CORROSION BEHAVIOUR AND EFFECTS OF DRILLING MUD

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ABSTRACT
Drilling mud as an essential chemical in the oil industry is widely applied in all drilling operations. A recent survey revealed that despite the incessant incidents of drilling equipment failures in service, corrosion assessment of drilling mud has been neglected. Hence, correlation between its chemical composition, properties and corrosion effect is lacking. Against this backdrop therefore, the corrosion effects of drilling mud on mild steel, the major component of drilling equipment used in the oil industry was undertaken in order to establish hindsight of the basic concept of drilling mud corrosion; and proffer necessary and acceptable control measures. Specimens were exposed to salt water mud, oil base mud and borehole water environments. The weight losses and corrosion rates were evaluated at intervals of seven days using the weight loss and electrochemical methods for a period of forty two days. The specimens were also subjected to visual examination. The two independent corrosion monitoring techniques gave similar results. The salt water mud was the most corrosive with average corrosion rate values of 3.55 X 10^{-4} mpy and -0.71mV which was attributed in part to the high concentration of Cl^{-} ions, followed by borehole water (2.40 X 10^{-4} mpy; -0.66mV) and lastly oil base mud (1.0 X 10^{-4} mpy; -0.48 mV). The result of the visual examination revealed general corrosion in all the environments investigated.

Keywords: Drilling mud, Mild steel, Corrosion rate, electrochemical method, General corrosion.

1. INTRODUCTION
Corrosion is becoming an increasing global threat to the integrity of oil and gas facilities whose major component is steel with its attendant economic wastages and associated environmental hazards [1]. These facilities include pipelines, platforms, vessels (storage tanks), drill pipes and well casings. The economic wastages include but are not limited to downtimes, production losses, contamination and equipment failures; whilst environmental hazards include pollution, spill, destruction of flora and fauna, fire outbreak and fatalities [2].

In the petroleum sector, particularly in the drilling industry, drilling mud is widely applied in drilling operations. Drilling mud refers to a suspension of solid materials in water or oil, or of solids and droplets of one of these liquids dispersed in the other [3]. These solids consist of clays and organic colloids added to provide the necessary viscous and filtration properties [4].

The three main types of drilling mud are water base mud, oil base mud and gas mud. The solid particles when suspended in either fresh water or salt water constitute a water base mud. Hence, we have freshwater mud and salt water mud which is dependent on the nature of the water. Oil base mud is formulated with only oil as the liquid phase and is often used as a coring fluid. Although oil base muids pick up water from the formation, no additional water or brine is added.

Oil base mud systems are special drilling muds developed to overcome certain undesirable characteristics of water base mud primarily due to the properties of water such as its abilities to dissolve salts, to interfere with the flow of oil and gas through porous rocks, to promote the disintegration and dispersion of clays, and to effect corrosion of steel [5].

The application of drilling mud in drilling operations is mainly for lubricating the drillstring thereby reducing friction, transportation, suspension and dropping off cuttings, supporting the walls of the wellbore, controlling pressure and stabilization of the wellbore [4,5].

Drilling additives (chemicals) are usually added to the drilling mud to promote required functions and changes in the properties of the mud. Such properties include; density (weight), viscosity, yield point, gel strength, fluid loss and surface tension. The most commonly used chemicals in rotary drilling are but not limited to barite (BaSO_{4}), bentonite clay and organic polymers.

Barites and similar weighting materials possessing high specific gravity (>4.0) have been used to successfully raise drilling mud density, to control formation pressures, check formation caving and facilitate pulling dry pipe [4,5,6].
Bentonite clay is added to fresh water mud or oil base mud for the purposes of increasing hole cleaning capacity (increasing viscosity), reducing water seepage or filtration into permeable formations, forming a filter cake of low permeability, promoting hole stability in poorly cemented formations and avoiding or overcoming loss of circulation. The colloidal properties of organic polymers such as starch, guar gum (Variflo), carboxy methyl-cellulose (CMS), polyacrylamide-polyacrylate (INSTAPAC-425), and polyanionic cellulosic polymer (REL-PAC) are used in drilling muds to reduce filtration, stabilize clays, flocculate drilled solids, increase carrying capacity and incidentally to serve as emulsifiers and lubricants [5,6,10].

