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Performance evaluation of the combined process of ozonation, biological activated carbon reinforced by bacterial consortium, and ultrafiltration in greywater treatment

Ebrahim Shahsavani[1], Mohammad Hassan Ehrampoush[1], Mohammad Reza Samaei[2], Ehsan Abouee Mehrizi[1], Farzan Madadizadeh[3], Alireza Abbasi[2], Parvaneh Talebi[1], Amin Mohammadpour[2], Ali Asghar Ebrahimi[1*]

[1]Environmental Science and Technology Research Center, Department of Environmental Health Engineering, School of Public Health, Shahid Sadoughi University of Medical Sciences, Yazd, Iran
[2]Department of Environmental Health Engineering, School of Health, Shiraz University of Medical Sciences
[3]Center for Healthcare Data Modeling, Departments of Biostatistics and Epidemiology, School of Public Health, Shahid Sadoughi University of Medical Sciences, Yazd, Iran

Abstract
Background: Background: Because of the growing population and increasing freshwater consumption, treatment and reuse of greywater have been widely considered. The application of a new and environmentally friendly treatment method for synthetic and real greywater (RGW) is of utmost importance. This study aimed to evaluate the efficiency of the combination of ozonation, biological activated carbon, and ultrafiltration (O_3/BAC/UF) in the removal of chemical oxygen demand (COD), turbidity, five-day biochemical oxygen demand (BOD_5), and linear alkylbenzene sulfonates (LAS) from synthetic greywater and RGW.
Methods: *Bacillus Subtilis*, *Acinetobacter radioresistens*, *Pseudomonas aeruginosa*, and *Ochrobactrum oryzae* were selected from nine pure bacterial species and transferred to granular activated carbon (GAC), then, mineral culture medium was added to the reactor for the growth and establishment of bacterial consortium. The SEM method was employed to ensure the formation of a microbial layer on GAC. Then, the continuous flow of synthetic greywater (for six months) at a low: 6.1, medium: 12.2, and high: 18.3 gCOD/L.d organic loading rates as well as RGW (for two weeks) entered the treatment system.
Results: The percentages of COD removal in low, medium, and high organic loads of synthetic greywater and RGW were 85.12%, 79.05%, 85.3%, and 98.65%, respectively. Moreover, the percentages of BOD_5 removal were 87%, 82%, 51%, and 92%, respectively. Furthermore, the percentages of turbidity removal were 93.5%, 97%, 96.69%, 73.33%, and the percentages of LAS removal were 91.4%, 88.1%, 84.8%, and 93.7%, respectively.
Conclusion: The treatment system has a remarkable ability to remove pollutants from greywater and can be used as a new method of greywater treatment in Iran.
Keywords: Ozone, Ultrafiltration, Pseudomonas, Environmental pollutants, Iran
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***Correspondence to:**
Ali Asghar Ebrahimi,
Email: ebrahimi20007@gmail.com

Introduction

Today, due to the population growth and increasing demand for freshwater, water management and wastewater reuse have become very important. The treatment and reuse of municipal wastewater have been discussed for many years. Moreover, the use of new wastewater treatment methods to remove pollutants has been widely considered (1). Therefore, in recent years, greywater treatment and reuse have been also taken into consideration as a valuable source of wastewater reuse in the world (2).

Greywater is the produced wastewater in residential areas except for toilet waste. However, sometimes, the greywater produced in the kitchen is called dark greywater based on its high organic load (3). The major compounds in greywater include carbohydrates (foodderived), proteins, fats and oils (including fatty acids), glycerides, surfactants (anionic, cationic, and amphoteric caused by shampoo and detergent), as well as soap compounds (4). The main contaminants of greywater are anionic surfactants such as linear alkylbenzene sulfonate (LAS), phosphate, and xenobiotic organic compounds. Various physical, chemical, biological, and even modern treatment methods have been used to reuse greywater (5). Moreover, several studies have been conducted to remove LAS, as the most common surfactant found in laundry detergents, from greywater (6-8).

