Metals, heavy metals and microorganism removal from spent filter backwash water by hybrid coagulation-UF processes

Mokhtar Mahdavi, Mohammad Mehdi Amin, Amir Hossein Mahvi, Hamidreza Pourzamani and Afshin Ebrahimi

ABSTRACT

Spent filter backwash water (SFBW) reuse has attracted particular attention, especially in countries that experience water scarcity. It can act as a permanent water source until the water treatment plant is working. In this study, the concentrations of Fe, Al, Pb, As, and Cd with total and fecal coliform (TC/FC) were investigated in raw and treated SFBW by hybrid coagulation-UF processes. The pilot plant consisted of pre-sedimentation, coagulation, flocculation, clarification, and ultrafiltration (UF) units. Poly-aluminum ferric chloride (PAFCL) and ferric chloride ($FeCl_3$) were used as pretreatment. The results showed that, at the optimum dose of PAFCl, the average removal of TC and FC was 88 and 79% and with PAFCl-UF process, it reached 100 and 100%, respectively. For $FeCl_3$, removal efficiency of TC and FC were 81 and 72% and by applying $FeCl_3$-UF process, it reached 100 and 100%, respectively. In comparison with $FeCl_3$, PAFCl showed better removal efficiency for Fe, Pb, As, and Cd, except residual Al concentration. Coagulation-UF process could treat SFBW efficiently and treated SFBW could meet the US-EPA drinking water standard. Health risk index values of Fe, AL, Pb, AS, and Cd in treated SFBW indicate no risk of exposure to the use of this water.

Key words | coagulation-UF, $FeCl_3$, poly-aluminum ferric chloride (PAFCl), spent filter backwash water reuse, spent filter backwash water treatment

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INTRODUCTION

Recently, water reuse of spent filter backwash water (SFBW) has attracted particular attention in most countries because of water scarcity. The main point is that the SFBW acts as a permanent source until the water treatment plant is working. During most water treatment processes, SFBW is generated from 2 to 10% of the total plant production (Raj *et al.* 2008). Filter backwashing is conducted to remove all captured material through the filter bed during filtration. Thus, there are some concerns regarding its reuse because of high concentration of metals, heavy metals, natural organic matters, microorganisms, and colloidal materials (Walsh *et al.* 2008).

Heavy metals' exposure routes include absorption, inhalation, and ingestion. Ingestion through drinking water is the major source of heavy metals' exposure in some areas. Heavy metal contamination in drinking water causes health problems such as shortness of breath, neurotoxic, mutagenic and teratogenic effects with various types of

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cancers depending on the heavy metal type (Chowdhury *et al.* 2016). It is obvious that direct recycling of SFBW can jeopardize the quality of the treated water because of the high concentration of contaminants. SFBW treatment can be conducted by different methods. Previous studies have shown that membrane separation is an effective way. Membrane filtration such as microfiltration and ultrafiltration (UF) remove particulates, colloids, and pathogens effectively and has been believed to be the water treatment technique of the 21st century. They need a smaller footprint, have low energy consumption and produce clean water (Ang *et al.* 2015); however, fouling is a big problem in membrane processes, especially for SFBW treatment.

To overcome this problem, a combination of membrane system with chemical or physical processes, such as coagulation and sedimentation, has been introduced (Wang *et al.* 2014; Lai *et al.* 2015). UF acts as an effective barrier to microorganisms, suspended particles, and colloids (Peter-Varbanets *et al.* 2011; Chen *et al.* 2014). Coagulation is an effective process to remove the majority of the particulate matter, suspended solids, colloids, organic matter and some dissolved matter (Gao & Yue 2005; Zhao *et al.* 2008; Yu *et al.* 2013) before the membrane process.

Most previous articles about backwash water treatment have addressed the fouling issue (Huang *et al.* 2011; Li *et al.* 2012; Yu *et al.* 2013; Wang *et al.* 2016). Only a few have dealt with the quality of treated water for drinking or other application (Raj *et al.* 2008; Zhang *et al.* 2008).

The purpose of this study was to understand the level of contaminants and health risk related to metals (Fe and Al), heavy metals (Pb, As, and Cd), and microorganisms (total and fecal coliforms (TC/FC)) in the SFBW of Isfahan Water Treatment Plant before and after treatment with pilot-scale hybrid coagulation-UF processes, and comparison between the two coagulants: poly-aluminum ferric chloride (PAFCl) and $FeCl_3$, as pretreatment.

