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Investigating the Corrosivity of KCl/Polymer Drilling Mud on Downhole material

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Abstract: *The corrosive effect of drilling fluids was analysed by testing the corrosivity of a KCl/Polymer formulation, with temperature and salt concentration as the measurement variables. This was carried out using the weight loss technique in order to measure the effect of KCl/polymer muds on carbon steel, testing the mud behaviour for three different temperatures and the salt concentrations these helps in knowing the behaviour of the mud on downhole materials. From the Experiment it was confirmed that drilling fluids are corrosive and with the presence of salt and temperature, the corrosivity increases but decreases with increase in salt concentration. The rise in corrositivity continues with increasing temperature, but with the retardation in oxygen solubility the rise ceases. The corrosion rate of KCl/Polymer mud with these variables indicated high corrosion rate, which could be effect of other parameters that aided conductivity and the effect of temperature in the process. Those could have been based on the additives used in the mud that also contributed in aiding corrosion. However these effects were not regarded as prominent due to the addition of caustic soda that gave the mud a reasonably high pH of 9.5 to 10, which also inhibits corrosion. Other factors such as oxygen, whose effect was controlled by temperature, could have contributed to the corrosion rate. A low weight loss was shown after 72 hours exposure of the specimen to the mud. This was anticipated to be the inhibiting nature of potassium chloride, the static nature of the mud based on zero shear stress effect on the carbon steel surface and less oxygen transportation to the corroding specimen due to zero agitation of the mud. The minimum corrosion rate of the mud was 0.32 mm/year which was at the highest salt concentration and the lowest temperature of 40 ^{0}C. The maximum corrosion rate was 0.96 mm/year which was at the lowest salt concentration and the highest temperature of 80^{0}C, this agrees in principle with the behaviour of temperature and salt concentration.*

I. Introduction

1.1 Drilling Fluids and Corrosion

Corrosion is the destruction of metal by direct chemical reaction or by electrochemical reaction of a metal with its environment. Corrosion occurs usually at higher temperatures (above 260 ^{0}C) and seldom occurs in drilling. However corrosion by drilling fluid is one of the paramount issues in drilling engineering problems with attendant enormous economic lose. The most common type, electrochemical corrosion of solid/liquid interface occurs at almost every instance where water or brine contacts a metal/alloy equipment, and this type of corrosion is the principal concern in drilling operations (Asrar 2010).

Drilling fluids constitute a major component in drilling operations and their performance contribute immensely to the success or otherwise of drilling operations. They serve as the electrochemical environment in which anode/cathode interaction occurs, and can result in corrosion at a rate that depends on the mud type, pH and temperature. For every environment of operation such as offshore, deep water, or other hostile environments, drilling fluids are needed to facilitate smooth operation. Ascertaining the fluid performance requires evaluating all the key parameters involved in drilling operations while the effectiveness is judged by its influence on the overall well performance and cost.

Drilling fluid is usually a mixture of water, clay, weighing material and a few chemicals. Sometimes oil may be used instead of water, or oil added to the water to give the mud certain desirable properties (Versan, 2001). According to Williams (2009), the basic components of KCl/polymer mud are: fresh water or sea water, KCl, inhibiting polymer, viscosity building polymer, stabilized starch, caustic soda and Lubricants. This mud is most suitable for drilling shale sections due to its superior sloughing-inhibition properties. It is also suitable for drilling potentially productive sands (Williams, 2009). The advantages of this type of mud is its higher shear thinning, high true yield strength, improved borehole stability, good bit hydraulics, and reduced circulating pressure losses. While their disadvantage is their instability at temperatures above 121^{0}C (Versan 2001).

The type of corrosion usually occurring during drilling operation is the electrochemical corrosion. this is a form of corrosion that occurs when metal and salt water mix together. Metal ions dissolve in the water/salt solution and conducts electricity. During electrochemical corrosion, electrons from other compounds are attracted to the metallic ions. Salt water attacks the metal and corrosion occurs in the process (Sharma, 2011).