Rainfall in Iran is less than one-third of the annual world average, so the national rainfall and freshwater resources are rapidly declining (9). Besides, the costs of transferring sewage to a wastewater treatment plant and the complexity of treating mixed wastewater necessitates the separation of wastewater at the production point and treatment of greywater in the next step (10).

For more efficient treatment of greywater, in addition to simple physical methods, advanced treatment is also required. The usage of advanced oxidation processes, such as ozonation, is required to remove a considerable amount of trace organic matter. The ozonation can be used as a suitable pre-treatment method for biological processes (11). In an economic analysis, ozonation was the least expensive advanced treatment method among other advanced methods (12). One of the problems with granular activated carbon (GAC) operation is that due to the presence of organic matter, the adsorption capacity of the GAC filter is reduced, and then, clogged. Therefore, it needs backwashing at short intervals (13). An alternative solution is giving time to microorganisms to attach to the GAC pores, grow, and multiply in the activated carbon bed. The formed biofilm on the activated carbon is called biological activated carbon (BAC). Since BAC is a combination of physical adsorption and biodegradation, it has a higher adsorption capacity than other biofiltration systems (14). In particular, a combination of ozonation and BAC is a promising alternative to advanced wastewater treatment, and an O_3/BAC system can effectively reduce resistant materials, and can mineralize soluble organic matter. Besides, it can eliminate toxic pollutants and oxidize the ozonation by-products (15). The membrane processes such as ultrafiltration (UF) are very effective in removing contaminants such as surfactants and turbidity, but one of the disadvantages of membrane processes is membrane fouling (16). Therefore, combining the membrane process with other processes can reduce membrane fouling and increase UF efficiency.

Several studies have been performed on greywater treatment and the removal of LAS, turbidity, chemical oxygen demand (COD), and five-day biochemical oxygen demand (BOD_5) from greywater by physical chemical and biological methods (6,7,17,18). While physicochemical processes can effectively remove suspended solids, organic materials, and surfactants, they are not cost-effective for removing the full array of dissolved components in the wastewater. Physical processes alone are not sufficient to guarantee an adequate reduction of dissolved organic or inorganic pollutants from greywater. Aerobic biological processes in combination with physical or chemical processes have been found to be efficient for greywater treatment (19).

Although ozonation and BAC have been used in wastewater pre-treatment (20) and post-treatment (21, 22), few studies have been performed on greywater treatment with this method (23). Also, to the best of our knowledge, there is no integrated system of ozonation, BAC and UF (O_3/BAC/UF) in greywater treatment in other studies.

Therefore, the aim of this study was to investigate the efficiency of the combined system of O_3/BAC/UF in the removal of COD, turbidity, BOD_5, and LAS from synthetic greywater with low, medium, and high organic loads and real greywater (RGW). The reason for choosing this system is that it relies more on biological and physical treatment. This method is also relatively inexpensive because GAC is abundantly produced in Iran. In addition, there is no need to replace the activated carbon granules if periodic backwashing of activated carbon is performed. The energy cost is also low in Iran, so electricity consumption of pumps and ozone generators is economically justified (24). Although membrane processes are expensive, the operating cost mitigates when the membrane operates under the gravity-driven circumstances. Moreover, by increasing the greywater quantity (i.e., shared greywater treatment), the total cost can be reduced. Furthermore, consortium bacterial species were isolated from inexpensive and available resources (oil-contaminated soil and compost).

Materials and Methods

Pilot set-up

At first, a research pilot, including a feed tank, a pre-filtration cartridge (with pore size of 5 microns), ozonation reactor (with ozone dose of 5 mg/L), BAC reactor (with the filling height of 28 *cm*), and UF unit was developed (Figure 1).

Synthetic greywater preparation

Chemical compositions were used according to Table 1 (6) to prepare low concentration greywater. For the preparation of medium- and high-concentration greywater, the formula was thickened.