MATERIALS AND METHODS

Raw SFBW

Samples of SFBW were collected from Babashaikhali water treatment plant in Isfahan, Iran, during the winter season. This plant treats 12 m^3/s of water using coagulation, flocculation, clarification, and sand filtration processes. In this plant, PACl is used as a coagulant and 48 filters purify the water. Each filter backwash needs 500 m^3 of water. Considering 48 filters with a 24 h cleaning interval, it accounts for over 2.25% of the raw water entering the plant. Hence, during the water treatment process, approximately 24,000 m^3/d of SFBW is generated. The characteristics of raw SFBW are listed in Table 1. In this study, about 3,000 L of raw SFBW was collected from the water treatment plant. It was transferred to the laboratory and used for examination.

Experiment protocol

In this study, continuous processes including primary sedimentation, coagulation, flocculation, clarification, and UF were used for SFBW treatment. For all the sections of the pilot unit, except the UF membrane, the flow rate was 10 L/h. Hydraulic retention time (HRT) for this section, except the UF membrane, was 60, 6, 48, and 192 min. Figure 1 shows the experimental set-up of the pilot unit used in the experiments. According to the authors' previous study (Mahdavi *et al.* 2016), coagulation with PAFCl and $FeCl_3$ was conducted at the natural pH of SFBW (8.3), and pre-determined dosage of PAFCl (15 mg/L) and $FeCl_3$ (40 mg/L) was continuously added into the rapid mixing unit (speed was 80 rpm and HRT was 6 min). The

Table 1 | Characteristics of the raw SFBW and raw water in the water treatment plant

Parameter	Raw SFBW	Raw water	(EPA 2012) (MCL)
Turbidity (NTU)	600 (± 7.7)	8 (± 0.4)	> 5 NTU
Color (Pt. Co. units)	103 (± 4.2)	17 (± 2)	15 color units
pH	8.3 (± 0.02)	8.1 (± 0.02)	6.5–8.5
Fe (mg/L)	4 (± 0.14)	0.13 (± 0.03)	0.3
Al (mg/L)	0.4 (± 0.028)	0.068 (± 0.008)	0.05–0.2
Pb (μg/L)	217 (± 9.9)	4 (± 1.41)	10
As (μg/L)	2.36 (± 0.5)	1 (± 0.28)	10
Cd (μg/L)	4 (± 0.7)	0.5 (± 0.14)	5
TC (MPN/100 mL)	7,500 (± 707)	3,300 (± 210)	0
FC (MPN/100 mL)	2,200 (± 550)	900 (± 280)	0

coagulated water then passed though the two flocculation tanks, with a 40 rpm mixing intensity. After this, water was introduced for clarification, and then the treated water was fed to the UF membrane module. Investigation for the optimum dose selection was carried out for both coagulants in a continual manner for 4 days separately (Figure 1, section 4). The optimum dose was selected to produce the best water quality based on turbidity and color results. These parameters were analyzed after two HRT of the second clarification (inflow was 10 L/h). After that about 1,000 L of raw SFBW was treated with PAFCl and $FeCl_3$ separately. Then, 800 L of treated water with PAFCl and 800 L of treated water with $FeCl_3$ entered the UF membrane process separately (inflow was $8\ L\ m^{-2}\ h^{-1}$). Some parameters, such as turbidity, color, pH, TC, and FC were detected about ten times during the pilot operation, but metals and heavy metals were detected three times in the optimum dose and quality of treated water.

The UF membrane was made of hollow-fiber polypropylene, with a nominal pore size of 0.01–0.2 μm. The total membrane area of UF was $0.1\ m^2$/module. The UF module was operated in dead-end mode with constant filtration of about $8\ L\ m^{-2}\ h^{-1}$ at a trans-membrane pressure of 300 Pa. It was operated in a cycle of 60 min filtration and 1 min backwashing with permeate in the reverse direction.

Analytical methods

Samples were analyzed for residual aluminum (Al), iron (Fe), lead (Pb), arsenic (As) cadmium (Cd), TC, and FC. All the experiments were conducted according to the Standard Methods for the Examination of Water and Wastewater.

Turbidity, color, and pH of the samples were measured by TN-100 (EUTECH) turbid meter, DR 5000-HACH LANGE and pH-meter model CG 824, respectively. Al was analyzed by DR 5000-HACH LANGE, method 8326. Fe, Pb, As, and Cd were analyzed by inductively coupled plasma (ICP).

