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"Effect of Packed Bed Filter on the Bio removal of Fe and Mn from Ground Water"

By

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Abstract

Pilot-scale experiments were conducted to study the removal of iron (Fe) and manganese (Mn) from groundwater. Experiments were carried out using a pilot plant constructed at Dair Brawa Village, Ehnasia town, Beni Suef Governorate (Egypt). The pilot plant consisted of a cascade aerator and a sand bio filter.

A packed bed filter (PBF) was added before the bio filter to study its effect on the overall performance of the system for Fe and Mn removals. Three types of media; plastic balls (80 mm) gravel (5-8 mm) and coarse gravel (15-30 mm); were tested in the PBF separately. Water samples before and after each treatment unit in the pilot plant were collected for analysis. Water samples were analyzed for pH, dissolved oxygen (DO), oxidation reduction potential (ORP) and Fe and Mn concentrations. The pilot plant was tested for groundwater Fe and Mn concentrations up to 9.5 mgL^{-1} and 11.0 mgL^{-1}, respectively.

The results show the importance of PBF to improve the performance of the integrated system of the cascade aeration and the bio filter in Fe and Mn removals. PBF significantly improves the abiotic oxidation of Fe. In addition, it can improve the conditions for biotic oxidation of Mn and Fe in the bio filter through improving the aerobic conditions (increases in the positive ORP values and DO concentrations). Using this system including PBF, removal efficiencies up to 94.3% and 99.2% can be achieved for Fe and Mn, respectively.

***Key words*:** Iron, Manganese, Bio removal, Groundwater and Filter.

Introduction

Groundwater is one of the water resources in Egypt, it represent 7.8% of total water resources. It is an integral part of the national policy in Egypt and is currently widely used for agriculture and drinking purposes in the Nile valley and Delta areas, adjacent inhabited parts of the desert areas and coastal zones, also the groundwater provide more than 30% of citizen requirements from potable water.

Groundwater has many favors over surface water, because of its excellent and consistent quality, and because, generally, it requires little or no treatment before consumption.

Unfortunately, many groundwater supplies are contaminated by varying levels of iron (Fe) and manganese (Mn) in concentrations that exceed the Drinking Water Guidelines. The presence of Fe and Mn, even at low concentrations, in groundwater supplies is associated with some problems. These problems could be aesthetic, technical or economical on both domestic and industrial levels.

The problems would include discoloring of water, staining of kitchen and bathroom fixtures, biofouling in distribution networks which cause taste and odour, fouling of heat exchangers and boilers, etc. In water distribution systems, these metals, if present in certain concentrations, may promote the growth of certain types of chlorine tolerant micro-organisms.

The main treatment method of Fe and Mn in Egypt is the physico-chemical treatment. This is the majority of Fe and Mn treatment plants and well known system in Egypt, in both Upper and Lower

Egypt as well as the new valley, also, there are some trials of biological treatment system in Egypt.

Although, there are several treatment methods for removing various Fe and Mn from groundwater these technologies are costly in running cost due to the chemical consumption; also generate chemical sludge that without good management may be contaminate the soil and water resources.

The objective of the current research was to study the impact of using a Packed Bed Filter on the performance of Fe and Mn bioremoval system from groundwater.

Materials and Methods

Pilot -scale setup

A pilot plant was installed for this purpose and comprises the following stages: aeration by cascaded aerator and down-flow roughing biofiltration.

A packed-bed filter (PBF) was added to the pilot plant to study its impact on the bioremoval of Fe and Mn, Figure 1.

The experiments lasting about 18 months, using groundwater pumped from well. The well is located at Dair Brawa Village, Ehnasia town, Beni Suef Governorate.

The cascaded aerator was used for the initial aeration of the pumped groundwater. It has a surface loading rate (SLR) of 100 $m^3/m^2/s$, outlet weir flow velocity of 0.02 m/s. The use of water from outlet of cascaded aerator has the advantage of not requiring an external air supply for the treatment process.

The PBF consists of a 12 liters plastic vessel with inlet and outlet ports equipped with poly vinyl chloride (PVC) valves. The vessel contains 10 liters of packing media.

The last unit of the pilot plant is the bio filter. The bio filter column is made of opaque poly vinyl chloride (PVC) tube to avoid algal growth on the tube walls, with an inside diameter 200 mm and 2350mm height, giving a surface area of 0.0314 m^2. The lower 250 mm is a collecting basin for treated water. The bottom of the column is equipped with a perforated tray designed to prevent loss of the filter media during filtration.

Along the filter depth there are 6 sampling points, each one is fixed every 150 mm, starting from the perforated tray at the bottom up to 900 mm height.

