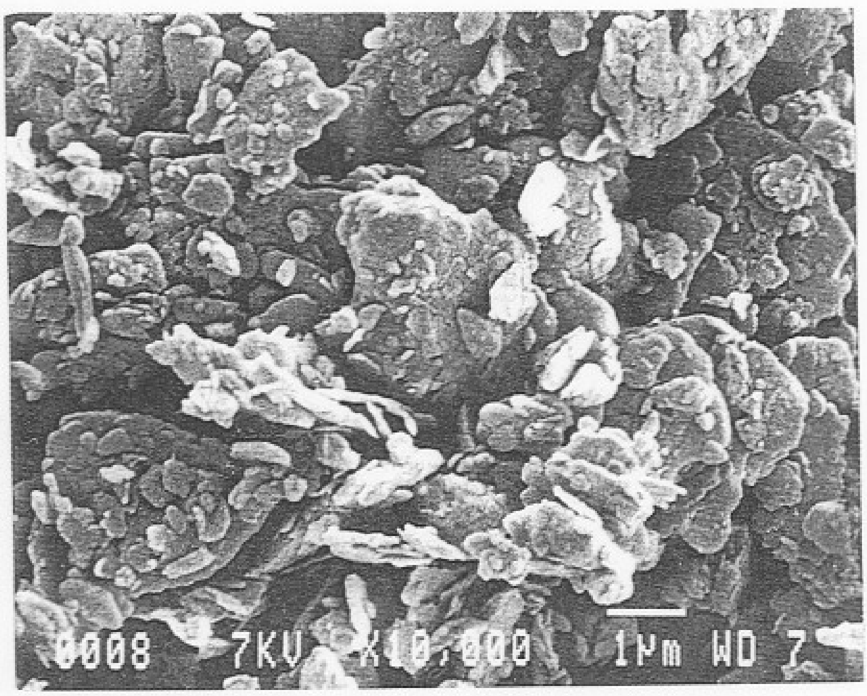


2θ	d, Å	In
8.946	9.8846	487
12.456	7.1062	848
17.883	4.9598	222
19.938	4.4531	443
20.462	4.3403	337
20.948	4.2406	448
21.372	4.1574	344
22.052	4.0307	218
23.144	3.8430	222
23.749	3.7465	216
24.991	3.5629	767
26.765	3.3308	1161
27.640	3.2272	266
27.922	3.1952	312
29.556	3.0222	488

Figure 3. X-ray diffractogram of Tabuk formation clays, raw samples 1 and 2, at 25°C