RESULTS AND DISCUSSION

Water characteristics

From Table 1 it can be seen that the SFBW sample had high turbidity, color, Fe, Al, and heavy metals' concentration in comparison with raw water. Of course, the quality of raw water was very high because of very low turbidity, metals and heavy metals' concentration. From Table 1 it can be concluded that the concentrations of metals and heavy metals in raw water were lower than the EPA guideline. On the other hand, raw SFBW has a very high concentration of turbidity, color, Fe, Al, Pb, TC, FC and, to some extent, Cd. Results showed that during the water treatment process, water contaminants were removed or accumulated on filter beds. Subsequently, filter backwash removed this material from the filters. Low concentrations of TC and FC in SFBW may be related to pre-ozonation and pre-chlorination in the water treatment plant. Metals and heavy metal concentrations in SFBW samples were found to be in the order: Fe > Al > Pb > Cd > As.

Microbial quality of treated SFBW

The effect of various doses (5 to 60 mg/L) of PAFCl and $FeCl_3$ is presented in Figure 2, to determine the optimum

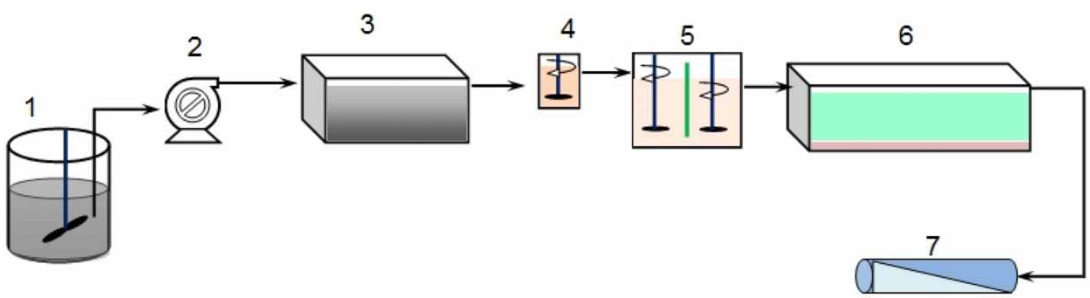

Figure 1 | A schematic of the experimental set-up. 1: reservoir tank, 2: pump, 3: primary sedimentation, 4: coagulation (place for addition of coagulants), 5: flocculation, 6: second clarification, and 7: UF module.

dose. Results showed that the optimum dose for PAFCl and $FeCl_3$ was 15 and 40 mg/L, respectively. At these doses, turbidity removal was 99.6 and 99.4%, respectively (Figure 2). For each dose, turbidity was measured after two HRT. The removal efficiency of turbidity for PAFCl was increased to 15 mg/L. Above this point, re-stabilizing of colloidal suspension and, subsequently, an increase in turbidity occurred. While for $FeCl_3$, the removal efficiency of turbidity increased until 40 mg/L and then it worsened above 40 mg/L due to re-stabilization of colloidal suspension. Therefore, coagulation was conducted with two doses and treated water was analyzed for predetermined parameters.

For the membrane process, the quality of input water is very important because of fouling problems. In this study, by applying optimum doses of PAFCl and $FeCl_3$, treated water turbidity reached 2.4 and 3.9 NTU, respectively. After this, treated SFBW was used in the UF membrane process and microbial quality of treated water was investigated.

With regards to coagulation and flocculation, most bacteria and protozoa are considered as particles, and most viruses as colloidal organic particles. Thus, removal of turbidity has an indirect relationship with microbial reduction. In this result, the two coagulants showed a different influence on microbial reduction. From Figure 3 it can be seen that PAFCl showed good removal efficiency in comparison with $FeCl_3$.

Under optimal coagulation conditions with PAFCl (15 mg/L), the average removal of TC and FC was 88 and 79%, and by PAFCl-UF process, it reached 100 and 100%, respectively. Also for $FeCl_3$ (40 mg/L), removal efficiency for TC and FC was 81 and 72%, respectively. This value in the $FeCl_3$-UF process reached 100 and 100%, respectively.

