CORROSION OF FERROUS ALLOYS IN GROUND WATERS: A SIMPLEST WAY TO INVESTIGATE THE CORROSIVITY OF WATERS

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Abstract:

Water quality parameters are considered as Corrosivity parameters in the present study. Corrosivity is investigated through physico-chemical analysis of Ground water .Twenty two ground water samples were selected from Thane region, on the basis of different habitat as it can give reliable information about impact on ferrous alloys. Ferrous alloys were selected as it is use for water transmission and distribution lines. Four ferrous alloys were selected to study the corrosion of alloys in ground water environment in Thane region. Corrosion study was carried out by laboratory immersion test method according to standard procedure of ASTM G31 – 72 standards. It was found that water containing high dissolved solids, electrical conductivity, high sodium and potassium contains shows high corrosion rate of ferrous alloys. Water with high chloride and sulphate content shows high corrosion rate. It was found that water samples containing high Chemical oxygen demand affect to lower side on corrosion rate. Out of four alloys, mild steel undergoes higher corrosion rate as compared to other three alloys.

Key words: Ferrous alloys, chloride, sulphate, dissolved solids, weight loss, corrosion rate

1.0 Introduction:

Human being is dependent on the aquatic environment to satisfy his technological and social needs. The water present on the surface of the earth is put to use for many works .Water present in all sources form a resource of man's domestic, agricultural and industrial use [1]. Used water containing the residuals of the activities are loaded with organic and inorganic pollutants, which are not only harmful to plants and animals but also to the metal structures in the water body namely pipe-lines, bridges, boats, electric poles, motor pump installed in bore well. [2].

It has been observed that the rural and agricultural lands are increasingly converted into industrial, urban and sub-urban areas. As a result of which population increases as well as industries also increases. The increase in population and industries with the subsequent rise in demands for drinking water places an intolerable burden on the natural resources leading to a disturbed groundwater system. In the recent past, many studies have reported that the water bodies are getting contaminated increasingly due to domestic as well as industrial waste waters in many parts of our country [230-234]. Disposal of industrial waste in the open space and abandoned dug wells have thus caused the pollution of ground water in some parts of India [3-5].

The main ions present in natural waters are the cations, such as calcium, magnesium, sodium and the anions like chloride and sulphate. Chloride and sulphate ions are highly aggressive form corrosion point of view and their concentrations are of importance in this connection. The rates of corrosion of the metals immersed are, however, controlled by the amount of dissolved oxygen in water. Generally, pipes and vessels made of stainless steel, aluminum and its alloys and copper and its alloys are used in the storage and transportation of surface and groundwater. In remote areas even galvanized iron utensils are used. The corrosive effect is more important in such water because even a slight dissolution of metal may form toxic metallic salts giving rise to off flavors [8]. Higher quantities of toxic metals can affect the public health to great extent when used for drinking and bathing purposes. Therefore, keeping in mind the problems associated with the corrosion of metals and alloys in surface and groundwater exposed to the water samples collected in and around Thane city.

Literature survey reveals that no work has been reported on the Corrosivity of surface and groundwater's in Thane region. Hence it was decided to carry out systematic study of Corrosivity of water on selected ferrous alloys namely, mild steel, SS-304, SS-316 and SS-430. These ferrous alloys were selected because these are used in diverse field.

2.0 Materials and Methods

2.1 The Study Area

The area under investigation is in the vicinity of Mumbai city with long coast line and associated features such as creeks, small creeks, marshy land etc. The important creeks viz, Ulhas, Thane, Kharekuran-Murbe are also located in this region. The waste water generated from the cities located in the region along with industrial effluent is finally disposal in the creeks[3] .The untreated domestic waste waters from cities like Kalyan-Dombivali, Ulhasnagar, Ambernath, etc. reaches Ulhas Creek besides treated effluent from industrial areas in Thane, Belapur road ,Dombivali, Ulhasnagar, Ambernath etc. deteriorating the quality of creek water along with increasing stress on the water environment of the area. It has been reported that the area in general is characterized by hard water and high salinity hazard due to its proximity and hydraulic connection with the sea[6]. All these interactions with environments impair material's usefulness as a result of the deterioration of its mechanical properties, e.g. ductility, conductivity and strength[7].

2.2 Ground water Sample Collection and Information of sampling stations

Twenty two groundwater sampling stations (bore wells and dug wells) from the study area were selected as sampling stations and their habitat is presented in fig.1.Water samples were collected during post-monsoon season. The water samples were preserved to maintain original composition.

2.3 Investigation of Water quality Parameters to find out Corrosivity of water

The physico-chemical analysis of water samples was carried out by following the standard procedures[10].Water quality parameters such as colour, odour, clarity, presence of suspended matter were recorded in the field itself. The physico-chemical parameters such as pH, electrical conductivity, total dissolved solids, total hardness, total alkalinity, dissolved oxygen, chemical oxygen demand, chlorides sulphates, calcium, magnesium, sodium and potassium are shown in Table-3, and these are the average of duplicate analysis performed for every sample collected.

