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Performance of Up-Flow Roughing Biofilter in Iron Removal from Groundwater

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Abstract: Hand pump attachable iron (Fe) removal plants (IRPs) based on up-flow roughing biofilter principle were installed for potable water supply from the tube well water in rural areas containing excess iron. The performances of the IRPs were evaluated for the removal of Fe and Mn (manganese). Desirable modifications were made in IRPs in order to improve the Fe removal capacity and dissolved oxygen content in the treated water in order to make the water suitable for drinking. After desirable modifications in IRPs, it was observed that the iron content reduced up to permissible limit (1 mg/L or less as per BIS: 10500, 1991 standard) in treated water from 3-6.8 mg/L of Fe in raw water. Hand pump attachable IRPs based on up-flow roughing biofilter along with controlled aeration and proper O&M can be used for Fe removal. This may be helpful in appropriate and sustainable water quality improvement in iron-affected areas.

Key words: Iron removal plant · Up-flow roughing biofilter · Permissible limit · Water quality

INTRODUCTION

Iron is one of the earth's most plentiful resources, making up about 5% of the earth crust. Fe and Mn cause aesthetic, organoleptic and operating problems when they are present in groundwater. These metals consume chlorine in the disinfection process and promote biofouling and microbiological induced corrosion in water networks. In groundwater, Fe and Mn are present as Fe(II) and Mn(II). The processes available for their removal are either physico-chemically or biologically based. The advantages of biological treatments compared with conventional physico-chemical treatments can be summarized as: no use of chemicals, higher filtration rates, the possibility of using direct filtration and lower O&M costs [1]. Fe and Mn removal by biological processes are based on different stages of biofiltration where beds are colonized by Fe-Mn oxidizing bacteria.

In nature, iron oxidizing bacteria (IOB) and manganese oxidizing bacteria (MnOB) are widespread. They are prevalent in groundwater, swamps, ponds, in the hypolimnion of lakes, in sediments, soils, wells and water-distribution systems. In the latter they can cause significant clogging problems [2]. These bacteria, present in raw water, can multiply in sand filters under appropriate conditions and are able to oxidize divalent ions Fe(II), Mn(II) and precipitate them into their oxide of Fe(III) and Mn(IV). IOB and MnOB have been recognized for their ability to deposit Fe hydroxide or Mn oxide in structures outside their cells. Many researchers have studied the physiology of these microorganisms and the mechanisms involved [2-5]. However, many aspects of Fe and Mn deposition are still poorly understood. The main groups of IOB are [2, 6].

- Stalked bacteria, e.g. *Gallionella spp*., which are chemolithotrophic and microaerophilic, sheathed bacteria, e.g. *Leptothrix sp., Sphaerotilus*, etc., which are facultative autotrophic-heterotrophic,
- Unicellular bacteria, e.g. *Siderocapsa, Siderocystis*, etc., which are heterotrophic and more difficult to recognize by microscopic observation than the previous ones.

Study Area: Four hands pump attachable Fe removal plants (IRPs) were installed and commissioned in the Karmandi village in Korba district in Chhattisgarh state. These IRPs were evaluated for their performance. Available water quality report of tube wells indicated the presence of Fe in the range of 3.0-6.8 mg/L.

Components of IRP: The IRPs were constructed of RCC (Fig. 1) and comprised of the following components:

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Fig. 1: IRPs installed in Korba

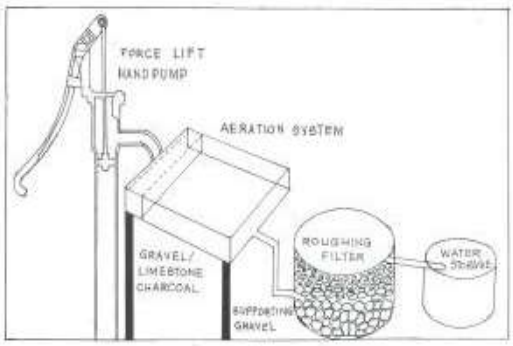

Fig. 2: Up-flow Roughing Filters

Aeration Chamber: It is a rectangular tank of RCC holding gravels of size 20-40 mm. The aeration chamber is placed over the cement platform with a slotted PVC header and lateral pipes embedded firmly to the periphery of the chamber. The aeration chamber receives water through a MS/GI pipe welded to the delivery sprout of the hand pump. In the aeration chamber CO_2 from the water escapes and ferrous iron is oxidized and precipitates. The precipitated hydrated iron oxide forms a coat over the gravels and accelerates subsequent conversion of ferrous iron.

