Defence Life Science Journal, Vol. 7, No. 1, January 2022, pp. 33-39, DOI : 10.14429/dlsj.7.17342

A Modified Non-Electrical Filter for Decontamination of Iron Rich Water for Rural Application

Iohborlang M Umlong*, Dhiraj Dutta, Rama Dubey and Sanjai K. Dwivedi
DRDO-Defence Research Laboratory (DRL), Tezpur - 784 001, India
**E-mail: iohbor2002@gmail.com*

ABSTRACT

A non-electrical filter is designed to cater the need of providing iron free water in forward and rural areas. The features of the unit are equipped with the aeration system and activated sand chemically coated by iron oxide as catalytic and filtering media which can bring down iron concentration from 12 mg/L to desirable limit. It increases the pH of water from acidic to pH above 7. This is in contrast to some indigenous water filter which existed in the North Eastern India that tend to remove iron below 4 mg/L. The modified filter is effective in reducing excess total dissolved solids (TDS) from drinking water. All other physical parameters found to be within the prescribed limit. It can give iron free water with output capacity of 25L/hr. The added advantage of the unit is the provision for back washing of the filter media and collection point of the precipitated iron at the lower bottom of the tank for safe discharge.

Key words: Water filter; Iron; Physical parameters; Non-electrical; pH

1. INTRODUCTION

North Eastern states of India comprise of eight states namely Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura. The weather of the region varies from hot and humid in the plains and cold and dry in the hilly areas. The region receives very heavy rainfall during the monsoon season. The region is very rich in mineral resources, petroleum and petroleum products, biodiversity hot spot of India and rivers like the Brahmaputra, the Surma, Kameng, Byrni, Subansiri, Lohit and many other small rivers are either originating or flowing through the region. It is very rich in water resources with surplus electricity generated from hydropower stations spread across the region. But its difficult terrains and varied landscapes make the region not susceptible to tap the rich surface water resources for consumption.

The main drinking water sources are shallow dug well, deep tube well, open well, ring well, spring, stream, river etc. Drinking water scarcity exists in the region especially the hilly terrains which mainly depend on surface water and rainwater for drinking purpose whereas in the plains the drinking water sources are mainly from ground water.

In plains of Assam there is heavy contamination of iron with a maximum recorded 21 mg/L (ground water source from deep tube well)[1-3]. Recent study on iron contamination in the hilly areas found to be very less as compare to the plain areas as the source of drinking water in the hilly areas is mainly surface water from spring, streams and rain water[4].

Iron is one of the essential element being used by almost all living organisms and it actively participates in various metabolic processes, like oxygen transport, deoxyribonucleic acid (DNA) synthesis, and electron transport. However, as iron can form free radicals, its concentration in body tissues must be tightly regulated because in excessive amounts, it can lead to tissue damage[5]. Presence of iron beyond the prescribed limit may also lead to many health complications[6].

Iron in water is of different types- soluble ferrous hydroxide, ferrous bicarbonate, organic, colloidal iron and insoluble ferric hydroxide which appear red in water. The soluble iron when exposed to atmosphere appear rusty red or yellowish in colour due to oxidation by the atmospheric oxygen forming ferric hydroxide

Study on the removal of iron using charcoal prepared from bamboo[7], removal of iron along with arsenic by adding cooking soda (sodium bicarbonate), potassium permanganate and ferric chloride solution was also reported to remove iron and arsenic from water[8]. Researchers tried sand as filter and with time the sand layer get coated with iron oxide for removal of iron[9], slow sand filter by researchers as a biological process to remove iron and manganese from water was reported[10]. Variation in temperatures also vary the removal capacity of iron which favours warm temperature when sand filter was used[11], removal of high iron concentration using some biofilters for low temperature condition[12-15]. A household scale filter to remove iron, bacteria, manganese and arsenic was also developed but flow rate is very low[16].

In this study we present the recent water quality study in the selected location and conducted a study on the iron removal capacity of the existing indigenous filtration system used by the villagers as compare with our modified non-electrical filter to improve the removal capacity by improving

---

Received : 19 July 2021, Revised : 09 December 2021
Accepted : 24 December 2021, Online published : 21 January 2022

the contact time of water with the filtering media by allowing the gravity flow of water followed by up flow against gravity in the modified non electrical filter unit for better removal of iron. Other features of the modified filter are the provision for back washing and collection of the concentrated iron precipitation for safe discharge.

