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Wastewater reuse from hemodialysis section by combination of coagulation and ultrafiltration processes: case study in Saveh-Iran Hospital

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ABSTRACT

Nowadays, water and wastewater reuse is an important approach to deal with the water shortage in most countries. The present study focused on the feasibility of wastewater reuse form the hospital hemodialysis unit (Saveh, Iran). The combination of coagulation, flocculation, sedimentation (CFS), and ultrafiltration (UF) processes have been investigated to improve wastewater quality for its reusability assessment. In raw hemodialysis wastewater, the average amounts of total dissolved solids, chemical oxygen demand (COD), and total coliform (TC) were 7,440 ± 28 mg/L, 2,400 ± 70 mg/L, and 6.7×10^7 MPN/100 mL, respectively. Based on the results, by applying the CFS process, the removal efficiency for turbidity, color, COD, and TC were 96%, 95%, 54%, and 93%, respectively. With a combination of CFS and UF processes, the removal efficiency of studied parameters was enhanced to higher than 99%. Comparing to the removal efficacy of the CFS process without application of clay, the optimum dose of poly-aluminium chloride (PACl) with the addition of 0.7 g/L of clay was 300 mg/L and resulted in 70% reduction of PACl consumption. It was observed that treated wastewater was brackish with a high concentration of organic matter content that could not be used for irrigation. It was concluded that by reusing reverses osmosis reject for irrigation (2,300 L/d), it could be possible to irrigate 287.5 m^2 of the hospital green space.

Keywords: Wastewater; Reuse; Hemodialysis wastewater; Coagulation; Ultrafiltration

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1. Introduction

The population growth, higher quality standards, development of industrial activities, climate change, and limitation of water resources as a result of precipitation reduction, lead to numerous efforts, and attention to water and wastewater reuse approach. Of course, wastewater reuse is one of the best ways to deal with water shortage. In Iran, due to the critical conditions of water shortages in recent decades, some cities have turned to water reuse from different sources of wastewater like wastewater treatment plants (WWTPs), filter backwash water of water treatment plants, and wastewater from industrial factories. Most countries need to find water resources that have the potential for water retrieval. Wastewater is an important option that can be used for such purposes which has attracted much attention in many countries facing water scarcity. Today, in such countries, treated industrial, domestic, and agricultural wastewater is used for many purposes. The use of any of these resources depends on specific conditions, technology, expertise, economic costs, and water shortage priority [1–4].

Another resource that can be used for water reuse is hospital wastewater, also it must be considered that hospital wastewater is a general concept that may contain various mineral or organic matters (OM) [5–8]. Therefore, it may be impossible for every hospital to treat or reuse their wastewater as a consequence of mixing all types of wastewater from different sections of the hospital. In order to take steps toward green hospital management, it is worth to reuse water from the sections, which needs the least complexity or low costs. One of these sections is the hemodialysis section of the hospital. Recycling of wastewater from these sections can be used for irrigation, laundry, and sanitation purposes. It should be noted that hemodialysis wastewater (HWW) has a very high-risk potential for health, because it may be contaminated with biologically hazardous agents. Thus, its treatment is necessary.

Healthy kidneys clean blood and remove extra fluid in the form of urine. When kidney failure occurs, treatment like hemodialysis is conducted on patients. In hemodialysis, the dialyzer unit has two parts. One part for blood and the other one for a washing fluid called dialysate. In order to separate these two sides, a thin membrane is used. Blood cells, protein, and other important things remain in blood, because they are too big to pass through the membrane; but, smaller waste products such as urea, creatinine and extra fluid pass through the membrane and are removed [9]. The previous studies showed that hemodialysis water conservation projects cause positive environmental and financial savings [10,11]. The results of a study on potential environmental toxicity from hemodialysis effluent by Machado illustrated that the effluents of hemodialysis contain high concentrations of nitrites, phosphates, sulfates, ammonia, and total nitrogen, as well as elevated conductivity, turbidity, salinity, biochemical oxygen demand (BOD), and chemical oxygen demand (COD) which exceed the thresholds defined in the CONAMA resolution 430 [12]. Also, Ali-Taleshi [13] study on characterization of HWW from Yazd educational hospitals revealed that some parameters like electrical conductivity (EC), BOD, and COD of this wastewater is not very high. Although there are many studies on hospital wastewater treatment, but, there is none about hemodialysis section in the hospital for specific and individual treatment.

It was indicated that, through a 4 h dialysis session, patients are exposed to 120 L of purified water. Hence, without considering the water rejected during treatment by the carbon filters and reverse osmosis membranes that produce treated water for dialysis usage, which is about 120 L of wastewater being generated during each dialysis session of course. It is estimated that there are over 31,000 dialysis patients in Iran. Thus, at least the produced wastewater for each dialysis session is something about 3,720 m^3. It must be noted that most patients go to a clinic (dialysis center) three times a week. It is worth recycling this volume of effluent. The city of Saveh located in Iran has semi-arid weather. The water resources of this city (surface and groundwater) are brackish water so, desalination is one of the most important processes for supplying drinking water.