The filter was equipped with necessary PVC valves and ports for filter backwash, over flow, raw water inlet, treated water outlet, air scour inlet and sampling. Sampling points were equipped with faucets for collecting water samples. At the top of the filter, there was a fixed nozzle to evenly distribute the influent water over the filter surface.

Sand was selected as a bio filter bacteria carrier media, because it is available, cheap and gave good results. It was 400mm depth of Sand 0.8-1.4mm with diameter effective size 1.18mm and the top layer was 350mm depth of 0.8-1.4mm diameter Sand bearing bacteria which was collected from biological treatment plant (brought from a biological filters of treatment plant at Saft-Rashin village-Ehnasia town, Beni Suif governorate).

A 150mm depth of supporting layer of Gravel 10-15mm diameter was used under the above mentioned media. Experiments were carried out at surface loading rates of 4.7m/h.

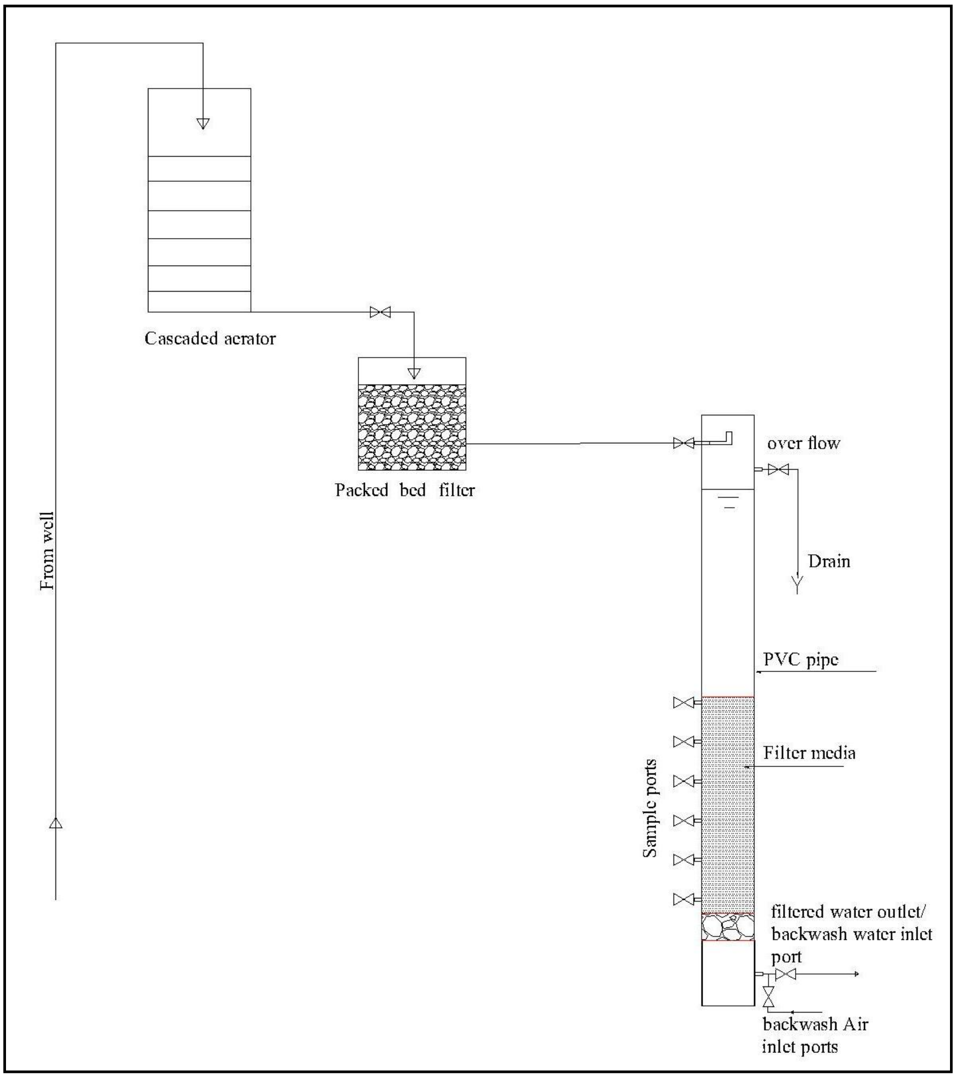


Figure 1. Flow diagram of the pilot plant for Fe and Mn bioremoval using PBF.

Packed bed filter Media

Three types of media were tested in the PBF. Plastic balls (80 mm), gravel material (5-8 mm) and gravel material (15-30 mm) were used as a packing media, Figure 2.

Plastic balls of about 80 mm diameter have an approximate surface area of 100 m^2/m^3. This is compared to an approximate average surface area of 480 m^2/m^3 for gravel size of 5-8mm (average size of 6.5mm as a compromise) and 140 m^2/m^3 for gravel size of 15-30 mm (average size of 22.5mm as a compromise).