Filter Plant: This is also made up of RCC and has a perforated bottom plate and over it rests 40-50 cm gravel column of 10-20 mm size. Water from aeration chamber enters through the bottom of the filter and flow upward through the filter. The filtered water pass through the pipe attaches to the top of the chamber and get collected in storage tank.

Storage Tank: After filtration, water from filter chamber gets collected in storage tank from which water can be used directly for the household purposes.

Principles of Working of IRP: Roughing filtration is a filtration process through a coarse medium using low filtration rates. It is mainly used as pretreatment in order to retain solid matter before slow filtration [7, 8]. This process has been used successfully as pretreatment to remove turbidity, being subsequently followed by slow sand filtration [9, 10]. Given the high solid retention capability of roughing filtration, this process was considered to be an appropriate treatment for the removal of Fe and Mn from groundwater by means of biological processes. The system proposed in this paper comprises: aeration, up flow roughing filtration and storage.

Aeration / Oxidation: Atmospheric oxygen gets in contact with dissolved ferrous form and oxidizes to insoluble ferric and hydroxide forms. Aeration has two important functions:

- CO_2, H_2S and odour to escape into atmosphere and raise the pH of raw water.
- Increases dissolved oxygen to assist oxidation.

Iron removal is accomplished through oxidation of ferrous iron with atmospheric oxygen when in contact with air and the following reaction takes place:

$$2Fe^{2+} + ½O_2 + 5H_2O \rightarrow 2\,Fe(OH)_3 + 4H^+$$

The production of H^+ in the reaction is not significant. Alkalinity of waters containing Fe is usually sufficient to neutralize the acid. If the alkalinity is below 1 meq/L, raising the pH becomes necessary to ensure conversion of ZFe^{2+} to Fe^{3+}. About 15 minutes are adequate for 90-95% conversion of Fe^{2+} into Fe^{+3}. Ferric form is almost insoluble at neutral pH. This property of iron is utilized in its removal from groundwaters.

Up-Flow Roughing Filter: Up-flow roughing filters (URF) are used as sand filters for removal of course particulate/sediments from water. URF consists of 3 layers of gravels (2-18 mm) with 30 cm depth. These layers rest on the supporting gravels (20-50 mm) in the bottom as shown in Fig. 2. Maintenance of the plant includes backwash of the filters, clearing sludge from sedimentation chamber, removal of slimes and algal growths on the external surfaces, clearance of openings of header and lateral pipes of aeration chamber, correction of leaks.

Biological Activity: The biological Fe removal process is governed by bacteria, which are present in raw water (e.g. *Gallionella sp., Siderocapsa sp., Sphaerotilus sp.*). These bacteria can multiply on sand filter bed under appropriate conditions and oxidize bivalent ions to trivalent (Fe^{3+}) ferric form [11-13]. Biological activity develops in the filter when organic particles are deposited on filter gravel. Biochemical oxidation promotes conversion of organic matter into smaller aggregate.

RESULTS AND DISCUSSIONS

The performances of the IRPs were evaluated during pre-monsoon and post-monsoon seasons. Water samples were collected and analyzed for physico-chemical, heavy metals, biological and bacteriological parameters to assess the water quality of raw and treated water as per standard methods [14]. Lacky's microsect drop method was used for qualitative estimation of phytoplankton and organisms were expressed as number per milliliter. Quantitative estimation of zooplankton was carried out with the help of Sedgwick-Rafter cell.

Performance of IRPs (Pre-Monsoon Season)

Physico-Chemical Parameters: The pH for raw water and treated water were recorded as 6.2-7.0 and 6.7-7.8 respectively (Table 1). Turbidity of raw and treated water was 0.7-3.7 NTU and 0.5-1.4 NTU whereas TDS were 56-221 mg/L and 200-239 mg/L respectively. The alkalinity and total hardness were observed within the desirable limit of BIS standards. For raw water, chloride and sulphate ranged between 16-40 mg/L and 10-12 mg/L whereas for treated water, they ranged between 20-38 mg/L and 8-11 mg/L respectively and observed within the desirable limits [15]. Total PO_4 in raw water and treated water were ranged between 0.1-0.4 mg/L and 0.2-0.4 mg/L whereas NO_3 content was 8-14 mg/L and 10-16 mg/L respectively. For raw water, Na and K values were 13-20 and 10-20 mg/L whereas for treated water their respective contents were 11-16 and 13-22 mg/L.

