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Corrosion of Low Carbon Steel Influenced by the Presence of Iron-oxidizing Bacteria (*Leptothrix discophora*)

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Abstract: Corrosion of low carbon steel influenced by the presence of *Leptothrix discophora* (Iron bacteria) has been studied, using the weight loss technique. At an exposure time (weeks) of 4, 6, 8, 10 and 12 the corresponding calculated corrosion rates in mpy in the presence of *Leptothrix discophora* were 1.36, 1.46, 1.69, 1.94 and 2.09 while the corrosion rates in the absence of the microorganism were 0.65, 0.69, 0.84, 0.91 and 0.97, respectively. Visual inspection of the coupon retrieved after 12 weeks of the test period showed the presence of mosaic deposits of rusty materials on its surface. Linearity between the log of weight-loss and period of exposure showed that the reaction was a first order reaction. The adsorption of rusty materials on the surface of the coupons in batch reactor 1 was due to physiosorption (physical adsorption).

Key words: Biocorrosion, *Leptothrix discophora*, first order reaction, physiosorption

INTRODUCTION

System failures resulting from corrosion influenced by microorganisms have been widely reported in petrochemical and gas industry (Ibe, 1989; Abu, 1992), nuclear power stations, (Videla, 1996), geothermal plants (Pryfogle, 2002), fire protection systems (Mittelman, 2003) and water treatment plants (Characklis and Marshall, 1990). This type of corrosion is known as biocorrosion or microbiologically influenced corrosion (MIC) or microbial corrosion and is defined as an electrochemical process where the participation of microorganisms is able to initiate, facilitate or accelerate the corrosion reaction without changing its electrochemical nature (Videla, 1996).

Corrosion of metals influenced by microorganisms is due to its ability to alter the kinetics of the interaction. The presence of microorganisms can increase corrosion rates by 1000-100,000 times than in their absence (Costello, 1969). MIC has the potential to produce extraordinary corrosion rates of 25 miles per year (mpy) and more, which is sufficient to destroy a piping system in just a few years (Corrview, 2004).

A number of microorganisms have been implicated in the corrosion of metals. For example, sulphate reducing bacteria (*Desulfovibrio* sp.); sulphide oxidizing bacteria (Thiobacillus ferroxidans); iron bacteria (*Gallionella* sp.); nitrogen utilizing bacteria (*Pseudomanas* sp.) and filamentous fungi (*Cladosporium resinae*). However, of all the species of microorganisms implicated in the corrosion of metals, the most notorious, most studied and most insidious is the sulphate reducing bacteria (Abu, 1992).

The petroleum and process industry in Nigeria has over the years experienced a number of corrosion problems (Ajayi, 2003). Most of these corrosion problems have been attributed to abiotic factors. In particular, knowledge of the roles play by microorganisms in the corrosion of metals in Nigeria is still lacking. The objectives of this study were to determine the effects of iron-oxidizing bacteria (*Leptothrix discophora*) on the corrosion of low carbon steel under aerobic conditions. The result of the study will contribute to this increasing wealth of knowledge concerning the role of microorganisms in influencing the rate of corrosion of metal.

MATERIALS AND METHODS

Preparation of corrosion coupons: Sheets of low carbon steel (0.1-0.2% of carbon content and density of 7.82 g cm^3 as was reported by the manufacturer) were obtained from NEK Technical in Port-Harcourt, Nigeria and cold cut to the dimension of 10×5×0.5 cm. The cold cut technique was used so as to maintain the integrity of the steel and hence avoid the probable effects of the heat-affected zone (HAZ) on corrosion. Each coupon was perforated with a hole of the same diameter at the side to allow the passage of thread.

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The coupons were surfaced finished by scrubbing with sand paper and sterilized by dipping in absolute ethanol and degreased by washing in acetone. The coupons were then dried in an over at a temperature of 60°C for 15 min. The coupons were cooled over night in a dissector. The methods of coupon preparation were consistent with known methods (Avwiri and Tay, 1999). Weights of the prepared coupon were determined before and after each test period. The weights of the coupons were determined to the nearest 0.001 g (Mettler Balance Model A E, 166). 10 corrosion coupons were prepared for the study.