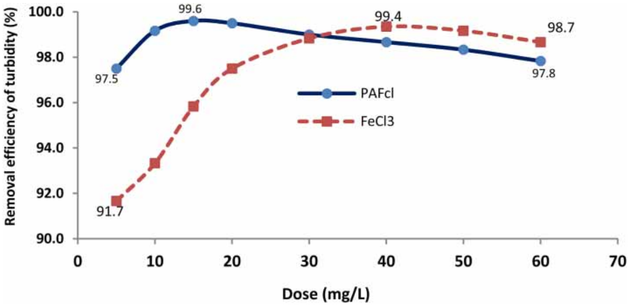

Figure 2 | Optimum dose selection for turbidity removal with PAFCl and $FeCl_3$.

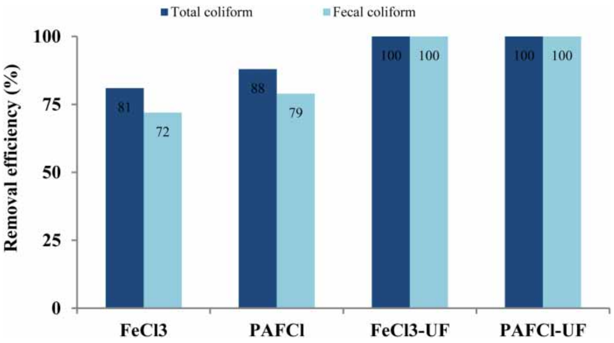

Figure 3 | Total and fecal coliforms removal by coagulation-UF process.

During coagulation processes, turbidity, colloids and microorganisms were removed by various mechanisms such as adsorption, precipitation, charge neutralization, and enmeshment (Ebrahimi *et al.* 2015).

Low coagulant consumption and good removal efficiency is related to the charge neutralization mechanism. In this study, PAFCl with a lower dose of 15 mg/L gave better efficiency for turbidity, TC and FC removal and is related to positively charged PAFCl flocs that can adsorb negatively charged colloids and microorganisms. While for $FeCl_3$, it is necessary to add a higher dose to get enough positive charge. Therefore, in this situation, the mechanism changed to sweep-flocculation. PAFCl is a pre-hydrolyzed coagulant that had more positive charge in comparison with the traditional coagulants. This coagulant has Al and Fe ions and can produce $Fe(OH)_3$ and $Al(OH)_3$ complex (Edzwald 1993). In UF membrane process, physical sieving and straining was the main mechanism for the removal of particles and microorganisms. The size of most bacteria is about 0.1 to more than 10 μm, while the pore sizes of UF membranes are smaller than bacteria, so in this study, the very low pore size of UF removed all TC, FC, and particulate matter; this result is in accordance with the study of Xiao *et al.* (2012). Also, Reissmann & Uhl's (2006) study on reuse of SFBW from drinking water treatment showed that during the whole experiment, coliforms, *Escherichia coli* and Clostridium were not detected in the permeate. Thus, these results prove that UF is a very good barrier for TC/FC.

Metals and heavy metals quality of treated SFBW

The quality of SFBW treated with coagulation and the UF membrane process is presented in Table 2. Coagulation was conducted with PAFCl and $FeCl_3$ at optimum doses. It can be seen that the two coagulants showed a different influence on SFBW quality. From Table 2, it can be concluded that PAFCl showed good removal efficiency for all the experimental parameters, except residual Al concentration.

As indicated in Table 2, residual turbidity and true color after coagulation with PAFCl and $FeCl_3$ reached 2.4 ± 0.14, 3.9 ± 0.14 NTU and 2 ± 0, 5 ± 1.4 Pt. Co. units, respectively, and in PAFCl-UF and $FeCl_3$-UF output, they reached 0.1 NTU and 0 Pt. Co. units, respectively. The level of these parameters in the UF filtrate is very low and meets the US-EPA drinking water standard. The most important parameters in SFBW reuse are metals and heavy metals that have very important effects on human health (Berthon 2002). They are removed by different mechanisms such as adsorption, precipitation, and enmeshment during water treatment processes. Also, under different conditions, diverse mechanisms such as charge neutralization, precipitation, bridge-aggregation, adsorption, and sweep-flocculation help to remove particles, organic substances, and other pollutants during coagulation (Ebrahimi *et al.* 2015). The results of this study showed that the concentration of iron and aluminum in raw SFBW was 4 ± 0.14 and 0.4 ± 0.028 mg/L, respectively. After coagulation with PAFCl and $FeCl_3$ at optimum doses, Fe concentration reached 0.02 ± 0.01 and 0.12 ± 0.01 mg/L, respectively and after PAFCl-UF and $FeCl_3$-UF processes, it reached 0 and 0.08 ± 0.004 mg/L, respectively. Al concentration after coagulation with PAFCl and $FeCl_3$ at optimum doses was 0.046 ± 0.02 and 0.031 ± 0.01 mg/L, respectively, and after PAFCl-UF and $FeCl_3$-UF processes, it reached 0.031 ± 0.002 and 0.02 ± 0.001 mg/L, respectively. SFBW treated with PAFCl has, to some extent, more Al concentration than SFBW treated with $FeCl_3$, and SFBW treated with $FeCl_3$ has, to some extent, more Fe concentration than SFBW treated with PAFCl. Maybe it is related to composition property of the coagulant that repels some Fe or Al in treated water. However, the concentrations of Fe and Al in treated SFBW were low and met the drinking water standards.

