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Corrosion Inhibition of Alkaline Solution on Low Carbon Steel In Local Water (Oku River)

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Abstract: *This study reports corrosion inhibition of alkaline solution, sodium hydroxide (NaOH), added to local water from Oku River in Ekiti State, Nigeria. Addition of sodium hydroxide to the water reduces the rate of corrosion. The temperature, PH value and the conductivity of the local water affects the rate of corrosion when alkaline solution is not added i.e. Blank solution. The rate of corrosion in blank solution is 0.4453 mg/mm2/year. When 0.1 M of sodium hydroxide, the corrosion rate is reduced to 0.2229 mg/mm2/year. Concentration of alkaline solution in local water determines the effectiveness of the inhibition and efficiency. When 0.1 M of sodium hydroxide is added to local water, the efficiency is 49.94%, 1.0 M gives 97.59% respectively. Therefore, increase in alkaline solution will increase the inhibition efficiency and reduce the rate of corrosion.*

***Keywords** -Corrosion, inhibition, alkaline, sodium hydroxide, mild steel*

I. INTRODUCTION

Low carbon steel is commonly used for construction purposes due to its availability, low cost and good mechanical properties, but it is highly susceptible to corrosion, especially when exposed to atmospheric oxygen in the presence of water [1]. Corrosion occurs due to the spontaneous tendency of the materials to return to the forms in which they were originally found (thermodynamic stable state), and this causes deterioration of the material properties which eventually leads to huge losses. For this reason, studies have been conducted to provide possible methods of protecting and reducing the rate of corrosion of the engineering material.

Proper choice of material selection, design and coating has been reported to be used to control corrosion. Protective coatings which effectively isolate the steel from the electrolyte are frequently employed in combating corrosion, and it is crucial to have good adhesion between the coatings and protected materials. Also, cathodic protection and anodic protections are adopted in addition to coating to reduce the rate of corrosion in corrosive media. While these mentioned methods have not been able to reduce the corrosion rate but only prevents, the environmental alteration through addition of small quantities inhibitors (special chemicals) to large volumes of corrosive solutions can be effective in reducing corrosion and sometimes less expensive [2].

A number of naturally occurring polymers from plants origin such as tobacco, black pepper, bitter leaves, castor seed, orange seed and akee seed extract contain organic compounds (e.g. alkaloids, tannins, pigments, organic and amino acids) have shown potentials as metal corrosion inhibitors in different corrosive environments [3-8]. Synthetic inhibitors contain hetero atoms such as nitrogen, sulphur and phosphorous have also been used to control corrosion of engineering materials [9]. However, their use has been discouraged due to its high cost, non-biodegradability and toxicity [10]. While authors suggested that the geometrical configuration and functional groups within inhibitor molecule were the main factors that influenced their inhibition efficiency, results from the investigations also revealed that the inhibition efficiency offered by inhibitor increased with increase in the concentration but decreased with rise in temperature.

The inhibition of the corrosion of mild steel by penicillin V and G potassium have been studied by Eddy et al. [11]. The inhibitors were found to be a good inhibitor for the corrosion of mild steel in H2SO4. The inhibition efficiency of the inhibitors decreased with increase in temperature. The adsorption of the inhibitor on the surface of mild steel was found to be exothermic, spontaneous and followed the mechanism of physical adsorption.

Recently, Ikechukwu et al. [12] investigated the corrosion rates of carbon steel in NaCl, Na2SO4 and Na2CO3 environments maintained at different concentrations with a view to determining the most aggressive environment that should be avoided especially in the protection of pipeline. It was concluded that, the rate of corrosion of carbon steel is dependent on both the concentration of media (environmental conditions) and chemical properties of the steel. Olorunda studied the corrosion inhibition of Na2CO3 on low carbon steel in local seawater environment [13]. Corrosion was investigated in seawater with 0 M, 0.01M and 0.1M Na2CO3. 40.4% and 98.6% of inhibition efficiency of Na2CO3 on the low carbon steel were obtained at 0.01M and 0.1M concentration respectively. The author concluded that Na2CO3 could be introduced to the local seawater for cleansing of steel structure on car body.

Protective coatings are usually employed to prevent metallic materials from corrosion in motor vehicle and other engineering structure. They are fairly coated thick to reduce the possibility of surface scratches which compromised the protective layer [14]. Nevertheless, motor vehicles are exposed to environmental hazard that compromised the protective layer and when washed in local stream water caused the exposed steel to corrode. Carbon steel has been introduced in sea water with varied concentration of its constituents but investigation with local waters is limited[13]. The salinity of sea water is known to differ from others, but that of the local waters also needs to be looked into because of its availability.