Heavy Metals: Iron content in raw water from HP-1, HP-2, HP-3 and HP-4 were recorded as 4.8, 4.8, 5.3 and 5.2 mg/L respectively, whereas treated water samples showed Fe within the permissible limit of 1 mg/L as per BIS standard (Table 2). Mn content in raw water and treated water

Table 1: Physico-chemical parameters for water quality

Source	Season	pH	Cond. (uS/cm)	TDS	Turb. (NTU)	T.Alk.	T. Hard.	Ca Hard.	Mg Hard.	Na	K	Cl^-	SO_4^{--}	NO_3^-	PO_4^-
						as $CaCO_3$									
HP-1 R.W.	Pre-mon.	6.8	322	193	5.5	150	103	79	24	19	14	12	9	6	0.2
	Post-mon.	7.0	304	182	2.1	156	132	76	56	18	20	16	10	12	0.1
HP-1 T.W.	Pre-mon.	7.6	350	210	1.0	142	97	70	27	20	10	10	10	10	0.1
	Post-mon.	7.8	398	239	0.5	180	156	112	44	16	22	20	11	10	0.2
HP-2 R.W.	Pre-mon.	6.0	268	161	2.9	140	94	68	26	18	33	24	12	12	0.1
	Post-mon.	6.2	94	56	0.7	132	114	82	32	20	18	22	12	8	0.1
HP-2 T.W.	Pre-mon.	7.2	346	208	1.0	136	121	88	33	10	18	20	10	9	0.3
	Post-mon.	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
HP-3 R.W.	Pre-mon.	6.6	306	184	7.6	152	116	84	32	13	28	22	9	10	0.1
	Post-mon.	6.7	120	72	3.7	150	108	76	32	13	10	22	10	14	0.3
HP-3 T.W.	Pre-mon.	7.6	390	234	4.3	130	100	70	30	14	22	24	10	8	0.3
	Post-mon.	7.5	333	200	0.5	158	100	80	20	11	13	20	8	16	0.4
HP-4 R.W.	Post-mon.	7.0	369	221	1.4	136	144	92	52	13	17	40	12	10	0.4
HP-4 T.W.	Post-mon.	7.1	387	232	1.4	148	148	88	60	14	18	38	9	14	0.3

R.W. – Raw Water; T.W.- Treated Water; Pre-mon. - Pre-monsoon; Post-mon. – Post-monsoon

Table 2: Heavy metal contents in water (mg/L)

Source		Season	As	Zn	Pb	Ni	Cd	Co	Mn	Fe	Cr	Cu
HP-1	Raw water	Pre-monsoon	ND	0.3	ND	ND	ND	ND	0.7	4.8	ND	ND
		Post-monsoon	ND	0.4	ND	ND	ND	ND	0.5	6.7	ND	ND
	Treated water	Pre-monsoon	ND	0.2	ND	ND	ND	ND	0.3	0.7	ND	ND
		Post-monsoon	ND	0.4	ND	ND	ND	ND	0.2	0.6	ND	ND
HP-2	Raw water	Pre-monsoon	ND	0.3	ND	ND	ND	ND	0.9	4.8	ND	ND
		Post-monsoon	ND	0.6	ND	ND	ND	ND	0.9	6.3	ND	ND
	Treated water	Pre-monsoon	ND	0.2	ND	ND	ND	ND	0.4	0.8	ND	ND
		Post-monsoon	ND	0.5	ND	ND	ND	ND	0.3	0.8	ND	ND
HP-3	Raw water	Pre-monsoon	ND	0.4	ND	ND	ND	ND	0.3	5.3	ND	ND
		Post-monsoon	ND	0.4	ND	ND	ND	ND	0.5	6.5	ND	ND
	Treated water	Pre-monsoon	ND	0.4	ND	ND	ND	ND	0.2	0.9	ND	ND
		Post-monsoon	ND	0.2	ND	ND	ND	ND	0.1	0.3	ND	ND
HP-4	Raw water	Pre-monsoon	ND	1.2	ND	ND	ND	ND	0.9	5.2	ND	ND
		Post-monsoon	ND	1.3	ND	ND	ND	ND	0.7	5.7	ND	ND
	Treated water	Pre-monsoon	ND	1.0	ND	ND	ND	ND	0.3	0.8	ND	ND
		Post-monsoon	ND	1.0	ND	ND	ND	ND	0.4	0.9	ND	ND