According to Almisned (2008) the corrosion rate caused by drilling muds depends on many parameters, including mud type, its pH (Hydrogen ion concentration), temperature, drilling duration, and technique involved. Several factors affect the rate at which corrosion proceeds, however, most of the factors are interrelated and impose a compound effect on the corrosion rate of the drilling fluids. According to Baker Hughes (2006) the basic relations include; temperature, pressure, pH and dissolved salts. The corrosivity of KCl/Polymer mud on drill metals is however not fully analysed. This paper investigated the corrosion by KCl/Polymer mud during drilling process when the mud is in static condition (while drilling is suspended for a time); it also investigated the level of the corrosion on downhole materials i.e. the casing and drillstring.

II. Materials And Method

2.1 Mud Formulation

To build up a water-based KCl/polymer mud; Brine, Prehydrated bentonite, Potassium Chloride, PAC R, PAC UL, Xanthan Gum, Caustic Soda, carboxymethyl cellulose (CMC) and barite, was mixed as a base mud. NaCl was used to increase the salinity of the water in the mud to see the effect of its increase. Composition for the base mud can be seen in Table 1:

Table 1. Base Mud Formulation

Component	Water (ml)	Prehydrated bentonite (g)	Caustic soda (g)	PAC R (g)	PAC UL (g)	Xantham Gum (g)	Barite (g)	KCl (g)
Mass or Volume	350	5	0.5	1	1	0.2	10	90

Key: PAC R, PAC UL: polyaniomic cellulose.

2.2 Mixing and Ageing

Before mixing the fluid, additives are weighed using A Kern EW-6200-2NM electronic balance (Figure 1) which can measure in grams. After weighing the additives A Hamilton Beach Standard mixer (Figure 2) is used to mix the drilling fluid. The specified salt amounts in grams are mixed into 350ml of water containing prehydrated bentonite in the cup of the mixer; the ingredients are then added into the water in order listed in table 1, with a control mixing time of 2 minutes for each additive.

After adding the additives, the mud is mixed in The Hamilton Beach Standard mixer for 30 minutes, After 25 minutes the pH was measured, using a pH meter and universal pH paper (phydrion) simultaneously the pH was maintained at 9.5-10 and the mixing was continued for the remaining 5 minutes. The mud was transferred into a jar and sealed; it was allowed to stand for 16 hours at room temperature in order for it to age. Same procedure is conducted for three separate formulations having different salt concentrations of 10.5g, 35g, and 52.5g respectively in solution of 350ml water.

Figure 1 Kern EW- Electronic Balance

Figure 2. Hamilton Beach Standard mixer

2.3 Description of Specimen Used

A 1.2×7cm rectangular Alloy 1018 was used in the study, it was specially selected due to its remarkable physicochemical properties (Table 2) that suits it as drilling equipment and ease of machining.

Table 2. AISI/SAE 1018 Steel Specification 1018 Mild (Low-Carbon) Steel

1018 Mild (low-carbon) steel		
Minimum Properties	Ultimate Tensile Strength, psi	63,800
	Yield Strength, psi	53,700
	Elongation	15.0%
	Rockwell Hardness	B71
Chemistry	Iron (Fe)	98.81 - 99.26%
	Carbon (C)	0.18%
	Manganese (Mn)	0.6 - 0.9%
	Phosphorus (P)	0.04% max
	Sulphur (S)	0.05% max
Dimension	1.2 × 1 × 7 cm	

Source: AISI-SAE Standard Lists 2008

2.4 Experimental Procedure

Prior to use the specimen the following preparation was made: The specimens were washed with tap water using different emery paper grades and were again washed with tap water followed by distilled water. They were dried with clean tissue paper, immersed in ethanol, and dried with clean tissues paper, and then they were immersed in acetone, and dried with clean tissue paper. They were then left to dry for one hour before weighted and used.

The experiments were conducted over a period of nine days with each experiment taking three days (period the specimen was in the mud). For weight loss measurement, the metal samples were immersed in 100 ml of KCl/Polymer water base drilling mud at different salt concentrations (35g/350ml, 52.5 g/350ml, 70 g/350ml), and different temperatures (40 °C, 60 °C and 80 °C) in a Carbolite furnace in such manner that part of the specimen (19.24cm^2) was exposed in the test solution for 3 days each (72 hours) with a pre-weighed 1018 alloy (Carbon Steel) specimen in the solution. After each of such exposure the Carbon Steel specimen was cleaned washed with running tap water, removing the corrosion product, followed by distilled water, dried with clean tissue paper and degreased with acetone, and dried for one hour before weighted, the weight loss was determined by reweighing the specimen using the Kern electronic balance, and weight loses were computed as shown on table 3.Plate 1 shows the specimens after exposure.