Isolation of *Leptothrix discophora*: *Leptothrix discophora* was isolated using environment culture technique in a mineral medium with the following composition (g L^{-1}): NH_4NO_3 0.5; $NaNO_3$ 0.5; K_2HPO_4 0.5, Mg SO_4. $7H_2O$ 0.5; $CaCl_2.6H_2O$ 0.2, ferric ammonium citrate 10 and agar powder 15. The various components were dissolved in 20 mL of distilled water and autoclaved at 121°C and 1.2 kg cm^{-2} for a period of 15 min. Once after sterilization, the medium was allowed to cool to between 50 and 53°C before dispensing into 2 petri dishes. The plates were allowed to cool at room temperature.

Water sample was aseptically collected from New Calabar River near Wilbros (Nig) Ltd, Port Harcourt using a 10 L plastic container that has been pre-treated. The plastic container was pretreated by washing with dilute hydrochloric acid (0.2 M), rinsed with distilled water and sun dried. At the point of water sample collected, container was rinsed twice with the water sample and filled to the rim. The petri-dishes containing the medium was inoculated by transferring 0.1 mL of the water sample into it using a sterile pipette and finally the spread plate technique was adopted with the aid of a Hockey stick.

The plates were left for 4 days at room temperature and colonies formed examined for *Leptothrix discophora* using the hanging drop technique.

Methodology: The research was conducted at the University of Port-Harcourt, Nigeria; post-graduate microbiology laboratory within the study period of February-June, 2004. At the laboratory, 9 L of the water sample was equally poured into two batch reactors. Into batch reactor 1 inoculum of *Leptothrix discophora* was added and to provide nutrient for the microorganism, 2 g of the prepared nutrient medium was added on a weekly basis throughout the period of the test and in batch reactor 2, inoculums of *Leptothrix discophora* was not added.

Into each of the batch reactor 5 prepared coupons were introduced. The experimental set-up was left for a test periods of 4, 6, 8, 10 and 12 weeks. At the end of each test period, a coupon was retrieved from each reactor, washed, dried and weighed. The amount of metallic corrosion was determined by the weight-loss method.

Temperature and total microbial count in each batch reactor was monitored throughout the test period. Total microbial count was determined using the rapid agar dip stick technique. The dip stick was dipped into each of the reactor such that sufficient quantity of water adhered to the agar stick. The stick was then incubated in a sealed container for 24 h at room temperature. Total microbial count was estimated using a calibration chart provided by the manufacturer. Temperature was measured using a simple laboratory mercury-in-glass thermometer.

RESULTS AND DISCUSSION

Identifying characteristics of *Leptothrix discophora*: Identifying characteristics of *Leptothrix discophora* observed from microscopic examination are;

- Straight rods occurring in chains within sheath
- Motile swarmed cells with singular flagellum
- Ferric oxides deposited upon sheaths
- Rusty-coloured slimy deposit (Fig. 1)

All observed characteristics are consistent with earlier report (Cook, 2004).

Corrosion rates: The weights of the prepared coupons ranged from 19.95 to 20.03 g. Results of corrosion rates of low carbon steel in batch reactor 1 (water sample inoculated with *Leptothrix discophora*) and that in batch reactor 2 (water sample without microorganisms) are presented in Table 1 and 2, respectively. Total microbial count and temperature in the reactors monitored throughout the test periods are presented in Table 3. Percentage change in the observed corrosion rates in batch reactors 1 and 2 are presented in Table 4.

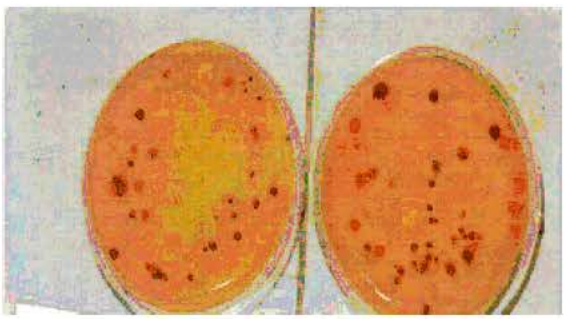

Fig. 1: Rusty colouration of colonized *Leptothrix discophora*

Table 1: Corrosion rates for low carbon steel influenced by *Leptothrix discophora* (Batch reactor 1)