The concentration of Pb, As, and Cd in raw SFBW was 217 ± 9.9, 2.36 ± 0.5 and 4 ± 0.7 μg/L, respectively. After coagulation with PAFCl (at optimum doses), it reached 0, 0, and 0.19 ± 0.012 μg/L, respectively. Also, for $FeCl_3$, it reached 0, 0. and 0.35 ± 0.08 μg/L, respectively. The concentration of Pb, As, and Cd in SFBW treated with PAFCl-UF process was 0, 0, and 0.15 ± 0.01 μg/L, respectively, and for SFBW treated with $FeCl_3$-UF process, it was 0, 0, and 0.3 ± 0.07 μg/L, respectively. It can be seen that both coagulants had good efficiency for heavy metals' removal. However, PAFCl removed heavy metals better than $FeCl_3$. Metals and heavy metals' concentrations in SFBW treated with PAFCl were found to be in the order: Al > Fe > Cd > As and Pb. For coagulation with $FeCl_3$, this order was Fe > Al > Cd > As and Pb. After the PAFCl-UF process, the order of metals and heavy metals was Al > Cd > Fe, As and Pb. Eventually, this order for the $FeCl_3$-UF process was Fe > Al > Cd > , As and Pb.

It can be seen that coagulation reduced most of the metals and heavy metals in treated SFBW, therefore, it can be concluded that the highest amount of metals and heavy metals are related to constituents that are attached to particles, organic matter, clay or silt during the water treatment process. Thus, with the removal of particles, colloids, and suspended solids during coagulation, most of the metals and heavy metals were removed effectively. Previous studies have

Table 2 | Quality of treated SFBW with coagulation and coagulation-UF process

Parameter	Treated water with PAFCl	Treated water with $FeCl_3$	PAFCl-UF output	$FeCl_3$-UF output
Turbidity (NTU)	2.4 (± 0.14)	3.9 (± 0.14)	0.1 (± 0)	0.1 (± 0)
Color (Pt. Co. units)	2 (± 0)	5 (± 1.4)	0 (± 0)	0 (± 0)
pH	8 (± 0.1)	7.6 (± 0.1)	7.9 (± 0.1)	7.5 (± 0.1)
Fe (mg/L)	0.02 (± 0.01)	0.12 (± 0.01)	0 (± 0)	0.08 (± 0.004)
Al (mg/L)	0.046 (± 0.02)	0.031 (± 0.01)	0.031 (± 0.002)	0.02 (± 0.001)
Pb (μg/L)	0	0	0	0
As (μg/L)	0	0	0	0
Cd (μg/L)	0.19 (± 0.012)	0.35 (± 0.08)	0.15 (± 0.01)	0.3 (± 0.07)

shown that clay and soil have very good potential for heavy metal sorption and heavy metals like Pb were primarily located in the silt fraction (Appel & Ma 2002; Sutherland 2003). Also, other studies have proposed that Fe-oxide fraction has the ability to capture heavy metals (Orrono & Lavado 2009).

In this study, coagulation with $FeCl_3$ that occurred under relatively higher coagulant concentration (40 mg/L), could have resulted from the sweep-flocculation process; so, by enmeshment of particles and organic matter in the formed flocs, all attached metals and heavy metals were consequently removed. PAFCl is a pre-hydrolyzed coagulant that has more positive charges in comparison with the traditional coagulants. It has both Al and Fe ions; so, it uses both properties of $Fe(OH)_3$ and $Al(OH)_3$ complex. Thus, positively charged PAFCl flocs can adsorb negatively charged organic matter, colloids, and particles that attracted metals and heavy metals (Ebrahimi et al. 2015). On the other hand, coagulation with PAFCl occurs under relatively lower coagulant concentration which could be a sign of the adsorption mechanism. Thus, it is predicted that the dominant mechanism for metals and heavy metals' removal by PAFCl is adsorption.