Despite these wide and fundamental applications of drilling mud in drilling operations, correlation between it’s chemical composition, properties and corrosion behavior is lacking. It is against this background that this research is carried out to evaluate the corrosion behavior of drilling mud and assess its effects on the drilling facilities.

2. EXPERIMENTAL METHOD

The test specimens used for this work were mild steel coupons obtained from Shell Petroleum Development Company (SPDC) Limited, Port-Harcourt, Nigeria. The coupons were of uniform dimension (7.30 X 2.20 X 0.50 cm) and the chemical composition as supplied by the manufacturer is given in table 1.0. The chemical compositions of the drilling muds (salt water mud and oil base mud) as supplied by MISWACO Ltd, Port-Harcourt, Nigeria and borehole water used in this research are given in tables 2.0 and 3.0 respectively; while the pH values of the environments at room temperature are shown in table 4.0. The initial weights of the coupons were taken to the nearest 0.001 g on a digital electronic weighing machine (OHAUS Adventurer), degreased and dried in acetone (Analar grade) before total immersion in the different storage tanks containing the mud samples and borehole water. The mud tanks were stationed at the on-going drilling site (Well 4/6, OSSU Field) owned by NNPC/Addax petroleum Development Nigeria Limited. Corrosion rates of the coupons were monitored by weight loss technique and electrochemical method (Potential measurement). The weight loss of each of the coupons was determined at intervals of seven days for a period of six weeks (Four two days) while the corrosion potential measurement was taken at the same interval using Cu/CuSO₄ reference electrode connected to the digital multimeter. The weight loss within the immersion period was determined as the difference between the initial weight prior to immersion and final weight after immersion, and the corresponding corrosion rate calculated.

The coupons were visually examined progressively with the aim of identifying the nature of the oxide scales clinging to the surfaces of the specimens and the type of corrosion occurring.

| Table 1.0: Chemical composition of the mild steel |
|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|
| Element          | C    | Si    | Mn    | Cu    | P    | S    | Cr    | Ni    | Sn    | Fe    |
| Weight %         | 0.18 | 0.24  | 0.50  | 0.20  | 0.03 | 0.04 | 0.10  | 0.12  | 0.02  | Bal   |

| Table 2.0: Compositions of Salt Water Mud and Oil Base mud |
|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|
| Mud type         | Specific Gravity | Water (ECD99) bbl/bbl | Oil (Brine) Ib/bbl | CaCl₂ (Brine) Ib/bbl | BaSO₄ (Barite) Ib/bbl | Ca(OH)₂ (Lime) Ib/bbl | Ba²⁺ mg/L | Ca²⁺ mg/L | Cl⁻ mg/L | OH⁻ mg/L | SO₄²⁻ mg/L |
| Salt water       | 1.20             | 0.93             | -                | 95.30             | -                | -                | -               | 98,200         | 173,700         | -               | -               |
| Oil base         | 4.35             | -                | 1.00             | 10.00             | 208.10           | 12.40            | 15,40          | 3,900           | 6,900           | 17,100          | 27,000         |

| Table 3.0: Composition of Borehole water |
|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|
| Ions             | OH⁻ %            | Cl⁻ %            | NO₃⁻ %           | Fe²⁺ %           | Na⁺ %            | Mg²⁺ %           | CO₃⁻ %           | SO₄²⁻ %         |
| Percentage       | 7.97             | 1.20             | 0.29             | 0.20             | 4.70             | 3.00             | 0.85             | 0.73             |

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Table 4: pH Values of the environments at room temperature

<table>
<thead>
<tr>
<th>Environment</th>
<th>pH Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salt water mud</td>
<td>6.20</td>
</tr>
<tr>
<td>Oil Base mud</td>
<td>10.00</td>
</tr>
<tr>
<td>Borehole water</td>
<td>5.46</td>
</tr>
</tbody>
</table>

3. EXPERIMENTAL RESULTS

The corrosion behavior of mild steel in drilling mud and borehole water (control) was studied by monitoring the electrode potential and weight loss. The results of the weight loss which were converted to corrosion (penetration) rates and the electrochemical (electrode potential) measurements are given in tables 5.0, 6.0 and 7.0 respectively. The corrosion rates were calculated using the following relationship [27]:

\[
CR = \frac{534W}{DAT}
\]

Where CR = corrosion rate in mils per year (mpy)
W = Weight loss in grams (g)
D = Density of the steel = 7.87g/cm³
A = Total surface area of coupon = 40.85 cm²
T = Exposure time in hours (hr)

The graphs of weight loss, corrosion rate and electrode potential dependence with time are shown in figures 1.0 - 3.0.