2.4 Experimental Procedure for Corrosion Studies:

Ferrous alloys like mild steel, SS-304, SS-316, and SS-430 were selected to study corrosion in ground waters of Thane region. The strips of alloys were purchased from the market. Rectangular strips of $5\ x 1 x\ 0.1\ cm$ were used in laboratory immersion corrosion test method [11.] 2 mm hole was drilled in the corrosion coupons near one end for mounting. A few of these coupons were chosen for elemental composition analysis. The elemental composition analysis was determined using optical emission spectrometer (Foundry Master, Germany) [12]. The elemental chemical composition is presented in Table-1.

The procedure for preparing, cleaning and evaluating of corrosion coupons was carried according to ASTM Standard G1-90 [11].

Before the measurements the coupons were abraded successively with 100, C-150, C-300 and C-400 grade emery paper until surface was cleaned to mirror finished. The coupons were degreased with double distilled acetone, dried in warm air and kept in desicator for 1 hour and weighed with an accuracy of 0.00001 gm (0.01mg) using Mettler Toledo balance (Model A X 205 CE Switzerland). Coupons were kept in desicator until the experiments were started.

The minimum solution volume to specimen area ratio was 20 ml cm^{-2} of specimen surface area as recommended in ASTM G31-72 [15]; therefore volume of corrosive solution was kept 224 ml for entire corrosion study.

The ground water samples were filtered and then used for corrosion studies. In the weight loss experiment 7 Perl pet bottles were labeled as A, B, C, D, E, F and G. 224 ml of filtered sample was placed in bottle. The weighed coupon of mild steal, S.S.304, S.S.316 S.S.430, was hung by means of nylon thread and was immersed into water samples.

The coupons were retrieved from the samples after one hour and were cleaning by following the method of ASTM G1-90. The coupons were cleaned with cleaning agents (Table-2) for a particular metal. Coupons were washed with distilled water, dried between paper towels, dried with warm air, cooled in desicator and reweighed. The weight loss was recorded for each coupon. Precaution was taken to avoid the strips from touching each other and also any other objects.

The same procedure was followed for two, three, six and ten hours study of corrosion in groundwater's. The corrosion rate in each case was calculated using the formula.

$$\textbf{Corrosion rate}\ (\mathrm{mgdm^{-2}day^{-1}}) = \frac{W_i - W_f\ x\ K}{A\ x\ T}$$

Where;

W_i = Weight of coupon before corrosion in (g)

W_f = Weight of coupon after corrosion in (g)

A = Geometric area of the coupon

T = Time of exposure in hours.

$K = 1\ x\ 10^5$

3.0 Results

Water quality parameters which are considered as Corrosivity parameters in the present study are presented in Table-3.The Corrosivity of groundwater's of Thane region was monitored with respect to ferrous alloys such as (Mild steel, S.S.-304, S.S.-316 and S.S.-430) by laboratory immersion test method [11]. The corrosion rates were studied as function of time for post-monsoon season. The results of the corrosion rate with respect to various Corrosivity parameters are presented in Table-4&5. Some of the important observations related to Corrosivity parameters and corrosion rate, are summarized below.

3.1 Immersion Period and Corrosion rate

It has been observed that corrosion rate at various time intervals with different ferrous alloys coupons in groundwater samples, reveals that the rate of corrosion is initially high for each coupon, followed by slow decrease in the rate of corrosion up to 6 hours and finally becoming constant after 10 hours for all the corrosion coupons (fig.2 for sample 1).

3.2 Dissolved Oxygen and Corrosion rate

The variation of corrosion rate at various concentrations of dissolved oxygen in different surface and groundwater samples for ferrous alloys is shown in fig. 3. It has been observed that the rate of corrosion is proportional to the concentration of dissolved oxygen in sample of interest for most of ferrous alloys.

3.4 Chloride Concentration and Corrosion rate

The critical analysis of data on corrosion rate with concentration of chloride in different groundwater samples (fig. 4) for ferrous alloys and non ferrous metals and alloys show that rate of corrosion increases with concentration of chloride for most of alloys.

3.5 Sulphate Concentration and Corrosion rate

The examination of the variation of corrosion rate with concentration of sulphate groundwater samples (fig.5) for ferrous alloys indicates that the rate of corrosion is high for mild steel, SS.430 in most of the water samples.

3.6 Habitat of Water samples and Corrosion rate

Groundwater sample No. 3, 6, 8, 10, 14, 16, 17, 18 and 19 show high corrosion rate for most of ferrous alloys as compared to remaining groundwater samples. These habitat indicates that there may improper waste management which impact on metal degradation.