(a) Sample 1



(b) Sample 2

Figure 4. Scanning electron micrographs of Tabuk formation clays

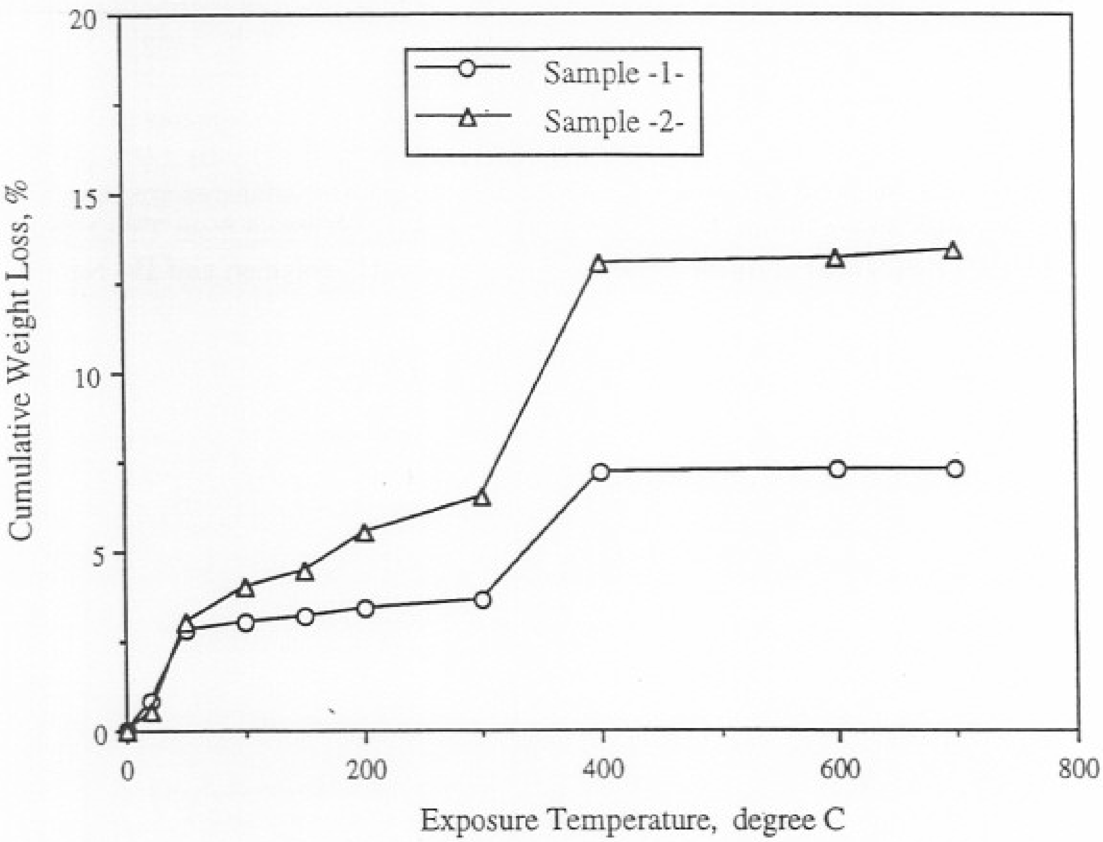


Figure 5. Dehydration curves of Tabuk formation clays

Rheology

The rheological properties of drilling fluids play a very important role in determining the overall success of drilling operations. In order to obtain properly functioning drilling fluids, the rheological properties should be carefully investigated. Thus, the ability to use material in a drilling fluid depends on the material's flow, filtration and electrochemical characteristics. The testing of other properties can be achieved in many ways, the most important of which is the measurement of rheological behavior. In the case of mineral suspensions,this type of measurement is influenced among other things by the temperature, weight percent of solids, quantity and sign of superficial charges, clay mineralogy, and type of mixing water [9,10]. It is practically impossible to study individually the effect of each of the previous parameters on the rheological behavior of clay suspensions. However, the establishment of rheograms and viscosity measurements can indicate modifications in suspension's behavior. Figures 6 and 7 give typical examples of shear stress-shear rate relationships obtained when formulating Tabuk formation clays in freshwater. These figures indicate the presence of relations which accurately describe the flow characteristics of a drilling fluid over the shear rate ranges normally encountered in the wellbore. The suspensions possessed a pesudo-plastic behavior even with concentrations of clay solids below 10%. Table 2 gives the typical relationships of plastic and the apparent viscosities, yield point and density of Tabuk formation clays suspensions in freshwater. Such rheological behavior is typical for clay-water systems formed using illite and kaolinite clays. The filtration loss was too high for it to be used as a drilling fluid without using fluid loss control additives. In order to obtain a drilling fluid exhibiting minimum corrosion rates, NaOH was added, and concentrations of 0.5 to 1.0% by weight, were found adequate to develop the desired properties. 0.5 percent XC-Polymer by weight was added to improve the fluid rheology and filtration loss. Figure 8 shows the reheograms of the drilling fluids prepared from 10% by weight Tabuk formation clay (sample 2) plus 1.0% NaOH with the addition of various additives; the filtration behavior of the best additives are shown in Fig. 9. Figure 10 shows a comparison between the drilling fluid formulated from Tabuk formation clay suspension (10% Tabuk formation clay sample 2, 0.5% XC-polymer, and 1% NaOH) with common drilling clays.