2. METHODOLOGY

2.1 Materials

Physical parameters were analysed using multi-parameters (Eutech Instruments-CD650), pH (Eutech pH-620) Turbidity (Eutech instrument, TN-100), iron was analysed by double beam UV-Vis (Analytik Jena, Spectro-205) at maximum wavelength of 510nm. Stocks of different solutions were prepared using type-I water having a conductivity of 18 μS cm^{-} (Elga, Purilab Option Q). Lime stone were collected from Mawlong limestone mining site (Meghalaya) and crushed into small pieces of size about 4mm (approx.). Lime water was prepared by mixing 5 gram of locally available lime powder (calcium oxide) in 5 litres of water. All other chemicals used in the study were of analytical grade and were used without further purification.

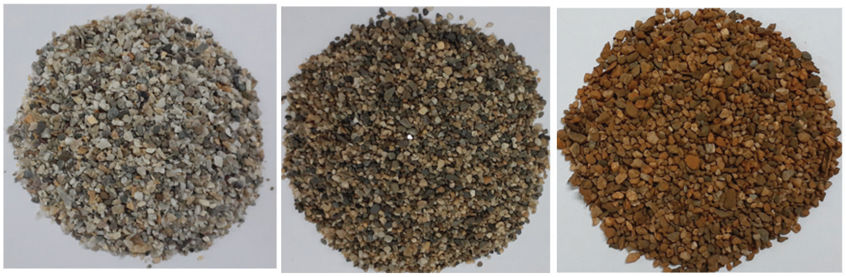
2.2 Experimental Setup

The experimental setup for the actual indigenous filter was conducted for comparison purpose. The water from the well (using electrical pump) was poured onto the filter. The filtered water was collected from the outlet at the bottom of the filter (Fig. 2). The analysis of different parameters of the water quality before and after treatment were analysed in the laboratory.

The modified non-electrical filter was fabricated to enhance the iron removal capacity. The modified filter is shown in Fig. 3 (Patented as 'water purifier')[17]. The raw water was first aerated and then passed through the catalytic reacting cell in the first chamber containing the activated sand. The water is then passed through gravity flow in the first chamber containing the activated sand and then against gravity flow passing through gravel of limestones, filter sand to the filtered water chamber (Fig. 4) and the iron free water is collected from the tap.

2.3 Preparation of Iron Oxide Coated Sand

The river sand of particle sizes between 0.1 mm to 1.4 mm was repeatedly washed with tap water till the runoff was clear. It was then sun dried. About 200 g of ferrous sulphate heptahydrate was dissolved in 10 Ltr of water. The previously washed river sand was taken in a flat container and to it small volume of ferrous solution was sprinkled onto the sand. It was allowed to dry in the sun. After drying, again small volume of ferrous solution was sprinkled and again allowed to dry. The process was repeated till the sand turned to light reddish colour indicating that iron is coated onto the sand surface (Fig.1 (b)).



(a) Uncoated sand (b) Coated sand (c) Used coated sand

Figure 1. Showing (a) uncoated, (b) coated and (c) used coated sand.

2.4 Indigenous Filtration System

The indigenous filter which existed in the rural areas of the plain region of Assam (Fig. 2) has come up with different designs and shapes. With changing time, some structural changes also occur from cotton cloth to earthen pot and then to concrete structure. Despite changes in structural materials and shape, the filtration media almost remain the same. The main components of the indigenous filtration system are given in Fig. 2.

Lower part of the filter is filled with the broken brick pieces of different sizes between 25 mm to 55 mm. On top of which is the sand layer with sizes varying between 0.1 mm to 1.4 mm. This layer covers most part of the filtration system. On top of this layer some burnt charcoal is placed. One interesting observation is that the top layer of filter sand found to be reddish brown in colour indicating that iron oxide is coated on the sand.

Figure 2. Indigenous water filtration system (Concrete based).

2.5 Modified Non-Electrical Filter

The modified filter[17] is intended to improve the removal of more than 98 per cent of iron from water, to reduce the turbidity and TDS of water to desirable limit and is designed in such a manner so as to include the aeration system, the pH adjustment system and the catalytic conversion of iron from +2 state (water soluble state) to +3 state (water insoluble state).