3.7 Discussion

It is well known that the corrosion of metals and alloys in water environment is an electrochemical phenomenon. In this phenomenon an electrochemical reaction composed of two half cell reactions, an anodic reaction and cathodic reaction. The anodic reaction releases electrons, while cathodic reaction consumes electrons. Corrosion cells are created on metal surface in contact with an electrolyte (water) because of energy difference between the metal and the electrolyte. Different area on the metal surface could also have different potentials with respect to electrolyte. These variations could be due to (i) metallurgical factors i.e. differences in their composition, microstructure, fabrication and field installations, and ii) environmental factors i.e. concentration of aggressive ions in the environment.

It is observed that the corrosion rate in groundwater's is initially fast and soon slows down and becomes constant as the immersion time increases with the progress of reaction, surface of the metal is gradually coated with the film of oxide or the corrosion products[19, 42] .This film offers a considerable resistance to the corrosion process as indicated by the gradual decrease in corrosion rate.

Temperature is one of the factors which can accelerate the corrosion rate. There are some exceptions to the general rule that increasing temperature increases the corrosion rate. One is the reduction in rate of attack on steel in water as temperature increased, because the increase in temperature decreases the oxygen content of the water, especially as the boiling point of water is approached other exceptions arise where a moderate increase in temperature results in the formation of thin protective film on the surface of metal or in passivation of the metal surface.

In the present case corrosion study was carried out at room temperature between 28^0c to 30^0C where oxygen solubility in water sample are found to be 2.83 to 5.6 mg lit.$^{-1}$ which is directly proportional to the corrosion rate for most of the metal.

It is reported that [13] the corrosion rate of metals in aerated water is also function of pH. In the pH range 4 to 10, the rate is controlled by the availability of oxygen or the rate at which dissolved oxygen diffuses to the metal surface. In more acidic solutions (lower pH) the corrosion rate is accelerated and the reduction of hydrogen replaces the reduction of oxygen because of rate controlling cathodic reaction. In the present study, the pH of water sample ranges from 5.93 to 9.30 which suggest that, there is no direct effect of pH on the corrosion rates for all the metals alloys.

Lower dissolved oxygen concentration is accompanied by higher values of COD. Several studies [14-16] found that natural organic matter (NOM) decreased the corrosion rate of both galvanized steel and cast iron. NOM was also found to encourage a more protective scale [17], and alter the redox chemistry[18] by reducing Fe^{3+} colloids to soluble Fe^{2+} finally, NOM can complex metal ions. Metal ion binded with organic matter will not alter the corrosion rate [19]. In the present study organic matter present in water samples affects more or less in the corrosion rate of metals and alloys depending on the dissolved oxygen and aggressive behavior of chloride and sulphate ion in the water samples.

In natural waters, carbon dioxide is also present and is linked with total hardness of water. The total hardness is generally caused by the calcium and magnesium ions present in water. This (CO_2) carbon dioxide, in the amount usually present in natural water is of little importance [20.]

An Indication of the Corrosivity of water can be obtained from Langelier saturation index [21]. The L.S.I. is expressed as the difference between the actual system pH and the saturation pH. (Water) In other words, the S.I. is the algebraic difference between the measured pH of water and the computed pHs, that is;

S.I. = pH (measured) – pHs (computed)

If the value of S.I. is positive (pH > pHs) the water becomes supersaturated with calcium carbonate and hence is less corrosive, while if the value is negative (pH < pHs) the water is considered to be aggressive, then the corrosion rate is more. In practice higher total hardness values are usually accompanied by high total dissolved solids and high chloride and sulphate concentrations. In the present investigations, the direct correlation is not observed with hardness and the corrosion rate of the metals in surface and groundwater samples.

It was also reported that hardness alone is not the only factor that determines whether protective film is possible. Ability of $CaCO_3$ to precipitate on the metal surface also depends on the total acidity or alkalinity, pH, and concentration of dissolved solids in the water [22].

Electrochemical corrosion directly relates to electrochemical actions that are influenced by total dissolved solids. A higher dissolved solid increases the electrical conductivity of water. It was reported that [23-24] in presence of dissolved solids large no. of electrochemical cells are formed which increases the corrosion rate. In the present study higher is the total dissolved solids, higher would be the corrosion rate because of the increase in electrical conductance. Such trend has been observed (Table-4&5). The main ions present in natural waters are the cations, such as calcium, magnesium and sodium and anions like chloride and sulphate, these ions contributes in the conduction of corrosion current.

The chloride and sulphate ions are highly aggressive from the corrosion point of view and their concentrations are of importance in this connection. It is observed that higher is the chloride and sulphate content, the more is the corrosion rate in most of ferrous alloys (figure-4&5) for groundwater's (sample No. 3, 6, 10, 14, 16, 17, 18, 19). Increasing concentration of Cl^- can speed up metal anodic reaction and make the corrosion stronger. In the oxygen concentration cell, Cl^- would accelerate anodic dissolution rate. The chloride ion effect is dependent on the cation, with the rate increasing in the order lithium chloride (LiCl), sodium chloride (NaCl), and potassium chloride (KCl) partially because of differences in oxygen solubility in the presence of these salts [32.] In the present study concentration of chloride and sodium ion is high in most of natural water samples, which can be correlated to the and high corrosion rate for most of metals and alloys samples [25-26.] There results illustrate that the effect of concentration is often dependent on other environmental variables. Similar results are also reported by many research workers[27-28.]