Table 3: Bacteriological parameters for water quality

	Source		TC (CFU/100 ml)	FC (CFU/100 ml)
HP-1	Raw water	Pre-monsoon	29	ND
		Post-monsoon	24	1
	Treated water	Pre-monsoon	30	ND
		Post-monsoon	48	3
HP-2	Raw water	Pre-monsoon	ND	ND
		Post-monsoon	14	1
	Treated water	Pre-monsoon	NC	NC
		Post-monsoon	NC	NC
HP-3	Raw water	Pre-monsoon	30	ND
		Post-monsoon	ND	ND
	Treated water	Pre-monsoon	40	ND
		Post-monsoon	20	2
HP-4	Raw water	Pre-monsoon	40	ND
		Post-monsoon	23	1
	Treated water	Pre-monsoon	20	ND
		Post-monsoon	28	2

HP - Hand Pump, ND - Not Detected, NC - Not Collected

Table 4: Colony counts of Iron bacteria in water samples of IRPs

		Colony Count / 100 ml			
Source		Raw Water	Backwash	Filter Water	Filter media
HP-1	Pre-monsoon	600	NC	NC	200
	Post-monsoon	450	3500	ND	4700
HP-2	Pre-monsoon	1300	1500	450	1100
	Post-monsoon	6600	350	100	15200
HP-3	Pre-monsoon	1650	1250	350	NC
	Post-monsoon	1200	2400	320	12200
HP-4	Pre-monsoon	950	1600	NC	NC
	Post-monsoon	2400	NC	700	900

NC- Samples not collected

were ranged between 0.3-0.9 and 0.2-0.4 mg/L respectively. The heavy metal content in raw water was within the permissible range of BIS standard except Fe and Mn.

Bacteriological Parameters: Total Coliforms (TC) were detected in three raw water samples i.e. HP-1, HP-3 and HP-4 whereas Fecal Coliforms (FC) were detected only in raw water sample of HP-4 (Table 3). TC were recorded in all the treated water samples and ranged from 20-40 CFU/100 ml which is above the tolerance limit of 10/100 ml whereas FCs were not detected.

Iron Bacteria: Water samples from all the four IRPs were collected for analysis of different groups of Fe bacteria like stalk bacteria, e.g. *Gallionella* sp., sheathed bacteria, e.g. *Leptothrix* sp. *Sphaerotilus* sp.; unicellular bacteria e.g. *Siderocapsa* sp., *Siderocystis* sp., *Siderococcus* spp., *Crenothrix* spp. and *Hyphomicrobium* sp. (Pacini, 2003; Katsoyiannis, *et al*. 2002; Pacini, *et al*. 2005). Keys given in the Standard Test Method for Fe Bacteria [16], Standard Methods [17] and papers by different authors were used for the identification of bacteria [18-19]. Only two groups *Leptothrix* sp. and Sphaerotilus sp. are present in the samples collected from hand pumps. Later group was found to produce black colonies due to presence of sulfur oxidizers. Tentative isolation on *Leptothrix / Sphaerotilus* agar medium / Lab lemco agar reveal that only one or two types of Fe bacteria groups *Leptothrix* sp. *Sphaerotilus* sp. are developed in the filter bed. *Sphaerotilus* sp. was also isolated from filter media beds of HP-1 and HP-2. Minimum value ranged from 200-count/100 ml at HP-1 filter media and maximum from 1650 count/100 ml at HP-3 raw water (Table 4).

