



Studies on pipeline corrosion under the influence of aggressive ions present in drinking water supplied in some areas of Patna city.

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Abstract: Ground water is utilized as the main resource in water distribution system of Patna city as it is available easily. Water purification is not practiced and water is distributed directly from the source to consumer through pipelines. Reports of some investigations carried out earlier by some agencies confirm the presence of microorganisms and harmful ions in drinking water collected from some areas of Patna city.

Corrosion of fixtures and other parts of distribution system has been evidenced by staining of material at several locations. Severity of attack on the material of pipes depends on the type of ion present in water. For example chloride ions present in water cause severe destructive attack on material of pipes and may lead to holes and cracks. Cast iron and galvanized steel which are used as construction material of pipes dissolve as a result of corrosive attack; rate of corrosion at a constant temperature being dependent on amount of aggressive ions and inhibitors present. In present system corrosion rate is decided by the deleterious effect of chloride ions as well as by inhibitory action of carbonate ions at a constant temperature. In this paper Freundlich adsorption equation is tested for the present system.

Key words: corrosion, water distribution system, harmful ions.

I. Introduction

It is witnessed that unprotected pipelines exposed to water environment are susceptible to corrosion. Corrosion of pipelines weakens its structural integrity and as a result transport of hazardous materials may take place making water unsafe. Corrosion of pipes is influenced by PH of water, dissolved oxygen and presence of aggressive ions in water. Lead, copper and zinc are used in pipe work in water distribution system. On coming in contact with water, corrosion of pipes and fixtures starts as a result of formation of anodic areas leading to dissolution of material of pipes and fixtures. As a result harmful ions like copper, zinc and lead etc enter water deteriorating the quality of drinking water.

In Patna city ground water is the main resource used in the water distribution system. It is distributed without any treatment as underground water is considered to be pure and safe for drinking. But as water is a universal solvent and on coming in contact with different underground rocks it dissolves minerals thus increasing the concentration of different ions in it. Dissolved ions may change the pH as well as corrosiveness of water.

There have been reports about contaminated water being supplied in Patna city which is evident from a large number of patients suffering with water born diseases. As water which is supplied is germ free (underground water) it certainly gets contaminated with germs in the distribution system itself. There are also reports about leakage and rupture of pipelines in Patna city. Ruptured underground pipes suck the sewage water of sewer pipelines making drinking water contaminated.

It has been investigated by researchers that iron gets corroded when it is in acidic and aqueous environment containing aggressive ions [1- 5]. Stainless steels which are resistant to corrosion in many environments undergo pitting corrosion in presence of chloride ions [6 -9]. Corrosion studies on material of supply pipes in aqueous environment are limited [1-3]. Extensive study on corrosion of pipelines in Indian cities in aqueous environment containing aggressive ions is rare. It necessitates proper investigations on quality of water which is distributed through supply lines and study of the impact of different ionic constituents present on the corrosion of the material of pipes. Quantitative analysis of water is important in order to ascertain whether concentration of aggressive ions is sufficient to cause appreciable pitting attack on material of pipes. Further if any other ion is present in water which has inhibitory effect it is to be taken into account. This paper includes the results of quantitative analysis of chloride ion as well as carbonate ions and study of their impact on deterioration of pipes resulting in health hazards.

II. Experimental

Samples of water were collected from different areas of Patna city. Each water sample was analyzed to find out its pH and presence of chloride ions in it. Standard methods were adopted for analysis. For determination of concentration of chloride ions present in samples of water, titration of water with AgNO_3 in presence of indicator

potassium chromate (K_2CrO_4) was carried out which involved silver ion precipitation. Chloride ions in the presence of silver ions get precipitated as $AgCl$. Excess drop of $AgNO_3$ gives brick red coloration with K_2CrO_4 indicator. N/10 silver nitrate was used for titration. Precaution was taken so that other ions present in water such as HCO_3^{1-} and S^{2-} may not interfere in the precipitation of chloride ions.

For determination of corrosion rate of different samples weight loss technique was utilized. Sample was weighed prior to immersion in aqueous environment and after a fixed duration of time sample was taken out, cleaned and weighed again.

Corrosion rate of material of pipe in aqueous environment was calculated by using equation,

$$\text{Corrosion rate (in mm.year}^{-1}\text{)} = 87.6 (W_i - W_f) / A.t.d$$

Where,

W_i = initial weight of the sample

W_f = final weight of the sample

A = surface area in cm^2

t = exposure time in hours

d = density of sample in $g.cm^{-3}$

$$As \quad x/m = k.c^{1/n} \quad (1)$$

Where x = amount of ion adsorbed

M = mass of metal on which adsorption takes place

C = concentration of ions in solution

As corrosion rate depends on weight loss per unit time, which itself depends on the amount of aggressive ions adsorbed for a fixed mass of adsorbent (metal)

$$\text{Corrosion rate} \propto c^{1/n} \quad (2)$$

Considering attack of chloride ions on metal surface to be initiated by adsorption, Freundlich's law is applied for adsorption phenomenon.