Z Plastic balls | Gravel | Gravel

Z Plastic balls:
- Volume: 10 liters
- Diameter: 80 mm
- Surface area: 100 m2/m3
- Weight : 76 kg/m3

Gravel:
- Volume 10 liters
- Diameter:15-30mm
- Surface area: 140m2/m3
- Weight : 2650 kg/m3

Gravel:
- Volume 10 liters
- Diameter: 5-8 mm
- Surface area: 480m2/m3
- Weight : 2650 kg/m3

Figure 2. The types of media used in the PBF.

Operating conditions

Raw water temperature ranged between 22.0 and 24.8ºC, while pH value around the neutral and ranged between 7.0 and 7.8. DO of raw water lies between 0.9 and 1.5 mgL^{-1} and ORP always in negative value and ranged between -46 and -17 mV. Surface loading rate was 4.7 m/h.

A complete raw water chemical analysis was carried out by Potable Water & Sanitation Company Laboratories, Beni Suef. Initial concentration of Fe and Mn was ranged between 0.43 to 9.54 mgL^{-1} and 0.49 to 11.0 mgL^{-1}, respectively.

Sampling and Sample analysis

Water samples were collected every day from inlet and outlet through sampling points, in acid wash and reagent water rinse container (Standard Method, 2019) pH, temperature, samples for Fe and Mn are collected in Polyethylene (PE) bottles and send to the central laboratory of Potable Water & Sanitation Company at Beni-Suef. pH was analyzed frequently on-site using (pH meter, Prace Tronic, MV 870 Digital-pH-Meter), total Fe concentration and total Mn concentrations were determined by Atomic Absorption-Flame Technique (AAS ZEEnit 700 # 150ZH0111). ORP determined using (ORP-meter, Hanna HI 98201) and Dissolved oxygen determined using (DO-meter, Oxi313i/set WTW).

Results and Discussions

Packed bed filter (PBF) as a pretreatment and its impact on removal efficiency of Fe and Mn.

Aeration by atmospheric installations includes trickling over cascades or over contact media (with or without air circulation), open air spraying, diffused aeration or mechanical aeration.

The PBF was added to the pilot plant to improve the abiotic oxidation of Fe and thus to improve the overall system removal of Fe. As mentioned above, three types of PBF media have been tested. Two sizes of gravel, in addition to plastic balls.

Figure 3. illustrates the effect of the use of different media; gravel (size15– 30 mm), gravel 5 – 8 mm) and plastic media; in the PBF on the removal efficiency of Fe and Mn.

It was noticed that the addition of PBF with all kinds of backing media to the bioremoval system improve the removal of Fe significantly. **Carlson and Schwertmann (1987)** mentioned that total Fe decreases through aeration in the treatment plants by 40-60%. Also, it was noticed that gravel with particle sizes in the range of 5-8 mm diameter provides the lowest effluent Fe concentrations after PBF, which means highest removal efficiency of Fe with an average value of 75.3%. However, less removal efficiencies were obtained using other media, average removals of 70.4% and 66% were obtained using plastic balls and gravel with particle sizes of 15-30 mm, Figure 3.