This study aimed to evaluate the feasibility of the reuse of HWW from an educational hospital in Saveh, as an alternative source of water for irrigation of hospital green space or landscape. In this study, pretreatment with coagulation, treatment by ultra-filtration (UF), and recycling of brine reject from reverses osmosis (RO) was investigated. Parameters like COD, UV absorbance at 254 nm (UV_{254nm}), pH, electrical conductivity (EC), total dissolved solids (TDS), total coliform (TC), heterotrophic plate count (HPC), turbidity, true color, potential salinity, Na%, and sodium adsorption ratio (SAR) were investigated.

2. Materials and methods

2.1. Wastewater sampling from hemodialysis machine and RO plant

The hemodialysis unit of Shahid Modares hospital in Saveh has 57 patients who undergo dialysis three times a week (12 times in each month). The required influent water volume for each hemodialysis machine (Eurothechnic and BMA models, Belgium and Germany) was 30 L/h per patient. The flow diagram of produced wastewater from hemodialysis and RO treatment process is schematically shown in Fig. 1.

The produced wastewater by each hemodialysis machine for a 4 h dialysis period was around 120 L and corresponds to the total wastewater flow rate of 2.736 m^3/d. The produced wastewater is discharged to receiving well without treatment. The wastewater samples were collected from HWW drain pipe and RO concentrate (RO reject). The physical, chemical, and biological characteristics of HWW and RO reject water is presented in Table 1.

The wastewater sampling form hemodialysis unit was carried out in 3 months (March–May) in 2018. To obtain

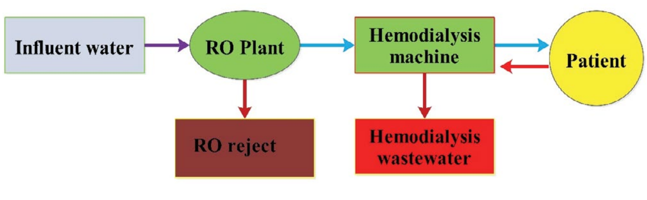

Fig. 1. Diagram of produced wastewater from hemodialysis and RO treatment process.

Table 1
Characteristics of hemodialysis wastewater, RO reject, and influent water in hospital

Parameter	Well water in hospital	Produced water by RO	Hemodialysis wastewater	RO reject	AAMI standards [14,15]
Turbidity (NTU)	0.32 ± 0.18	0.16 ± 0.03	141 ± 4.2	0.21 ± 0.03	–
Colour (Pt. Co.)	3 ± 1.4	2 ± 1.4	1,191 ± 11.3	2 ± 1.4	–
EC (µs/cm)	3,640 ± 48	29 ± 3	13,630 ± 98	878 ± 28	–
TDS (mg/L)	1,712 ± 28	14.5 ± 2	7,440 ± 28	420 ± 14	–
pH	7.91 ± 0.2	8 ± 0.4	7.2 ± 0.3	6.4 ± 0.3	–
Total hardness (TH) (mg/L as $CaCO_3$)	320 ± 14	6 ± 1.2	556.5 ± 28	88 ± 11.3	–
Alkalinity(mg/L as $CaCO_3$)	480 ± 32	8 ± 2.1	1,850 ± 71	148 ± 8.4	–
SO_4^{-2} (mg/L)	580 ± 32	6 ± 2.4	960 ± 11	135 ± 8	100
Cl^- (mg/L)	530 ± 11	4 ± 1.4	3,639 ± 70	90 ± 8	–
Ca^{+2} (mg/L)	121.6 ± 7	2.4 ± 0.4	116 ± 7	26 ± 3	2
Mg^{+2} (mg/L)	3.9 ± 0.6	1.46 ± 0.4	65 ± 4.3	5.7 ± 1.8	4
Na^+ (mg/L)	470 ± 90	1 ± 0.2	3,082 ± 25	115 ± 11	70
K^+ (mg/L)	92 ± 8	0.5 ± 0.1	101 ± 8	15 ± 4.2	8
Sludge volume (mL/L)	Negligible	Negligible	Negligible	Negligible	–
UV_{254nm} (cm^{-1})	0.05 ± 0.004	0.01 ± 0.001	2.5 ± 1.1	0.04 ± 0.004	–
COD (mg/L)	7 ± 0.3	ND	2,400 ± 70	4 ± 0.3	–
TC (MPN/100 mL)	480	ND	6.7×10^7	ND	–
FC (MPN/100 mL)	480	ND	1.95×10^5	ND	–
HPC (CFU/mL)	276	ND	6.25×10^5	34	<100

ND, Not detected.

enough volume of wastewater for experiments, the combined wastewater sample was collected from all the hemodialysis unit in services. From 12 hemodialysis unit, the collected wastewater was mixed in an equalization tank, and used as influent wastewater for experiments. As well as, to specify characteristic of RO reject, the samples were collected from drainage pipe of receiving well (about 40 L).