$$\text{Corrosion rate} \propto [Cl]^{1/n} \quad (3)$$

Concentration of carbonate ions also effects corrosion resulting in inhibitory action.

$$\text{Hence, Corrosion rate} \propto 1/[CO_3^{2-}]^{1/n} \quad (4)$$

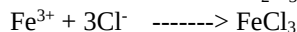
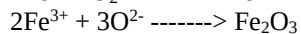
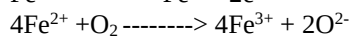
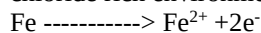
$$\text{Corrosion rate} = k \{ [Cl^-] / [CO_3^{2-}] \}^{1/n} \quad (5)$$

To study the variation of corrosion rate with concentration of chloride ions and carbonate ions a graph is plotted between logarithm of corrosion rate and logarithm of (chloride ion concentration/carbonate ion concentration). From this plot k and n are determined.

III. Result and discussion

It is clear from Table-1 that pH of all water samples is greater than 7. It means that water is slightly alkaline in nature which is due to presence of different ions such as carbonate and bicarbonate ions. As corrosiveness of water increases with the increase in acidic nature of aqueous environment and water in present investigation is not acidic, there may be any other cause of high corrosive nature of water.

It has been reported that iron undergoes severe corrosive attack in presence of chloride ions in weakly alkaline aqueous environment [5]. Chloride ions are very aggressive in nature and increase the corrosiveness of water to such an extent that it may lead to pitting attack on material in contact. Pit formation is evidenced even on stainless steel surface in acidic environment containing chloride ions [8, 9-11]. In the present study, chloride ion concentration in different samples of water ranges from 250 $mg.l^{-1}$ to 350 $mg.l^{-1}$. It has been investigated that stainless steel 410 shows pitting corrosion or rusting in presence of aqueous environment containing chloride ion concentration 100 $mg.l^{-1}$ or more. Pit depth increases with increase in chloride ion concentration. Cast iron offers lesser resistance against corrosion in comparison to alloy steel. The corrosion rate of grey cast iron pipes in aqueous environment ranges between 0.1- 0.3 $mm.year^{-1}$ depending on corrosiveness of the environment. In many localities of Patna city water pipelines have not been replaced for a long time. Chloride ions may cause destructive attack deteriorating the quality of water and resulting in water leakage due to corrosion of pipes. Corrosion products formed on the inner surface of pipes are dictated by the material of pipes and the environment in contact. It is expected that as a result of conversion of Fe^{2+} to Fe^{3+} and $FeCl_3$ the formation of Fe_3O_4 takes place in aerated chloride rich environment. Reactions taking place are:



Chloride ions being aggressive in nature replace oxygen ions present in oxide film on the metal surface. It removes oxygen from metal ion and forms its own chloride which being soluble enters in water flowing in pipes. There is

carbonate ion also present in supply water which has inhibitory effect on the corrosion of the material of pipelines. Rate of corrosion of metal is decided by the ratio $[\text{Cl}^-]/[\text{CO}_3^{2-}]$. The defects in oxide film promote the adsorption of chloride ion on metal surface forming metal chlorides. It creates cation deficiency on metal surface which is compensated by M^{n+} ions being provided by inner layers of material of pipe thus creating cation deficiency there itself. Cation vacancies are generated at metal-oxide interface and keep on disappearing in the bulk. When the rate of generation of cation vacancies exceeds the rate of their disappearance in the bulk, the void grows beyond a critical size and pitting occurs. Pit or hole formation on inner surface of pipes and other parts of water distribution system such as fixtures results in leakage of pipes which obstructs the supply of drinking water in Patna city. Underground pipes with holes suck the sewage water thus making it contaminated with microorganisms and harmful ions.

To study the corrosion phenomena occurring in the present condition, Freundlich adsorption equation is applied to understand how corrosion rate varies with concentration of chloride and carbonate ions present in solution. From the plot of log of corrosion rate vs log of concentration of chloride ions it is found that it is a straight line graph having a slope and y intercept is obtained. The trend of the plot follows the equation $y = 0.020x - 0.883$ for which slope of the plot is 0.020 and y intercept is -0.883

Hence dependence of corrosion rate on concentration of chloride ions may be expressed as $\log(\text{corrosion rate}) = 0.020 \log\{[\text{Cl}^-]/[\text{CO}_3^{2-}]\} - 0.883$ or corrosion rate $= 0.131 \{[\text{Cl}^-]/[\text{CO}_3^{2-}]\}^{0.020}$. From this equation it is inferred that corrosion rate is proportional to $\{[\text{Cl}^-]/[\text{CO}_3^{2-}]\}^{0.020}$. When compared with the equation, corrosion rate $= K C^{1/n}$ value of n and K are found to be 50 and 0.131 respectively where corrosion rate is expressed in mm.year⁻¹ and concentration of chloride ions and carbonate ions is expressed in (Mole/l) $\times 10^{-3}$. The plot shows that adsorption of chloride ions takes place according to Freundlich's law obeying the equation, corrosion rate $= K C^{1/n}$. At higher concentration of chloride ions there is an increase in corrosion rate due to surface coverage to a greater extent resulting in an increase in creation of cation vacancies. The vacancies created at the surface of metal are compensated by cations present in the bulk of the metal thus continuing the movement of cation vacancies from surface to bulk of the metal. As carbonate ions are also present in aqueous medium they impart an inhibitory effect on corrosion by the formation of metal carbonates which cover the surface partially preventing attack of chloride ions. It is competitive coverage of metal surface by chloride and carbonate ions that decides the fate of the material of pipes in aqueous medium.

