

IMPACT OF GROUND WATER CHLORIDE ION CONCENTRATION ON CORROSION SUSCEPTIBILITY OF MATERIAL OF WATER DISTRIBUTION SYSTEM IN SOME AREAS OF PATNA, CAPITAL CITY OF BIHAR, INDIA

Rita Khare*

Key words : Pipeline corrosion, aggressive ion, ground water.

Ground water is utilized as the main source of water distribution system in Patna. Corrosive degradation of fixtures and other parts of distribution system such as pipelines has been evidenced by staining of material at several locations. In the presence of ground water containing aggressive ions, such as chloride ions, material of pipe dissolves as a result of corrosive attack on it. The present study emphasizes on causes of increase in chloride ion concentration in ground water and its influence on the corrosion susceptibility of material of pipes exposed to drinking water samples collected from some localities of Patna.

INTRODUCTION

It is witnessed that unprotected pipelines exposed to water environment are susceptible to corrosion. Corrosion of pipeline weakens its structural integrity and as a result transport of hazardous material may take place making water unsafe. In Patna, ground water is utilized as the main source of water distribution system without any purification through pipelines. As water is a universal solvent, it dissolves minerals on coming in contact with different underground rocks, thus increasing the concentration of different ions in it. Dissolved ions may change pH as well as corrosiveness of water. Material of water distribution system suffers severe destructive attack particularly in presence of chloride ions.

There has been an increase in concentration of chloride ions in underground water. Recent studies show that chloride ion concentration in ground water in many parts of world is beyond the permissible limit (Burch, 2004; Selvakumar *et al.*, 2017). Studies conducted on ground water of Patna city in 2015 show that chloride ion concentration ranges from 2 mg/l to 247.9 mg/l (Sukumaran *et al.*, 2015). According to this report, the maximum content of chloride ion detected in ground water of Patna is about to cross the permissible limit of 250mg/l. Studies reported in 2016 show that chloride ion concentration in drinking water supplied in some areas of Patna city exceeds the maximum permissible limit (Khare, 2016). From the point of view of corrosive attack on pipes made up of cast iron and galvanized iron, chloride ion concentration of 100mg/l is sufficient to cause dissolution of metal in the form of chlorides and chloro complexes (Khare, 2016).

There are various factors responsible for increase in chloride ion content in ground water of urban areas. Seepage

of the surface water takes along with it chloride ion which enters into it by natural phenomena as well as by pollution. This communication includes studies on factors responsible for alarming increase in chloride ion in ground water supplied in some localities of Patna as well as studies on corrosive attack on the material of pipes under the influence of chloride ion in underground water supplied in these localities.

In addition to chloride ion deposited on a basin by precipitation, weathering of rocks and minerals also adds up to this aggressive ion. Chloride ion which is present in several minerals gets released into water in a slow process and through processes other than dissolution. Major source of chloride ion in surface water and ultimately ground water is pollutant in the form of sodium chloride. This salt is used in agriculture, food processing, metal processing, paper production, textile and dyeing, petroleum production, water treatment and other manufacturing processes. Domestic and industrial wastes include salt from food wastes as well as from rubber, metal and paper products. As a result of its direct or indirect use, chloride and sodium ions end up being discharged to ground water and surface water. After human consumption or activity salt is discarded and is thrown with garbage in municipal landfills. Chloride concentration is typically high in landfill leachate or in ground water beneath or down gradient from landfills. For example, the median chloride concentration in leachate for seven landfills in Illinois was established to be 1284mg/l (Burch, 2004). Hence as a result of long groundwater travel times, landfills can be a long term source of salt aquifers and streams.

When present in the environment, chloride ion is nonreactive and very little loss of it takes place when salt is

* Department of Chemistry, Government Women's College, Gardnibagh, Patna, Bihar, India, E mail: drritakhare@gmail.com

discharged to the environment in the form of waste water containing food, beverages and household cleaning products. Another source of chloride ion to the environment is water softeners. Discharge of chloride ion to the environment from water softeners is through drains in which waste water is thrown. In recent times water softeners are used in homes with self supplied domestic groundwater supply systems and in areas where ground water supplies are publicly provided. There are various factors responsible for increase in chloride ion content in ground water of urban areas of Indian cities. The taste threshold of chloride anion in water is dependent on the associated cation.