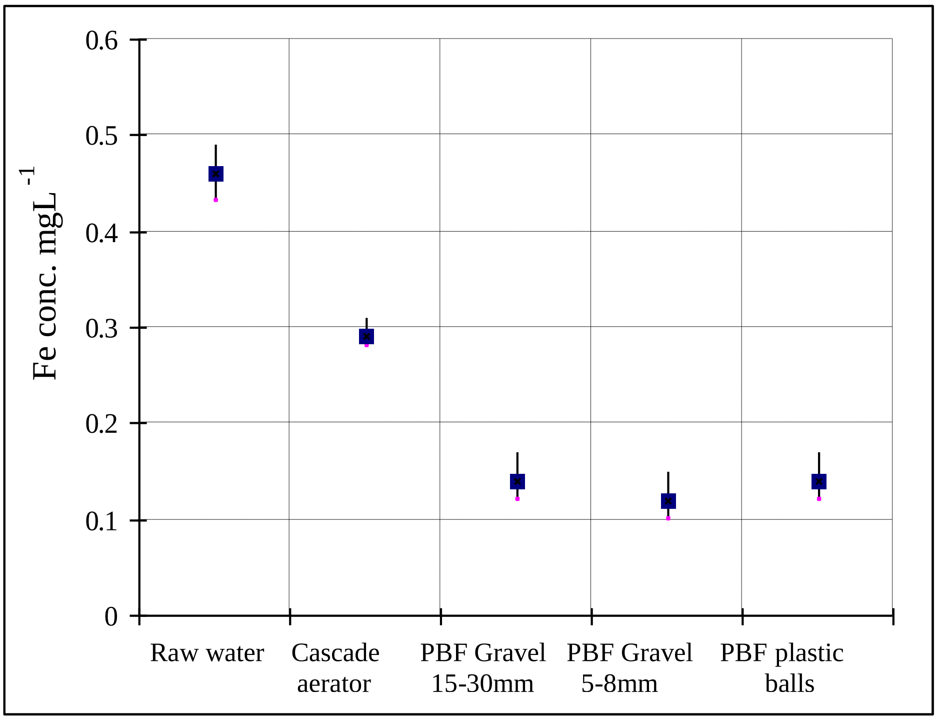


Figure 3. Changes in Fe concentration (mgL^{-1}) after cascade aerator & PBF at different PBF media.

Also, it was noted that oxidation and removal efficiency of Mn due to PBF was negligible.. Removal efficiencies of 9.3 % to 24 % were observed, Figure 4**.**

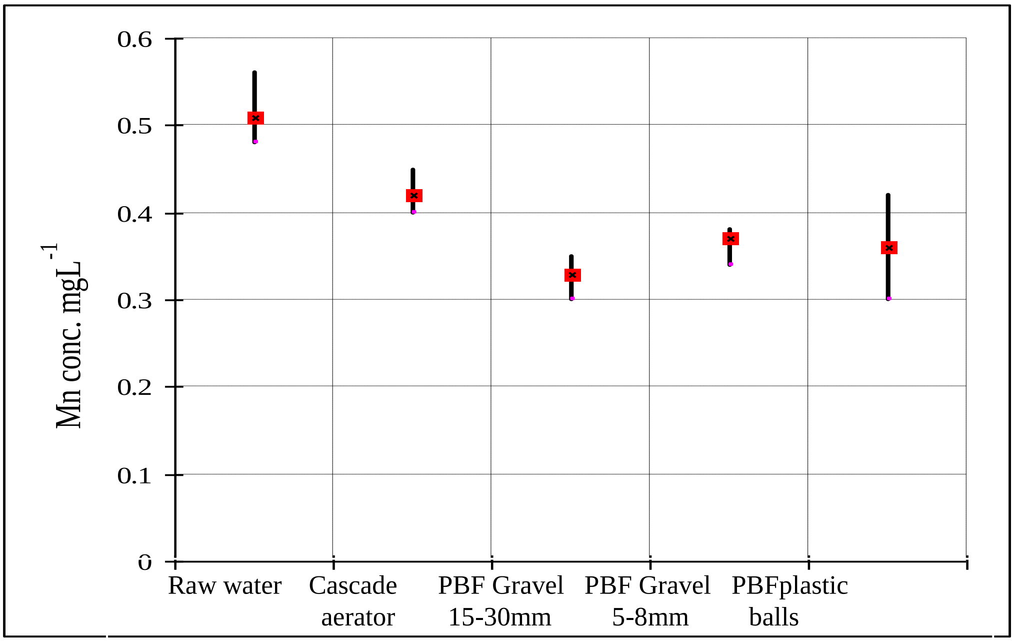


Figure 4. Changes in Mn concentration (mgL^{-1}), after cascade aerator & PBF at different PBF media.

The weight of the plastic balls was found to be approximately 76 kg/m³. This is compared to 2650 kg/m³ for the gravel media. Therefore, plastic balls are recommended for use in the PBF. They can reduce the construction cost of the packed bed filter. Also, they are easier in handling and maintenance. In addition, plastic balls provide acceptable removals of Fe (up to 70% in average).

It was obvious that the addition of PBF to the treatment system was more efficient to Fe removal than Mn removal, as Mn is more difficult to remove than iron.

It is believed that media with higher surface area increase the contact area between air and water and therefore, increase the diffusion of oxygen to water. This will result in the increase in abiotic oxidation of Fe.

Dissolved oxygen (DO) and oxidation reduction potential (ORP) relationship

The evolution of ORP, pH and DO concentration for raw, aerated and filtered water was summarized in Table 2. There was no significant change in water pH among raw, aerated and filtered water. It was ranged between 7.10 and 8.03. It was noted that ORP values of raw water are very low and not suit for the field of either physico-chemical or biological oxidation of Fe and/or Mn. After aeration DO doesn't change significantly, may be due to the consumption of some oxygen in aerobic oxidation of Fe and Mn. Also it was noted that ORP increased after PBF rather than the cascade aerator.

The variations in total ORP values are ranged from +238 to +298 mV and these values are very close to those observed by **Hatva 1988** who reported increases in ORP values from +261 to +479mV in a biological treatment system composed of a dry contact filter, a wet contact filter and a slow sand filter.