IV. CONCLUSION

In present investigation corrosion rate is of the order which is sufficient to result in holes on material of pipes after exposure for a particular duration of time. Localized corrosion of material of pipes results in either supply of polluted water to public or failure of water supply system. Pipeline corrosion is mainly due to presence of aggressive ions present in water although inhibitory effect of other ions results in retardation of the corrosion rate. To tackle the problem of pipeline corrosion, regular monitoring is recommended. It necessitates the proper analysis of ground water at regular intervals to check the concentration of aggressive ions. As concentration of aggressive chloride ions in some areas of Patna city is found to be beyond the limit which is sufficient to initiate cracks or pits their concentration is to be reduced either by water treatment or by blending it with rainwater. Old Pipes and fixtures in water distribution system should be replaced in the city.

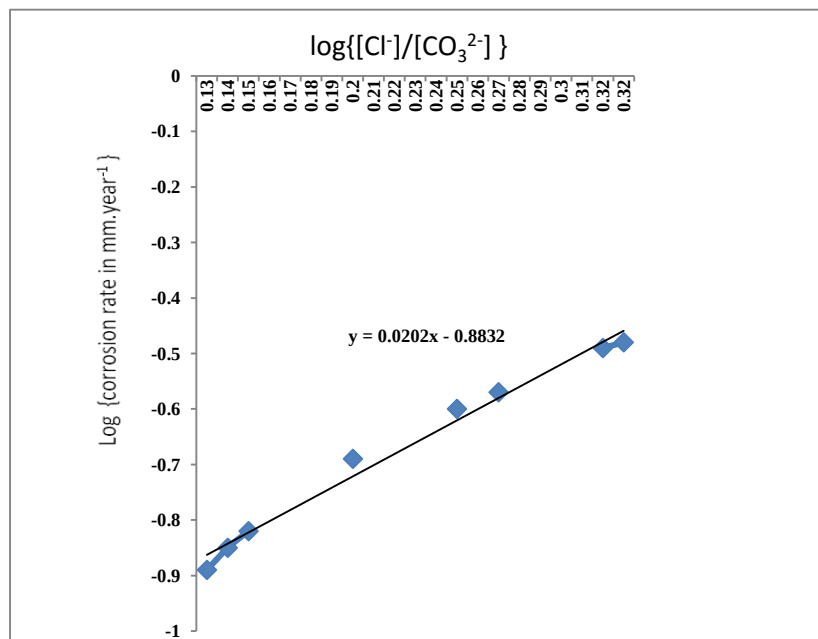
Table-1: Concentration of some ions present in the samples of water collected from different areas of Patna city.

Sample number	PH of sample	Cl^- Mg.l^{-1}	CaCO_3 Mg.l^{-1}
1	7.5	250	226.8
2	8.1	326	230.4
3	7.8	304	228.0
4	7.5	285	229.2
5	8.5	350	226.2
6	7.7	365	228.0
7	7.5	340	226.8
8	7.9	260	224.4
9	8.0	322	229.2
10	7.4	350	228.6
11	7.7	344	229.8
12	7.7	285	227.4
13	7.6	299	229.2
14	7.5	321	229.8
15	7.9	364	225.6

Table-2 Variation of corrosion rate with concentration of chloride ions present in different samples of water.

Sample number	Concentration of chloride ions		Concentration of carbonate ions		Corrosion rate (mm.year-1)
	(mg.l ⁻¹)	(Mole/l)x10-3	(mg.l ⁻¹)	(Mole/l)x10-3	
1	250	7.04	226.8	3.78	0.13
2	326	9.18	230.4	3.84	0.22
3	304	8.56	228.0	3.80	0.15
4	285	8.03	229.2	3.82	0.14
5	350	9.86	226.2	3.77	0.25
6	365	10.28	228.0	3.80	0.32
7	340	9.58	226.8	3.78	0.25
8	260	7.32	224.4	3.74	0.13
9	322	9.07	229.2	3.82	0.21
10	350	9.86	228.6	3.81	0.24
11	344	9.69	229.8	3.83	0.27
12	285	8.08	227.4	3.79	0.15
13	299	8.42	229.2	3.82	0.14
14	321	9.04	229.8	3.83	0.20
15	364	10.25	225.6	3.76	0.30

Fig -1 Plot of logarithm of corrosion rate versus logarithm of concentration of (chloride ions/carbonate ions) .



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