Table 5: Biological parameters for water quality

			Phytoplankton		Zooplankton	
Source		Season	Count/ 100ml	SWI	Count/ m^3	SWI
HP-1	Raw water	Pre-monsoon	80	0.2	ND	0
		Post-monsoon	70	0.2	ND	0
	Treated water	Pre-monsoon	ND	ND	ND	0
		Post-monsoon	ND	ND	ND	0
HP-2	Raw water	Pre-monsoon	60	1.1	ND	0
		Post-monsoon	50	1.0	ND	0
	Treated water	Pre-monsoon	NC	NC	NC	NC
		Post-monsoon	ND	ND	ND	0
HP-3	Raw water	Pre-monsoon	40	0.7	ND	0
		Post-monsoon	50	0.8	ND	0
	Treated water	Pre-monsoon	ND	ND	ND	0
		Post-monsoon	ND	ND	ND	0
HP-4	Raw water	Pre-monsoon	50	0.1	ND	0
		Post-monsoon	40	0.2	ND	0
	Treated water	Pre-monsoon	ND	ND	ND	0
		Post-monsoon	ND	ND	ND	0

HP - Hand Pump, ND - Not Detected, NC - Not Collected

Biological Parameters: Biological diversity of phytoplanktons in raw water ranged between 40-80 count/100 ml (Table 5). Phytoplankton was not detected in treated water. SWI was recorded up to 1.1 which indicates moderate pollution. Zooplankton was not detected in any of the water sample.

Performance of IRPs (Post-Monsoon Season)

Physico-Chemical Parameters: There is no significant change in physicochemical parameters of groundwater from the four sources. The water quality parameters were observed within the permissible range of BIS standard for drinking water.

Fig. 2: Leptothrix sp. / Sphaerotilus sp. colonies on LSA medium

Heavy Metals: Iron content in raw water from HP-1, HP-2, HP-3 and HP-4 was 6.7, 6.3, 6.5 and 5.7 mg/L respectively whereas in treated water Fe contents were within the permissible limit of 1 mg/L as per BIS standard (Table 2). Mn content in raw water and treated water were ranged between 0.5-0.9 and 0.1-0.4 mg/L respectively. Heavy metal contents in raw water were within the permissible limit [15] except Fe and Mn.

Acteriological Parameters; TC and FC were detected for raw and treated water samples of HP-1, HP-3 and HP-4 (Table 3). HP-2 water sample was not collected for bacteriological analysis because the plant was not in working condition. For treated water TC and FC were ranged from 20-48 and 2-3 CFU/100ml respectively which were above the tolerance limit [15].

Iron Bacteria: Iron is commonly observed in reduced (Fe^{2+}) states in groundwater and represents the soluble and mobile forms. As water lifted up through tube well to storage tank, frequently iron gets oxidized to Fe^{3+} species and comes in contact with sheath forming iron bacteria and precipitated ferric salts on its sheaths. *Leptothrix discophora/ Sphearotilus natans* are sheath-forming bacteria and characterized by the precipitation of Fe (which is often thought to be a non specific process resulting from the binding of reduced iron species to anionic groups on the sheath surface followed by non-biological oxidation to Fe oxides). Iron bacteria *viz., Leptothrix discophora* and *Sphearotilus natans* ranged between ND to 1400/100ml and ND to 14000/100ml in the water samples (Fig. 2).

Biological Parameters: Biological diversity of phytoplanktons in raw water ranged between 40-70 count/100 ml (Table 4). Phytoplanktons were not detected in treated water. SWI was recorded upto 1.0 which indicated moderate pollution. Zooplanktons were not detected in any of the water sample.

Operation and Maintenance of The IRPs:

- Backwashing of the filter unit at regular interval
- Close the back wash valve and outlet and replace secondly the filter cover
- Open the treated water cap and allow the water to flow till it is clear.
- Desludging of the IRP should be done at the interval of 90-120 days
- Scrape the top layer of the sand bed gently till clear water is observed over the bed
- Disinfection of the water in storage tank

CONCLUSIONS

The Fe content in treated water was reduced up to permissible limit (1 mg/L or less as per BIS standard) from 3 to 6.8 mg/L of Fe in raw water. It was observed that Mn was also present in measurable quantity in the groundwater, which was also removed to certain extent. Hand pump attachable IRPs based on up-flow roughing bio-filter along with controlled aeration and proper O&M can be used for iron removal. This may be helpful in appropriate and sustainable water quality improvement in Fe affected areas.

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