Exposure periods (weeks)	W_o(g)	W_f(g)	$W_g = W_o - W_f$	Corrosion rates (mpy)
4	19.98	19.77	0.21	1.36
6	20.00	19.65	0.35	1.46
8	19.91	19.35	0.53	1.69
10	20.01	19.25	0.76	1.94
12	20.03	19.05	0.98	2.09

Table 2: Corrosion rates for low carbon steel in the absence of *Leptothrix discophora* (Batch reactor 2)

Exposure periods (weeks)	W_o(g)	W_f(g)	$W_g = W_o - W_f$	Corrosion rates (mpy)
4	19.98	19.85	0.10	0.65
6	20.00	19.84	0.16	0.69
8	19.97	19.71	0.26	0.84
10	19.98	19.62	0.36	0.91
12	20.03	19.57	0.46	0.97

Table 3: Temperature and total microbial count (TMC) monitored throughout the test periods

Exposure periods (weeks)	Temp (°C)	TMC (Cfu L^{-1})	Temp (°C)	TMC (Cfu L^{-1})
	26.8	10^7	26.7	10^2
6	27.1	10^5	27.2	$<10^1$
8	27.1	10^3	27.1	$<10^1$
10	27.3	10^2	27.3	$<10^1$
12	26.3	10^2	26.9	$<10^1$

Table 4: Percentage change in the corrosion rates in batch reactors 1 and 2

Exposure periods (weeks)	Corrosion rates reactor 1	Reactor 2	Percentage change
4	1.36	0.65	52.21
6	1.46	0.69	52.74
8	1.69	0.84	50.30
10	1.94	0.91	53.10
12	2.09	0.97	53.59

There were substantial differences in the corrosion rates obtained from low carbon steel influenced by *Leptothrix discophora* and that from low carbon steel in the absence of *Leptothrix discophora*. At the end of the test period of 4 weeks corrosion rates increased by 52.21% (from 0.650 to 1.36 mpy). After the exposure periods of 6 weeks and 8 weeks, corrosion rates increased by 52.74 and 50.30% corresponding to 0.690 to 1.46 mpy and 0.840 to 1.69 mpy, respectively. After 10 weeks of exposure, corrosion rates increased from 0.910 to 1.94 mpy representing 53.10% and at the end of the test period of 12 weeks corrosion rates increased form 0.970 to 2.09 mpy (53.59%). The study showed that the presence of the microorganism (*Leptothrix discophora*) strongly influenced the reaction kinetics of corrosion of low carbon steel under aerobic conditions. The results confirm earlier observation (Costello, 1969) that the most direct effect of MIC reaction is in the increase of corrosion rates.

Although sulphate-reducing bacteria (SRB) has the potential to produce extraordinary corrosion rate of 25 mpy (Corrview, 2004), the highest calculated corrosion rate was 2.09 mpy. This implies that a pipeline of wall thickness 0.25 inches will corrode after 12 years of installation.

The underlying mechanism for the observed increase in corrosion rates can be attributed to the formation of biofilms on the surfaces of the metal. Biofilm, an assemblage of microorganism (*Leptothrix discophora*) has the potential to create differential aeration cells (Allsopps and Seal, 1945). In a differential cell the area under the colony acts as the anode while the area surrounding the colony acts as the cathode. Once a region of anode and cathode has been established a potential difference (p.d) will be set up and corrosion current will be initiated and localised corrosion can be said to have started.

Temperature in the reactors monitored throughout the test periods ranged between 26.7 and 27.3°C. The temperature of the test environment was suitable for *Leptothrix discophora* growth because optimal temperature for bacteria growth range between 25 and 30°C (Booth, 1971).

Bacteria population in reactor 1 ranged between 10^6 Cfu mL^{-1} at the start of the test to 10^2 Cfu mL^{-1} at the end of the test. The initial population of 10^6 Cfu mL^{-1} of *Leptothrix discophora* is an excellent condition for corrosion, because it has been suggested that a relative number of 10^6 Cfu mL^{-1} of microorganisms in an environment is a concern of potential corrosion problem (Videla, 1996). With increase in the test period, population of the microorganism decreased, because the initial free floating organism (Planktonic) became attached on the

Fig. 2: Patch of rusty colouration on the surface of coupon

Fig. 3: Mosaic deposition of rusty colouration on surface of coupon

Fig. 4: Absence of rusty materials on the surface of coupon

surfaces (sessile) of the coupons. In batch reactor 2, population of microorganism at the start of the experiment was 10^2 Cfu mL^{-1} and hence the implication of microorganisms in the corrosion process was ruled out.

