Effect of Intake Work Corrosion on Water Quality and Remedial Measures

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Abstract: The e*ffect of intake works corrosion on water quality and remedial measures were investigated to generate data and information on the corrosion of intake work members and various means through which this problem can be fixed while giving the intake work members a longer lifespan. Primary and secondary data were collected for studies. Analysis of water sample collected at the intake point was carried out to estimate some water quality parameters such as total dissolved solids (TDS), pH, temperature, dissolved oxygen (DO), total hardness and calcium hardness, concentrations of iron, zinc, aluminum and fluoride. A corrosion rate of iron bars immersed in water for 7 days, 14 days and 49th days were calculated. A simple mathematical linear relationship connecting the corrosion rate and total dissolved solids was established. The results obtained indicated the existent of a simple linear regression equation that is suitable for the prediction of some water quality parameters. It was also deduced from the results that there is a development of an electrochemical cell consisting of the cathode with the intake water serving as an electrolyte and a sacrificial anode (used to close the circuit). The setup enhances the intake works members to gain weight in the process becoming cathodically protected and the water finally at the intake point becoming purer and clearer.*

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1.0 Introduction

The first practical use of cathodic protection is generally credited to Sir Humphrey Davy in the 1820s. Davy's advice was sought by the Royal Navy in investigating the corrosion of copper sheeting used for cladding the hulls of naval vessels. Davy found that he could preserve copper in seawater by the attachment of small quantities of iron or zinc; the copper having been coated with zinc or iron became as Davy put it, "cathodically protected (Dean, 2003; Denny, 2004). Corrosion of water work structures most particularly at the intake has brought significant pollution of the water body, including damages to the structures, poor water quality, and increasing cost for the treatment of the contaminated water (Eddy *et al*., 2010, 2012; Mercer, 2004).

Effect of Intake works corrosion on the surface water quality can be controlled for sustaining the quality of the water and increasing the life span of the metal in the aquatic environment (Hosseini *et al*., 2010). Several studies have been reported on cathodic protection of waterworks.

2.0 Materials and Methods

Materials employed to obtain the primary data were; water sample from Cross River State Water Board Calabar, 32 mm diameter iron bar of 30 cm length, water testing kit (water

analyzer), spectrometer, electric oven, ammeter, 2.5 Ω resistor, wires, pure iron bar, water sample collected after 7 days interval of iron bar immersions, thermometer, conical flasks, 100 ml burette, buffer solution (ammonium chloride), diluted tetraoxosulphate (VI) acid solution, diluted hydrochloric acid solution, sodium hydroxide solution, distilled water, Ethylenedianemetetracetic acid (EDTA), eriochrome black T indicator and methyl orange indicator. The tests were carried out in the water analysis laboratory of Civil Engineering Department, Akwa Ibom State Polytechnic, Ikot Osurua, Ikot Ekpene, Akwa Ibom State.

The electrical conductivity, total dissolved solids and salinity were measured using a water meter equipped with a switch to turn to the respective parameters as required. For example, the measurement of conductivity, the electrical sensors of the water analyzer were rinsed with the water sample and submerged into the water sample contained in a conical flask, the device was switched on and the knob was turned to conductivity mode, the sensor was allowed into the water sample for 5 minutes and the displayed results for conductivity were recorded., The alkalinity of the water sample was analyzed by a titrimetric method using tetraoxosulphate (VI) acid to a phenolphthalein endpoint. The alkalinity was estimated after the titration using the following equation (Eddy and Ekop, 2007)

$$Total\ Alkalinity = \frac{TV \times 0.1 \times 1000}{Volume\ of\ sample}$$

$$(1)$$

where; TV is the difference between initial and final readings of the burette, the factor, 0.1 is the

alkalinity normality factors procedures were repeated for other samples of the water and the same titration is used for acidity, total hardness, and calcium hardness.

The corrosion rate was determined using standard protocol for gravimetric methods (Eddy, 2010). A sample of iron bar of diameter 32 mm and length of 30 cm was weighed, the iron bar was inserted into the water which was simulated to acidic condition through the addition of dilute hydrochloric acid . After seven days, the metal was retrieved from the solution, washed and re-weighed. The average weight loss after 49 days was estimated as a mean value of weight loss for each seven days interval. The corrosion rate was calculated using the following equation (Ameh and Eddy, 2018)

$$Corrosion\ rate\ (mmpy.) = \frac{87.6 \times W}{DAT} \qquad (2)$$

where:W is the weight loss in milligrams, D is the density of the metal in g/cm^3, A is the area of the metal sample in cm^2, T is the period of immersion and 87.6 is the conversion factor.

Corrosion rate expressed in millimeter per year (mm/yr)(Quraishi, 2004).