The system was fabricated using steel sheet keeping in mind that the unit can be modified in future if need arises. The system consists of a rectangular shaped as shown in Fig. 3 with the upper part consists of the aeration system, the cover of the aeration system and lower part is the main tank. In the main tank there is a reactor chamber, the filtration chambers and the filtered

Figure 3. Non-electrical filtration system for iron removal (stainless steel).

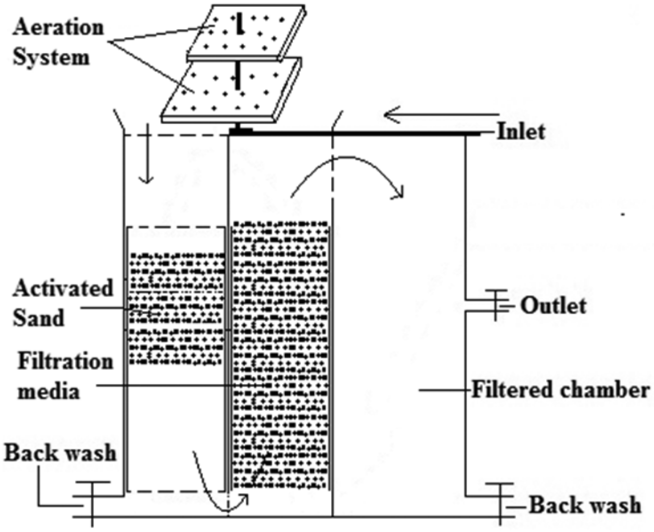


Figure 4. Schematic diagram of steps for iron removal mechanism.

water chamber. The order of water flow is schematically given in Fig. 4.

2.6 Desorption Studies

Desorption study was conducted by dissolving 10 g of the iron coated sand in 4.1 mL of concentrated HCl then immediately diluted with 45.9 mL of distilled water to adjust the acid concentration to 1M. (Direct dissolving the iron oxide from the coated sand using 1M HCl was not successful). Fresh iron coated sand as well as coated sand after repeatedly used in the experiment were taken for desorption study. The concentration of desorbed iron from coated sand before and after use was measured using UV visible spectrophotometer at wavelength of 510 nm.

3. RESULT AND DISCUSSION

3.1 Online Experiment

Iron rich water from the well of concentration 4.2 mg/L is passed through the filtration system of both indigenous as well as modified non-electrical system.

In both the process the soluble iron (II) get oxidised to insoluble iron (III). In the indigenous filtration system, the iron (III) gets accumulated along with the filtration sand in the form of iron (III) hydroxide. The iron (III) hydroxide when expose to sunlight and in contact with air get converted to iron oxide and settle on top of the filtration sand. When the iron rich water from the tube well is passed through the filtration system, the iron concentration of the filtered water found that the iron content is very much reduced with almost 78 per cent iron removed. Turbidity and the TDS were also found to decrease. The iron concentration in the filtered water was found to be 0.92 mg/L, a total reduction of almost 3.28 mg/L from 4.2 mg/L raw water (Table 1).

Table 1. Comparison of raw and treated water using indigenous water filter and non-electrical filter at low iron concentration

Parameters	Raw water-1	Treated water	
		Indigenous filter	Modified non-electrical filter
Iron onc (mg/L)	4.2	0.92	Trace
pH	6.6	6.7	7.2
Turbidity (NTU)	44.3	1.0	0.0
TDS (mg/L)	254.0	98.63	137.1
Electrical conductivity (µS/cm)	243.1	96.18	132.4
Salinity (mg/L)	213.5	97.84	135.3
Total Hardness (mg/L)	45.0	40.5	75.0
Dissolved Oxygen (mg/L)	5.35	6.10	6.11

Further, to optimise the removal capacity of the non-electrical filter system, the raw water was further spiked with external iron solution to vary the concentrations of iron. Removal of iron using both the units are given in the Table 2. It can be seen that the iron removal capacity of the non-electrical filter system is far better than the indigenous unit. This is expected as there is a limitation on the indigenous unit such as (i) The iron contaminated water is less exposed to air (oxygen) while passing through the indigenous filter (ii) Provision for pH adjuster is not available. Our findings on the effect of oxygen on the removal of iron as well as the increase of pH from acidic pH to slightly alkaline pH indicate that both the parameters enhanced the removal of iron. Considering these points, the non-electrical system was provisioned for pH adjuster (using limestones chips and lime water) and aeration system.