**TABLE 5.0: WEIGHT LOSS OF SAMPLES (g)**

<table>
<thead>
<tr>
<th>MEDIUM</th>
<th>1ST DAY</th>
<th>7TH DAY</th>
<th>14TH DAY</th>
<th>21ST DAY</th>
<th>28TH DAY</th>
<th>35TH DAY</th>
<th>42ND DAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>SALT WATER MUD</td>
<td>0.00</td>
<td>0.052</td>
<td>0.089</td>
<td>0.129</td>
<td>0.125</td>
<td>0.123</td>
<td>0.120</td>
</tr>
<tr>
<td>OIL BASE MUD</td>
<td>0.00</td>
<td>0.02</td>
<td>0.026</td>
<td>0.030</td>
<td>0.032</td>
<td>0.030</td>
<td>0.028</td>
</tr>
<tr>
<td>BOREHOLE WATER</td>
<td>0.00</td>
<td>0.04</td>
<td>0.068</td>
<td>0.074</td>
<td>0.080</td>
<td>0.076</td>
<td>0.071</td>
</tr>
</tbody>
</table>

**TABLE 6.0: CORROSION RATE MEASUREMENTS (mpy X 10⁴)**

<table>
<thead>
<tr>
<th>MEDIUM</th>
<th>1ST DAY</th>
<th>7TH DAY</th>
<th>14TH DAY</th>
<th>21ST DAY</th>
<th>28TH DAY</th>
<th>35TH DAY</th>
<th>42ND DAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>SALT WATER MUD</td>
<td>0.00</td>
<td>5.14</td>
<td>4.40</td>
<td>4.25</td>
<td>3.09</td>
<td>2.43</td>
<td>1.98</td>
</tr>
<tr>
<td>OIL BASE MUD</td>
<td>0.00</td>
<td>1.98</td>
<td>1.29</td>
<td>0.99</td>
<td>0.79</td>
<td>0.59</td>
<td>0.46</td>
</tr>
<tr>
<td>BOREHOLE WATER</td>
<td>0.00</td>
<td>3.96</td>
<td>3.36</td>
<td>2.44</td>
<td>1.98</td>
<td>1.50</td>
<td>1.17</td>
</tr>
</tbody>
</table>

**TABLE 7.0: ELECTRODE POTENTIAL MEASUREMENTS (mV)**

<table>
<thead>
<tr>
<th>MEDIUM</th>
<th>1ST DAY</th>
<th>7TH DAY</th>
<th>14TH DAY</th>
<th>21ST DAY</th>
<th>28TH DAY</th>
<th>35TH DAY</th>
<th>42ND DAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>SALT WATER MUD</td>
<td>-0.65</td>
<td>-0.71</td>
<td>-0.72</td>
<td>-0.75</td>
<td>-0.73</td>
<td>-0.70</td>
<td>-0.68</td>
</tr>
<tr>
<td>OIL BASE MUD</td>
<td>-0.47</td>
<td>-0.49</td>
<td>-0.49</td>
<td>-0.50</td>
<td>-0.48</td>
<td>-0.47</td>
<td>-0.45</td>
</tr>
<tr>
<td>BOREHOLE WATER</td>
<td>-0.60</td>
<td>-0.64</td>
<td>-0.68</td>
<td>-0.70</td>
<td>-0.70</td>
<td>-0.67</td>
<td>-0.63</td>
</tr>
</tbody>
</table>
Fig.1.0: Time dependence of the weight loss (g) of samples in the studied environments

Fig.2.0: Time dependence of the Corrosion rates (mpy) of samples in the studied environments
DISCUSSION OF RESULTS

The environments examined contain corrosion inducing ions predominantly \( \text{Cl}^- \), \( \text{OH}^- \) and \( \text{SO}_4^{2-} \) ions. Therefore, these environments are considered aggressive and toxic to most engineering materials including steel.

