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Pathogen Removal Under the Influence of Iron

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***Abstract*—**Drinking water is one of the most valuable resources available to mankind. The presence of pathogens in drinking water is highly undesirable. Because of the Lateritic soil, the iron concentrations were high in ground water. High concentration of iron and other trace elements could restrict bacterial growth and modify their metabolic pattern as well. The bacterial growth rate reduced in the presence of iron in water. This paper presents the results of a controlled laboratory study conducted to assess the inhibition of micro-organism (pathogen) in well waters in the presence of dissolved iron concentrations. Synthetic samples were studied in the laboratory and the results compared with field samples. Predictive model for microbial inhibition in the presence of iron is presented. It was seen that the bore wells, open wells and the field results varied, probably due to the nature of micro-organism utilizing the iron in well waters.

***Keywords*—**Disinfection, Disinfectant, Iron, Laterite.

I. Introduction

LATERITIC soils constitute an important group of soils in the coastal districts of Karnataka, India. Inadequate disposal schemes of solid and liquid wastes have resulted in massive pollution of soil and groundwater in the coastal districts of the west coast of India. Substantial releases of leachate from dump yards (landfills without top and bottom impermeable layers) and rainfall runoff from agricultural fields have resulted in extensive contamination of ground waters. A study was conducted to determine the effectiveness of lateritic soil in removal of organic matter from ground water. The study area is situated in southwest coast of India (Latitude 12° 52'N, Longitude 74° 49'E). Large areas of land are currently used for open dumping purpose. The high precipitation (3500 mm annually) in this region coupled with open dumping increases the chance of soil and ground water pollution.

In connection with any possible applications, knowledge of the geotechnical properties and behavior of contaminated soil is required. Past work [2],[5],[6],[8],[9],[10],[11],[14],[16],[17],[18],[20],[21] has shown that some types of contaminants change the properties of their host soils and this behavior has been shown to be dependent on the concentration of the contaminant solution. Open dumping is extensively practiced in India. The leachate generated from such landfill sites pose serious environmental risks to the surroundings by causing contamination of soil and groundwater systems.

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Laterite and its Properties

Laterite is a red colored, acidic soil common in tropical region. High iron clay formed in tropical areas. Laterites and lateritic soils have a very important place in civil engineering activities in South and Central parts of India. It is mainly used as building material. These are formed in tropical/sub tropical environment where just about all the original rock has been eroded, dissolved, weathered, leached away leaving only those soil components that are really insoluble. Lateritic soils are predominantly coarse grained and are ferruginous in character. These soils are composed of essentially of hydrated aluminium and iron oxides with small quantities of silica, manganese and titanium oxides[19]. Laterite is a pedogenic and highly weathered natural material formed by the concentration of hydrated oxides of iron and aluminium, further oxidized to form an insoluble precipitate of fine particles. Further concentration and dehydration and subsequent cementation forms hard concretionary nodules or the coalescence of particles into a hard vesicular mass of honeycomb structure where cavities may contain the host soil.

Table I shows the common chemical composition of the Indian laterite [15].

TABLE I
CHEMICAL COMPOSITION OF INDIAN LATERITE IN GENERAL

Sl. No.	Constituents	Percentage
1.	Alumina (Al_2O_3)	30 – 60
2.	Ferric Oxide (Fe_2O_3)	20 – 40
3.	Silica (SiO_2)	15 – 30
4.	Manganese oxide, Titanium oxide, etc.	01 – 05

Laterite is also known by the following names: Brick stone (India), Cabook (Ceylon), Canga (Brazil), Carapace (France), Cuirasse (France), Eisenkruste (Germany), Iron clay (India), Ironstone (Nigeria), Krusteneisensteine (Germany), Laterite (India), Mantle rock (Ghana), Moco de hierro (Venezuela), Murram (India, East Africa), Picarra (Brazil), Pisolite (Australia), Plinthite (USA) and Ferricrete (southern Africa).