The result on iron removal using the modified non-electrical system found to be more than 99 per cent iron removal when the raw water is 4.2 mg/L, 8.1 and 12.2mg/L (Table 1 and 2) and the comparison is depicted in Fig. 5.

Table 2. Showing the removal of higher concentration of iron

Parameters	Raw water 2	Treated water		Raw water 3	Treated water	
		Indigenous filter	Modified non-electrical filter		Indigenous filter	Modified non-electrical filter
Iron conc. (mg/L)	8.1	1.4	Tr	12.2	1.9	0.27
pH	6.5	6.6	7.1	6.6	6.5	7.2
Turbidity (NTU)	36.4	0.33	1.87	46.6	0.67	2.3
TDS (mg/L)	351.3	135.14	155.3	488.3	255.1	335.3
Electrical conductivity (µS/cm)	339.2	173.7	201.4	405.5	301.6	359.4
Salinity (mg/L)	321.5	159.2	154.2	394.3	250.4	332.8
Total Hardness (mg/L)	55	25.5	75.5	105	55.0	75.5
DO (mg/L)	4.71	6.34	7.12	4.57	6.27	7.26

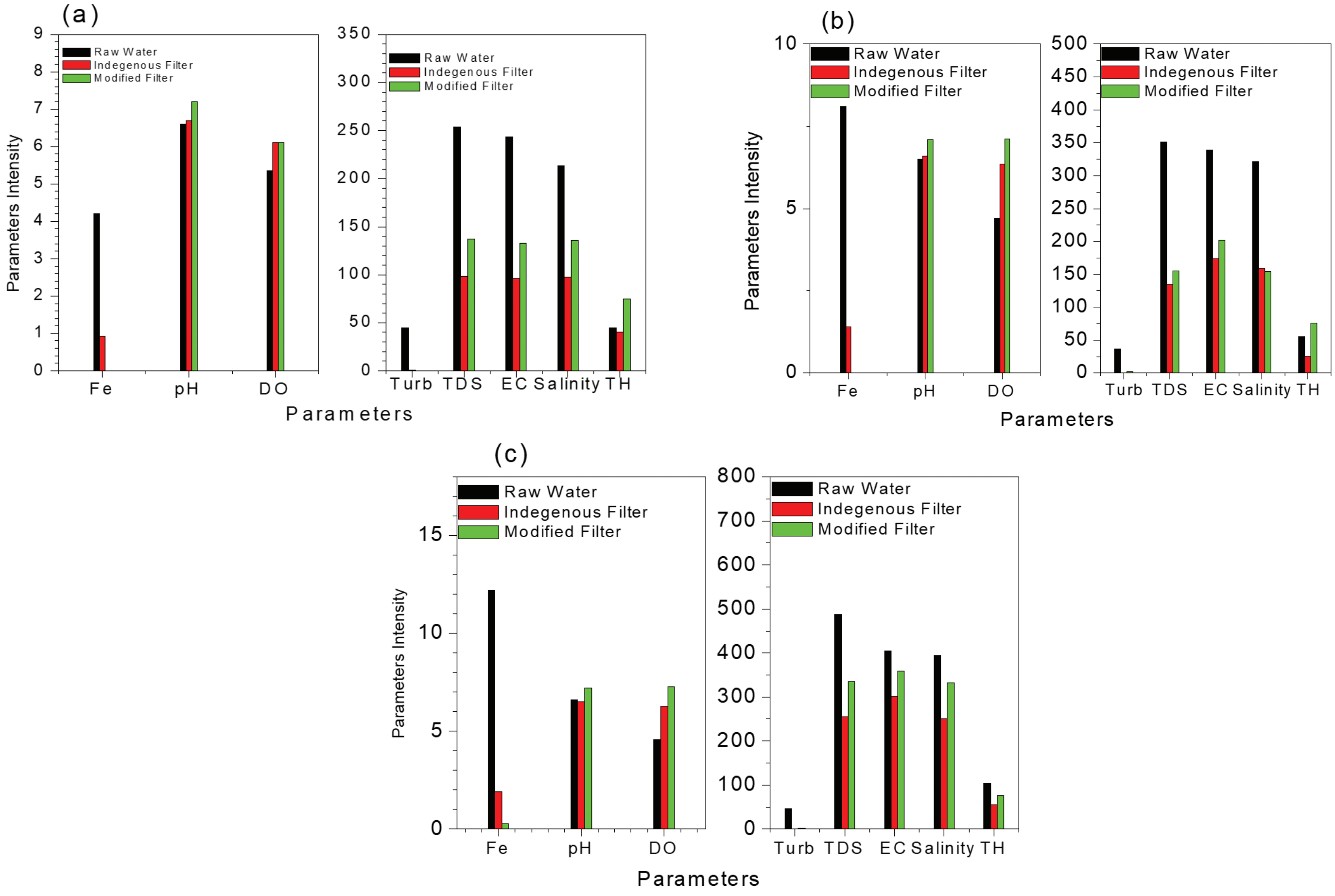


Figure 5. Comparison of the variation of different parameters of raw water with indigenous filter and modified filter (a) Raw water 1 (iron con: 4.2mg/L); (b) Raw water 2 (iron con: 8.1mg/L); (c) Raw water 3 (iron con: 12.2mg/L) (DO: dissolved oxygen (mg/L); Turb: Turbidity, EC: Electrical conductivity; TH: Total hardness).

3.2 Mechanism of Iron Removal

3.2.1 pH Adjuster

The dependence of oxidation on the rate of $[OH]^-$ to convert iron (II) to insoluble iron (III) depends on the pH of water. At lower pH value of less than 4.5, there is marked decreased in the oxidation of ferrous ion to ferric ion. As the pH increases, the oxidation also increases sharply. Lime water is mainly used to adjust the water from acidic pH to slightly alkaline pH value of up to 7.5. by adding drop wise during the aeration period. Care was taken not to exceed pH beyond 7.5 to minimise the TDS and turbidity in the treated water.

Reaction

$$CaO + H_2O = Ca(OH)_2$$
$$Fe^{2+} + 3OH^- = Fe(OH)_3$$

3.2.2 Aeration System