2.2. Coagulation, flocculation, sedimentation, and ultrafiltration pilot and experiment protocol

To investigate the efficiency of the coagulation, flocculation, sedimentation (CFS) process as a pretreatment, a Jar test apparatus (Phipps and Bird, Richmond, VA 23221-0475 USA) was used for HWW treatment (Fig. 2).

After coagulant addition, the HWW was undergone rapid mixing (120 rpm for 2 min), flocculation (40 rpm for 10 min), and settling for 20 min at room temperature (22°C). The jar tests were conducted to study the effect of solution pH (5–9.5), dose of poly-aluminium chloride (PACl) (30–2,000 mg/L), coagulant aid (polyelectrolyte, Zetag 8180), and weighing agent (clay) on treatment efficiency of CFS process [16]. After optimizing CFS process, the treated HWW with CFS process was stored in a reservoir tank and then fed to UF pilot with a dead end flow separation unit presented schematically in Fig. 3.

The UF pilot was operated in constant filtration feed flow of 6 L/m^2 h at a transmembrane pressure (TMP) of 600 Pa. The characteristics of the UF membrane module are summarized in Table 2 [17].

To assess UF membrane fouling, the variation of TMP was monitored. After each experiment, the UF system was backwashed with demineralized water for 10 min at 3 bar until the water flux of the membrane was restored. If it was necessary, chemical cleaning by recirculating a 0.3% HNO_3 solution was also performed. The experiments were performed duplicate and averaged data are presented.

2.3. Chemicals and reagents

In this study, PACl was used as a coagulant and provided by chemical suppliers from Chinees Company. The PACl stock solution was prepared by dissolving 5 g of PACl in 1 L of distilled water. As well as polyelectrolyte (Zetag 8180) being utilized as a coagulant aid, clay was provided from local shop of Saveh, Iran. For pH adjustment of the samples, 0.1 M of HCl and NaOH solutions with analytical grade was applied.

2.4. Analysis of samples

All test procedures were adopted from Standard Methods for Water and Wastewater Examination. During CFS and UF operation, influent, and effluent turbidity, TDS, EC, and pH were routinely measured by HACH turbidity meter (model: 2100Q, Germany), HACH TDS meter (model: HQ40d, Germany), pH meter (model: Sens ION™ pH 31, Germany), respectively. For UV_{254} and color measurements, at first, the samples were filtrated via a 0.45 µm membrane (Whatman. No. 42, GE Healthcare, UL Limited, Amersham) and then analyzed by UV-Vis spectrophotometer (DR 6000, HACH LANGE, Germany). The influent and effluent COD were measured by closed reflux calorimetry (COD digital reactor, model: DRB200, Germany).

Fig. 2. Photograph of Phipps and Bird jar apparatus.

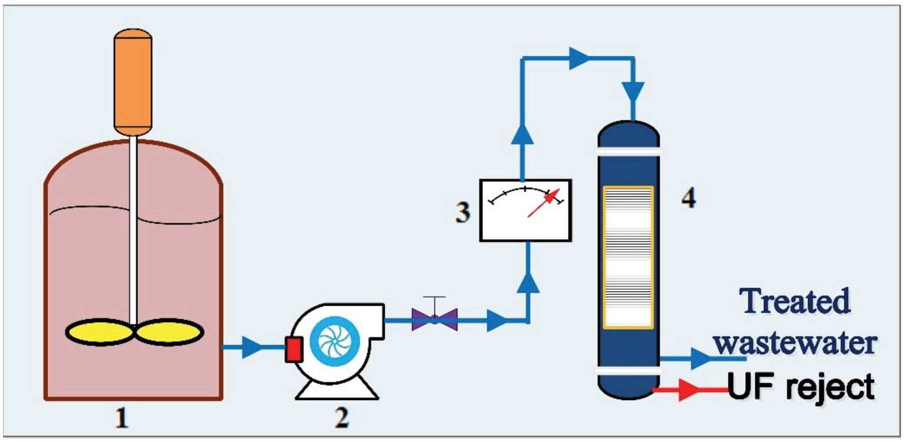

Fig. 3. Schematic of UF set up. (1) Storing tank, (2) peristaltic pump, (3) barometer, and (4) UF module.