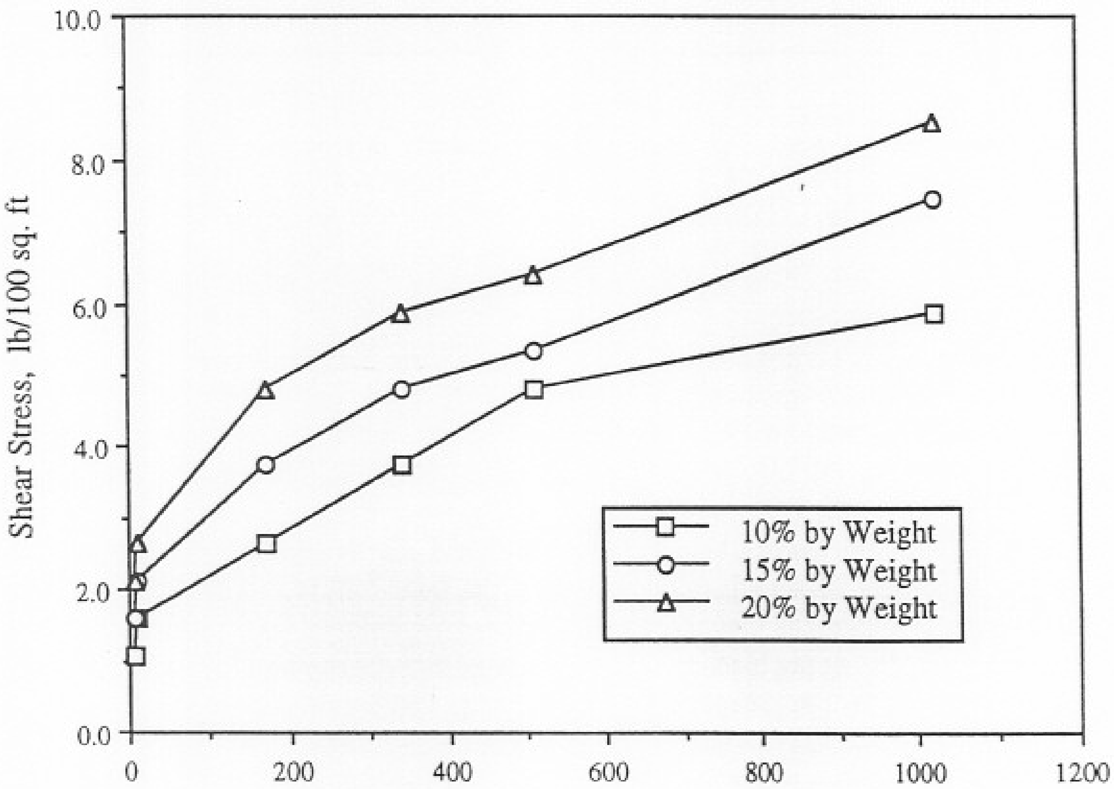


Figure 6. Shear stress-shear rate relationships for Tabuk formation clay (sample 1) suspension using freshwater

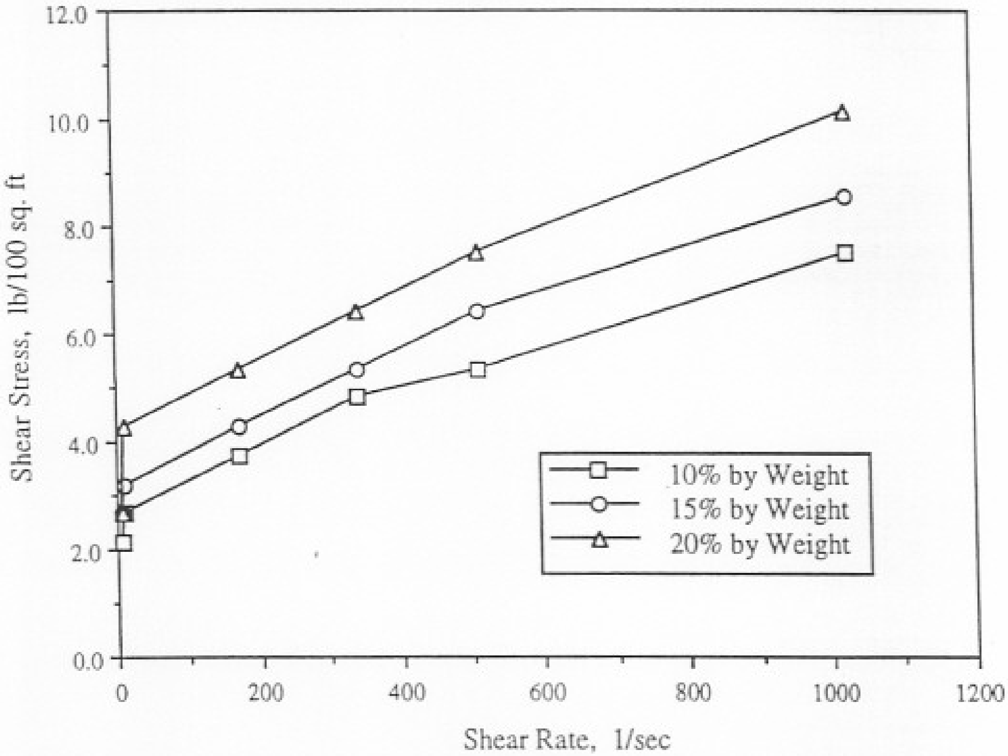


Figure 7. Shear stress-shear rate relationships for Tabuk formation clay (sample 2) suspension using freshwater