The rate of oxidation of iron II by oxygen is the first order in the concentration of ferrous ions and oxygen and second order in the concentration of hydroxide ion at pH value between 6.0 and 7.5. The reaction took place very rapidly at a pH greater than 6.5[18]. Deferrisation treatment of water employs the rapidity of the oxidation reaction in order to remove the influent soluble iron (II) to insoluble iron (III) as hydroxides precipitate.

Reaction

$(4\ Fe^{2+} + O_2 \rightarrow 4\ Fe^{3+} + 2\ O^{2-})$ (Slow)

$Fe^{3+} + OH^{-} = Fe\ (OH)_3$ (Fast)

3.3 Filtered Sand as Source of Iron Oxide

The soluble ferrous ions present in water when in contact with iron oxide gets oxidised to ferric ions and in presence of hydroxyl ions get precipitated to iron (III) hydroxide. The filtered sand after two to three days gets coated with iron oxide. The ferrous ions when oxidised to ferric ions gets settled on the surface of sand and slowly coated the sand making the sand surface reddish in appearance.

Reaction

$4Fe^{2+} + 6H_2O + 3O_2 = 4Fe\ (OH)_{3(solid)}$

$Fe\ (OH)_3$ dehydrated to form $Fe_2O_3.nH_2O_{(s)}$ which coated on the surface of sand.

3.4 FTIR Analysis

The Fourier transformed infrared spectra of sand, rust iron, iron oxide coated sand and iron precipitated were given in Fig. 6. The absorption band of sand exhibits prominent bands at 467 cm^{-1} and 474 cm^{-1} which is due to Si-O-Si and Fe-O respectively. The Si-O symmetric bonding of sand appeared at 695 cm^{-1}, the band at 796 is due to O-Si-O[19]. The bands at 1022, 1084 cm^{-1} is due to the Si-O bond of quartz[20] and the band at 2343, 2362 is due to C=O stretching from iron carbonate. The FTIR spectra of iron rust shows band at 467 cm-1, 1022, 1629, 2930 and 3437 cm^{-1}. When the sand is coated with iron oxide, the bands exhibit the same wavelength but with decreased in intensity of the percentage transmittance. The FTIR of iron precipitation is also taken and found to be similar with the bands of iron coated sand.