3.0   Results and Discussion

Table 1 shows the results obtained for the analysis of the control water sample that was obtained from the intake waterworks. The result shows that the corrosion effect has already been noticed in the assessed water parameters. This was evident when the concentrations of some minerals were matched with the standard permissible values for portable water (NSDWQ) and the World Health Organization (WHO) standard.

Table 1: Chemical analysis results for the control water sample

Parameter	Result	NSDWQ	Remark
Appearance	Clear	Clear	acceptable
Temperature (ºC)	26.1	Ambient	
pH	5.42	6.5-8.5	Unaccceptable
Turbidity (NTU)	16.7	5	unacceptable
Iron (Fe³⁺) mg/l	4.8	0.3	unacceptable
Salinity (%)	0.1	0.50	Acceptable
Electricity conductivity μs/cm	119.6	1000	unacceptable
Total dissolved solid mg/l	54.4	500	Acceptable
Suspended solid mg/l	17.1	10	unacceptable

Total Hardness mg/l	58	500	Acceptable
Calcium Hardness (Ca^{2+})	56	75.0	Acceptable
Magnesium Hardness mg/l	2	0.2	
Acidity mg/l	0.12	4.5-8.2	Acceptable
Total alkalinity mg/l	10.8	100-200	unacceptable
Chloride (Cl) mg/l	5.5	250	Acceptable
Aluminium (Al^{3+}) mg/l	5.9	0.02	unacceptable
Selenium (Se) mg/l	1.7	-	Acceptable
Copper (Cu^{3+}) mg/l	5.9	1	unacceptable
Zinc (Zn) mg/l	15.7	3	unacceptable

The pH of the control sample was varied to 5.40 dilute diluted hydrochloric acid solution. The changes in the water quality parameters recorded in Table 1, after seven days of the addition of HCl solution are shown in Table 2 was added. Also, the corrosion rate obtained after each seven days interval are recorded in Table 3.

Table 2: Chemical analysis results of corrosive water sample after 49 days of iron immersion

Parameter	Result	NSDWQ	Remarks
Appearance	Not clear	Clear	Unacceptable
Temperature (ºC)	39.40	Ambient	
pH	4.60	6.5-8.5	Unacceptable
Turbidity (NTU)	148.90	5	Unacceptable
Iron (Fe^{3+}) mg/l	26.9	0.3	unacceptable
Salinity (%)	0.60	0.50	Acceptable
Electricity conductivity μs/cm	396	1000	unacceptable
Total dissolved solid mg/l	196.80	500	Acceptable
Suspended solid mg/l	35.20	10	unacceptable
Total Hardness mg/l	468	500	Acceptable
Calcium Hardness (Ca^{2+})	242	75.0	Acceptable
Magnesium Hardness mg/l	226	0.2	
Acidity mg/l	1.96	4.5-8.2	Unacceptable
Total alkalinity mg/l	5.40	100-200	unacceptable
Chloride (Cl) mg/l	18.80	250	Acceptable
Aluminium (Al^{3+}) mg/l	20.10	0.02	unacceptable
Selenium (Se) mg/l	12.10	-	Acceptable
Copper (Cu^{3+}) mg/l	17.20	1	unacceptable
Zinc (Zn) mg/l	32.40	3	unacceptable

Table 3: Results of corrosion rates, weight loss with respect to duration in days

Duration (Day)	Corrosion rate (mm/yr.)	Weight loss (mg)
0	0.00	0
7	1656.38	2000
49	2919.37	3525

Given the fact that water quality and corrosion can be defined in terms of the total dissolved solid (TDS) in mg/l. and iron concentration in mg/l; the results of the total dissolved solids (TDS) in mg/l. and iron concentration in mg/l. of

the water sample over the period of immersion intervals are summarized in Table 4.

Table 4: Mathematical data for modeling TDS and iron.

TDS (mg/L)	[Fe] (mg/L)
51.4	6.8
71.9	9.2
107.5	13.4
167.6	20.3
236.2	28.8
234.0	37.2
432.9	49.8
556.4	62.9

These results were used for the mathematical modeling.

For the mathematical modeling of the water quality in terms of TDS (mg/l.) and corrosion in terms of the concentration of iron in the water, a plot shown in Fig. 1 was developed
The relationship obtained from the plot is as shown in equation 3

$$[Concentration\ of\ Fe] = 0.111[TDS] + 1.501 \qquad (3)$$

Therefore, the concentration of iron in the water changes with the total dissolved solids at a rate of 0.111 while the correction factor is 1.50. Consequently, dissolved solid has a significant contribution to the rate of corrosion of the iron metal in the water. Studies have shown that dissolved solids are consequences of soluble electrolytes in the water, which has the potential of enhancing corrosion.