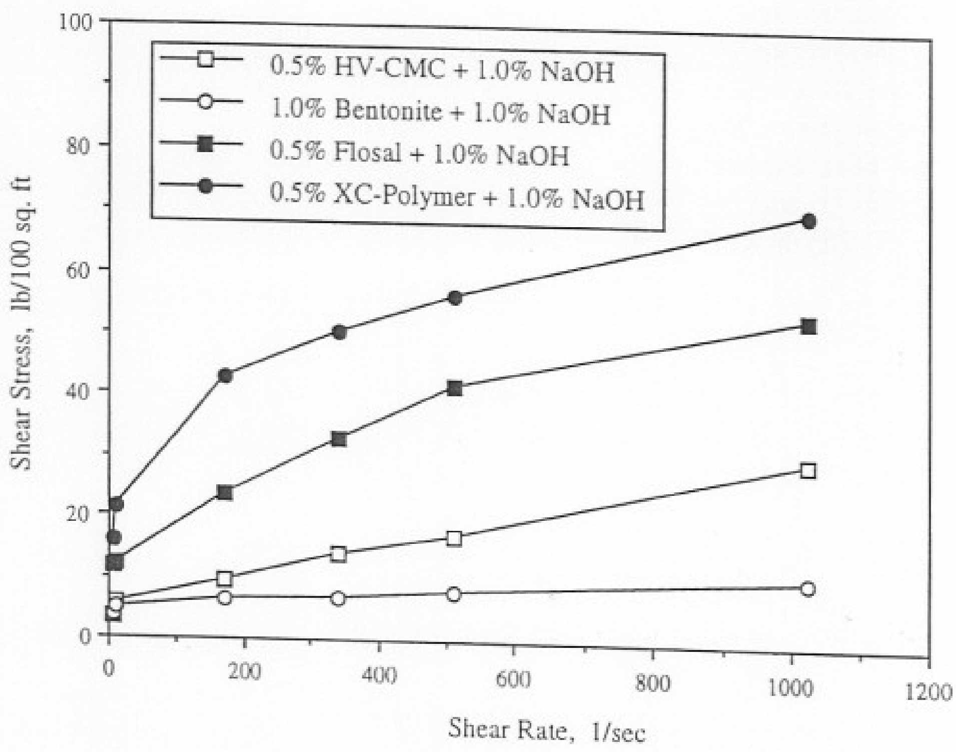


Figure 8. Shear stress-shear rate relationships for 15% Tabuk clay (sample 2) suspension with various additives