Introduction of alkaline solution as inhibitor in sea water, or any other water can reduce the rate of corrosion of low carbon steel and to ensure longer use of the material. NaOH is relatively cheap, soluble in medium (water) and less harmful to the environment as compared with acidic type inhibitors and phytochemicals such as tobacco. For this reason, the present research is conducted to provide information on possible means of reducing corrosion of steel in motor vehicles and other engineering structures in contact with local water from Oku River in Ekiti State, Nigeria through addition of sodium hydroxide (NaOH) in different concentrations.

II. MATERIALSAND METHODS

1. Work materials and specimens preparation

Low carbon steel was sourced from part of vehicle in Ado-Ekiti, Nigeria, and the steel was found to have density (ρ) of 7.836 g/cm3. Table 1 shows the nominal percentage chemical composition of the steel test specimen used for the study, and this was determined using a solid technique optical emissions spectrograph.

Table 1: Chemical composition of the low carbon steel

Element	C	Si	Mn	S	Cu	Cr	Fe	others
Composition (%)	0.179	0.017	0.275	0.041	0.055	0.0805	98.611	0.628

The mild steel was mechanically cut into 3.8 x 2.8 x 1.2 cm dimension (with a surface area of 37.12 cm2 and mass of 100 g) specimen samples. They were descaled by wire brushing and then polished mechanically using series of silicon carbide abrasive paper from grit 60 up to grit 120 to ensure a smooth surface and reduce corrosion attack on the samples. These specimen samples were then thoroughly cleaned with distilled water, degreased with ethanol, dipped into acetone, dried in air and kept in desiccators until needed so as to reduce risk of environmental pollution and corrosion on them.

The local water used for the study was collected from Eku River in south-west area (Ijan Ekiti) of Ekiti State, Nigeria. The results of qualitative composition analysis of the water are shown in Table 2. Three alkaline solutions of sodium hydroxide (NaOH) were prepared; the first medium was a blank solution of local water with no inhibitor added while the second and the third media were solutions with concentration of 0.1 M and 1 M of sodium hydroxide, respectively.

Table 2: Chemical analysis of Eku River

Temperature (^oC)	29.50
pH value	9.20
conductivity ($uscm^{-1}$)	340
chloride present (mgL^{-1})	64.82
Acidity	25.10
Alkalinity (mgL^{-1})	207.00
Free CO_2(mgL^{-1})	47.70
Total hardness (mgL^{-1})	130
Calcium hardness (mgL^{-1})	72.71
Magnesium hardness (mgL^{-1})	31.05

2. Preparation of test solution

Approximately 40 g of NaOH pellets was dissolved in 500 cm3 of the local water and then made up the solution to 1000 cm3 with the water to obtain the 1 molar solution. 0.1 molar solution of NaOH was obtained by making up 100 cm3 solution of already prepared 1 molar solution to 1000 cm3 with the water.

3. Test procedure

During the corrosion test, Autolab Pgstata204 model linked with personal computer running on NOVA software was used for data collection and processing. Three samples were tested in the prepared different media (blank solution with no inhibitor, solutions with concentration of 0.1M and 1M of sodium hydroxide). Potentiodynamic polarization measurements were carried out using a scan rate of 1.0 mV/s at a potential initiated at -200 mV to +250 mV. The prepared steel specimens were used as the working electrode whilst silver chloride was used as reference electrode and platinum foil as a counter electrode in the electrochemical measurement. The electrochemical measurement is then linked autolab running on NOVA software for the data collection. The data collected were saved and later used for the calculation of current density, corrosion rate and the inhibition efficiency. The experimental setup to obtain the electrochemical measurement is shown in Fig. 1.

Fig. 1: Experimental setup of electrochemical measurement

III. RESULTS AND DISCUSSION

Spectrometric analysis of low carbon steel showed that carbon steel contains higher percentage of iron (as shown in Table 1) which is more responsible for the corrosion effect on the specimen. Iron is a reducing agent in Redox reaction as stated in equations below [15]:

$$2Fe_{(s)} + O_{2(g)} + 2H_2O_{(l)} \rightarrow 2Fe^{2+}_{(aq)} + 4OH^-_{(aq)} \quad (1)$$

$$Fe^{2+}_{(aq)} + 2OH^-_{(aq)} \rightarrow Fe(OH)_{2(s)} \quad (2)$$

$$4Fe_{(s)} + 3O_{2(g)} + 6H_2O_{(l)} \rightarrow 4Fe(OH)_{3(s)} \quad (3)$$

The inhibitor effectively reduces the corrosion by precipitates on the cathode and stifles the cathodic reaction. The precipitate forming on the electrode must be an electrical insulator in other to effectively slow down corrosion. Corrosion inhibitors can be divided into two broad categories namely those that enhance the formation of a protective oxide film through an oxidizing effect and those that inhibit corrosion by selectively adsorbing on the metal surface and creating a barrier that prevents access of corrosive agents to the metal surface.