2.5 Theoretical Analysis

The average weight loss of the carbon steel specimen, when statically exposed to drilling muds, was determined using the following equation to calculate the corrosion rate:

$$\mathbf{CR} = \frac{87.6 \times 10^4\, w}{\rho A t} \qquad \textbf{(1.0)}$$

Using the equation (1.0) the corrosion rate for 35gm NaCl concentration was calculated as follows;

w = weight loss (gm)	ρ = density (gm/cm³)	A = Surface Area (cm²)	t = time in hours
0.07gm	7.86g/cm^2	19.24 cm^2	3 days × 24 hours

The same calculation method was used for weight loss when 52.5g and 70g NaCl were added to the Mud.

III. Discussion Of Results

3.1Temperature effect on Mud Formulation

The KCl/Polymer mud corrosion rate increased as the temperature rises from 40^0C to 60^0C, However from 60^0C to 80^0C it was noted that the corrosion rate started decreasing as shown in figure 3, this is because with an increase of temperature up to 60^0C corrosion rate increases and above temperatures of 60^0C protective carbonate layers were observed which retards the corrosion rate. (Vuppu and Jepson, 1994). It has been shown that for salt water only, the corrosion rate increases with temperature up to approximately 60-70^0C and then decreases. For many materials such as steels where the oxygen content of the water directly affects the corrosion rate, the effect of temperature is minimal as in situations where the corrosion rate would be increased by increased temperature, the solubility of oxygen is decreased with increasing temperatures and the two effects counteract each other. Steels and copper alloys are particularly insensitive to temperature effects in normal saltwater immersion (Borgmann, 1937). This can also be true as the difference in the rate of corrosion as the temperature rises in the experiment is not large and that can be related to reduced oxygen solubility. For most chemical reactions, the reaction rate increases with increasing temperature, temperature affects the corrosion rate of metals in electrolytes primarily through its effect on factors which control the diffusion rate of oxygen

(Gerassimov et al, 1956). The corrosion of iron and steel is an example of this because temperature affects the corrosion rate by virtue of its effect on the oxygen solubility and oxygen diffusion coefficient. As temperature increases the diffusion coefficient of oxygen also increases which tends to increase the corrosion rate. However as temperature is increased oxygen solubility in aqueous solutions decreases until at the boiling point all oxygen is removed; this factor tends to decrease the corrosion rate. The net effect for mild steel is that the corrosion rate approximately doubles for a temperature rise of 30^{0}C up to a maximum temperature at about 80^{0}C**.** It may not have doubled for this experiment as it showed negligible differences in most cases, and however this may be as the result of the inhibition by the mud system itself. The rate then falls off in an open system because the decrease in oxygen solubility becomes the most important factor. According to Speller (1958) in a closed system where oxygen cannot escape the corrosion rate continues to increase indefinitely with temperature until all the oxygen is consumed.

Table 3. Weight losses of Carbon Steel at three different temperature

Temp. (^{0}C)	**NaCl (g/350ml)**	**Initial weight of carbon steel (g)**	**Weight after exposure (g)**	**Weight loss (g)**
40	35	63.80	63.73	0.06
40	52.5	63.80	63.74	0.07
40	70	63.80	63.76	0.04
60	35	64.93	64.81	0.11
60	52.5	64.13	64.02	0.12
60	70	64.68	64.60	0.08
80	35	64.42	64.33	0.08
80	52.5	64.34	64.26	0.09
80	70	63.02	63.97	0.05

Table 4. Computed corrosion rates of carbon steel at 40 ^{0}C, 60 ^{0}C, and 80 ^{0}C.