Health risk assessment

Health risk indicators such as chronic daily intakes (CDIs) and health risk indexes (HRIs) of metals were calculated for SFBW treated with coagulation and UF processes. The chronic daily intake of metals (CDI) (μg/(kg·day)) and heavy metals through water ingestion was calculated using Equation (1) (Muhammad et al. 2011; Kumar et al. 2016):

$$CDI = \frac{C_m \times I_w}{W_b} \quad (1)$$

where C_m (μg/L) is the concentration of metals or heavy metal in water, I_w (L/day) is the average daily intake of water (2 L/day for adults and 1 L/day for children), and W_b (kg) is the average body weight (72 kg for adults and 32.7 kg for children), respectively.

Health risk indexes (HRIs) were calculated using Equation (2) (Shah et al. 2012):

$$HRI = \frac{CDI}{RfD} \quad (2)$$

where RfD (μg/(kg·day)) is the oral toxicity reference dose. It represents the daily dosage that the exposed individual can sustain at this level of exposure over a long period of time without experiencing any harmful effects. The oral reference doses (RfD oral) for the respective toxicants were used. RfD values for Fe, Al, Pb, Ar, and Cd are illustrated in Table 3 (EPA 2005; Muhammad et al. 2011).

The CDI and HRI values of the selected metals and heavy metals, before and after treatment, are summarized in Tables 4 and 5. HRI value less than one is considered to be safe for consumers (Khan et al. 2008).

The results showed that CDI values of Fe, Al, Pb, As, and Cd in raw SFBW were 111.1, 11.1, 6, 0.1, and 0.11 μg/kg-day, respectively, for adults and they were 122.3, 12.2, 6.6, 0.07, and 0.12 μg/kg-day, respectively, for children. For SFBW treated with PAFCl, the CDI values of Fe, Al, Pb, As, and Cd for adults reached 0.556, 1.278, 0, 0, and 0.005 μg/kg-day, respectively. Also for children, these amounts reached 0.612, 1.4, 0, 0, and 0.006 μg/kg-day, respectively. For SFBW treated with $FeCl_3$, the CDI values of the mentioned parameters for adults reached 3.33, 0.861, 0, 0, and 0.01 μg/kg-day, respectively, and for children they reached 3.67, 0.948, 0, 0, and 0.011 μg/kg-day, respectively.

The amounts of CDI for Fe, Al, Pb, As, and Cd in SFBW treated with PAFCl-UF process were 0, 0.861, 0, 0, and 0.004 μg/kg-day, respectively, for adults and 0, 0.948, 0, 0, and 0.005 μg/kg-day, respectively, for children. For SFBW treated with $FeCl_3$-UF process, the CDI values of Fe, Al, Pb, As, and Cd for adults were 2.22, 0.556, 0, 0, and 0.008 μg/kg-day, respectively, while for children they were 2.44, 0.612, 0, 0, and 0.009 μg/kg-day, respectively. It can be seen that CDI values in raw SFBW were greater than

Table 3 | The oral toxicity reference dose value (Rfd) of metals and heavy metals in water

Metals and heavy metals	Oral RfD (μg/(kg·day))
Fe	700
Al[a]	7,000
Pb	3.5
As	0.3
Cd	0.5

[a]The RfD value proposed by FAO and WHO (WHO 1989).

Table 4 | Chronic daily intakes (CDIs, μg/(kg·day)) of metals and heavy metals through consumption of treated SFBW

Parameter	Individuals	Raw SFBW	Treated SFBW with PAFCl	Treated SFBW with $FeCl_3$	PAFCl-UF output	$FeCl_3$-UF output
Fe	Adults	111.1	0.556	3.33	0	2.22
	Children	122.3	0.612	3.67	0	2.44
Al	Adults	11.1	1.278	0.861	0.861	0.556
	Children	12.2	1.4	0.948	0.948	0.612
Pb	Adults	6	0	0	0	0
	Children	6.6	0	0	0	0
As	Adults	0.1	0	0	0	0
	Children	0.07	0	0	0	0
Cd	Adults	0.11	0.005	0.01	0.004	0.008
	Children	0.12	0.006	0.011	0.005	0.009