Many authors [29-30] reported the role of chloride in the corrosion behaviour of reinforcing steel. Steel bars embedded in concrete are protected from corrosion by thin oxide layer formed on their surface because of highly alkaline environment of the surrounding concrete. However break down of the passive film and hence, corrosion can be stimulated either by carbonation, which reduce the pH of water or the presence of significant quantities of chloride ions at the reinforcement level in the concrete. Chlorides may depassivate steel even at high pH.

It seems that Cl^- and SO_4^{2-} ions play an important role in determining the corrosion rate of all metals apparently in the same manner as Cl^- ions appears to be slightly more corrosive than Na^+ and K^+ ions. Alkaline earth metal ions (Mg^{2+} and Ca^{2+} ions) are slightly less corrosive than alkali metal ions (Na^+, K^+). (The mobility of ions depends upon charge, size and Mass) Mobility of Na^+ and K^+ ions are more in water environment than Ca^{2+} and Mg^{2+}, which increases the corrosion current [31-32].

Another important factor affecting the corrosion behavior of metals alloys are usually chemical composition and metallurgical properties. The amount of chromium and nickel content in the metals and alloys is very important from the corrosion point of view. The carbon content in the metal has no effect on corrosion [33]. In the present study ferrous alloys such as S.S.304, and S.S. 316 and S.S. 430 are more corrosion resistant than the mild steel alloy.

Similarly the small amount of arsenic and antimony content in brass makes more corrosion resistant than copper. Other factors such as surface conditions, type and shape of crystal, temperature charges, etc. also affect on corrosion process.

4.0 Conclusions

Corrosion rate on ferrous alloys in different groundwater samples in the present study reveal the following conclusions. The corrosion rate in groundwater samples is initially fast and slows down afterwards and becomes constant beyond certain immersion times.

Dissolved Oxygen plays a vital role in enhancing the initial corrosion rate of all the metals and alloys under investigation. It appears that corrosion rate of metals and alloys are more or less affected by chemical oxygen demand, however its effect depends on the concentration of chloride sulphate ions in water.

Chloride and sulphate ions are highly aggressive and their concentrations in groundwater's are important in determination of corrosion rate. The rate of corrosion of metals and alloys depends on the electrical conductivity and total dissolved solids present in groundwaters. The alloys such as S.S.-304, S.S.-316, S.S.-430 are found to be less corrosive as compared to mild steel in groundwater's.

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References

1. H. A. Hawkes, Effect of Pollutants in the Aquatic Environment, University of Lancaster, (1970).
2. L. S. Van Delinder, Corrosion Basics, Houston, TX NACE, (1984).
3. Central Pollution Control Board, Status of Groundwater Quality Part-II, (2008)GWQS/10/20072008
4. Madhavi A. Rao, Journal Environmental Biology, 24, (2) (2003), 187-192
5. P.C. Mishra, P.V.Behra and R.K. Patel, Journal Environmental Science Engineering, 47, (2) (2005), 141 – 154.
6. P.K.Naik, B.N. Dehury and A.N. Tiwari, Environment Monitoring Assessment, 132,

(1-3) (2007) 207 -233.

7. S.L. Kakani and Amit kakani, Material Science, New age International, Publishers, New Delhi, (2008) 640.
8. C.M.Leung, J.J.Jiao, Water Research, 40, (4) (2006), 753 – 767
9. Philip A. Schweitzer, Fundamentals of Metallic Corrosion, Corrosion Engineering Handbook; Second Edition, Taylor and Francis Group, CRC Press, New York, (2007)
10. APHA – AWWA and WPCF, Standard Methods for the Examination of Water and Waste Water, 20th Edition, Washington, DC, (1998).
11. ASTM Standard G1-90, Standard Practice for Preparing, Cleaning and Evaluating Corrosion Test Specimens, G 01-05. (2004).
12. ASTM Standard E1086-94, Standard Test Method for Optical Emission Vacuum Spectrometric Analysis for Metals, (2005).
13. W.G. Whitman, R.P. Russell and V.J. Altieri, Industrial Engineering Chemistry 18: 370, (1924).
14. A.H. Sontheimer, W.Kolle and V.L. Snoeyink, Journal American Water Works Association, 73, (11) (1981), 572.
15. ASTM G31 – 72, Standard Practice for Laboratory Immersion Corrosion Testing of Metals, 2004.
16. E. Lind Johansoon, Importance of water compositions for Preventation of Internal Copper and Iron Corrosion, Ph.D. Thesis, Chalmers University of Technology, Goteborg, Sweden, (1989).
17. H.S. Champbell and M.E.D. Journal The Institute for water Engineering and Science, 4, (55) 1983
18. Cao Chunan, The Electrochemical Corrosion Theory (The chemistry Industry Press, Bejing) (1985). 316.
19. Y. Deng and W. Stumm, Reactivity of aquatic Iron (III) Oxyhydroxides, Applied Geochemistry, 9:1:23 (1994) .
20. American Water Works Research Foundations and DVGW- Technologiezentrum Wasser. Internal corrosion of water Distribution systems, second edition. AWWA, Co (1996).
21. W.F. Langelier, Journal American Water Works Association, 28 (10) (1936) 1500.