Mangalore is one of the oldest cities on the west coast of India, located at 12°52'N latitude and 74°53'E longitude. Mangalore is situated on the west coast of India, and is bounded by Arabian Sea to its west and the Western Ghats to its east. The urban population is 4,19,306. The geology of the city is characterized by hard laterite in hilly tracts and sandy soil along the seashore. The percapita water supply in the city is 135 Litres/Capita/day, as claimed by Mangalore City Corporation [12]. The increase in population is increasing the demand for quality water, which has forced many to own wells or bore wells. Hence the water quality is of prime importance with health point of view. The study areas are selected in and around the mangalore city. The interaction with the residents in the locality revealed that the water supply pipelines are old, and many new high rise apartments have been constructed in the past few years, which has increased the water demand in this area. Apart from domestic use the water is also used for the industrial purpose, washing vehicles, washing clothes in washing machines, watering the garden etc., and has resulted in the shortage of water supply. This has forced many of the residents to go for deep bore wells as some open wells. Elevated iron concentrations (>0.04mg/L) upto 18.50mg/L were observed in the ground water at many places within the Mangalore Urban Development Area during post monsoon season of October-November 2006 [13]. Earlier tests on ground water quality in the current study area in Mangalore also indicated the presence of iron, with levels above permissible limit (greater than 1.0mg/L), for iron in drinking water according to Indian Standards [3]. Total Coliform (>30CFU/100ml) upto 1675CFU/100ml were observed in the ground water samples which are collected from the above mentioned places [13]. Earlier tests on ground water quality in the current study area in Mangalore also indicated the presence of Coliform, with levels above permissible limit (greater than 10CFU/100ml), for Coliform in drinking water according to Indian Standards ([)] The aim of disinfection is to reduce the number of microorganisms to a safer limit. The disinfection of potable water and wastewater provides a degree of protection from contact with pathogenic organisms including those causing cholera, polio, typhoid, hepatitis and a number of other bacterial, viral and parasitic diseases.

Elemental iron, Fe(0), can adsorb and inactivate viruses in water, presumably by serving as a precursor of ferrous and ferric oxides and hydroxides, many of which are known to remove and inactivate viruses. continuous-flow column packed with sand and Fe(0) is used for the removal and Deactivation of viruses. The more than 10-fold increase in virus removal was attributed to production of new adsorption sites (i.e., iron oxides) through continuous Fe(0) corrosion in water. viruses are removed and inactivated by Fe(0) probably via interactions with corrosion products, such as magnetite and dissolved Fe(II), under anoxic conditions. High concentration of iron and other trace elements could restrict bacterial growth and modify their metabolic pattern as well. The bacterial growth rate reduced in the presence of 0.5 mM/L concentration of Fe^{+2} or Fe^{+3}, in comparison with control and the growth of bacteria was inhibited by 1 mM/L concentration of iron. So in this paper the disinfection methods were compared under the influence of iron.

With these aspects in mind, a study was conducted to assess the different pathogens removal Techniques under the influence of iron for the synthetic water sample, and to arrive the best pathogens removal technique at a low cost effective techniques.

II. Methods And Materials

The disinfection of the synthetically prepared water samples by chlorine and potassium permanganate under the influence of iron was studied. All the laboratory reagents were prepared as per Standard Methods [1]

Stock Solution Preparation

Raw sewage collected from a nearby sewage treatment Plant was used to prepare the stock solution of samples. The water was kept in the water tank for seven or eight days. Distribution systems are vulnerable to microbial contamination. Residual chlorine concentrations of approximately 0.2-0.3 mg/L are often maintained in distribution systems. Hence the collected water from the tap was stored in water tank for seven days. After the seventh day, the water sample was seeded by the addition of raw sewage. The samples were prepared with three different densities of microorganisms. The nutrients such as magnesium sulphate solution, calcium sulphate solution and phosphate buffer solution were added to the water sample [1]. The seeded water samples were checked after two days for the microbial growth. The initial Most Probable Number (MPN) of the water samples was checked to find out the density of the microorganisms. The Laboratory iron stock solution was prepared by using ferric chloride. The water samples with different iron concentrations (0-1.5mg/L of Fe in the interval of 0.25mg/l) were prepared. The water samples were kept for two days contact time. The iron content, pH, ammonia nitrogen, available chlorine and MPN values were calculated for the water samples containing iron after the two days.