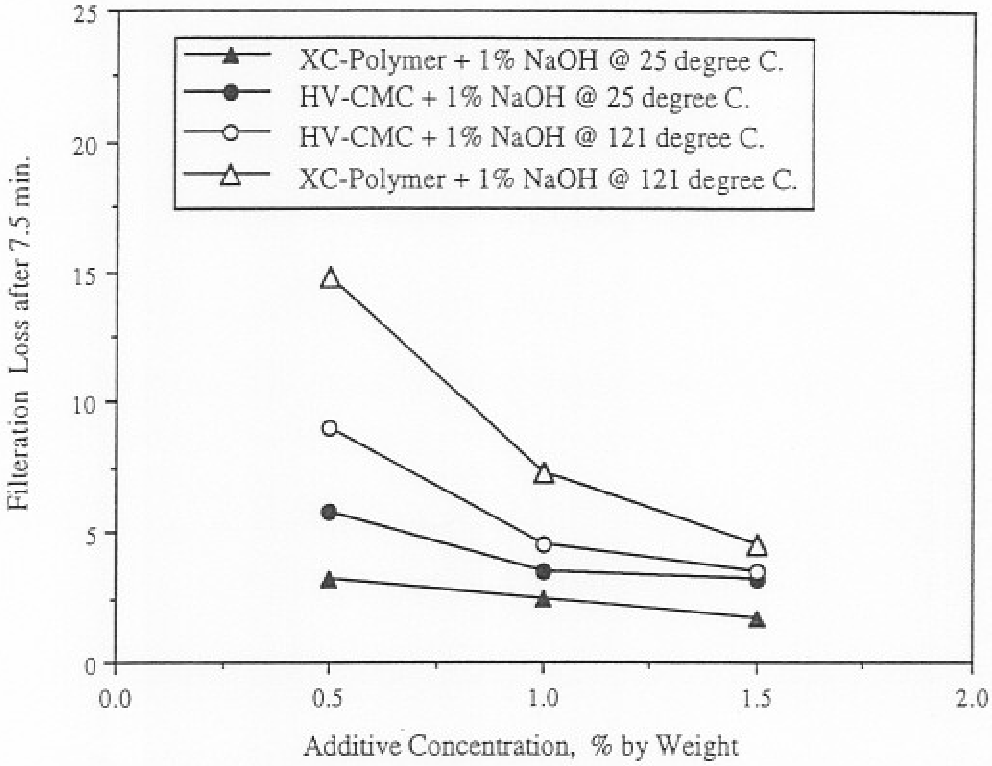


Figure 9. API and HT-HP filteration loss of 10% by weight of Tabuk formation clay (sample 2) suspension in freshwater

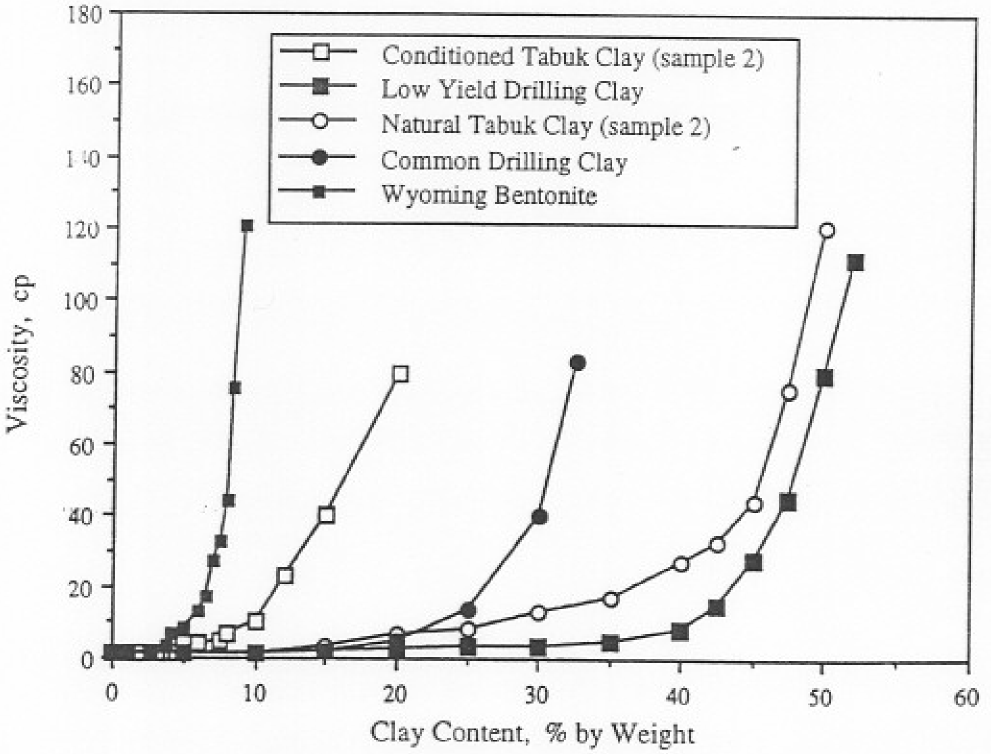


Figure 10. Natural and conditioned (10% Tabuk clay + 0.5% XC-polymer + 1% NaOH) clay suspensions formulated from Tabuk formation clay (sample 2) compared to common clays

Table 2. Rheological Properties of Tabuk Formation Clays

Clay weight (%)	Density (ppg)		Yield Point (lb/100 ft^2)		Apparent Viscosity (cp)		Plastic Viscosity (cp)	
	Sample 1	Sample 2	Sample 1	Sample 2	Sample 1	Sample 2	Sample 1	Sample 2
10	8.9	8.9	4.5	3.0	2.94	2.94	1.1	1.1
15	9.3	9.1	5.0	4.0	3.74	3.74	2.14	2.14
20	9.7	9.4	7.5	6.3	5.27	5.27	2.15	2.15