The results of figure 1.0 showed that the weight loss of the steel in salt water mud increased with time during the first 21 days while the steel in oil base mud and borehole water increased up to 28 days. This observation was attributed to the fact that the rate of chemical reaction increases with time [28].

However, further exposure of the steel samples to the media resulted in a decrease in weight loss, and this behavior could be explained from the concept of passivity [29]. As shown in figure 1.0, the highest weight loss occurred in salt water mud (1.29g) at the 21st day, followed by borehole water (0.08g) and oil base mud (0.032g) obtained at the 28th day of the test.

The highest weight loss associated with salt water mud was as a result of high concentration of chloride ions it contained (see table 2.0) which have concomitant high corrosion inducing effects. The \( \text{Cl}^- \) ions combine with the iron (II) ions (\( \text{Fe}^{2+} \)) component of the steel to produce \( \text{FeCl}_2 \) (solid product) which further reacts with dissolved oxygen and water.

\[
\text{Fe}^{2+}(\text{aq}) + 2\text{Cl}^-(\text{aq}) \rightarrow \text{FeCl}_2(s) \quad (1.0)
\]

\[
2\text{FeCl}_2(s) + \frac{1}{2}\text{O}_2(g) + 2\text{H}_2\text{O}(l) \rightarrow \text{Fe}_2\text{O}_3(s) + 4\text{HCl}(\text{aq}) \quad (1.1)
\]

\( \text{Fe}_2\text{O}_3 \) (s) is the corrosion product observed on the surfaces of the steel samples which is permeable to oxygen and water. Hence, it does not form a protective layer on the steel surfaces, and the corrosion process continues [20, 30]. \( \text{OH}^- \) and \( \text{SO}_4^{2-} \) ions in borehole water and oil base mud played similar roles as \( \text{Cl}^- \) ions, but were affected by their low concentrations as contained in the media, hence loss corrosion effects.

In the relationship between corrosion rate and exposure time of steel as depicted in figure 2.0, the corrosion rate was highest in the salt water mud, followed by borehole water and oil base mud. The corrosion rates decreased with exposure times in all the environments examined. This experimentally observed behaviour was due in part to the formation of an impermeable protective oxide film on the surfaces of the steel. This is called passivation. In this state, the steel is said to be passive or noble [31, 32], and does not corrode easily. The aggressive ions in the various environments could not be absorbed into the passive layers, hence decrease in corrosion rates.

Figure 3.0 showed that the electrode potentials of the steel in all the examined environments decreased with time within the first 21 days, and increased on further exposure to the environments. The electrode potential (Voltage) decreased as
the resistance increased (in obedience to Ohm’s law) due to the corrosion product formed on the steel surfaces [33]. Hence, the lower the electrode potential, the higher the corrosion. The increase in electrode potential (decrease in corrosion) observed after 21 days of the test was attributed to the concept of passivity as explained in figure 2.0. Due to the chemical, physical and electronic properties of the oxide films, metal dissolution (chemical reaction) is lowered resulting to increase in electrode potential. Therefore, the steel samples exposed to salt water mud exhibited the lowest electrode potential (highest negative potentials) indicating high weight loss and corrosion rate, followed by borehole water and oil base mud respectively.

The visual examination of the steel samples in all the environments were observed with brownish coloured corrosion products uniformly distributed on the steel samples. These corrosion products were hydrated iron oxides, hence general corrosion. Black deposits (which occurred as patches) suspected to be iron sulphides were also observed on the surfaces of the steel samples.

The severity of the corrosion product was highest in the steel exposed to the salt water mud, followed by borehole water and oil base mud. This was attributed to the high concentration of corrosion inducing ions particularly chloride ions predominant in the salt water mud.

4. CONCLUSIONS

The following conclusions can be drawn from the results of this investigation:

- The steel investigated was found to undergo general (uniform) corrosion in all the environments.
- Chloride ions are approved to be a very aggressive corrosion inducing ions.
- Salt water mud was the most corrosive due to the presence of high concentration of Cl- ions, followed by borehole water and oil base mud.

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