22. NACE International Basic Corrosion Course Handbook, Houston, TX, NACE, (2000)
23. Gurudip Singh, International Journal of mine Water Association,www.IMWA.info, (2006).
24. Gurudip Singh, International Journal of mine Water Association,www.IMWA.info, (2006).
25. M.Maltoz ,D.Landolt,R.Aogaki,Y.Sato and J.B. Talbot, Fundamental Aspects of Electrochemical Deposition and Dissolution, The Electrochemical Society ,(2000).438.
26. J. A. Lewis, 10th International Congress on Marine Corrosion and Fouling, University of Melbourne, February, (1999).
27. T.H. Merkel and S.O. Pehkonen, Journal Corrosion Engineering Science and Technology, 41, (2006).
28. Ravi V. Patil, Corrosion of Metals and Alloys, Analytical Studies of some Natural Waters, Effluents and Soil Environment of Pune Region. Ph.D. Thesis, University of Pune (1997).
29. Yoon Seok, Jung – Gakim, Kwang- Myong Lee, Corrosion Science, 48, (2006) 1757.
30. Raj Narayan. An introduction to Metallic Corrosion and Its Prevention, Oxford and IBH Publishing Co. New Delhi, (1983), 246.
31. ASM, Metal Hand Book, Volume 13 A, Fundamentals, Testing and Protection, ASM International, Material Park Ohio, (2006).
32. C. Borgmann, Industrial Engineering Chemistry, 29, (84) (1937).
33. U.S.E.P.A. Report on Corrosion of Certain Alloys, Office of Environmental Information, Washington Dc, 20460, (2001).

Table- 1 ELEMENTAL CHEMICAL COMPOSITIONS OF FERROUS ALLOYS

ELEMENT	Mild Steel %	SS-304 %	SS-316 %	SS-430 %
Aluminum (Al)	0.042	-	-	-
Bismuth	-	-	-	0.0029
Carbon (C)	0.063	0.08	0.08	0.0479
Chromium (Cr)	0.034	18	16-18	16.222
Copper (Cu)	0.069	-	-	0.211
Iron (Fe)	99.39	71.39	69.99	82.6
Lead (Pb)	<0.05	-	-	-
Manganese (Mn)	0.280	2.0	2.0	-
Magnesium (Mg)	-	-	-	-
Molybdenum (Mo)	0.025	-	2.0-3.0	0.0213
Nickel (Ni)	0.030	8-10.50	10-14	0.210
Phosphorus (P)	0.0 16	0.045	0.045	0.026
Silicon (Si)	0.011	1.00	-	0.249
Sulphur(S)	0.0 16	0.03	0.03	0.0090
Tin (Sn)	0.003	-	-	-
Titanium (Ti)	<0.002	-	-	0.0064
Zinc (Zn)	-	-	-	-

TABLE-2 CLEANING AGENTS FOR SURFACE CLEANING OF COUPONS BEFORE AFTER CORROSION

Sr.No.	Metals/Alloys	Cleaning agents
1.	Mild steel	5 ml of con. HCl (Sp.gravity 1.19) + 1gm Sb_20_3 diluted to 1 liter with glass distilled water.
2.	S.S.304,316,430	5 ml of conn.HNO_3 (Sp.gravity 1.42) diluted to 1 liter with glass distilled water