Table 2
Characteristics of UF membrane module

Parameter	Description
Membrane type	Hollow fiber
Membrane material	Polypropylene
Capillary pore diameter	0.01–0.2 μm
Membrane area	0.1 m^2
Feed pH range	7
Operating pressure (bar)	600 Pa
Operating temperature (°C)	21

3. Results and discussion

3.1. Quality of hemodialysis wastewater and RO reject

The characteristics of raw water, treated water by RO, HWW, and RO reject are summarized in Table 1. Comparing to proposed standards by Association for the Advancement of Medical Instrumentation (AAMI), the feed water to hemodialysis unit (produced water by RO) has a very good quality and meets AAMI standard. The previous studies on influent water quality to hemodialysis unit in Zahedan [18] and Bojnurd [19] showed the same results.

As summarized in Table 1, the amount of turbidity, color, TDS, TH, alkalinity, COD, TC, FC, and HPC in raw HWW are very high and classified as supper strong wastewater. The main concern is related to high TDS, COD, and also microbial quality especially TC. In raw HWW, the average values of TDS, COD, and TC were 7,440 ± 28 mg/L, 2,400 ± 70 mg/L, and 6.7 × 10^7 MPN/100 mL, respectively. The obtained results are in line with a previous study that demonstrated HWW had a high EC [20]. Furthermore, the high COD concentrations in HWW are related to creatinine separation from patient blood during hemodialysis.

Ali Taleshi and Nejadkoorki [13] studied the characterization of hemodialysis RO wastewater of Yazd hospitals and reported that the average of TDS and COD in RO wastewater were 564 and 16.1 mg/L, respectively. We found that TDS and COD in RO reject were 420 ± 14 and 4 ± 0.3 mg/L, respectively. This difference is putatively related to influent water quality to the RO plant. The interesting point of the obtained result in this study was related to quality of RO reject. As seen in Table 1, the RO reject was Iran's standard for drinking water without treatment and attributed to the quality of influent water to the RO treatment process. In the past, the influent water of RO treatment process came from brackish water of Saveh and lead to high operation and maintenance cost of the RO process. So, for reduction of operation and maintenance cost of the RO process, the water of Saveh city was treated by one step desalination system comprise of RO membrane and used as feed water to RO treatment process in hemodialysis unit. The treated water by a step desalination system has a high quality in respect of TDS of feed water. However, due to the high amount of COD, turbidity, color, and microorganism in HWW, the pretreatment method including CFS and UF was considered.

3.2. CFS and UF experiments

3.2.1. Effect of solution pH on CFS

As the previous study demonstrated, due to affecting on colloids surface charge, the functional group charge of OM and charge of the dissolved phase solubility, the solution pH is a very important parameter in the CFS process [16]. To examine the effect of solution pH on the CFS process, the experiment was conducted with a constant dose of PACl (60 mg/L) and coagulant aid of 2 mg/L under various solution pH ranging from 4 to 10 (Fig. 4). As depicted in Fig. 4, with increasing solution pH from 4 to 10, the removal efficiency of studied parameters was enhanced and then promptly abated. The highest removal efficiencies were occurred at a solution pH of 7. At this pH, the removal efficiency of turbidity, color and OM were 31.9% ± 1.9%, 26.9% ± 3%, and 14% ± 0.25%, respectively. With increasing solution pH, the carboxyl groups of OM lose protons and lead to more ionization and subsequently the surface charge of OM becomes increasingly negative owing to the presence of OH^-. So, the positive charges of metal coagulants will not overcome negative charge and consequently deteriorates the coagulation. At low solution pH, more concentration of H^+ are exist and affects the surface charge of particles and OM. On the other hand, the coagulant usually consists of positive cation and positive charges repel each other and results in deteriorate CFS efficiency. In order to avoid chemical consumption for pH adjustment, the pH of raw HWW (7.2 ± 0.3) was selected as working solution pH in the next experiment.

Jia et al. [21] studied the application of PACl for treating the Pi River water in winter and summer and reported that higher efficiency of PACl removal of turbidity, color, and UV_{254} was obtained at solution pH of 7.2–8.5. In addition, Dovletoglou et al. [22] demonstrated that that optimum pH for PACl was around seven when it was used as a coagulant for treatment of paint industry wastewater.

3.2.2. Effect of coagulant dose on CFS

The CFS is an effective process for the removal of colloids from aqueous solution and also assists in OM contaminants removal, especially those which cause color, taste, and odor as well as the microorganism. The experiments were performed to evaluate the effect of various PACl doses (30–2,000) on CFS process removal efficiency under constant dose of coagulant aid (2 mg/L) and optimum solution pH. Fig. 5 depicted the obtained results of the removal efficiency of the CFS process as a function of coagulant dose.