Set up a BAC unit

Mineral culture medium preparation: The mineral culture medium was prepared according to Table 2 (25). To provide bacterial growth, 15 g of agar was added to the medium and its volume reached to one liter with distilled

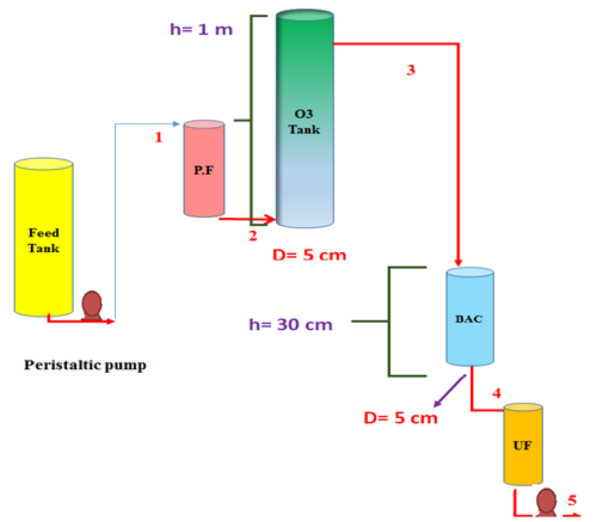

Figure 1. Schematic diagram of O_3/BAC/UF pilot system; P.F: Prefiltration cartridge, BAC: Biological activated carbon reactor, UF: Ultrafiltration, Sampling valves: 1, 2, 3, 4, and 5

Table 1. Chemical compositions of synthetic greywater

Chemical substance	Amount per liter	Commercial products	Amount (mg/L)
Secondary effluent	20 mL	Deodorant	10
H_3Bo_3	1.4 mg	Shampoo	720
$C_6H_{12}O_6$	28 mg	Laundry effluent	150
Na_2HPO_4	39 mg	Sunscreen or moisturizer	10-15
Na_2SO_4	35 mg	Toothpaste	32.5
$NaHCO_3$	25 mg	Vegetable oil	7
Clay	50 mg		

Table 2. Mineral salt medium composition

Chemical substance	Amount (g/L)
K_2HPO_4	0.8
KH_2PO_4	0.2
$MgSO_4.H_2O$	0.5
$FeSO_4$.7H2O	0.09
$(NH_4)_2$SO4	1
CaSO4.2H_2O	0.05

water. Then, the culture medium autoclaved at 121°C and 15 psi pressure for 15 minutes. Afterward, a drop of hexadecane, under the laminar hood, was added to each plate as a carbon source.

Selection of high-growth bacterial species

As an innovation and to optimize the BAC reactor performance, at first, nine pure bacterial species isolated from oil-contaminated soil and compost were prepared (26,27). These species had high metabolic properties for the biodegradation of organic materials in soil and water. They included *Bacillus subtilis*, *Sphingomonas* sp, *Ochrobactrum oryzae*, *Serratia marcescens*, *Acinetobacter radioresistens*, and *Pseudomonas aeruginosa*. Since it was aimed to choose the best species, each bacterium was inoculated into a mineral salt medium containing n-hexadecane as a carbon source. Then, the species were incubated at 32°C (26). After 12 days, the growth of bacteria was examined by a spectrophotometer at 595 nm. Afterward, four species including *B. subtilis*, *A. radioresistens*, *P. aeruginosa*, and *O. oryzae* were selected as a bacterial consortium. Then, each species was cultured on nutrient broth (NB) at 32°C for 21 hours. All experiments were done in a sterile condition. Five mL of this media was added to the Erlenmeyer flask containing 50% greywater to provide bacterial adaptation.

The cultures were transferred to a fresh medium once a week. After adaptation, each microorganism was cultured separately to the NB medium. For incubating bacteria in GAC, the first NB were centrifuged at 5000 rpm and entered equally in the GAC reactors. GAC was purchased from Kimiya Carbon Markazi Company, Arak, Iran (Table 3). The properties of the UF membrane are listed in Table 4.