Temperature (°C)	**NaCl (g/ 350 ml)**	**Weight Loss (g)**	**Surface Area (cm²)**	**Time (hours)**	**Corrosion Rate (mm/year)**
40	35	0.06	19.24	72	0.48
40	52.5	0.07	19.24	72	0.56
40	70	0.04	19.24	72	0.32
60	35	0.11	19.24	72	0.88
60	52.5	0.12	19.24	72	0.96
60	70	0.08	19.24	72	0.64
80	35	0.08	19.24	72	0.64
80	52.5	0.09	19.24	72	0.72
80	70	0.05	19.24	72	0.40

From the results obtained a graphical representation shows logarithmic trend of behaviour of weight loss of the carbon steel versus NaCl concentration as shown in Figure 2, 3 and 4 respectively.

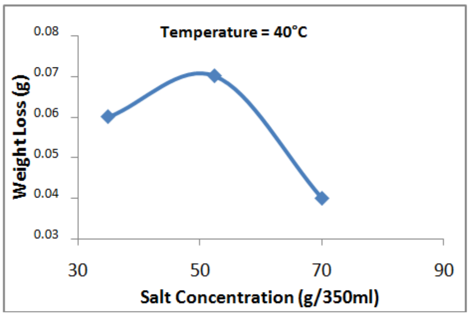

Figure 2,Weight loss with salt concentration at 40^{0}C

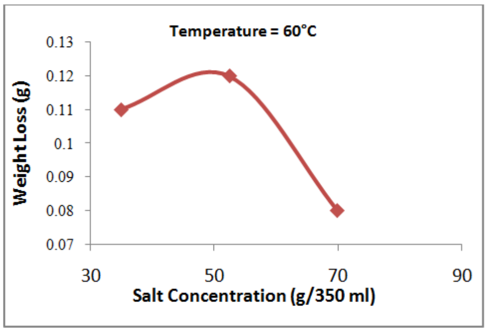

Figure 3. Weight loss with salt concentration at 60^{0}C

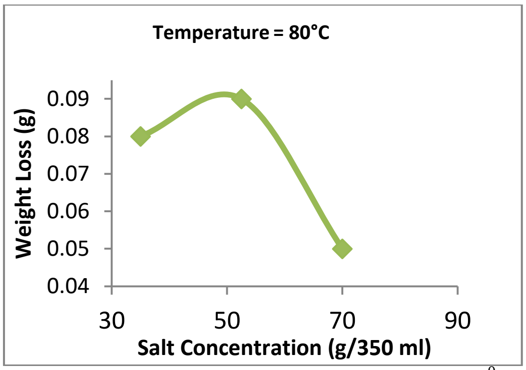

Figure 4.weight loss with salt concentration at 80^0C

3.2 NaCl effect on Mud Formulation

It was observed that the corrosion rate initially increases and then decreases with increasing salt concentration. As salt concentration increases conductivity rises increasing the corrosion rate, increasing salt concentration however reduces oxygen solubility, thereby decreasing corrosion rate.

According to Versan 2002, generally, the corrosivity of waters containing dissolved salts increases with increasing salt concentration until a maximum is reached, and then the corrosivity decreases. This may be attributed to increased electro-conductivity because of the increased salt content, until the salt concentration is great enough to cause an appreciable decrease in the oxygen solubility, resulting in a decreased rate of depolarization. The dissolved salts may also decrease the protectivity of any corrosion products which form, and thus increase corrosion. This can also be related to this experiment as shown by the increase and subsequent decreasing rate of corrosion with increase in salt concentration as shown in Figures 3, and Table 5.

Table 5. Minimum and Maximum Corrosion rates of Formulated KCl/Polymer Mud

Salt concentration (g)	Minimum weight loss (g)	Maximum weight loss (g)	Minimum corrosion rate (mm/year)	Maximum corrosion rate (mm/year)
35	0.06	0.11	0.482	0.88
52.5	0.07	0.12	0.563	0.96
70	0.04	0.08	0.321	0.64

From table 5 above it can be noted that minimum corrosion rate of the mud is 0.32 mm/year which is at the highest salt concentration and the lowest temperature (40^0C), and the maximum corrosion rate is 0.96 mm/year which is at the lowest salt concentration and the highest temperature (80^0C) which agrees in principle with the behaviour of temperature and salt concentration. However in contradiction with its inhibitive nature and low weight loss recorded, these values indicate that the corrosion rate of the mud in mm/year when correlated with the corrosion rates reported by various authors in table 6 is relatively moderate to high. (Frolund, 2002).