As shown in Fig. 5, with increasing coagulant dose from 30 to 1,000 mg/L, the removal efficiency for turbidity, color, and OM by CFS process were climbed from 14% ± 1.5% to 88% ± 2.9%, from 12% ± 9% to 89% ± 6%, and from 6% ± 0.24% to 31% ± 0.125%, respectively. Conducting CFS experiment with application of PACl dose higher than 1,000 mg/L leads to diminishing of removal efficiency due to the restabilization of constituents in suspension. The previous study showed that at low dose of coagulant the double layer compression mechanism of colloid particles cannot be achieved and also interparticle bridging doesn't occur. On the other hand, when the CFS process was operated with high coagulant dosage, there is not enough negative charges on the particle surfaces or colloidal matter to stabilize the positively charged particles. Subsequently, the precipitate suspension becomes unstable and influences on the quality of treated wastewater (TWW) [23].

The high coagulant dose requirement in this study may be related to the specific quality of HWW. As summarized in Table 1, HWW was contained high color and alkalinity with particulate matter and it is a very hard situation to achieve high removal efficiency by the CFS process [24]. The previous study demonstrated that the presence of particulate matter in suspension increased the number of collision sites and consequently enhanced the physical removal

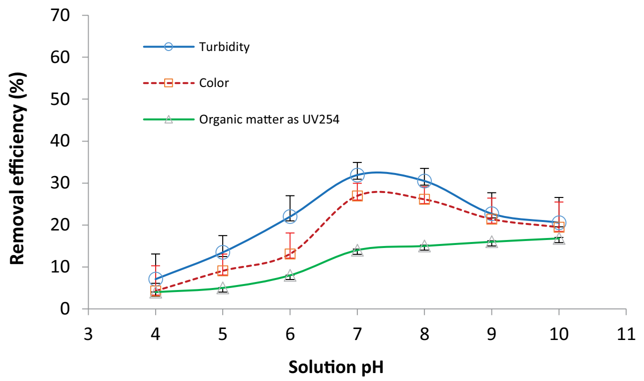

Fig. 4. Effect of solution pH on CFS efficiency (PACl dose: 60 mg/L and coagulant aid dose: 2 mg/L).

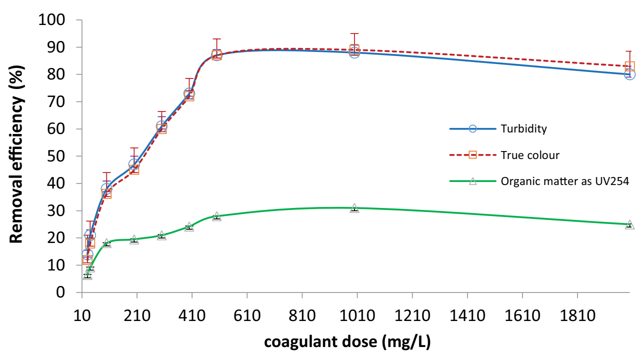

Fig. 5. Variation of removal efficiency of CFS process as a function of coagulant dose (solution pH: 7.2 and coagulant aid dose: 2 mg/L).

of colloids and solids during the CFS process [17]. Jia et al. [21] demonstrated that the optimum dose of PACl for treating the Pi River water was 14.4 mg/L and resulted in a 50% reduction in UV_{254}. Abdolahzadeh et al. [25] showed that by application of 15 mg/L of PACl, the OM removal as UV_{254} was 45% at the initial turbidity of 100 NTU. In addition, the wastewater treatment by PACl was studied by Uyak and Toroz [26] and described that COD removal by optimum dose of PACl (165 mg/L) was 95%. Lower optimum dose of PACl for water treatment was reported by Aziz et al. [27]. They reported that the removal of OM with the CFS process varies widely from 15% to 56%.

3.2.3. Effect of clay addition in CFS process

The observation on HWW showed that this wastewater has some critical specifications including sticky, very odorous, milky color, and without any suspended particle. As previously mentioned, the CFS process has low efficiency at lower particle matter content. For this purpose, clay was used as a weighing agent and source of particle matter. The experiment was carried out to determine the optimum dose of PACl under optimum solution pH with the addition of 2 mg/L of coagulant aid and 0.7 g/L of clay (Fig. 6).

As illustrated in Fig. 6, with PACl dose increment from 30 to 300 mg/L, the removal efficiencies for turbidity, color and OM were enhanced from 25% ± 2.25% to 96% ± 1.14%, from 22% ± 8% to 95% ± 4.4%, and from 11% ± 0.27% to 41% ± 0.1%, respectively. Application of PACl in CFS process with a dose of higher than 1,000 mg/L resulted in efficiency reduction of CFS process. Comparing to the removal efficacy of the CFS process without clay, the optimum dose of PACl with the addition of 0.7 g/L of clay was 300 mg/L and resulted a 70% reduction of PACl consumption. In fact, clay can provide nuclei to enhance floc formation and density by modifying surface charge of OM compounds or by adsorption [28].