Transferring the bacterial consortium to the reactor

The following steps were taken to transfer the bacterial consortium to the reactor:

1. Sieving GAC and selecting the granules that passed through the sieve with 10 mesh and remained on the sieve with 16 mesh (diameter 1.19 mm)
2. Washing with ionized water and drying the GAC at 120°C
3. Transferring prepared GAC to the pilot reactor
4. Preparation of mineral culture medium and adding glucose to it as a sole carbon and an energy source
5. Pouring mineral culture medium on GAC
6. Transferring 2 ml of each NB medium containing microorganisms to reactors
7. Aerating of the reactor to form biomass on GAC and regular addition of nutrients (glucose: 0.78 mg/L, ammonium chloride: 0.11 mg/L, and potassium dihydrogen phosphate: 0.033 mg/L) to the reactor for four months (28).

Operation of greywater treatment system (O3/BAC/UF)

In this study, a cartridge filter was placed as a pre-treatment at the beginning of the combined treatment process to reduce the problem of UF fouling. The SEM method was employed to ensure the formation of a microbial layer on GAC. In the last stage, the continuous flow of synthetic greywater entered the treatment system at a low (6.1 gCOD/L.d), medium (12.2 gCOD/L.d), and high (18.3 gCOD/L.d) organic loading rates for 6 months.

Therefore, considering the vastness of Iran and assuming a variety of pollutants concentrations in greywater in different parts of the country, synthetic greywater was prepared at low, medium, and high organic

Table 3. Specification of GAC

Specification	Value	Test method
Iodine number (mg/g)	980	ASTM
Moisture (%bwt)	Max1	ASTM
Total ash (%)	<5	ASTM
Surface area (m^2/g)	950	ASTM
pH	7.5	ASTM
Hardness number	94	ASTM 4058

GAC, granular activated carbon.

Table 4. Specification of UF membrane

Material	Polypropylene
Type	Hollow fiber
Capillary thickness	40~50 µm
Capillary outer diameter	450 µm
Capillary pore diameter	0.01~0.2 µm
Ventilation rate	7.0 × 10-2 cm^3/cm^2.s
Porosity	40~50%
Lengthways strength	120,000 KPa
Designed flux	6~9 L/M^2/H
Area of membrane module	0.1 m^2/module
Operating pressure	-.01~-0.03 MPa
Abnormal pressure	>-0.05 KPa

loads. RGW was also prepared from a residential complex in Shiraz to be used along with synthetic greywater. Then, RGW samples entered the treatment system for two weeks. The empty bed contact time of the BAC reactor was 50 minutes. The BAC and UF units were backwashed every two weeks.

Chemical analysis

COD was measured using the closed reflux method (5220-D, colorimetric method, Spectrophotometer, Hach Company, DR5000), BOD_5 was determined using standard dilution water (5210-B), LAS was measured by methylene blue active substance, 5540–C method, according to *Standard Methods for the Examination of Water and Wastewater*, 23th edition (29). Turbidity was measured by a turbidimeter (Hach, 2100Q), and pH was measured by a pH meter (Metrohm model 827).

Data analysis

In this study, mean, standard deviation, and analysis of variance (ANOVA) test were used to statistically compare the removal efficiency of parameters (COD, BOD_5, turbidity, and LAS) at different organic loads. All the experiments in this study were done duplicated.

Results

Figure 2 shows a comparison of raw activated carbon and BAC, which illustrates the growth of the biological layer on the activated carbon granules and the formation of a microbial consortium.