Table 6. Corrosion Rate from Literature

Author	**Corrosion rate (mm/year)**	**Report (as a result of corrosion)**
Kenneth Clear (1989)	< 0.006	No damage expected
	0.006-0.030	Damage after 10-15 years
	0.030-0.310	Damage in 2-10 years
	> 0.31	Damage in 2 years or less
Carmen Andrade (2000)	< 0.001	Negligible
	0.001-0.006	Low
	0.006-0.012	Moderate
	> 0.012	High
Thomas Frolund (2002)	< 0.006	Passive areas
	0.006-0.023	Negligible corrosion
	0.023-0.058	Low corrosion
	0.058-0.174	Moderate corrosion
	> 0.174	High corrosion

IV. Conclusion

From the experiment it is found that response of carbon steel to water based mud corrosion depends primarily on the increase in corrosion rate with increasing temperature and decrease in the rate of corrosion with increasing salt concentration. Both effects influence the dissolution of oxygen which decreases with increasing salt concentration due to increased conductivity, and keeps rising with temperature increase until it reaches a point when oxygen solubility ceases, at that point temperature ceases to effect corrosion.

This therefore confirms that the behaviour of KCl/Polymer mud is similar when subjected to temperature and salt concentration variations as with that of fresh water. For this experiment the corrosion rate decreased with salt concentration and increased with temperature increase and started reducing again from 60 ^{0}C. It can be noted that the corrosion rate of the mud is not as high, as shown in Table 10, this can be as a result of the inhibiting nature of potassium chloride; the static nature of the mud because of the zero shear stress affecting the carbon steel surface; and less oxygen transportation to the corroding specimen due to zero agitation of the mud. Further research is necessary to determine the effect of this mud in a dynamic condition where the there is high shear stress.

However it can be stated that the level of corrosion of the mud was agitated by the salt and temperature variables used, this is shown from the high level of corrosion recorded. This therefore indicates that these variables contribute to corrosion in drilling mud, with the rate of corrosion depending largely with either the increase or decrease of these variables (temperature and salt concentration). The type of corrosion by the mud indicated a pitting type with localized shallow pitting on the specimen in plate 1, which is characteristic of KCl/Polymer mud corrosion.

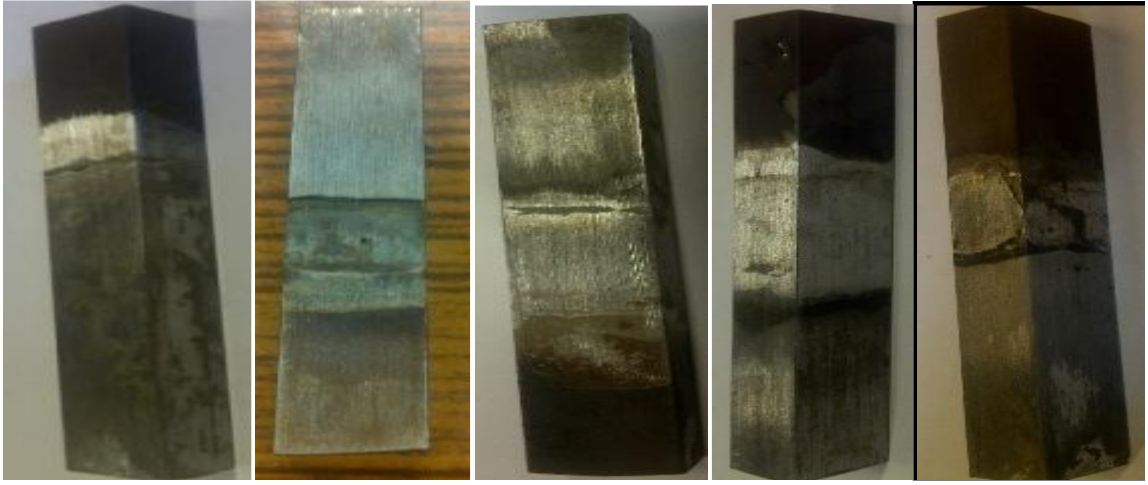

Plate 1. Specimens after exposure to mud solution.

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