The results of qualitative composition analysis of the water (Table 2) show that Eku River has a high temperature, conductivity and pH values. The local water has a high conductivity of 340 uscm-1 and alkalinity of 207mgL^(-1). The pH value and alkalinity of the water at this environment becomes very high as results of local activities (processing of farm products and other farming activities) which responsible for the pollution of the water apart from other refuse dump that serve as corrosion enhancer in the medium.

The potentiodynamic polarization curves (Tafel plots) of corrosion studies of the mild steel in the corrosive solutions are presented in Fig. 2, while the Tafel extrapolations of the corrosion current densities (Icorr) and corrosion potentials (Ecorr) are presented in Table 3. The corrosion current densities (Icorr) were then used to calculate the corrosion rate. From the Tafel plots, non-symmetrical curves are observed with each solution, with steeper changes observed with the solutions in their cathodic parts than anodic parts. However, minimum increase in corrosion current density was observed with blank solution of the local water, and followed by solution with 0.1 M NaOH in the local water. This behaviour results in a more positive potential in solutions with more concentration of NaOH in the local water. Positive displacement of polarization potential was displayed with polarization potential of -0.259 V, -0.486 V and -0.549 V against Ag/AgCl for blank local water, 0.1M and 1M NaOH concentrations, respectively.

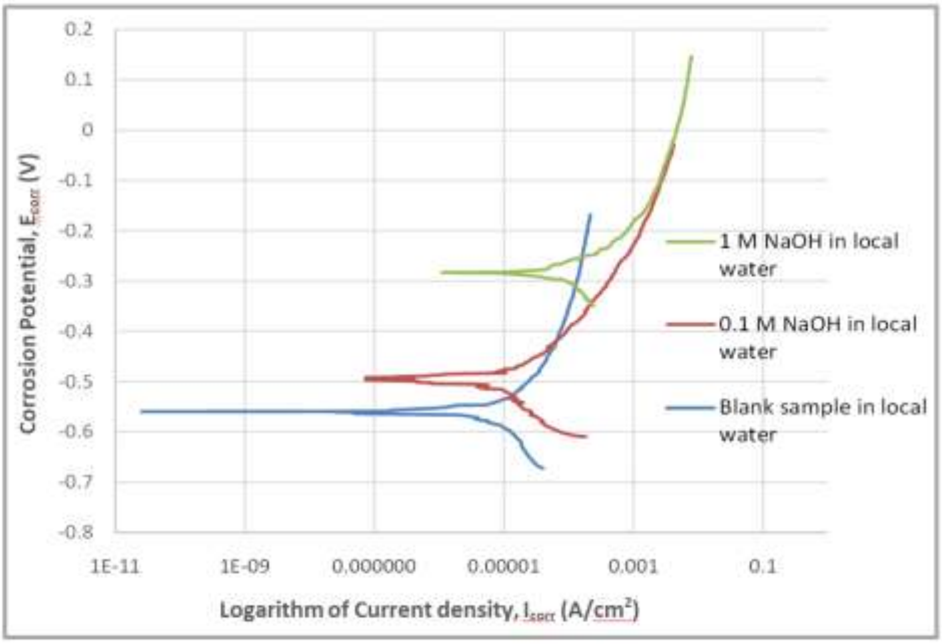

Fig. 2: Polarization curves of mild steel in Oku river with different concentration of NaOH

Corrosion current density is defined as the ratio of the corrosion current to the area of the steel in use, mathematically stated as:

$$I_{corr} = \frac{I(amp)}{A(m^2)} \quad (4)$$

where A is the total area of the mild steel specimen and I is the measured current obtained from the Tafel extrapolations.

To determine the corrosion rate, the equivalent weight (EW) of the sample is required. Thus the equivalent weight is determined by the dominant elements in the alloy. Iron (Fe) = 98.61 %, carbon (C) = 0.1787%, Manganese (Mn) = 0.2714% Phosphorous (P) = 0.04% Sulphur (S) = 0.0308%.

$$Equivalent\ weight\ (EW) = 100 \div \frac{\%\ of\ element\ in\ alloy}{mass\ of\ elements} \times valence\ electron \quad (5)$$

Using the equivalent weight (EW), corrosion rate was then determined as:

$$\text{Corrosion rate, CR} = \frac{K \times I_{corr} \times EW}{\rho} \quad (6)$$

where K = constant that defines the units for corrosion rate (3.272 mm/year); I_corr= corrosion current density; EW = Equivalent weight of the alloy; ρ = the density of the mild steel (7.835 gcm-3).

The inhibition efficiency expresses the measure of improvement of the inhibitor, and mathematically it is given as:

$$\text{Inhibition Efficiency, IE\%} = \frac{CR_u - CR_i}{CR_u} \times 100 \quad (7)$$

where CRu is the corrosion rate of sample in absence of inhibitor and CRi is the corrosion rate of sample in presence of inhibitor.