Corrosivity

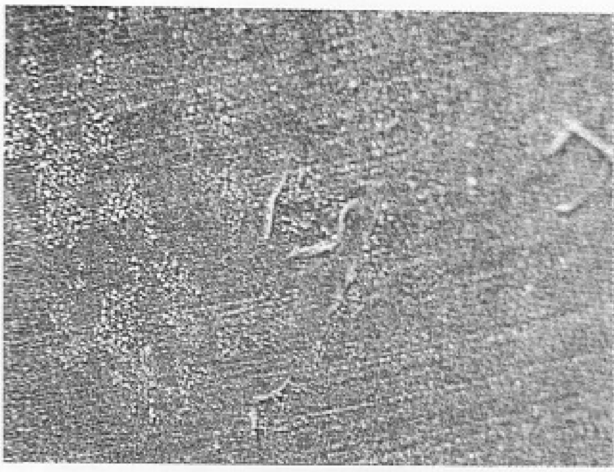
Corrosion is noted for its destructive effect on materials, and its consequences on the economy. Corrosion has been a problem in the petroleum industry throughout its history. Drilling fluid components play major roles in corrosion processes. To understand the influence of drilling fluids on the rate of corrosion, certain factors should be studied, such as their physical and chemical properties. Corrosion within a drilling well was simulated by immersing test specimens in the drilling fluid at a fixed exposure time and temperature in both static and dynamic conditions. The loss in weight of the test specimen served to measure the rate of corrosion. Drilling fluids formulated from Tabuk formation clays (sample 2) were investigated for their corrosivity on three different types of casing alloys, namely: mild steel, J-55 casing grade and K-55 casing grade. 10% by weight suspension of Tabuk formation clay (sample 2) was chosen to study the corrosivity of Tabuk formation clays with and without the addition of NaOH. Coupons made from the chosen alloys were made and appropriately placed inside either the static cell or the dynamic loop, depending on the type of test to be performed. Then the formulated drilling fluid was added to the test apparatus. Both tests were run for two week periods at 58°C. After termination of the test, the samples were cleaned with inert fluid, and their weights were recorded and their surfaces were carefully examined using a low-power microscope. The following formula was used to calculate the corrosion rate [11].

$$mpy = 22273 * \left(\frac{W * L}{D * A * T} \right) \quad (1)$$

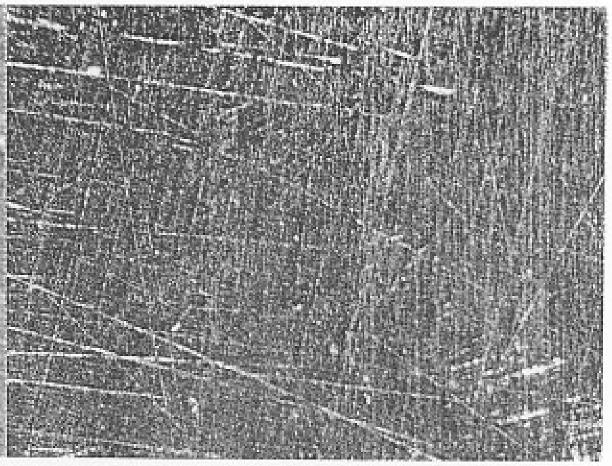
where

mpy = penetration rate in mm-inch/year,
W = weight loss in grams,
D = density in gm/cm^3,
A = area in contact with the test fluid in in^2, and
T = exposure time in hours.

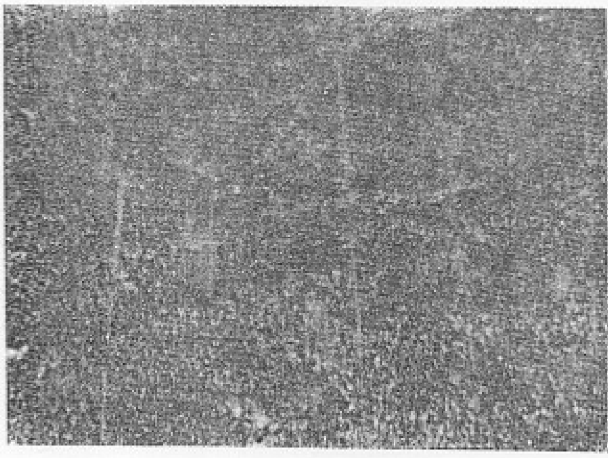
where mpy is the penetration (corrosion) rate in mm/year. As shown in Table 3, mild steel had corrosion rates under dynamic conditions that were two-fold greater than in static conditions. This can be attributed to the effect of shear forces on the surface of the metal caused by the