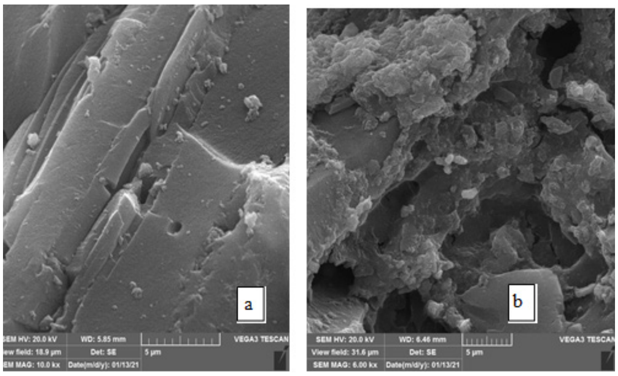

Figure 2. SEM images from media in BAC reactor; a: before the biofilm formation, b: after the biofilm formation

Figure 3 shows the average pH changes in different organic loads (low, medium, and high), and the RGW was taken from a residential complex in Shiraz, Iran. As seen in the figure, the pH in the integrated wastewater treatment system gradually increases and becomes neutral and slightly alkaline (suitable for the growth of microorganisms for biodegradation of organic matters).

Figure 4 shows the average concentration of COD at the entrance of synthetic greywater and RGW as well as the average COD concentrations at the outlet of the pre-filtration, ozonation, BAC units, and the whole treatment system at low, medium, and high organic load synthetic greywater. As illustrated in the figure, with the increase of organic load, the level of COD in the synthetic greywater outlet increased. The total removal rate of the treatment system at low, medium, and high organic load synthetic greywater as well as RGW was 85.12%, 85.30%, 79.05%, and 98.65%, respectively.

Figure 5 shows the average concentration of BOD_5 in greywater in the O_3/BAC/UF system. The total removal rate of BOD_5 in the treatment system at low, medium, and high organic load synthetic greywater as well as RGW was 87%, 82%, 51%, and 92%, respectively.

As shown in Figure 6, this treatment system can reduce turbidity, meeting the Iranian standard (Table 5) in low, medium, and high organic loads of synthetic greywater as well as in RGW. The outlet turbidity of this system in all cases was much lower than the effluent discharge standards in Iran (50 NTU) for discharge into surface water and agricultural and irrigation purposes. In addition, there is no standard for turbidity for disposal to absorbent wells. The removal percentages in low, medium, and high organic load synthetic greywater as well as RGW were 93.5%, 97%, 96.69%, and 73.33%, respectively.

Alkylbenzene sulfonate has been replaced with LAS for many years due to its lower biodegradability (31). As shown in Figure 7, this treatment system can effectively remove LAS. The total removal rate of LAS at low, medium, and high organic load synthetic greywater as well as RGW was 91.4%, 88.1%, 84.8%, and 93.7%, respectively.

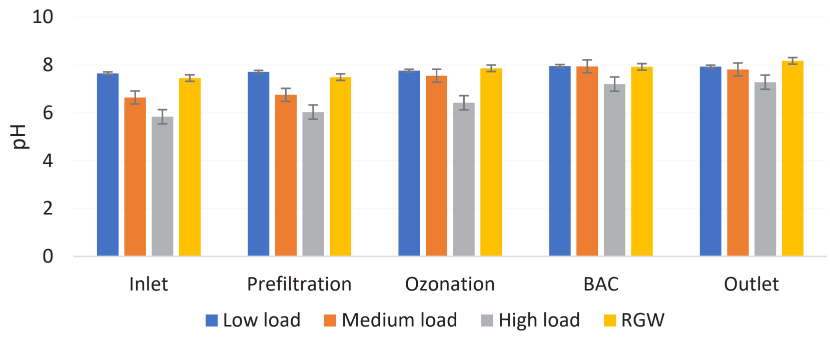

Figure 3. Comparison of pH changes in the O_3/BAC/UF system at different organic loads (low, medium, and high) and RGW