Table 2. pH, ORP and DO changes in raw (well) water, aerated water and filtered water.

Run	pH			DO (mgL⁻¹)				ORP (mV)			
	Raw water	Aerated water	Filtered water	Raw water	Aerated water		Filtered water	Raw water	Aerated water		Filtered water
					cascade	PBF			cascade	PBF	
1	7.69	7.79	7.73	1.2	6.6	6.8	5.1	-17	23	85	282
2	7.74	7.32	8.02	1.0	6.1	6.4	4.4	-23	35	98	258
3	7.76	7.80	8.05	0.9	6.0	5.8	5.1	-18	32	106	270
4	7.59	7.30	7.65	1.2	5.9	6.2	4.9	-28	19	92	287
5	7.72	7.68	7.50	1.1	6.3	7.0	5.3	-22	22	85	238
6	7.56	7.63	7.27	0.9	5.6	5.9	5.4	-46	37	115	288
7	7.50	7.54	7.09	1.3	5.1	5.8	4.7	-34	21	93	249
8	7.10	7.47	7.23	1.2	5.9	6.2	4.4	-29	43	106	252
9	7.35	8.03	7.82	0.8	6.2	6.1	4.8	-38	23	89	275
10	7.45	7.88	7.42	1.3	6.3	6.4	4.4	-44	18	78	269
11	7.15	7.93	7.63	1.4	5.4	6.0	4.6	-36	33	91	251
12	7.25	7.87	7.80	0.9	5.2	5.9	5.0	-32	37	83	259
13	7.52	7.60	7.20	1.6	4.9	6.7	5.9	-30	35	95	298
14	7.00	7.20	7.35	1.5	5.0	5.3	4.7	-26	36	89	278
15	7.30	7.45	7.70	1.3	5.6	5.4	4.6	-21	38	99	281
16	7.40	7.50	7.90	1.2	5.3	5.6	4.3	-19	44	101	259
17	7.10	7.35	7.47	0.9	5.6	5.8	4.9	-21	40	112	278

18	7.00	7.26	7.60	1.1	6.1	6.2	5.0	-27	41	90	292
19	7.30	7.38	7.70	1.2	6.3	6.0	4.3	-31	46	86	283

Figure 5 illustrates the changes in DO and ORP content in raw, aerated and filtered water. It was noted that when DO concentration in raw water rose after aeration, ORP values increased and seemed to suggest a proportional relationship, which according to **Mouchet 1992,** the increasing in DO increases ORP. Also with comparison to Figure 6 raw water becomes suit for the field of either physico-chemical or biological oxidation of Fe and/or Mn.

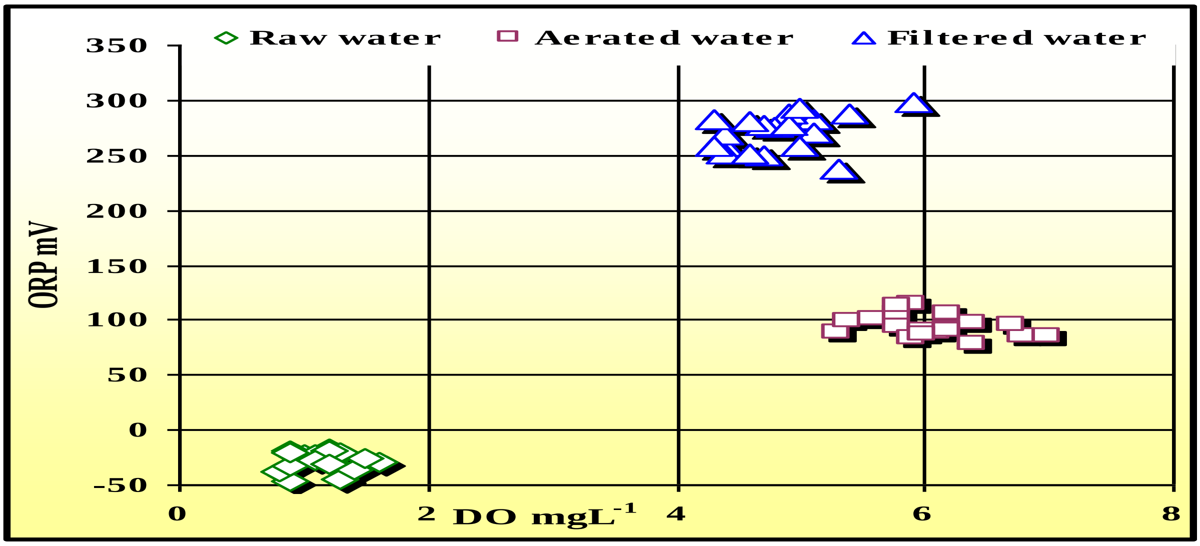


Figure 5. The changes in DO and ORP for Raw, Aerated and filtered water.