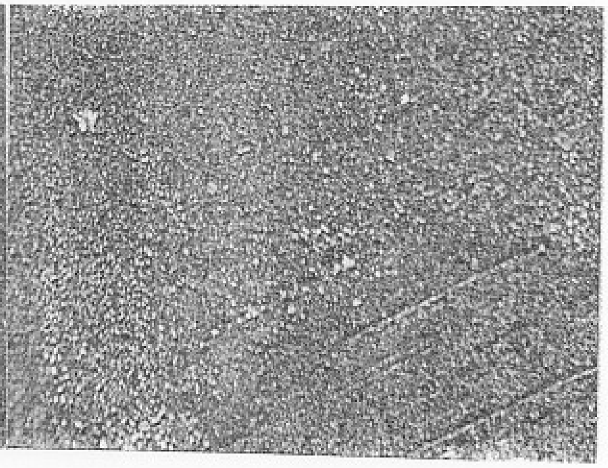
(a) Mild Steel @ 0.0% NaOH



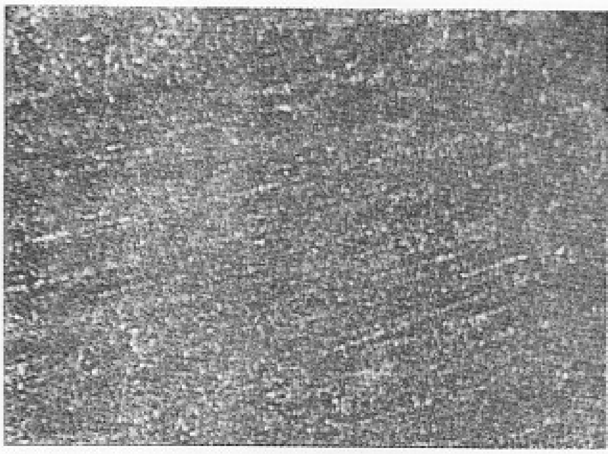
(b) Mild Steel @ 0.5% NaOH



(c) J-55 Alloy @ 0.0% NaOH



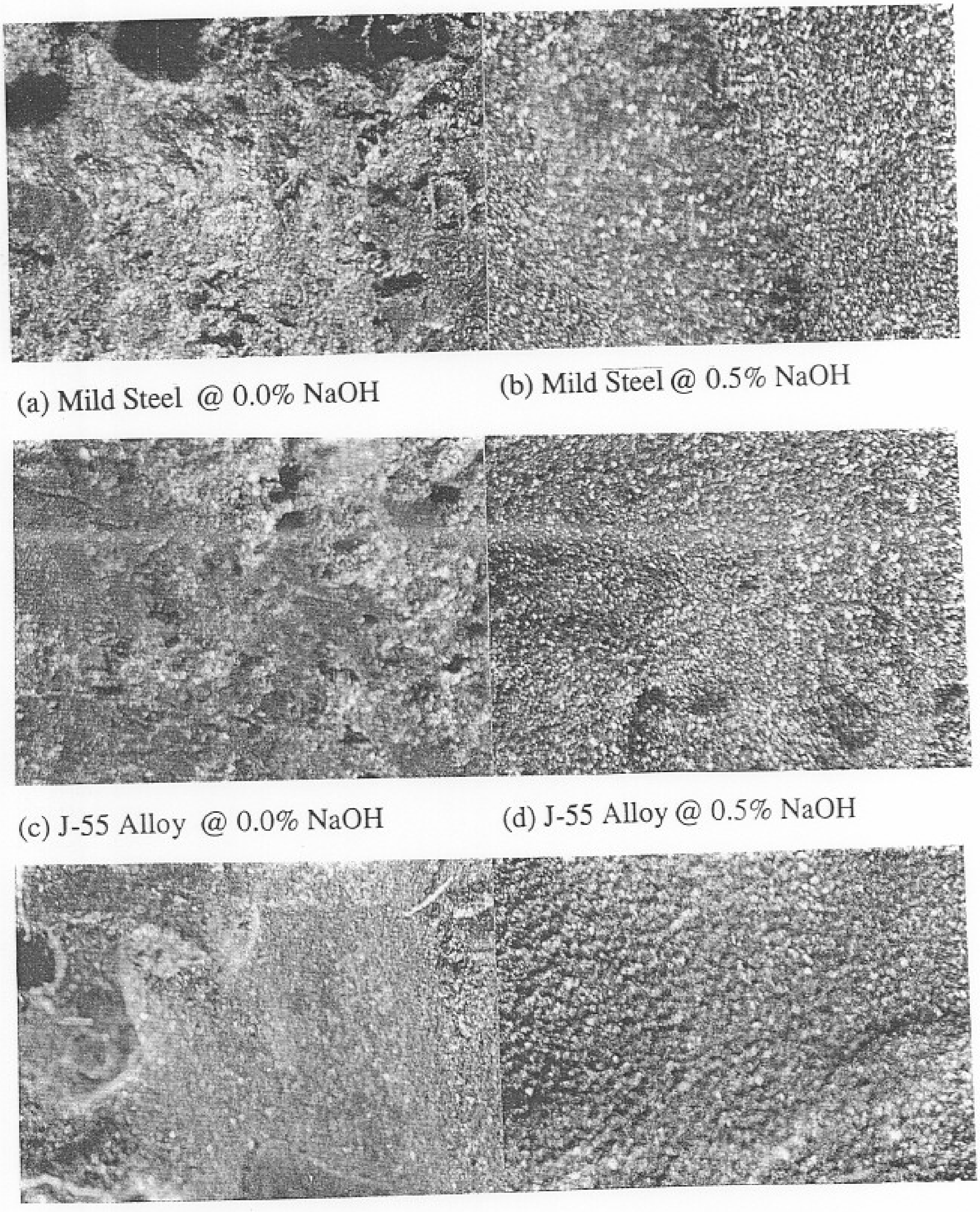
(d) J-55 Alloy @ 0.5% NaOH



(e) K-55 Alloy @ 0.0% NaOH

(f) k-55 Alloy @ 0.5% NaOH

Figure 11. Surface morphology of steel coupons tested under static conditions for 2 weeks using a drilling fluid formulated from 10% Tabuk formation clay (sample 2) + 0.5% XC-polymer with and without the addition of NaOH



(a) Mild Steel @ 0.0% NaOH

(b) Mild Steel @ 0.5% NaOH

(c) J-55 Alloy @ 0.0% NaOH

(d) J-55 Alloy @ 0.5% NaOH

(e) K-55 Alloy @ 0.0% NaOH

(f) k-55 Alloy @ 0.5% NaOH

Figure 12. Surface morphology of steel coupons tested under dynamic conditions for 2 weeks using a drilling fluid formulated from 10% Tabuk formation clay (sample 2) + 0.5% XC-polymer with and without the addition of NaOH

flow of the test fluid. Mild steel was found to have the lowest resistance to corrosion by activated Tabuk formation clays, while K-55 had the highest resistance to corrosion under the same test conditions. In the static tests, all three samples corroded at the same rate. The corrosion rates were significantly reduced when NaOH was added to the test fluids. This was due to the ability of NaOH to change the test fluid's environment from being acidic (pH = 5) to being alkaline (pH = 11), as shown in Table 3. The surface morphology of the tested steels before and after the addition of NaOH for both static and dynamic tests is shown in Figs. 11 and 12. It is clear from the figures that the metal surfaces were more severely corroded before the addition of NaOH.