TABLE- 3 CORROSIVITY PARAMETERS OF GROUNDWATERS

Sample No.	**Temp ^oC pH**	**pH**	**EC μScm^{-1}**	**TDS**	**TH**	**TA**	**DO**	**COD**	**Cl^-**	**$S04^{2-}$**	**Ca^{2+}**	**Mg^{2+}**	**Na^+**	**K^+**	**L S I**
11	29.8	7.48	1311	853	432	210	4.63	236	240	21.2	101	44	98	39	+ 0.63
12	28.8	7.51	7.54	490	286	270	4.013	326	199	28	58	35	81	2.0	+ 0.65
13	30	7.15	1134	737	430	262	1.83	195	157	147	81	56	50	0.7	+ 0.41
14	28.1	7.43	671	436	300	497	5.6	74	146.11	23.28	64	34	42	9.5	+ 0.87
15	28.4	7.31	1247	811	488	510	4.25	55.5	170	41.0	166	46	98	6.0	+ 0.90
16	29.5	8.47	2123	1381	270	393	3.532	805	574	64.0	95.5	8.0	223	6.0	+ 1.62
17	30	7.02	1320	858	556	262	3.44	429	122	148	125	60	43.2	0.0	+ 0.37
18	28.9	7.43	1190	775	160	250	4.10	117	270	20	20.0	27	104	16.0	+ 0.23
19	30	7.80	616	400	130	183.0	2.83	332	115	50	28	15	75	14.0	+ 0.45
20	28.8	7.80	2230	1450	386	220	4.38	351	719	88.56	92.0	30	29.0	15.0	+ 0.85
21	29.5	7.94	670	435	230	287	4.53	213	87.0	16.50	59.0	21.0	49.0	2.3	+1.03
22	29.5	7.91	903	587	276	327	3.7	732	141	40.16	53	35.0	69	4.5	+ 1.1
23	29.5	7.94	724	471	322	327	4.81	383	70.30	12.0	61.0	42.0	24.6	0.2	+ 1.22
24	29.5	5.93	1022	665	320	92.0	4.17	315	387.0	18.16	81.0	29.0	66.5	7.4	+ 1.38
25	28.4	9.30	704	458	312	490	3.92	2453	216	42.24	64.20	37	30	1.0	+ 2.72
26	29.6	8.52	1920	1248	624	580	3.73	1170	576	36.0	154	58.5	179	34	+ 2.21
27	29.6	7.89	1620	1045	770	520	2.73	897	387	30.0	116	117	48.5	2.0	+ 1.66
28	28.6	7.53	1671	1086	620	220	4.38	1166	288	150	176	44	81	2.0	+ 0.82
29	28.8	8.10	1940	1261	736	150	4.10	538	672	130	176	72	130	4.0	+ 1.24
30	30	7.89	764	497	308	250	3.64	1587	80.0	19.0	74	30.0	56	2.0	+ 1.01
31	30	8.45	704	462	222	230	4.38	1307	76	16.5	56.0	20.0	73	19	+ 1.42
32	30^0C	7.95	358	234	130	70	4.14	1377	64	14.0	32.0	12.2	7.0	3.6	- 0.24
Mean	**29.33**	**8.08**	**1162**	**756**	**378**	**300**	**4.13**	**730**	**262**	**53**	**87**	**40.0**	**75.3**	**8.0**	**---**

Note: All parameters are expressed in mg lit^{-1}, excluding E.C. μScm^{-1}, T ^0C and pH : EC. – Electrical Conductivity, DO – Dissolved oxygen, TDS- Total dissolved solids, TH – Total hardness, TA – Total alkalinity, COD -Chemical oxygen demand. LSI -Langelier Saturation Index

TABLE-4 CORROSION RATE (mg dm^{-2} hr^{-1}) OF FERROUS ALLOYS IN GROUNDWATERS. (SAMPLE No.1-11)

Type of Metal / Alloy	**Sample Numbers**											
	Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Mild Steel	1	5.78	5.35	10.63	5.08	5.63	13.51	5.08	7.23	4.28	8.21	4.20
	2	2.57	2.5	6.16	2.64	2.55	5.0	2.63	3.25	1.69	2.85	1.61
	3	1.33	1.78	3.36	1.19	1.27	2.70	1.36	2.32	0.86	1.66	0.98
	6	0.47	0.58	0.13	0.43	0.45	2.33	0.53	0.36	0.52	0.599	0.40
	10	0.11	0.24	0.07	0.16	0.11	0.150	0.26	0.33	0.18	0.33	0.18
SS 304	1	0.965	0.89	0.80	0.89	0.982	1.78	0.714	1.16	0.89	1.42	0.803
	2	0.401	0.80	0.35	0.40	0.401	0.938	0.22	0.53	0.35	0.312	0.35
	3	0.140	0.20	0.24	0.14	0.148	0.535	0.119	0.20	0.178	0.119	0.17
	6	0.04	0.04	0.08	0.04	0.04	0.22	0.089	0.05	0.05	0.029	0.05
	10	0.023	0.03	0.02	0.008	0.026	0.08	0.017	0.04	0.008	0.017	0.017
SS 316	1	0.82	0.80	0.625	0.72	0.80	1.42	0.803	0.98	0.714	0.71	0.714
	2	0.45	0.26	0.23	0.23	0.44	0.75	0.267	0.49	0.401	0.62	0.26
	3	0.17	0.11	0.119	0.08	0.14	0.50	0.148	0.208	0.147	0.089	0.11
	6	0.048	0.046	0.046	0.029	0.044	0.134	0.059	0.05	0.029	0.109	0.014
	10	0.025	0.08	0.026	0.027	0.026	0.071	0.017	0.053	0.026	0.035	0.007
SS 430	1	1.62	1.16	1.16	1.51	1.60	2.05	1.25	1.78	1.16	1.69	1.07
	2	0.57	0.58	0.40	0.523	0.53	0.98	0.80	0.80	0.49	0.45	0.49
	3	0.39	0.27	0.24	0.32	0.38	0.56	0.56	0.56	0.26	0.17	0.29
	6	0.13	0.13	0.059	0.119	0.133	0.20	0.133	0.133	0.13	0.09	0.104
	10	0.070	0.07	0.035	0.033	0.073	0.12	0.05	0.05	0.045	0.035	0.02