3.5 Desorption Studies

The desorption studies were carried out to ascertain whether the concentration of iron oxide coated on sand will decrease or increase with the repeated usage. The differences of iron concentration desorbed from coated sand before and after use will indicate the life of the iron coated sand. In this experiment it was observed that the iron concentration of the coated sand after use found to be more than 6 times the concentration of coated sand before use, thus increase the life of the iron coated sand and further increase the iron removal capacity. The data of the desorption studies is given in the Table 3.

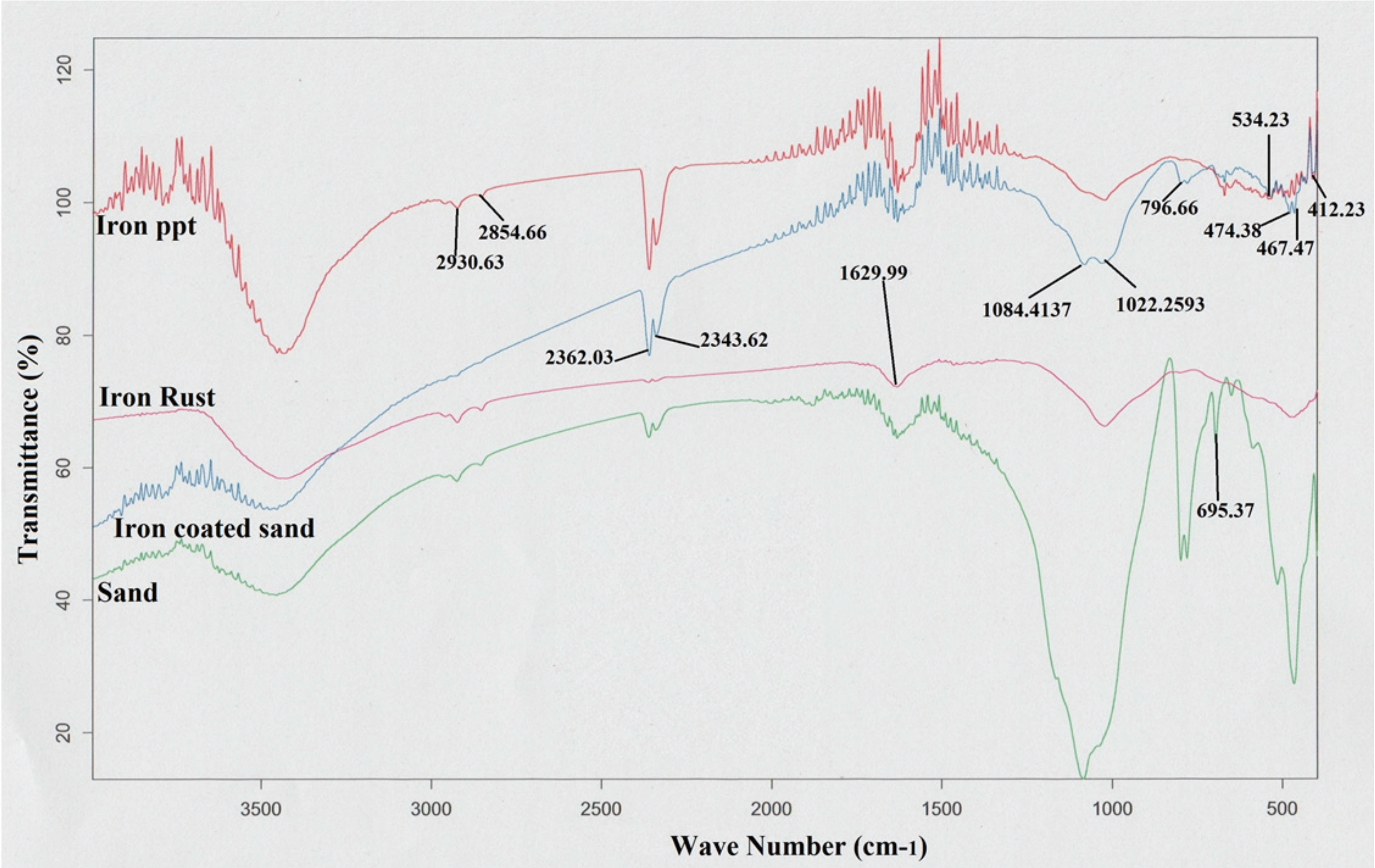


Figure 6. FTIR spectra of sand, iron oxide coated sand, iron adsorbed coated sand and iron rust.