Table 5 | Health risk indices (HRIs) of metals and heavy metals through consumption of treated SFBW

Parameter	Individuals	Raw SFBW	Treated water with PAFCl	Treated water with $FeCl_3$	PAFCl-UF output	$FeCl_3$-UF output
Fe	Adults	0.16	0.0008	0.0047	0	0.0031
	Children	0.175	0.00087	0.0052	0	0.0035
Al	Adults	0.002	0.00018	0.00013	0.00012	0.00008
	Children	0.002	0.0002	0.000135	0.00013	0.00009
Pb	Adults	1.72	0	0	0	0
	Children	1.89	0	0	0	0
As	Adults	0.22	0	0	0	0
	Children	0.241	0	0	0	0
Cd	Adults	0.22	0.01	0.0194	0.0083	0.0167
	Children	0.245	0.011	0.021	0.0091	0.0183

that of the treated SFBW. Also, for SFBW treated with PAFCl and PAFCl-UF processes, these values were lower in comparison with that of $FeCl_3$ and $FeCl_3$-UF processes, except for aluminum (Table 3).

With regards to the raw and treated SFBW quality in this study, the CDIs of metals and heavy metals for raw SFBW were found to be in the order: Fe > Al > Pb > Cd > As. For SFBW treated with PAFCl-UF process, the order was Al > Cd and the others were zero, while for $FeCl_3$-UF process, it was Fe > Al > Cd and the others were zero.

The health risk indices' values of Fe, Al, Pb, As, and Cd in raw SFBW for adult consumption were 0.16, 0.002, 1.72, 0.22, and 0.22, respectively (Table 5). It can be seen that raw SFBW has a very low concentration of metals and heavy metals. Also, HRIs calculation showed that the values were less than 1 except for Pb, which indicates no risk of exposure to the use of this water. The same results were observed for child consumption.

The HRIs indices' values of Fe, Al, Pb, As, and Cd in SFBW treated with PAFCl-UF process for adult consumption were 0, 0.00012, 0, 0, and 0.0083, respectively, and for children they were 0, 0.00013, 0, 0, and 0.0091, respectively. These values for SFBW treated with the $FeCl_3$-UF process and adult consumption were 0.0031, 0.00008, 0, 0, and 0.0167, respectively, and for children they were 0.0035, 0.00009, 0, 0, and 0.0183, respectively.

It can be seen that HRIs indices' values of Fe, Al, Pb, As, and Cd in SFBW treated with PAFCl-UF and FeCl3-UF processes were less than 1 which indicates no risk of exposure to the use of this water. By comparing between the quality of water produced with PAFCl-UF and FeCl3-UF processes, it can be seen that HRIs indices' values for Fe and As are lower in the PAFCl-UF process while HRIs' value of Al is lower in the $FeCl_3$-UF process. Maybe, this is because PAFCl contains the Al component. In this study, the concentration of Fe and Cd in water treated with PAFCl-UF was lower than that of the $FeCl_3$-UF process, and Pb and As concentration were zero for both processes. All the concentrations of metals and heavy metals in the SFBW treated with both processes met the drinking water standard according to EPA guidelines. Based on the quality of SFBW treated with the PAFCl-UF process, the HRIs of selected metals and heavy metals were found to be in the order: Cd > Al > Fe = Pb = As (HRIs values for Fe, Pb, and As were zero). For the $FeCl_3$-UF process, this order was Cd > Fe > Al > Pb = As (HRIs values for Pb and As were zero).

CONCLUSIONS

- SFBW treated with the coagulation-UF membrane process was colorless and had a turbidity of 0.1 NTU, and TC/FC were undetectable.
- All concentrations of metals and heavy metals in SFBW treated with both processes met the drinking water standard according to EPA guidelines.
- PAFCl showed good removal efficiency in comparison with $FeCl_3$.
- Based on the quality of SFBW treated with the PAFCl-UF process, the HRIs of selected metals and heavy metals were found to be in the order: Cd > Al > Fe = Pb = As (HRIs values for Fe, Pb, and As were zero). For the $FeCl_3$-UF process, this order was Cd > Fe >Al > Pb = As (HRIs values for Pb and As were zero).
- HRIs indices' values of Fe, Al, Pb, As, and Cd in SFBW treated with PAFCl-UF and $FeCl_3$-UF processes were less than 1, which indicates no risk of exposure to the use of this water.

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