Chloride ion increases the electrical conductivity of water and thus increases its corrosiveness. When present in contact with metal pipes, it reacts with metal ions to form soluble salts thus resulting in increase in the level of metals in drinking water. Being aggressive in nature, it causes destructive deterioration of material of pipes and other parts of water distribution system including pit formation resulting in cracks and holes. The present study emphasizes on corrosion susceptibility of the material of pipes exposed to drinking water samples collected from some areas of Patna, an urban city of Bihar.

EXPERIMENTAL

Water sample was collected from some densely populated localities of Patna. Each water sample was analyzed to find out its pH and presence of anions, viz., chloride and carbonate ions in it. For determination of concentration of chloride ions present in water sample, titration of water with AgNO_3 in presence of indicator potassium chromate (K_2CrO_4) was carried out which involved silver ion precipitation. Concentration of carbonate ions was determined by titrating water samples with HCl solution using indicators phenolphthalein and methyl orange.

For the determination of corrosion rate of different metal samples, "weight loss technique" was utilized. Samples were washed using acetone and dried. Samples were weighed prior to immersion in beaker containing 200ml of test solution (water) maintained at room temperature (30°C). After 90 days samples were taken out, cleaned and weighed again. The difference in weight of the metal before immersion and after immersion was noted as the weight loss.

Corrosion rate of material of pipe in aqueous environment is calculated by using equation :

$$\text{Corrosion rate (mm}\cdot\text{year}^{-1}) = 87.6 (w_i - w_f) A \cdot t \cdot d$$

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 metal sample in $\text{g}\cdot\text{cm}^{-3}$

Surface Analysis of the metal samples was carried out by Light Optical Microscopy to detect the change in texture and colour of the surface of material after immersion in water samples for 90 days.

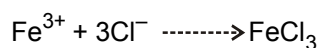
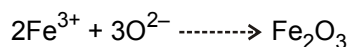
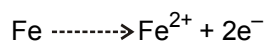
RESULT AND DISCUSSION

Table-1 shows the pH values, concentrations of chloride and carbonate ions and corrosion rate of material of pipe in contact with different water samples. pH value is observed to be greater than 7 in all the cases indicating that underground water in Patna is slightly alkaline in nature which is due to the presence of different ions present in it. As acidic nature of aqueous environment is one of the causes of high corrosiveness and water is not acidic in present case, there may be any other factor affecting the corrosiveness of water, e.g., presence of aggressive ions in the medium. In case of water sample no 1 to 15, the concentration of chloride ions ranges from $0.82 \times 10^{-3} \text{ mole}\cdot\text{l}^{-1}$ ($29.11\text{mg}\cdot\text{l}^{-1}$) to $2.62 \times 10^{-3} \text{ mole}\cdot\text{l}^{-1}$ ($93.01 \text{ mg}\cdot\text{l}^{-1}$). It has been reported that iron undergoes severe corrosive attack in presence of chloride ions in weakly alkaline aqueous environment (Makar and Tromans, 1995). 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 (Khare, 2012; Khare *et al.* 2002; Khare *et al.* 1995).

In the present study, chloride ion concentration in different samples of water collected from Patna is equal to or more than 250mg/l ($7.04 \times 10^{-3} \text{ mole}\cdot\text{l}^{-1}$). It has been investigated earlier that stainless steel 410 shows pitting corrosion in presence of aqueous environment having chloride ion concentration 100mg/l or more. Pit depth increases with increase in chloride ion concentration. Cast iron offers lesser resistance against corrosion in comparison to alloy steel. It is obvious that in water sample no 16 to 30 (collected from different areas of Patna), concentration of chloride ions is

sufficient to cause severe corrosive attack on metal surface. It is expected to result in localized corrosion leading to formation of pits.