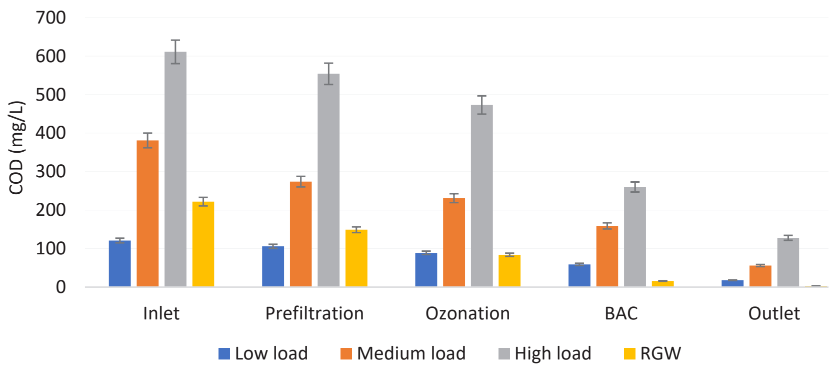

Figure 4. Comparison of COD changes in the O_3/BAC/UF system at different organic loads (low, medium, and high) and RGW

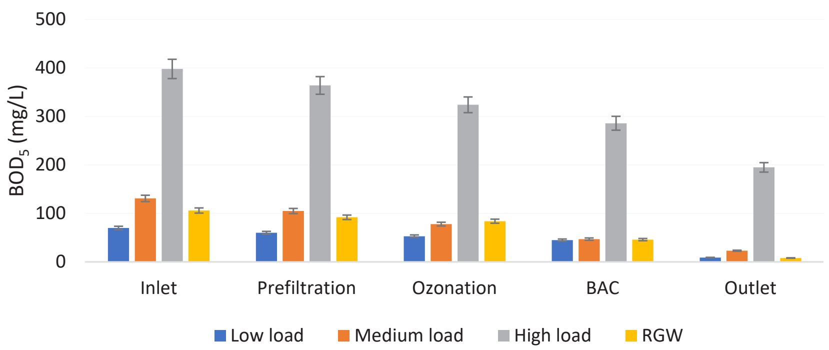

Figure 5. Comparison of BOD_5 (mg/L) changes in the O_3/BAC/UF system at different organic loads (low, medium, and high) and RGW

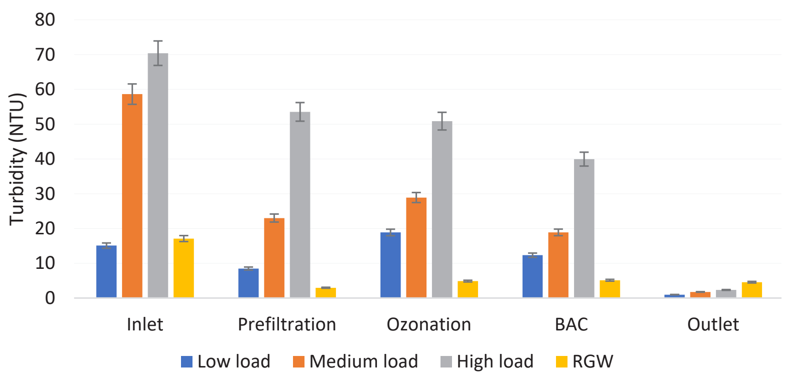

Figure 6. Comparison of turbidity changes in the O_3/BAC/UF system at different organic loads (low, medium, and high) and RGW

Table 5. The Iranian standard for reuse of effluent of wastewater for agricultural and irrigation purposes, disposal to absorbent wells and discharge into surface water (30)

Pollutant	Discharge into surface water	Disposal to absorbent wells	Agriculture and irrigation
pH	6.5-8.5	5-9	6-8.5
COD (mg/L)	60 (instantaneous:100)	60 (instantaneous:100)	200
BOD_5 (mg/L)	30 (instantaneous:50)	30 (instantaneous:50)	100
Turbidity (NTU)	50	-	50
LAS (mg/L)	1.5	1.5	1.5