Disinfection with Chlorine

Chlorine solution was prepared by using the sodium hypochlorite solution for the disinfection. Different chlorine dosages (0 to 7.5mg/L of Cl_2 in the interval of 0.5mg/l) were added to each bottle. After adding those bottles were kept under the dark place immediately. The contact time maintained for this chlorine disinfection was 30min. After the contact time, those samples were taken to find out the residual chlorine [1]. The chlorine demand was found out by plotting the graph between the chlorine dosage added to the water sample and the residual chlorine. The above procedure was repeated for the other water samples containing different iron concentration.

Field Samples

Field sampling was done in eight locations in and around the Mangalore City. Samples were taken from bore well and open well. The sampling was done in the month of February and March. The collected samples were analyzed in the laboratory of National Institute of Technology, Karnataka, Surathkal for iron and presence of pathogen in water.

III. Results And Discussions

The effect of disinfection in the presence of iron was studied at three microbial densities : MPN values of 900, 90 and 27 per 100 ml. This gave a range of values which were normally observed in the field. Table 2 shows the results of the tests conducted on water samples containing initial MPN of 900 per 100 ml. The pH, ammonia nitrogen and MPN were determined for water samples after a contact time of 2 days. The percentage removal of the microorganisms was then calculated to check the influence of iron on the pathogens removal without any other disinfection. After this period of two days, the iron concentration in the sample was increased and the characteristics studies again. The MPN value with 0 mg/l iron and 0 contact time was 900index/100ml. After two days contact time the MPN value was still 900 per 100ml. This indicates that the MPN value of the water sample did not change. The MPN value of the water samples started decreasing as the iron concentration started increasing. The percentage removal of pathogens of the water samples with various iron concentration were calculated. The results are shown in Fig. 1. The trend equations of pathogen removals along with the coefficient of determinations are given in table 3. The coefficients in the trend equations were correlated with the initial MPN values. Both the coefficients showed linear variation with the initial MPN values (Equations 1 & 2).

$$\text{Coefficient 'a'} = -15.502\,(\text{Initial MPN Value}) + 64.975 \quad (R^2 = 0.9974) \tag{1}$$

$$\text{Coefficient 'b'} = -1.6257\,(\text{Initial MPN Value}) + 5.0457 \quad (R^2 = 0.7280) \tag{2}$$

Substituting these coefficient equations (1 & 2) in the equations for trend lines, we can get a relationship between the Concentration of iron in water and the percentage removal of pathogens as follows :

$$\text{Microbial Inhibition, \%} = \left\{3.63\,\text{Ln}\begin{bmatrix}\text{Initial}\\ \text{MPN}\\ \text{Value}\end{bmatrix} - 3.63\right\}\text{Log.}\begin{bmatrix}\text{Iron}\\ \text{Concentration}\\ \text{in water, mg/L}\end{bmatrix} + \left\{15.6\,\text{Ln}\begin{bmatrix}\text{Initial}\\ \text{MPN}\\ \text{Value}\end{bmatrix} - 12\right\} \tag{3}$$

These results are in accordance with the findings of Kalantari [7] that the high concentration of iron helped inhibit the microbial growth of microorganisms. The iron concentration reduced the usage of the disinfectant dosage for the removal of microorganisms. Results obtained here demonstrated that the iron has inhibitory effects on bacterial growth at high concentration and Fe^{3+} is also a toxic substance. These findings are in agreement with results obtained from other studies which indicated that Fe (III) is a toxic substance that appears to act on an extracytoplasmic target of gram negative bacteria [4]. It satisfied the result of the another study also showed that increasing concentrations of Fe^{3+} and some other trace elements significantly decreased the surface hydrophobicity of *E. coli* to uroepithelial cells.