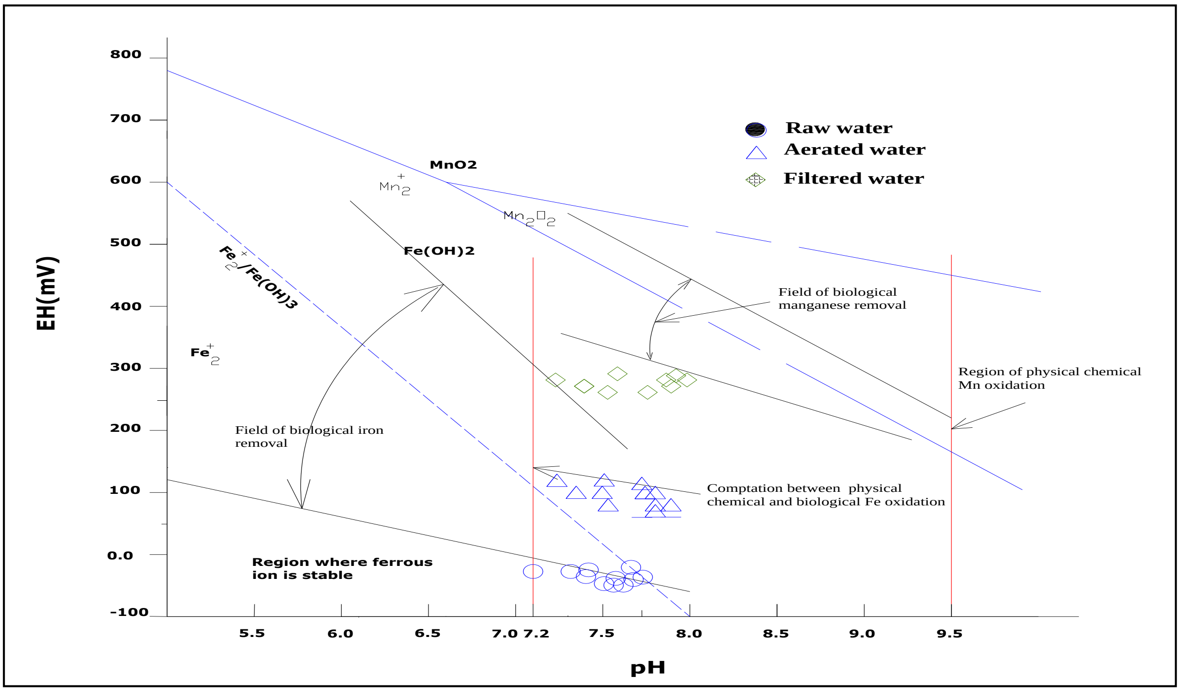


Figure 6. pH-Eh values of Raw, aerated and filtered water and the field of activity of Fe and Mn oxidizing bacteria in pH-Eh diagram.

Integration of PBF with biofilteration for the removal of Fe and Mn

Different levels of Fe and Mn concentrations were used during these experiments. Fe and Mn concentrations up to 9.5 mgL^{-1} and 11.0 mgL^{-1} respectively were used.

Tables 3 and 4 show the removal of Fe and Mn after different treatment steps of the pilot plant operated in a continuous flow mode, without using PBF and with PBF containing Plastic balls.

Fe removal

The removal efficiency of the biofiltration system without using PBF is shown in Table 3. It was noted that Fe maximum removal of 40% can be achieved with aeration step by cascade aerator in comparison to 78% of Fe removal with the using of PBF, Table 4. This is resulted in increasing total Fe removal after bio filtration to about 94% in case of using PBF in comparison to about 73% of total Fe removal after bio filtration system.

From Figure 7, it is noted that the major part of removed Fe could be due to the abiotic oxidation in the cascade aeration and PBF.

The reduction of total Fe concentration after cascade aerator and PBF step, due probably to physico-chemical oxidation, and the biological oxidation taking place in the biofilms, which developed on the plastic carriers and biofilter media. This is in agreement with other authors´ findings (**Hatva, 1988; Seppänen, 1988).**

Sharma, et al. 2005, mentioned that in the presence of oxygen, Fe (II) oxidation starts immediately (after the aeration step) in the supernatant and filter bed and the adsorption-oxidation mechanism will occur in the filter bed as well, implying that biological Fe removal is likely to be supplementary to conventional physico-chemical Fe removal.

Mn removal

In case of Mn, the removal efficiency after aeration step in general was low and didn't exceed about 27%, Tables 3 and 4. It is also noted that there is no significant change in removal efficiency in case of using PBF or not using it. However, high removal efficiency can be achieved in both cases by the biofilter which reached to about 99 % removal of Mn.