Table 3. Corrosion Tests Results of Tabuk Formation Clays

Test Coupon	Static Test (mpy)		Dynamic Test (mpy)	
	A	B	C	D
Mild Steel	0.26	0.10	1.7	0.255
K-55	0.25	0.10	1.0	0.212
J-55	0.23	0.10	0.8	0.189

A: Static test (10% sample 2 without additives, pH = 5)
B: Static test (10% sample 2 + 0.5% XC-polymer + 0.5% NaOH, pH = 11)
C: Dynamic test (10% sample 2 without additives, pH = 5)
D: Dynamic (10% Sample 2 + 0.5% XC-polymer + 0.5% NaOH, pH = 11)

CONCLUSIONS

1. The tested clays made from Tabuk formation clays contain more than 95% fines by weight (< 40 mm). They are exclusively composed of the clay minerals illite and kaolinite together with small amounts of interstratified minerals and quartz.
2. The rheological properties of the Tabuk formation clay suspensions indicate that they lie in the range of typical native clays. After the addition of common drilling fluid additives, the suspensions had more or less the same flow behavior as commercial clays. Therefore, it is recommended that this clay be used in formulating low-weight drilling fluids.
3. The formulated drilling fluids made from Tabuk formation clay (sample 2) are thermally stable up to the tested temperatures of 25-121°C.
4. Corrosion tests on the drilling fluids formulated from Tabuk formation clays (sample 2) indicated that the fluids possessed minimal corrosivity.
5. The application of Tabuk formation clays in oil well drilling is recommended especially after performing economical feasibility studies.

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