Corrosion rates of different pieces of material of pipe calculated from weight loss analysis after immersion in water sample no. 16 to 30 (collected from different areas of Patna) for 90 days are represented in Table-1. It is observed that corrosion rate varies with the concentration of chloride ion present in aqueous environment. Corrosion rate increases from $0.12\text{mm}\cdot\text{year}^{-1}$ to $0.30\text{mm}\cdot\text{year}^{-1}$ with increase in concentration of chloride ions from $7.0 \times 10^{-3} \text{ mole/l}$ ($248.5\text{mg}\cdot\text{l}^{-1}$) to $10.25 \times 10^{-3} \text{ mole/l}$ ($363.8\text{mg}\cdot\text{l}^{-1}$). It has been investigated that stainless steel 410 shows pitting corrosion or rusting in presence of aqueous environment containing chloride ion concentration $100\text{mg}\cdot\text{l}^{-1}$ 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 $0.1\text{-}0.3 \text{ mm}\cdot\text{year}^{-1}$ depending on corrosiveness of the environment. In many localities of Patna 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 Fe_3O_4 takes place in aerated chloride rich environment. Reactions taking place are:



Pit formation on inner surface of pipes and other parts of water distribution system such as fixtures result 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.

Fig1 shows light optical microscopic image (50X) of surface metal after exposure to water sample no. 15. It shows more or

less uniform texture with no red or brown colour. It appears that surface has undergone uniform dissolution but there is no trace of localized corrosion to have taken place. Fig 2 to Fig 31 show images of surface of metal (50X) after exposure to water sample no. 16 to 30. From the surface analysis of material of pipe after immersion in water for 90 days in case of sample no.16 to 30, it is observed that surface becomes brownish with increase in chloride ion concentration in sample of water. However, colour distribution is not uniform and some areas appear brown to grey in colour with some deposition. It is inferred that metal has dissolved preferentially at locations where surface is less smooth. It appears from surface analysis that non-uniform corrosion (localized corrosion) has occurred on metal surface with pit formation at some locations. There is corrosion product deposited at some places on the surface as is evidenced from surface analysis.

CONCLUSION

From the results obtained in the present investigation it is clear that anions play a decisive role in determining the susceptibility to corrosion of the tested material of pipe in potable water. It is concluded from the present investigation that corrosion rate (of material of pipe in water collected from some areas of Patna) 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 in water although inhibitory effect of some 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. Immediate steps should be taken to prevent ground water from getting polluted with excess of chloride ions. Proper management of waste is required so that chloride ion may not pollute the water that ultimately seeps through the layers of rocks to form underground water.

Table -1 Variation in corrosion rate with concentration of chloride and carbonate ions.

Sample No.	pH	Concentration of Cl ⁻ (mol/l × 10 ⁻³)	Concentration CO ₃ ²⁻ (mol/l × 10 ⁻³)	Corrosion rate(mm.year ⁻¹)
1	7.6	1.46	3.82	0.023
2	8.1	2.10	3.76	0.035
3	7.5	0.82	3.75	0.016
4	7.7	2.30	3.80	0.049
5.	8.0	1.80	3.82	0.032
6.	8.1	2.62	3.76	0.073
7.	7.4	1.58	3.77	0.030
8.	7.7	2.23	3.84	0.045
9.	7.9	2.39	3.60	0.074
10.	8.4	1.61	3.84	0.032
11.	7.8	1.66	3.86	0.034
12	7.5	1.80	3.66	0.060
13.	7.6	1.46	3.83	0.022
14.	7.7	1.35	3.75	0.010
15.	8.1	1.01	3.79	0.006
16.	8.0	7.0	3.72	0.120
17.	7.5	9.02	3.82	0.230
18.	7.4	8.52	3.78	0.140
19.	7.9	8.01	3.80	0.130
20.	8.2	9.84	3.73	0.230
21.	8.4	10.25	3.77	0.300
22.	7.6	9.54	3.76	0.230
23.	7.5	7.30	3.73	0.110
24.	8.0	9.04	3.80	0.200
25.	7.4	9.87	3.77	0.220
26.	7.7	9.67	3.82	0.250
27.	7.7	8.05	3.76	0.160
28.	7.5	8.40	3.80	0.130
29.	8.2	9.03	3.82	0.180
30.	8.1	10.22	3.74	0.320