TABLE-5 CORROSION RATE (mg dm^{-2} hr^{-1}) OF FERROUS ALLOYS IN GROUNDWATERS. (SAMPLE No.12-22)

Type of Metal / Alloy	Sample Numbers											
	Hours	12	13	14	15	16	17	18	19	20	21	22
Mild Steel	1	5.80	5.26	6.78	5.53	11.33	6.69	8.12	10.8	3.75	4.28	2.85
	2	2.64	2.67	5.63	3.48	4.10	2.63	3.08	4.9	2.50	1.69	1.29
	3	1.20	0.92	1.54	1.23	1.93	1.93	1.22	1.16	0.714	0.95	0.65
	6	0.32	0.25	0.54	0.49	0.61	0.55	0.47	0.58	0.267	0.38	0.133
	10	0.14	0.10	0.19	0.23	0.29	0.180	0.169	0.29	0.09	0.018	0.06
SS 304	1	0.98	0.89	1.25	0.98	1.07	1.39	1.16	1.25	0.71	0.89	0.71
	2	0.44	0.35	0.40	0.26	0.53	0.49	0.40	0.67	0.62	0.40	0.44
	3	0.29	0.17	0.29	0.23	0.20	0.267	0.13	0.35	0.14	0.12	0.14
	6	0.13	0.04	0.12	0.07	0.119	0.147	0.053	0.14	0.059	0.05	0.07
	10	0.05	0.02	0.06	0.008	0.05	0.053	0.10	0.06	0.017	0.02	0.035
SS 316	1	0.80	0.714	0.98	0.803	0.71	0.98	0.80	1.07	0.62	0.71	0.446
	2	0.35	0.22	0.40	0.44	0.27	0.04	0.35	0.35	0.58	0.26	0.22
	3	0.267	0.12	0.17	0.23	0.23	0.23	0.23	0.119	0.23	0.17	0.09
	6	0.119	0.02	0.06	0.08	0.07	0.107	0.10	0.089	0.059	0.029	0.014
	10	0.05	0.017	0.017	0.26	0.026	0.017	0.04	0.008	0.026	0.008	0.008
SS 430	1	1.60	1.51	1.42	1.69	1.42	1.51	1.60	1.87	0.98	1.07	0.89
	2	0.847	0.66	0.669	0.53	0.71	0.69	0.89	0.84	0.66	0.49	0.401
	3	0.505	0.38	0.27	0.50	0.17	0.35	0.35	0.68	0.26	0.26	0.29
	6	0.17	0.13	0.133	0.163	0.05	0.133	0.13	0.19	0.07	0.14	0.05
	10	0.07	0.044	0.04	0.08	0.02	0.04	0.08	0.80	0.008	0.026	0.026