Aboussabiq et al. [29] investigated OM and suspended solids removal from domestic wastewater by Moroccan clay and showed a significant reduction of waste pollution of about 66.8% for COD and 97.4% for total suspended solids (TSS) at 25 mg/L dose of clay. Environmental Protection Agency (EPA) declared that various forms of clay can be used as an aid to coagulation, when treating water low in turbidity, but with high alkalinity [30]. Also, clay addition to the CFS process may effect on its efficiency by increasing

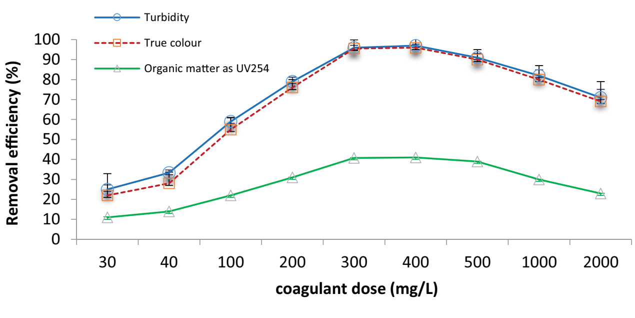

Fig. 6. Variation of CFS process efficiency under coagulant aid and clay addition (solution pH: 7.2, coagulant aid: 2 mg/L, and clay dose: 0.7 g/L).

the number of collision sites that enhances the physical removal of colloids. Previous study on filter backwash water treatment by coagulation showed that the particles in the water reduced the coagulant consumption and increased the removal efficiency [31].

3.2.4. Quality of treated wastewater after coagulation, UF, and dilution

When HWW was treated with CFS process at optimum PACl dose (300 mg/L), coagulant aid (2 mg/L), clay (0.7 g/L), and solution pH (7.2), the TWW collected in a storage tank and introduced to UF setup. The quality of TWW with CFS and UF process are summarized in Table 3.

The summarized results in Table 3 demonstrated that the CFS process has high removal efficiency as residual turbidity, color, COD, TC, FC, and HPC reached to 5.6 NTU, 53.6 Pt. Co unit, 1,100 mg/L, 4,200,000 MPN/100 mL, 1,500 MPN/100 mL, and 42,000 CFU/mL. In the case of dissolved constitute such as TDS, anions, and cations, the amount of these parameters don't significantly change. After UF filtration, the amount of turbidity, color, and COD reached 1.4 NTU, 42 Pt. Co, and 930 mg/L and correspondence to 75%, 21.65%, and 15% reduction, respectively. In addition, in the filtrated TWW by CFS process via the UF module, TC and FC weren't detected but HPC was 460 CFU/mL.

Also, to investigate the effect of dilution on TWW by the CFS process, the TWW was mixed with RO reject and groundwater as presented in Table 3. To determine parameters of mixed TWW by CFS with RO reject and groundwater, Eq. (1) was applied [17].

$$C_{\text{mix}} = \frac{\left(Q_{\text{raw}} \times C_{\text{raw}}\right) + \left(Q_{\text{TWW}} \times C_{\text{TWW}}\right)}{\left(Q_{\text{raw}} + Q_{\text{TWW}}\right)} \quad (1)$$

where C_{mix} is concentration of parameters in combined TWW, Q_{raw} is the flow rate of raw HWW, C_{raw} is concentration of parameters in raw HWW, Q_{TWW} is the flow rate of TWW and C_{TWW} is concentration of parameters in TWW. When TWW by CFS process was filtrated by UF module, there was no major changes in the quality of TWW especially for soluble materials, so, TWW by CFS process was used for mixing.

As presented in Table 3, the mixing of TWW by CFS process with RO reject as well as with groundwater are resulted in relatively high improvement in parameters including turbidity, color, TDS, and COD and reduced to 2.1 NTU, 19.2 Pt. Co, 2,713 and 316 mg/L, respectively. When TWW by CFS process was mixed with groundwater, the lower quality was occurred comparing with the mixing of TWW by CFS process with RO reject. However, the amounts of some parameters of mixed water including COD, sulfate, chloride, TC, and FC are higher than Iranian Standard for agricultural reuse and irrigation [32].