Figure 1- Material of pipe after exposure to water sample no 15



Figure 2- Material of pipe after exposure to water sample no 16



Figure 3- Material of pipe after exposure to water sample no 17

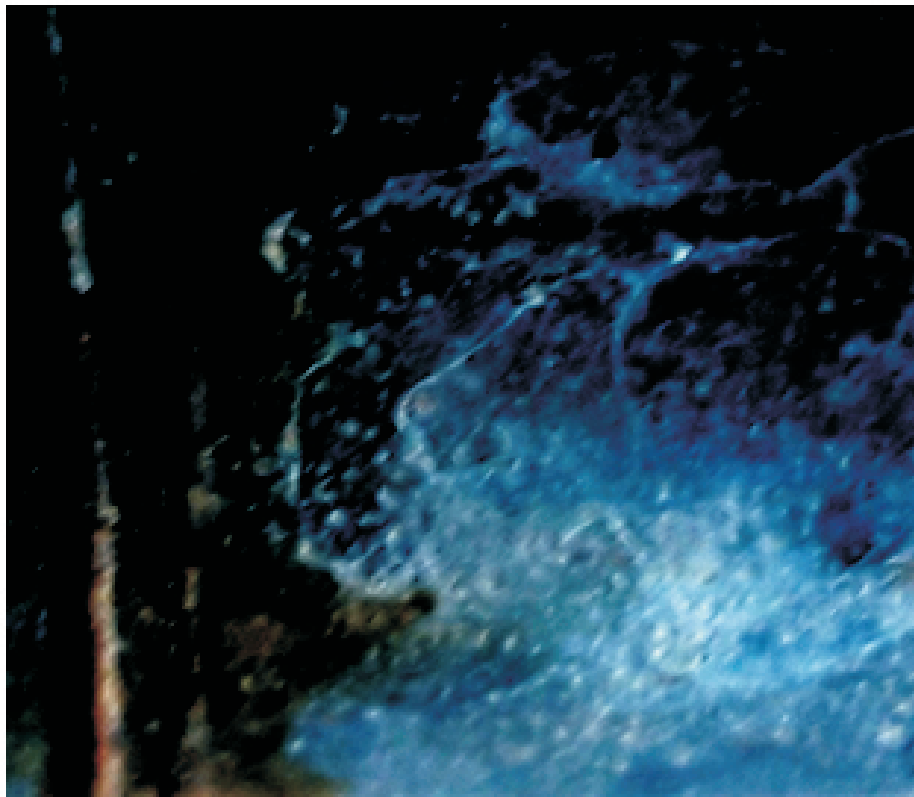


Figure 4- Material of pipe after exposure to sample no 18

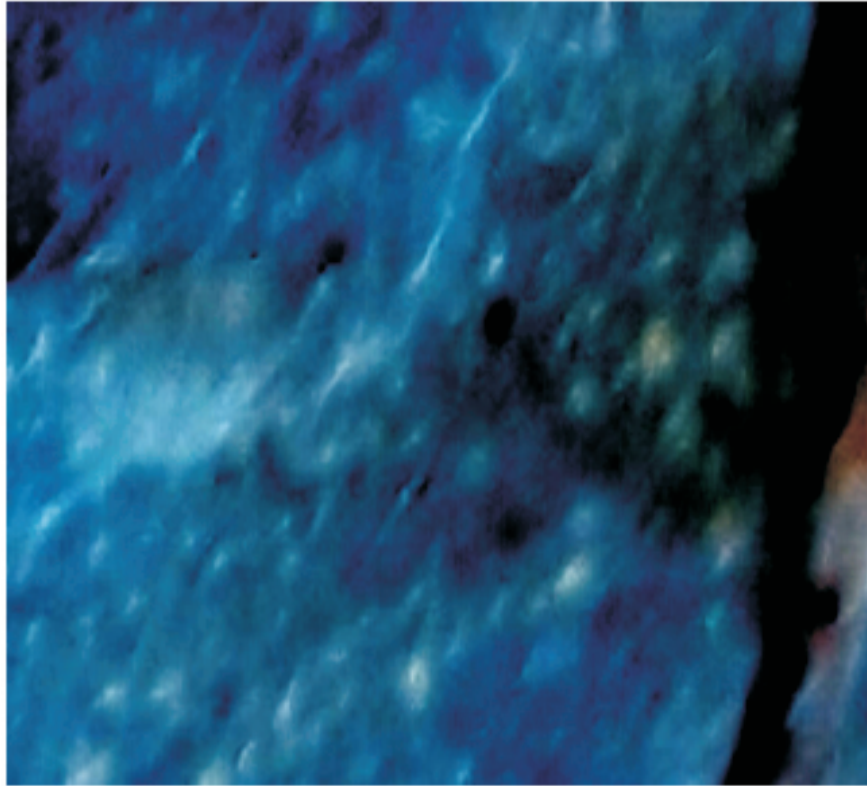


Figure 5- Material of pipe after exposure to water sample no. 19



Figure 6- Material of pipe after exposure to water sample no-20

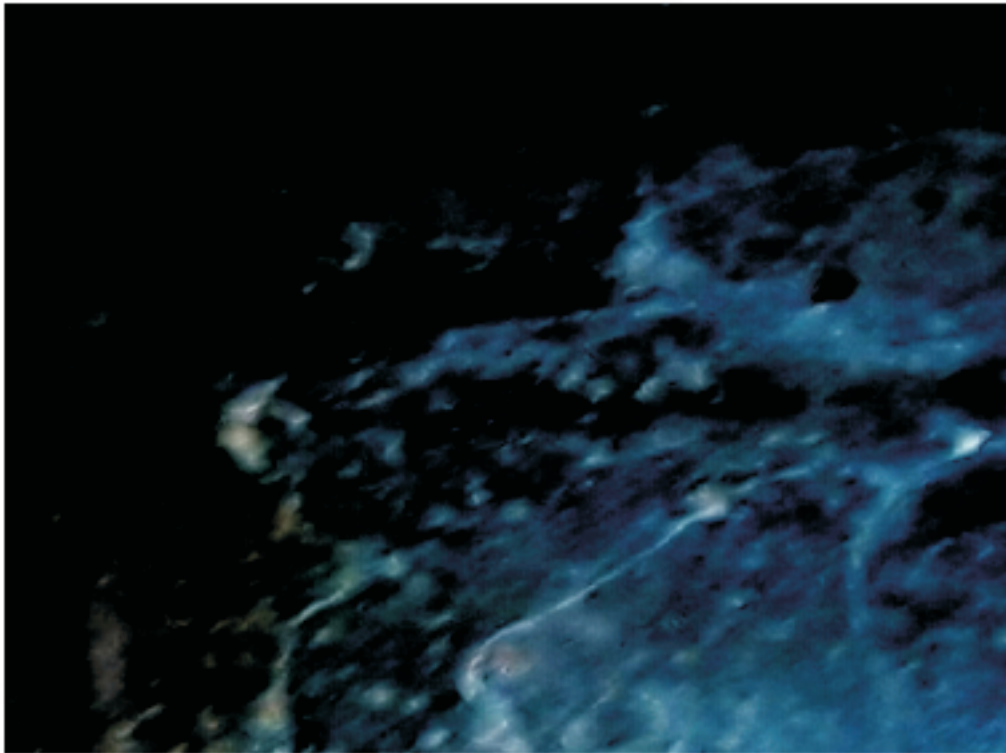


Figure 7- Material of pipe after exposure to water sample no-21



Figure 8- Material of pipe after exposure to water sample no-22



Figure 9- Material of pipe after exposure to water sample no-23