This indicates that the removal of Mn, unlike the Fe removal, takes place mainly through the biofilter by biotic oxidation, Figure 8.

The results show the importance of both PBF and the biofilter. Thus the removals of Fe and Mn considered to be achieved in the same unit and the applied system can be efficient for the removal of Fe and Mn concentrations up to 9.5 mgL^{-1} and 11.0 mgL^{-1}, respectively.

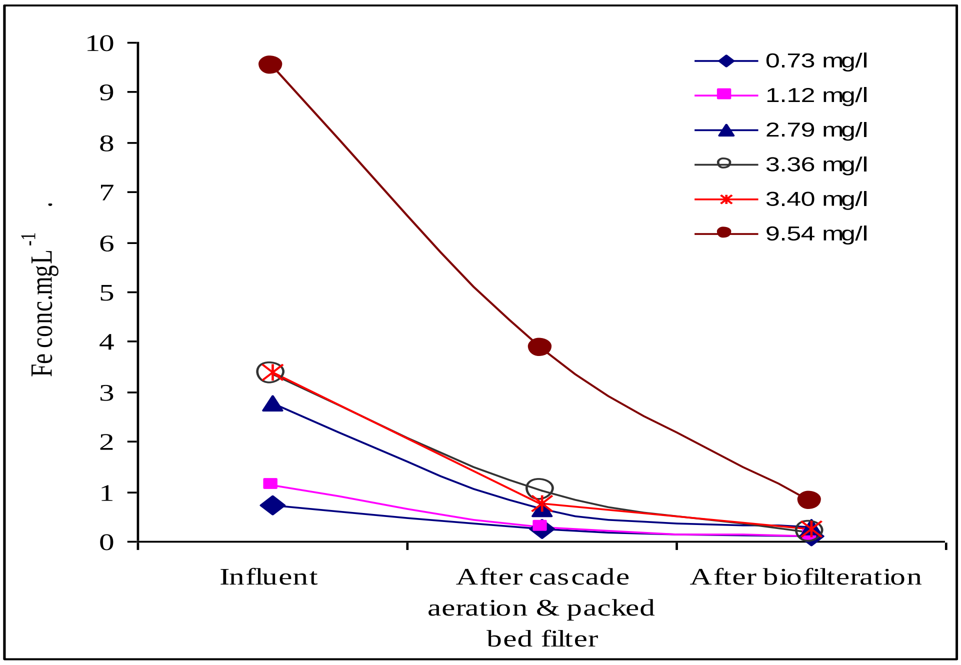
Table 3. Removal of Fe and Mn after different treatment steps of the pilot plant operated in a continuous flow mode, without using PBF.

Run	Fe mgL^{-1}		% Removal	Fe mgL^{-1} Filtered water	% Total Removal	Mn mgL^{-1}		% Removal	Fe mgL^{-1} Filtered water	% Total Removal
	Raw water	Aerated water				Raw water	Aerated water			
1	0.661	0.436	34	0.233	70	0.51	0.462	9.8	0.035	93
2	0.789	0.742	6	0.457	42	0.488	0.453	7.2	0.076	84
3	0.69	0.563	19	0.34	51	0.496	0.458	8.1	0.094	81