The weight gained by the iron bar was evaluated as follows, After the electrolysis of the water sample and cathodic protection of the corroded iron bar, the weight of corroded and non-corroded iron bar obtained by direct weighing were as follows (Oldfield, 2008)
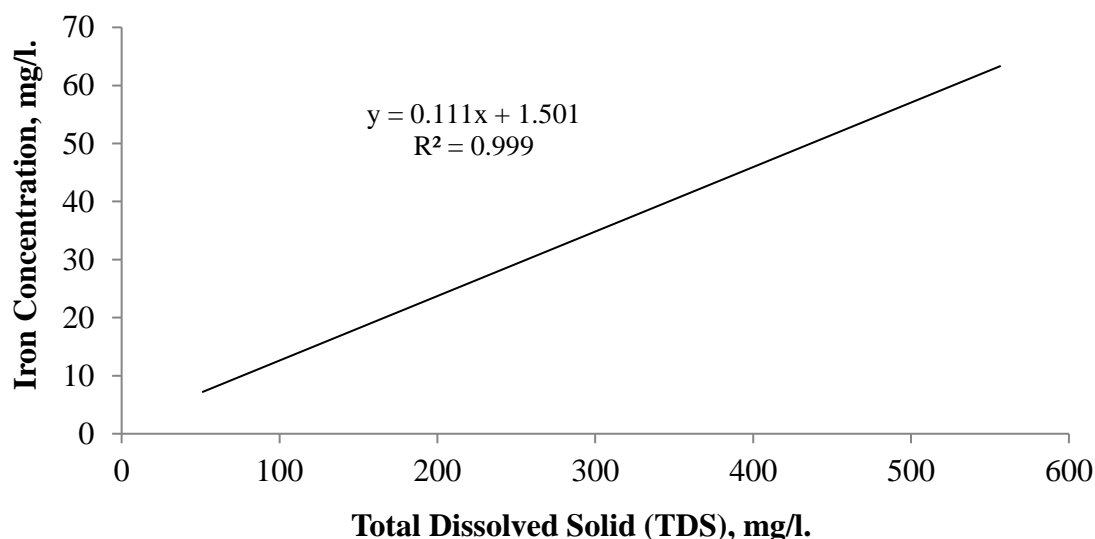

Fig. 1: Variation of the concentration of iron with the TDS (mg/l.) in the water sample.

Weight of corroded iron bar before electrolysis = 281 g, weight of non-corroded iron bar before electrolysis = 325 g, weight of the corroded iron bar after electrolysis = 307 g, weight of the non-corroded iron bar after electrolysis = 299 g. The application of Faraday's second law of electrolysis leads to the following formulations

Current recorded = 7.9 A, time of current flow t = 3 hours and Faraday constant = 96500 C. The molar mass of iron = 58.8 g
Based on the expected anodic and cathodic reaction in the water as a result of the corrosion of the iron ring, the following mechanism are adopted (Eddy *et* al., 2018;Oguzie and Ebenso,2005; Roberge, 2012)

$Cathodic\ reaction: 2Fe^{2+}_{(aq)} + 4e^- \rightarrow 2Fe_{(s)}$

$Anodic: \ 4OH^-_{(aq)} \rightarrow 2H_2O_{(l)} + O_{2(g)} + 4e^-$

$Anodic\ reaction\ 2: 4HCl_{(aq)} + O_{2(g)} \rightarrow$

$2H_2O_{(l)} + 2Cl_{2(g)}$

The overall reaction if the summation of the all possible reactions, which can be expressed as follows:

$2Fe^{2+}_{(aq)} + 4OH^-_{(aq)} + HCl_{(aq)} \rightarrow 2Fe_{(s)} +$

$4H_2O_{(l)} + 2Cl_{2(g)}$

Consequently, the quantity of electricity used is the product of time and applied current, which gives, (7.9 x 5 x 60 x 60) C = 142200 C and the following equivalent expressions are stiochiometrilally valid

$$Fe^{2+}_{(aq)} + 4e^- \equiv 2Fe_{(s)}$$
$$(2 \times 58.8)g \equiv 4F$$

Therefore, , 4×96500 C of electricity liberate 2×58.8 g of iron (117.6g of Fe), therefore, 142200 C of electricity generated 0.003132 g of iron, which is the theoretical change in weight of the iron metal, arising from the corrosion and the iron content of the water.

4.0 Conclusion

The results obtained reveals significant dependent of the amount of iron degraded (hence the corrosion rate on the total dissolved solid in the water system. The corrosion rate increases with increase in the concentration of the total dissolved solid, therefore any factor that affects the amount of the total dissolved solid in the water will impact a corresponding effect on the corrosion rate.

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Conflict of Interest

The authors declared no conflict of interest