Figure 10- Material of pipe after exposure to water sample no-24

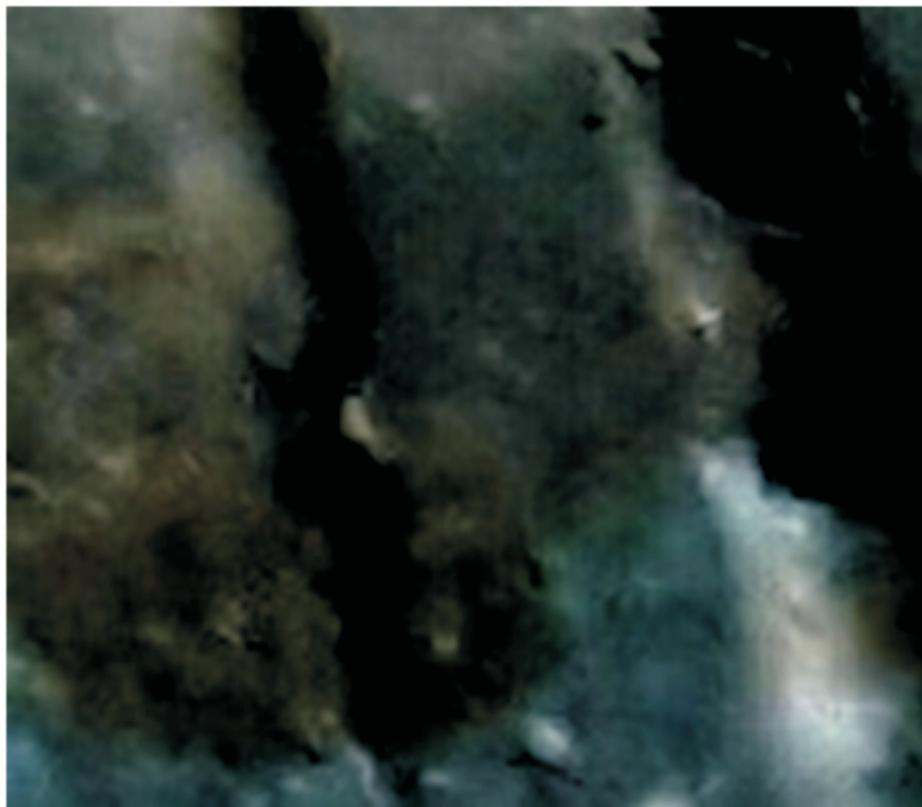


Figure 11- Material of pipe after exposure to water sample no-25



Figure 12- Metal sample after exposure to water sample no-26



Figure 13- Metal sample after exposure to water sample no-27

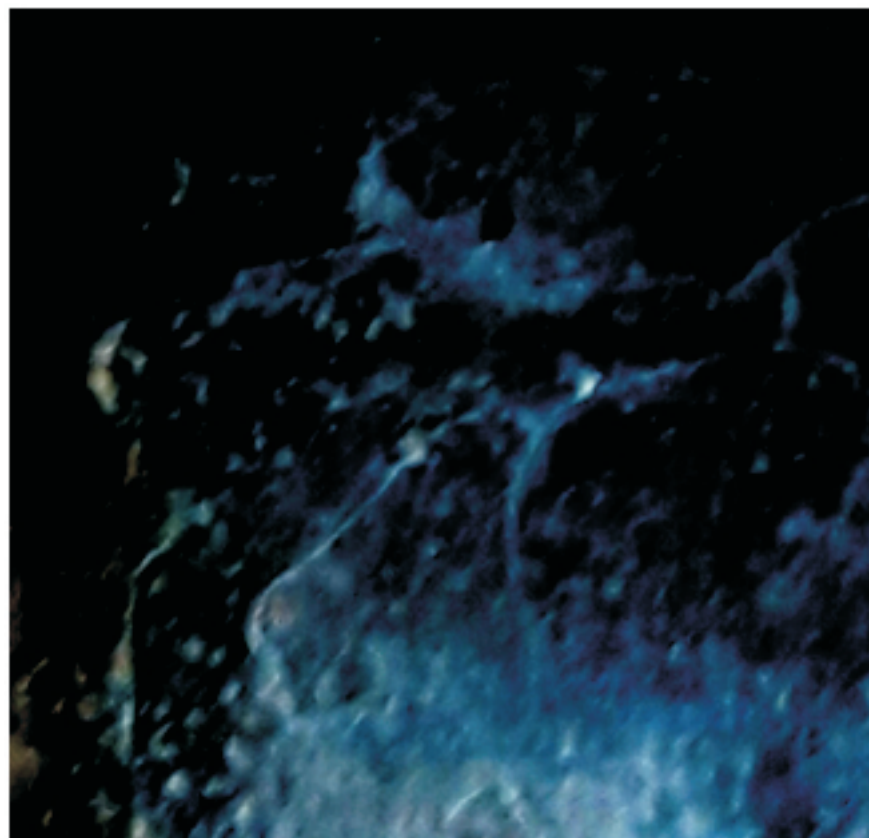


Figure 14- Metal sample after exposure to water sample no-28



Figure 15- Metal sample after exposure to water sample no-29

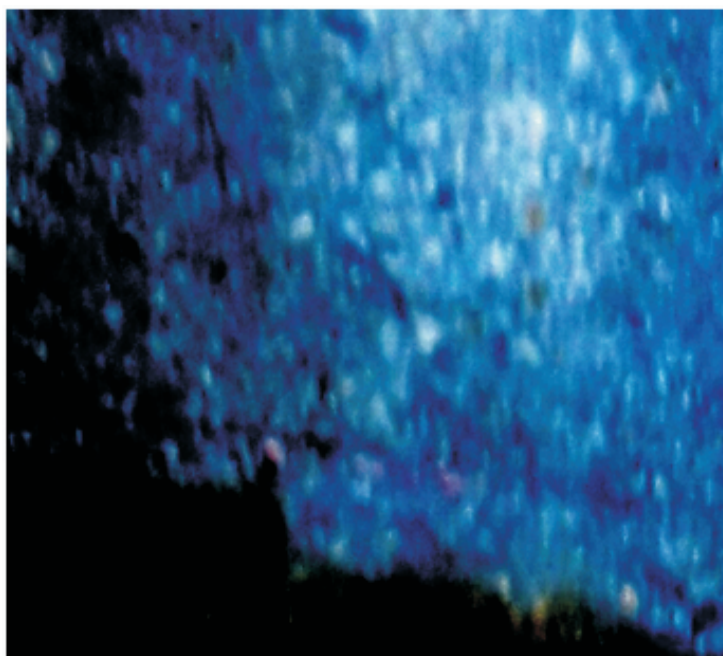


Figure 16- Metal sample after exposure to water sample no-30

References

Burch, S.L. 2004. Groundwater conditions of the principal aquifers of Lee whiteside Bureau and Henry Counties, Illinois State Water Survey.