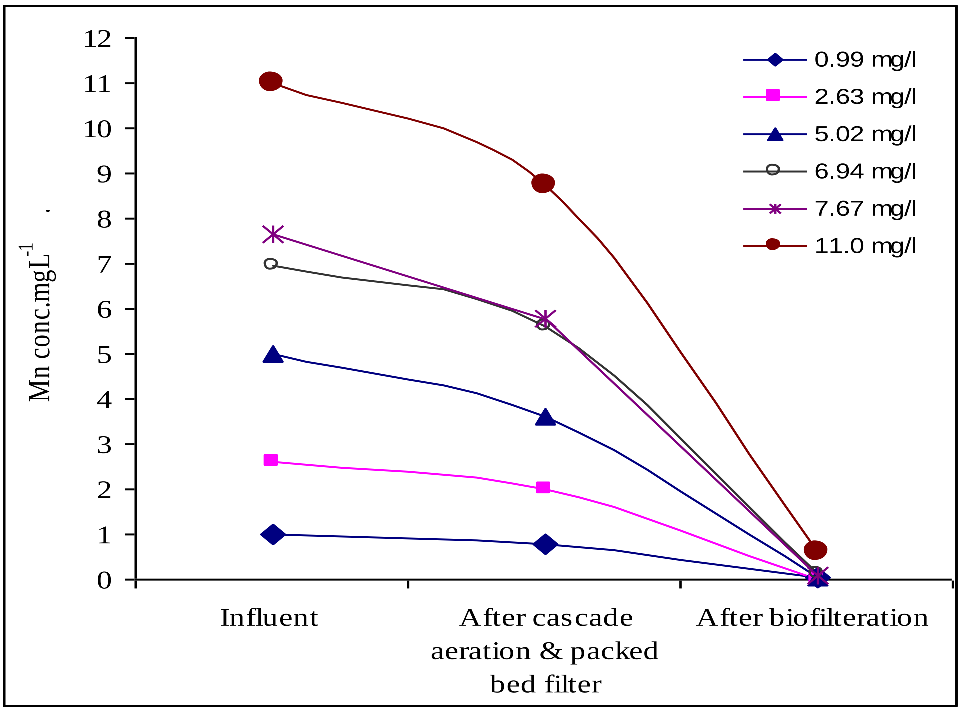
	8									
4	0.723	0.651	10	0.31	57	0.472	0.448	5.1	0.12	75
5	0.454	0.321	29	0.218	52	0.523	0.502	4	0.034	93
6	0.398	0.321	18	0.198	50	0.411	0.399	2.9	0.015	96
7	0.763	0.448	41	0.311	59	0.46	0.452	1.7	0.021	95
8	0.775	0.552	29	0.333	57	0.451	0.449	0.4	0.024	95
9	0.782	0.563	28	0.338	57	0.401	0.394	1.7	0.041	90
10	0.754	0.612	19	0.389	48	0.66	0.554	18.2	0.052	90
11	0.582	0.433	27	0.157	73	0.369	0.366	0.8	0.05	86
12	0.564	0.338	40	0.217	62	0.543	0.54	0.6	0.042	92
13	0.449	0.395	14	0.211	53	0.469	0.461	1.7	0.039	92
14	0.448	0.398	11	0.31	31	0.482	0.47	2.5	0.04	92
15	0.454	0.31	32	0.298	34	0.501	0.499	2	0.039	91.7
16	0.523	0.368	30	0.331	37	0.484	0.484	0	0.041	91.5
17	0.544	0.389	28	0.237	56	0.435	0.428	1.6	0.033	92.4
18	0.621	0.452	27	0.302	51	0.51	0.5	1.96	0.045	91.2
19	0.541	0.42	22	0.182	66	0.563	0.56	0.53	0.011	98

Table 4. Removal of Fe and Mn after different treatment steps of the pilot plant operated in a continuous flow mode, using PBF.

Run	Fe mgL^{-1}		% Removal	Fe mgL^{-1} Filtered water	% Total Removal	Mn mgL^{-1}		% Removal	Fe mgL^{-1} Filtered water	% Total Removal
	Raw water	Aerated water				Raw water	Aerated water			
1	0.73	0.24	67.8	0.11	84.9	0.99	0.79	20.2	0.051	94.8
2	1.12	0.30	72.8	0.12	89.3	2.63	2.00	23.9	0.020	99.2
3	2.79	0.66	76.3	0.28	90.0	5.02	3.63	27.7	0.041	99.2
4	3.36	1.02	69.7	0.19	94.3	6.94	5.60	19.3	0.143	97.9
5	3.40	0.75	78.4	0.24	92.9	7.67	5.79	24.5	0.094	98.8
6	9.54	3.88	59.3	0.82	91.4	11.00	8.75	20.5	0.605	94.5



Figures 7. Fe removal efficiency of the biofiltration system using different influent concentrations after each step.



Figures 8. Mn removal efficiency of the biofiltration system using different influent concentrations after each step.

CONCLUSION

1. Using of PBF as a pretreatment of Fe and Mn bioremoval will result in the improvement of the aeration step and increase the abiotic oxidation of Fe.
2. Average removal of 70.4% for Fe was obtained using plastic balls with diameter size of 80mm.
3. Oxidation and removal efficiency of Mn due to PBF was less than of Fe, where removal efficiencies of up to about 27 % were observed.
4. Plastic balls are recommended for use in the PBF due to there light weight, easier in handling and maintenance and provide acceptable removals of Fe.
5. It was noted that when DO concentration in raw water rose after aeration, ORP values increased and seemed to suggest a proportional relationship.
6. Overall Fe removal efficiency up to about 94% can be achieved using the system; the major part of removed Fe could be due to the abiotic oxidation in the cascade aeration and PBF.
7. Removal efficiencies up to about 99% of Mn can be achieved with the use of the bio filter. Most of removal due to bio filtration unit.

NOTATIONS

The following symbols have been adopted for use in this paper:

- DO = Dissolved oxygen ;
- Fe = Iron ;
- Mn = Manganese ;
- ORP=oxidation-reduction potential;
- PBF = Packed bed filter ;
- PE = Polyethylene and
- PVC = poly vinyl chloride.

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