Table 3. The desorption study of iron coated sand before and after used

Particular	Quantity taken (g)	Acid used to dissolve the coated iron	Concentration (mg/L) of released iron from coated sand
Fresh iron Coated sand	10	1M HCl	0.86
Used iron coated sand	10	1M HCl	6

4. Conclusion

The traditional water filter to remove contaminants from water existed in rural areas of NE region of India. It is effective to reduce low concentration of contaminants particularly iron and excess TDS. Iron concentration below 4 mg/L can be removed from drinking water. The modified filter is fabricated with steel sheet and removal capacity up to 12 mg/L of spiked iron concentration can be reduced to desirable limit. pH of filtered water found to be adjusted between 7.1 to 7.6. Physical parameters like turbidity, TDS, total hardness was found to be within the limit. It can run without electrical power and the best flow rate was found to be at 25 L/hr. The modified filter is small in size and can be carried to any location or it can be placed near the hand pump to obtain iron free water.

5. ACKNOWLEDGEMENT

We acknowledged Sh. DC Goswami, Sc. E (retd) and Dr. S Banerjee, Sc 'F' (presently at DMSRDE, Kanpur) for their immense contribution on the study of iron removal from water. Financial support from HQ DRDO, New Delhi is also highly acknowledged.

REFERENCES

1. Das, H.B. & Borah, K. Iron Excess in drinking water of Darrang District of Assam and some adjoining areas. *Def. Sci. J.*, 1983, **33**(1):31-37. doi: 10.14429/dsj.33.6126
2. Bhuyan, B. Assessment of arsenic and iron contamination of ground water in four development blocks of Lakhimpur district of Assam, Der Chemica Sinica, 2011, **2**(4), 316-323] (ISSN: 0976-8505). (Accessed on 06.08.2021)
3. Singh, A.K.; Bhagowati, S.; Das, T.K.; Yubbe, B; Rahman, B.; Nath, M.; Obing, P.; Singh, W.S.K.; Renthlei, C.Z.; Pachuau, L. & Thakur, R. Assessment of arsenic, fluoride, iron, nitrate and heavy metals in drinking water of North Eastern India, ENVIS Bulletin: Himalayan Ecology, 2008, **16**(1), 6-12. (Accessed on 07.06.2021)
4. Umlong, I.M.; Dutta, D.; Saikia, A.; Das, B.; Das, A.; Sarkar, A.; Jadhav. S.; Dubey, R. & Dwivedi S.K. Water quality survey of North East India at a Glance: Excessive Iron Contamination (From 2005 to 2019), Technical Bulletin No. DRDO-DRLT/TB-01/2020,
5. Abbaspour, N.; Hurrell, R.R. & Kelishadi, R. Review on iron and its importance for human health. *J. Res. Med. Sci.*, 2014, **19**, 164-174. (Accessed on 05.05.2021)
6. Chaturvedi, R.; Banerjee, S.; Chattopadhyay, P.; Bhattacharjee, C.R.; Raul, P. & Borah, K. High iron accumulation in hair and nail of people living in iron affected areas of Assam, India. *Ecotoxicol. Environ. Saf.*, 2014, **110**, 216-220. doi: 10.1016/j.ecoenv.2014.08.028_
7. Baruah, B.K.; Medhi, C. & Misra, A.K. Indigenous water filtration technique in rural areas of Assam: A study on iron removal by bamboo charcoals. *The IUP J. Chem. Eng.*, 2011 **3** (2), 61-67. https://ssrn.com/abstract=2056258 (Accessed on 16.10.2021)
8. Bordoloi, S.; Nath, S.K.; Gogoi, S. & Dutta, R.K. Arsenic and iron removal from groundwater by oxidation–coagulation at optimised pH: Laboratory and field studies. *J. Haz. Mat.,* 2013, **260**(15), 618-626. doi: 10.1016/j.jhazmat.2013.06.017
9. Hale, F.E.; Milligan, R.E.; Weston R.S. & Provost Jr., A.J. Iron removal by rapid sand filtration. *J. Am. Water Works Assoc.*, 1916, **3**(1), 123- 141. doi: 10.2307/41224278
10. Fadel, A. & Fadel, H.A. Slow sand filtration: A simple technology for iron and manganese removal - American water works association annual conference and exposition 2010, ACE 2010. (Accessed on 16.10.2021)
11. Kalvani, N.; Mesdaghinia, A.; Yaghmaeian, K.; Abolli, S.; Saadi, S.; Rashidi M.A. & Alimohammadi M. Evaluation of iron and manganese removal effectiveness by treatment plant modules based on water pollution index; a comprehensive approach. *J. Environ. Health Sci. Eng.,* 2021, **2**(19), 1005-1013. doi: 10.1007/s40201-021-00665-2
12. Li, D.; Cao, R.H.; Yang, H.; Wang, L.Y.; Zhang, J. & Zeng, H.P. Removal of high concentration of iron, manganese and ammonia nitrogen from low temperature groundwater using single bio-filter. *Huan. Jing. Ke. Xue.,* 2017, **8** 38(12), 5097-5105. doi: 10.13227/j.hjkx.201705096
13. Zeng, H.; Yin, C.; Zhang, J. & Li, D. Start-up of a biofilter in a full-scale groundwater treatment plant for iron and manganese removal. *Int. J. Environ. Res. Public Health.,* 2019, **16**(5), 698-709. doi: 10.3390/ijerph16050698
14. Sharma, S.K.; Petrusevski, B. & Schippers, J.C. Biological iron removal from groundwater: A review. *J. Water Supply Res. Technol. Aqua.,* 2005, **54**, 239–245. doi: 10.2166/aqua.2005.0022.
15. Yang, H.; Li, D.; Zeng, H.P. & Zhang, J. Autotrophic nitrogen conversion process and microbial population distribution in biofilter that simultaneously removes Fe, Mn and ammonia from groundwater. *Int. Biodeterior. Biodegrad.,* 2019, **135**, 53–61. doi: 10.1016/j.ibiod.2018.09.008
16. Singh, L.; Banerjee, S.; Devi, R.R.; Agnihotri, S.; Umlong, I.M.; Raul, P.K. & Das, B. An Improved water purification system/unit and process for purification/Removal of iron, arsenic, manganese, fluoride and bacteria contaminated water. Indian Patent No 294346 issued date 15.03.2018