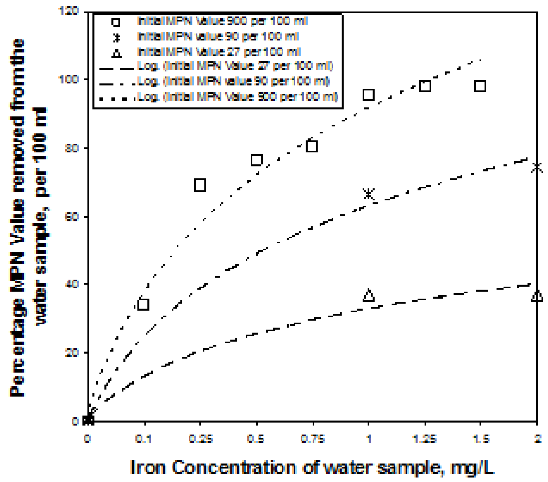

Fig. 1 Variation of percentage removal of pathogens in water sample with different iron concentration after the two days contact time

TABLE II
CHARACTERISTICS OF WATER SAMPLE (CONTAINING 900INDEX/100ML) AT DIFFERENT IRON CONCENTRATIONS AFTER THE CONTACT TIME OF TWO DAYS.

Initial MPN Value	Iron concentration in water sample mg/L	pH	Ammonia Nitrogen mg/L	MPN per 100 ml
900 per 100 ml	0	7.2	1.12	900
	0.1	7.2	0.952	595
	0.25	7.27	0.857	278
	0.5	7.42	0.771	212
	0.75	7.61	0.740	175
	1.0	7.7	0.724	40
	1.25	7.8	0.659	17
	1.5	7.8	0.612	17

Disinfection of Water Sample Under the Influence of Iron.

Disinfection of the water samples was carried out at varying iron concentrations in water using sodium hypochlorite solution. The chlorine demand value was calculated [1] for each water sample with different iron concentration. A 30 minute contact time was maintained. The chlorine demand value decreased exponentially when the iron concentration of the water sample increased (Fig. 2).

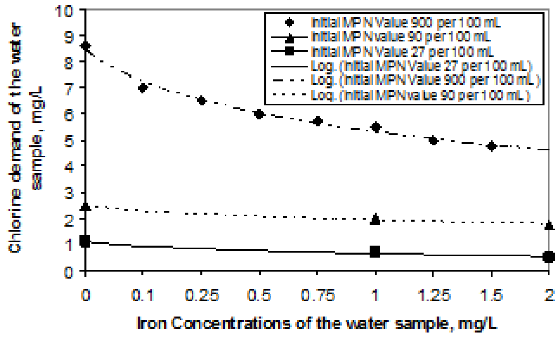

Fig. 2 Variation of Chlorine demand of the water sample with different iron concentration after a contact time of 30 minutes.

TABLE III
PATHOGENS REMOVAL TRENDS IN THE WATER SAMPLE AT VARIOUS IRON CONCENTRATIONS AFTER THE TWO DAYS CONTACT TIME

Initial MPN Value	Equation of trend line (y = a Log. x + b)	R^2
900 per 100 ml	Pathogen removal = 20.54 Log.(Iron Concentration) + 91.2	0.9765
90 per 100 ml	Pathogen removal = 14.18 Log.(Iron Concentration) + 65.6	0.9994
27 per 100 ml	Pathogen removal = 7.35 Log.(Iron Concentration) + 34.3	0.9855

R^2 = Coefficient of determination

Field Analysis

Water samples were collected from different places in and around the Mangalore city. The concentration of iron in different samples is listed in Table 4. All the samples collected from field had high level of iron concentration. The minimum value was 1.40 mg/L (Doctors colony) and the higher value was 8.16mg/L (PG hostel).