As shown in Table 1, the RO rejects quality showed a good quality and could pass Iran standard for agricultural reuse and irrigation without any treating. Amouei et al. [33] investigated the efficiency of hospital WWTP in the north of Iran and the reported that the most of treatment process was extended aeration activated sludge and the amount of TSS, BOD, COD, and TC in the effluent of the studied

Table 3
Characteristics of treated wastewater

Parameter	TWW by CFS	Filtrated TWW by UF	Mix of TWW by CFS and RO reject	Mix of TWW by CFS with groundwater	Iranian standard for agricultural reuse
Turbidity (NTU)	5.6	1.4	2.12	2.1	50
Color (Pt. Co)	53.6	42	19.2	19.8	75
EC (μs/cm)	13,860	13,788	5,205	7,046	–
TDS (mg/L)	7,300	7,290	2,713	3,574	–
pH	7	7	6.6	7.6	6–8.5
Total hardness (mg/L as $CaCO_3$)	560	550	245	400	–
Alkalinity (mg/L as $CaCO_3$)	1,775	1,760	690	911	–
SO_4^{-2} (mg/L)	960	960	410	706	400
Cl^- (mg/L)	3,720	3,720	1,300	1,593	600
Ca^{+2} (mg/L)	115.4	115.4	55.8	119.5	–
Mg^{+2} (mg/L)	64.4	64.4	25	24	100
Na^+ (mg/L)	3,082	3,082	1,104	1,340	–
K^+ (mg/L)	101	101	43	95	–
UV_{254} (cm^{-1})	1.5	1	0.5	0.5	
COD (mg/L)	1,100	930	369	371	200
Total coliform (MPN/100 mL)	4,200,000	ND	1,400,000	1,400,320	1,000
Fecal coliform (MPN/100 mL)	15,000	ND	5,000	5,320	400
HPC (CFU/mL)	42,000	460	14,022	14,184	–

*Dilution was conducted by applying two times ($Q_{wastewater}$: 2 and $Q_{ROreject}$: 4 m^3)

hospitals were higher than the Iranian reuse standard. Suarez et al. [34] investigated the pretreatment of hospital wastewater by the CFS process and revealed that the application of $FeCl_3$ as a coagulation agent at 50 mg/L lead to 65% of COD reduction. In addition, Dehghani et al. [35] study on hospital wastewater treatment by electrocoagulation, demonstrated that COD removal efficiency was 87% with initial COD of 398 mg/L. The treatment of wastewater by CFS process was examined by Aziz et al. [27] and demonstrated that when initial COD and TDS of wastewater were 228 and 458 mg/L, respectively, the optimum PACl dose was 160 mg/L and around 95% removal efficiency of COD was obtained. It should be noted that in present work initial COD and TDS of wastewater were 2,400 and 7,300 mg/L, respectively, and lead to 1,000 mg/L optimum dose of PACl as it was used as coagulant agent.

Based on the United States EPA guideline on TWW from the hospital and medical institutions, the amount of BOD, COD, SS, and *Escherichia coli* must be 30, 100, 30 mg/L and 2 × 10^5 MPN/100 mL, respectively.

In a few studies instead of coagulants, electrodes are used in electrocoagulaton process in order to reduce the amount of sludge production in water and wastewater treatment [36,37].

3.2.5. TMP variation during of UF system operation

Although the monitoring of TMP variation was not a specific goal of this study but, the removal of wastewater constituents by the UF system leads to the increasing of applied TMP. The variations in TMP during the UF system operation are illustrated in Fig. 7.

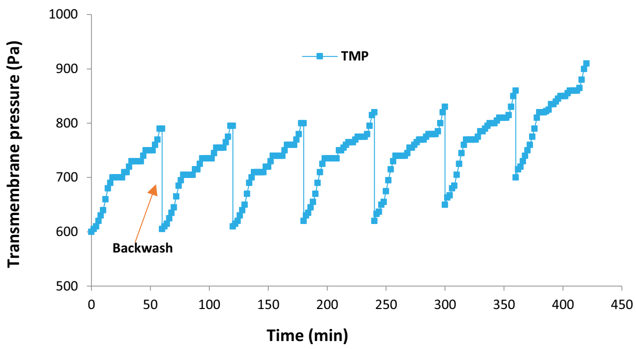

Fig. 7. Variations of TMP during UF system operation.

As shown in Fig. 7, during the 7 h operation of the UF system, the TMP was gradually increased with time from 600 Pa (low initial value) to 920 Pa (maximum value). As seen, the UF backwash process leads to vigorous reduction of TMP and then increasing gradually. This behavior was attributed to membrane fouling. When the UF system was in services, the turbidity, color, and OM were removed from feed wastewater and deposited on the membrane surface. During UF backwash, some of them were removed from the membrane surface and the remaining part also caused clogging and increased TPM.

Previous study demonstrated many mechanisms affecting in that membrane fouling such as (i) deposition of inorganic or organic particles and colloids on membrane surface, (ii) precipitation of OM and colloids, (iii) precipitation of inorganic dissolved components (Fe^{3+}, Mg^{2+}, and SiO_2), and (iv) deposition and growth of microorganisms on membrane surface [38]. In our study, the raw HWW did not contain colloid particles and probably the main cause of the UF clogging was related to high concentrations of OM and high value of bacteria. Kimura et al. [39] showed that high dosages of coagulant caused a greater degree of TMP and also the high TMP and UF fouling were related to high OM content as reported by Kennedy et al. [40].