The current density, corrosion rate and the inhibition efficiency of the mild steel in local water solution with different concentration NaOH are depicted in Table 3. As can be seen, the current density of 3.885E-5, 1.945E-5 and 0.9327E-6 are recorded for blank local water, 0.1M and 1M NaOH concentrations, respectively, which shows that the higher the concentration of the inhibitor, the lower the current density. Furthermore, it can be observed that the corrosion rate of mild steel in the solution containing different concentration of NaOH shown Table 3, and graphically displayed in Fig. 3, varies. The highest rate corrosion of 0.4453 〖mg/mm〗^2/year is seen with the mild steel in blank water without NaOH, whereas the lowest of 0.01069 〖mg/mm〗^2/year is observed with mild steel in water with 1 M of NaOH. This also indicates that the higher the concentration of the inhibitor, the lower the current density and corrosion rate. At high concentration, the anions may become inhibitive or behaves in a way as to plug pores in a passive film as explained by Tretheway and Chamberlain [16] and also reported by Oloruntoba [13] in his study.

Table 3: Electrochemical data of mild steel in Oku river with different concentration of NaOH

Blank water/inhibition concentration	E_{corr} (V)	I_{corr} (A/m^2)	Corrosion Rate $(mg/mm^2/year)$	Inhibition Efficiency, IE (%)
Blank	-0.25868	3.885 E-5	0.4453	__
0.1M	-0.48644	1.945 E-5	0.2229	49.94%
1.0M	-0.5493	0.9327 E-6	0.01069	97.59%

The inhibition efficiency expresses the measure of improvement of the inhibitor, and efficiency of an inhibitor increases with an increase in inhibition concentration as can be seen in the Table 3. When the percentage of concentration is higher, the inhibition efficiency becomes higher. Inhibition efficiency of 40.4% and 97.59% were recorded for solution with 0.1M and 1M NaOH concentrations, respectively. This behaviour has been attributed to formation of protective film oxides (Fe2O3 and Fe3O4) on the metal surface [17], and this prevent further chemical reaction by causing decrease in the corrosion current and thus the corrosion rate [13, 18].

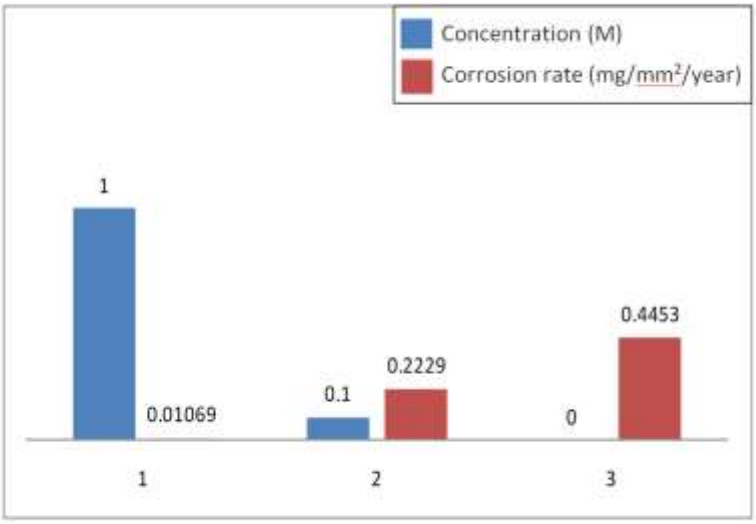

Fig. 3: Corrosion rate of mild steel in Oku river with different concentration of NaOH

The high corrosion rate exhibited by blank solution without NaOH inhibitor may be attributed to the high concentration of chloride ions (64.82 mgL-1) in the local water (Table 2). Therefore, the corrosion inhibition achieved for the mild steel in the presence of NaOH can be as a result of reaction of the inhibitor which reduced the concentration of the chloride ions in the water. Hence, the results from this study showed that the introduction of sodium hydroxide into the water from Oku river can be used to combat corrosion of car body cleansing with the water.

IV. CONCLUSION

Inhibitors are great method of preventing corrosion and are easy to apply. It has application in a wide range of sectors. The knowledge of the method of the action, facilitates the choice of the inhibitors, improves efficiency and reduce corrosion rate. This research studied the effectiveness of using NaOH as inhibitor to prevent corrosion of mild steel in water from a local river (River Oku) and the following inferences were drawn:

- Corrosion rate of low carbon steel in Oku river can be controlled with addition of NaOH in different concentration.
- Increasing concentration of the solution will determine the efficiency of the inhibitor; 0.1 M of NaOH produces 49.94% efficiency and 1M of NaOH produces 97.59% respectively.
- Increase in concentration of NaOH reduces the rate of corrosion in the media and rate of corrosion is high with low concentration.

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