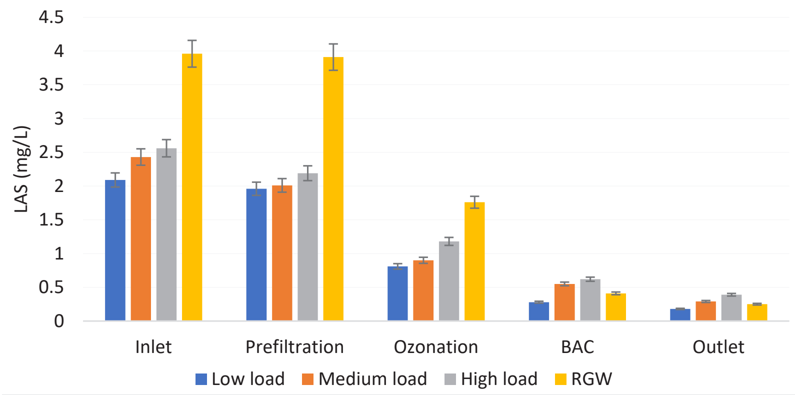

Figure 7. Comparison of LAS changes in the O_3/BAC/UF system at different organic loads (low, medium, and high) and RGW

Discussion

The bacterial consortium has a high capacity to remove organic matter such as total petroleum hydrocarbons (32). In BAC, not only GAC removes persistent compounds, but also a bacterial consortium is used as a bed on activated carbon for the decomposition of biodegradable compounds. Therefore, by combining adsorption and biodegradation in the BAC process, more organic matter can be removed. In the BAC process, persistent organic matter is removed by adsorption on activated carbon granules and biodegradable organic matter is removed by a bacterial consortium attached to activated carbon granules (33).

According to other studies, the pH range in greywater is usually between 5 and 9, depending on the water supply source (34). In this study, pH was within the standard range of using wastewater for agricultural and irrigation purposes (pH: 6-8.5), discharge into surface water (pH: 6.5-8.5), and disposal to absorbent wells (pH: 5-9) in Iran (Table 5). The results showed that pH had a relative increase in the treatment process. The pH varied from 7 to 8, which is very suitable for biological treatments of greywater (35).

COD removal

The results of ANOVA revealed no statistically significant difference in the efficiency level between low organic load and the medium organic load of synthetic greywater for COD removal. However, there was a significant relationship between RGW, medium organic load synthetic greywater, and the high organic load of synthetic greywater for COD removal. Therefore, this treatment system has the highest ability to remove COD from RGW and the lowest ability to remove COD from high organic load synthetic greywater.

In a study on the use of pre-treatment and SMBR process for RGW treatment, the average COD removal was 86.1% (2). In another study, on the use of a combination of multi-layer slow sand filter system containing GAC, microfiltration, and UF for synthetic greywater treatment, the average COD removal was 95.5% (6). In the other study, on the use of a slow sand filter, and activated carbon granules for greywater treatment, the average COD removal was 56% (36). Ozonation is used as a cost-effective method for degradation of resistant pollutants and improving the performance of the subsequent biodegradation unit (37). As organic matters are decomposed directly by O_3 and indirectly by OH radical, the ability of microorganisms to remove organic matter increases in the BAC reactor (38).

In a study in the Netherlands, the ability of three biological treatment systems to remove COD from RGW was investigated. The percentage of COD removal in the anaerobic system (up-flow anaerobic blanket reactor), aerobic system (sequencing batch reactor, SBR), and the combined anaerobic-aerobic system (up-flow anaerobic blanket reactor + SBR) was 51%, 90%, and 89%, respectively, and the anaerobic system had little efficiency in COD removal. Meanwhile, the results of the combined and aerobic treatment systems have been the same. As the percentage of COD removal in RGW in the present study was about 97%, it can be concluded that the ability of the process of O_3/BAC/UF is higher for COD removal and it is a more effective method for greywater treatment.