17. Dutta, D.; Umlong, I.M.; Saikia, A.; Lama, D.; Dubey, R. & Raju, P.S. Water purifier. Indian design registration No. 305387, issued date 07 May, 2018.
18. Singer, P.C & Stumm, W. Oxygenation of ferrous iron: The rate determining step in the formation of acidic mine drainage. US Dept of the Interior, Water Pollution Control Research Series, Federal Water Pollution Control Admin. Report 1968. (Accessed online on 07.06.2021)
19. Mandel, K.; Straber, M.; Granath, T.; Dembski, S. & Sextl, G. Surfactant free superparamagnetic iron oxide iron nanoparticle for stable nanofluid in physiological solutions. *Chem. Commun.*, 2015, **51**, 2863-2866. doi: 10.1039/c4cc09277e
20. Saikia, B.J.; Parthasarathy, G. & Sarmah, N.C. Fourier transform infrared spectroscopic estimation of crystallinity in SiO_2 based rocks. *Bull. Mater. Sci.*, 2008, **31**, 775-779. doi: 10.1007/s12034-008-0123-0

CONTRIBUTORS

Dr Iohborlang M. Umlong obtained his Ph.D in Surface Science and working as Scientist ‘E’. His present field of work is on water quality, contaminants remediation, etc.
In the current work he planned and conducted the field work, data interpretation and preparation of the manuscript.

Mr Dhiraj Dutta is currently working as scientist ‘D’. His field of work is on material and polymer science.
In the current work he contributed in fabricating of the modified filter unit and analysis of samples.

Dr Rama Dubey obtained her Ph.D. in Polymer Science and working as scientist ‘F’. Her field of interest is on polymer science, synthesis of carbon based graphene, etc.
In the current work she contributed in the design of the field work and help in the manuscript preparation.

Dr Sanjai K. Dwivedi received his Ph.D. in Horticulture from Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand. He is Scientist ‘G’ and Director, DRDO-DRL, Tezpur, Assam. His research area of interest is protected cultivation particularly low cost greenhouse technology, soil less (hydroponic) cultivation of crops, characterisation, propagation and conservation of plant genetic resources of high altitude regions, utilisation of local plant resources for defence purposes and skill/entrepreneurship development etc.
In the current work he has contributed in designing of the study, review of the manuscript and overall supervision.