Khare, R., Mukherjee, A.K. and Singh M.M. 1995. The effect of addition of HCl on the corrosion behaviours of 304SS in cocentrated H_3PO_4 at different temperature", Bulletin of Electrochemistry. vol 11, (10), p 457.

Khare, R., Singh, M.M. and Mukherjee, A. K. 2002. The effect of temperature on pitting corrosion of 316SS in concentrated phosphoric acid containing hydrochloric acid. Indian Journal of Chemical Technology, vol 9 no 5, p 407.

Khare, R. 2012, Surface analysis of steel samples polarized anodically in H_3PO_4 -HCl mixture by SEM and EDAX technique

International Journal MANTHAN, vol 13, pp22-25.

Khare, R. 2016. Studies on pipeline corrosion under the influence of aggressive ions present in drinking water supplied in some areas of Patna city. International Journal of Emerging Technologies in Computational and Applied Science, Vol 16-153, pp 63-67.

Makar, G.L. and Tromans, D. 1995. Pitting corrosion of iron in weakly alkaline chloride solutions, Corrosion Science, Vol 52 no. 4, pp250-261.

Selvakumar, S., Chandrsekhar, N. and Kumar G. 2017. Hydrogeochemical characteristic and groundwater contamination in the rapid urban development areas of Coibatore, India. Water Resources and Industry, Vol 17 p26-33.

Sukumaran, D. *et al.*, 2015. Ground water quality index of Patna, the capital of Bihar, India. American journal of water resources, Vol 13, No 1, pp17-21