The samples collected from different places were disinfected with chlorine in the laboratory and the dosages analyzed. The characteristics of the samples and the chlorine dosage required for the samples are shown in table 5. The results on field samples were slightly higher than the experimental values. In comparison, bore well samples required more chlorine dosage than open well water.

For example the water sample from the Doctor's Colony and the Sample 3 have almost equal iron concentration. But the required chlorine dosage was high in bore well water. Iron exists in soils and minerals mainly as insoluble ferric oxides. Under reducing (anaerobic) conditions, however, the ferric ion is reduced to ferrous ion, and solution occurs without difficulty. The past studies have clearly demonstrated that dissimulator ion-reducing bacteria can use Fe^{3+} as electron acceptors for energy metabolism under anaerobic conditions, leading to formation of the reduced forms Fe^{2+}. More chlorine dosage is required by the bore well sample to oxidize this ferrous form to ferric form.

In open well because of the aerobic condition, the Fe^{2+} was oxidized to Fe^{3+} form. This Fe^{3+} forms in the insoluble form. So it used in the pathogens removal. So the chlorine dosage required was less in the open well. Because of other factors like the nature and concentration of Bacteria and Viruses, the required chlorine dosage varied. But the chlorine dosage required by the field sample decreased while the Iron concentration increased similar to the laboratory experiments. In open wells the chlorine demand value was almost equal while the iron concentration was increased. The obtained results showed that the percentage removal of pathogens varied when the density of the microorganisms was varied. The results are not matching since the source of iron being derived from different sources

IV. CONCLUSIONS

Based on the results of the present investigation and from the available scientific literature, it could be concluded that the percentage of Pathogens removal can increase with the increase in iron concentration in the water sample and the microbial growth in the water sample can be inhibited by the presence of high iron concentration. Predictive models for the inhibition of microbial growth in the presence of iron concentration have been presented.

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TABLE IV
IRON CONCENTRATION IN WATER SAMPLES FROM FIELD

Name of area	Type of Well	Iron, mg/L	pH	NH_4-N, mg/L	Chlorine dosage, mg/L	MPN per 100ml
Venkate-swara colony	Bore Well	5.79	6.19	0.021	0.2	170
Campco staff quarters	Bore Well	2.47	6.13	0.013	0.125	80
MRPL near katipala	Bore Well	2.59	6.42	0.017	0.25	110
Hotel srinivas	Bore Well	2.42	6.01	0.049	0.5	220
Doctors colony	Bore Well	1.40	6.37	0.134	1.5	220
PF staff quarters vamanjoor	Open Well	2.75	6.52	-	-	-
PG hostel	Open Well	8.16	6.51	-	-	-
Professor quarters	Open Well	2.76	6.24	-	-	-
Derabail konchadi girinagar 1st cross	Open Well	4.15	6.21	-	-	-
Derabail konchadi girinagar 6th cross	Open Well	2.82	6.32	-	-	-
Sample 1	Open Well	0.2	6.43	0.005	0.07	50
Sample 2	Open Well	1.1	6.32	0.015	0.15	110
Sample 3	Open Well	0.45	6.35	0.007	0.08	60

TABLE V.
COMPARISON OF THE FIELD SAMPLE WITH THE LABORATORY RESULTS

Name of area	Iron conce-ntration, mg/L	MPN Index per 100ml	Chlorine dosage required in laboratory, mg/l	Chlorine dosage required for the field sample, mg/l
Venkateswara colony	5.79	170	2.6018	0.2
Campco staff quarters	2.47	80	1.8401	0.125
MRPL near Katipala	2.59	110	2.2414	0.25
Hotel Srinivas	2.42	220	3.1501	0.5
Doctors colony	1.40	220	3.3060	1.5
Sample1	0.2	50	1.4722	0.07
Sample 2	1.1	110	2.4091	0.15
Sample 3	0.45	60	1.6703	0.08