After the test period of 4 weeks, mosaic deposits of rusty materials were observed on the surfaces of the

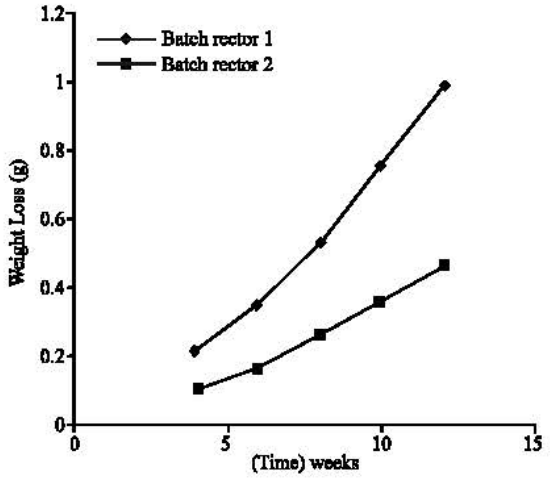

Fig. 5: Variation of weight-loss against time

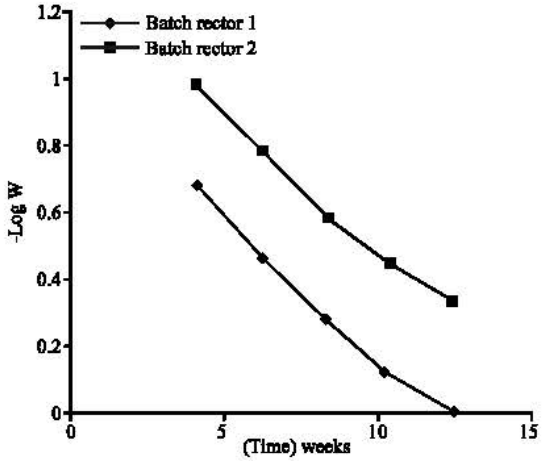

Fig. 6: Log of weight-loss against time

coupon retrieve from batch reactor 1 (Fig. 2), physical adsorption of the rusty materials on the surfaces of the coupon after 12 weeks of test increased tremendously (Fig. 3). After the test period of 12 weeks, coupon retrieved from reactor 2, did not show the presence of rusty materials (Fig. 4). Increased corrosion rates observed for coupons in batch reactor 1 relative to that observed for coupons in batch reactor 2 can be attributed to the formation of the rusty deposits occasioned by the microorganisms (*Leptothrix discophora*). Graphical illustration of the relationship between weight loss in grammes and time in weeks for the conditions in batch reactors 1 and 2 is depicted in Fig. 5. The graph indicates a linear relationship between the two variables. This relationship is given mathematically (Uhlig, 1948) (Eq. 1).

$$W_L = Kt\ 1$$

Where, W_L is weight loss in grammes, t is time in weeks and k is the proportionality constant, which

depends upon the factors contributing to the behaviour of the metal in a specific environment. K Value for the conditions in batch reactor 1 is 9.6×10^{-2} while that for batch reactor 2 is 4.4×10^{-2} and this can be attributed to the presence of microorganisms.

When log of weight loss was plotted against time for batch reactors 1 and 2, a linear relationship was obtained (Fig. 6). The linear relationship confirms to a first order kinetics with respect to the conditions in both reactors. This is consistent with the report on the kinetics of low carbon steel in produced water (Rim-Rukeh, 2004).

Using the integrated form of Arrhenius equation (Eq. 2), activation energies, Ea for the coupons retrieved from reactors 1 and 2 were calculated

$$\log\frac{K_2}{K_1} = \frac{Ea}{2.303}\left(\frac{T_2 - T}{T_1T_2}\right)$$

as 0.325 and 0.149 KJ mol^{-1}, respectively. The low activation energies values indicate that the process of corrosion was due to physiosorption (physical and adsorption) (Rase, 1977).

CONCLUSIONS

The influence of iron bacteria, *Leptothrix discophora* on the corrosion of low carbon steel has been studied. It shows that a colony of the microorganism at the interface altered the environmental conditions that promoted the corrosion reaction.

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