3.3. Applicability of TWW for irrigation

To determine the quality of TWW and RO reject of hemodialysis unit for irrigation propose, the indices include SAR and sodium content were taken into account. Eqs. (2) and (3) were used for indices calculation.

$$\text{SAR} = \frac{\text{Na}^+}{\left(\frac{\text{Ca}^{2+} + \text{Mg}^{2+}}{2}\right)^{0.5}} \tag{2}$$

$$\text{Na}^+(\%) = \frac{\text{Na}^+}{\text{Ca}^{2+} + \text{Mg}^{2+} + \text{K}^+ + \text{Na}^+} \times 100 \tag{3}$$

where Na^+ is sodium, Ca^{2+} is calcium, and Mg^{2+} is magnesium concentrations in meq/L. The calculated indices for all types of water and wastewater in the hospital are presented in Table 4. In addition, the general guidelines for SAR index interpreting and evaluating sodium hazard to soil are summarized in Table 5.

According to results, the RO reject and groundwater showed low sodium hazard to soil due to the SAR index lower than 10 (Table 5). Also, the calculated sodium content index was doubtful for both of them according to approved criteria for irrigation water by Food and Agriculture Organization (FAO) [41]. When calcium precipitated, magnesium replaces it and if manganese didn't have enough amounts the relative proportion of sodium is increased that is very hazardous for soil and plants [42]. The groundwater in Saveh has high TDS in comparison to other groundwater of in Iran and showed a high value of Na^+ (%) equal to 70% [43].

The field observations in the hemodialysis unit was showed that during the production of 2.736 m^3/d of HWW, around 2.30 m^3/d of RO reject produced. It is implied that the recovery rates of the RO system were about 54%. Most RO systems have recovery rates ranged between 40% and 60% and highly depending on quality and constituents of feed water, membrane type, and system configuration and operation [44].

The previous study demonstrated that required water consumption for irrigation of a public park and green space was 3–12 L/m^2 d [45]. Considering 8 L/m^2 d criteria for irrigation of Saveh hospital green space and existing 2,300 L/d of RO reject, it can be possible to irrigate around 280 m^2 of the hospital green space. On the other hand, around 45% of the consumed water in the hemodialysis unit will be reused.

Pourdara et al. [46] studied the application of hospital wastewater effluent for irrigation of green fields and found that the quality of effluent is to be suitable for agriculture except for MPN which is decreased by increasing the detention time during chlorination. The important parameters of water quality include EC, SAR, and Na (%) in the effluent were 420 μs/cm, 2.5 and 37.5, respectively that is classified as acceptable for irrigation.

Nowadays, application of reverse osmosis in desalination and water treatment to obtain a high quality of water is experienced and has become commercial [47–49].

Table 4
Calculated indices for TWW and RO reject

Type of water and wastewater	SAR	Na^+ (%)
TWW with CFS process	40	90
RO reject	3.7	69.8
Groundwater	8	70
Mix of TWW by CFS and RO reject	21.7	88.9
Mix of TWW by CFS with groundwater	20.6	84.8

Table 5
Guidelines for interpretation of SAR index

SAR values (meq/L)	Sodium hazard to soil
0–10	Low
10–18	Medium
18–26	High
>26	Very high

4. Conclusion

There is no attention on water reuse from the hemodialysis unit of hospitals and most of the studies are related to the quality of treated water with RO that entered the hemodialysis units. This study showed that the effluent HWW has a very specific quality and could affect the quality of whole wastewater that entered to the WWTP. High COD and TDS in HWW will have a destructive effect on WWTP function and pretreatment of H may be a corrective action for the hospital's WWTP. In this study, the combination of CFS process with UF has been investigated to improve HWW quality for its reusability assessment. The removal efficiencies of turbidity color and COD by CFS process at optimum condition (PACl dose: 300 mg/L, coagulant aid: 2 mg/L, and clay dose: 0.7 g/L) were 96%, 95%, and 54%, respectively. Application of clay as weighing agent showed an important role on the reduction of PACl consumption and comparing to removal efficacy of CFS process without clay, the optimum dose of PACl with the addition of 0.7 g/L of clay was 300 mg/L and revealed 70% reduction of PACl consumption. As HWW contains a high concentration of TDS and COD, it was found that the UF system should not be used because it has actually not much effect on the removal of these parameters. Water reuse from the hemodialysis unit with 46% recovery is an important issue, especially for cities facing water scarcity, and it should look promising.

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