FIGURE-1 NO. OF SAMPLING STATIONS AND HABITAT

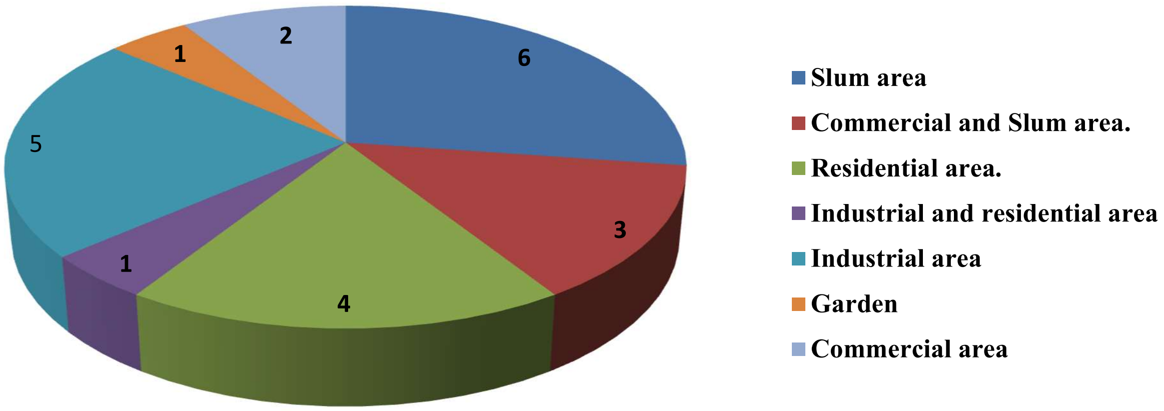

FIGURE-2 THE VARIATION OF CORROSION RATE AT VARIOUS TIME INTERVALS FOR FERROUS ALLOYS

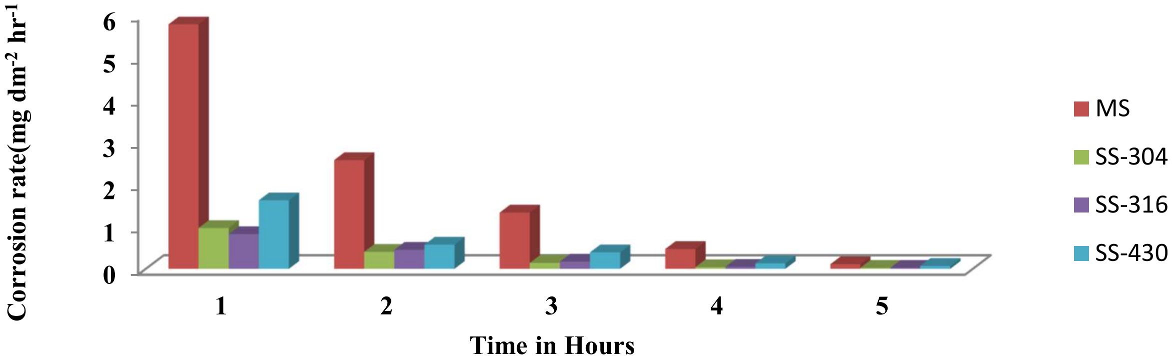

FIGURE-3 THE VARIATION OF CORROSION RATE AT VARIOUS CONCENTRATIONS OF DISSOLVED OXYGEN IN GROUNDWATERS FOR FERROUS

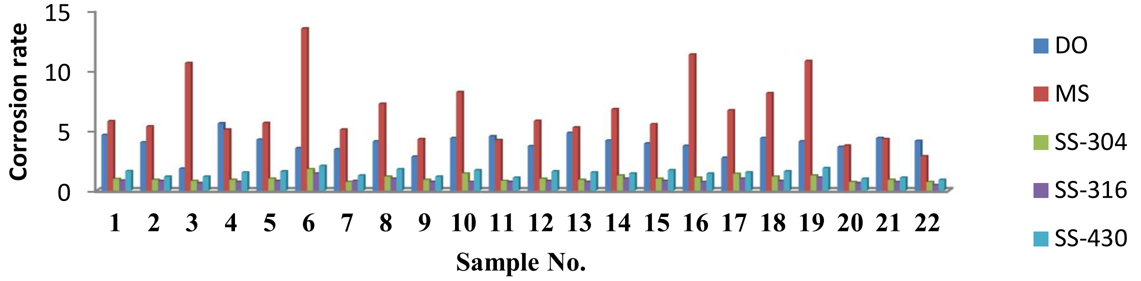

FIGURE-4 THE VARIATION OF CORROSION RATE AT VARIOUS CONCENTRATIONS OF CHLORIDE (50-700 mg/lit) IN GROUNDWATERS FOR FERROUS ALLOYS

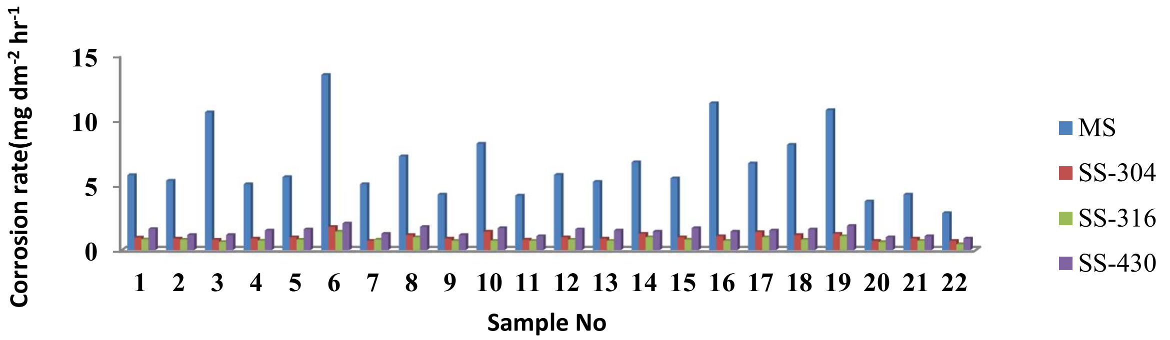

FIGURE-5 THE VARIATION OF CORROSION RATE AT VARIOUS CONCENTRATIONS OF SULPHATE (10-700 mg/lit) IN GROUNDWATERS FOR FERROUS ALLOYS