Obviously, at low and medium organic load synthetic greywater and RGW, this treatment system was able to remove COD effectively. According to the Iranian standard, there are no restrictions for using its effluent for agricultural and irrigational purposes as well as disposal to absorbent wells and surface water. On the other hand, a study on the removal of COD from RGW in a student dormitory at Shiraz University, Shiraz, Iran (39) showed that the input COD of the treatment system was low (COD = 80 mg/L), so the organic load of greywater in the actual samples was low. Therefore, this system has a high capacity to remove COD.

BOD_5 removal

The results of ANOVA revealed a significant relationship between the low, medium, and high organic load in synthetic greywater as well as RGW for BOD_5 removal. Therefore, this treatment system has the highest ability to remove BOD_5 from RGW and the lowest ability to remove BOD_5 from high organic load synthetic greywater.

This treatment system can remove BOD_5 from RGW and low organic load synthetic greywater, which can meet the US Environmental Protection Agency (EPA) standard (less than 10 mg/L) for unrestricted (urban uses, irrigation of crops eaten raw, recreational impoundments) and restricted uses (restricted access area irrigation, processed food crops, non-food crops, aesthetic impoundments, construction uses) of effluent (40). At low and medium organic loads of synthetic greywater and RGW, this treatment system was able to remove BOD_5 effectively. Therefore, according to the Iranian standard, there are no restrictions for using its effluent for agricultural and irrigational purposes as well as disposal to absorbent wells and surface water (Figure 5). Only in the case of high organic load, this system cannot meet the Iranian standards for wastewater discharge into the environment. However, the ability of this system for removing BOD_5 in RGW is not limited. On the other hand, it seems that in the real situation of the country, we will not encounter a high organic load in practice.

According to a study on the greywater treatment system by SBR (41), the efficiency of this system for removing BOD_5 was about 92%, which is equal to the capability of the treatment system of the present study for greywater treatment. Therefore, based on the high complexity of SBR, especially in larger systems and high maintenance costs, our treatment system can be considered as an efficient system in removing BOD_5. The results of this study also show that the efficiency of this treatment system is higher than some biological systems such as rotating biological contactor (BOD_5 removal efficiency: 27%-53%) (34).

Turbidity removal

The results of ANOVA revealed no statistically significant difference in the efficiency level between low, medium, and high organic loads of synthetic greywater for turbidity removal. However, there was a significant relationship between RGW and organic loads (low, medium, and high) of synthetic greywater for turbidity removal. Therefore, this treatment system has the higher ability to remove turbidity from synthetic greywater compared to RGW.

In a study, a combination of multi-layer sand filters containing activated carbon, microfiltration, and ultrafiltration was used and the results showed that the turbidity removal ability was about 99% (6). It should be noted that compared to our system which is more biological in nature, the mentioned system used a series of physical units resulted in higher turbidity removal. In another study, a combination of rotating biological contactor, sand filter, and disinfection was used to remove turbidity from light greywater. The ability of this system to remove turbidity was 98%, which is consistent with the results of the present study (42). Furthermore, the treatment system used in the present study has a high capacity (about 97%) in removing turbidity at low and medium organic loads. The outlet turbidity of the treatment system at low and medium organic loads of synthetic greywater was 0.98 and 1.76 mg/L, respectively, which is lower than the EPA reuse standard (less than 2 NTU) for unrestricted uses (2 mg/L).

LAS removal

Although LAS is widely used for household and industrial purposes, it has a negative effect on the environment (8). The results of ANOVA revealed a significant relationship between the low, medium, and high organic loads of synthetic greywater as well as RGW for LAS removal. However, our treatment system has the highest ability to remove LAS from RGW and the lowest ability to remove LAS from high organic load synthetic greywater. As shown in Figure 7, this treatment system can reduce LAS below the Iranian standard (1.5 mg/L) in low, medium, and high organic loads of synthetic greywater as well as RGW.

The further removal of COD, BOD, turbidity, and LAS in RGW seems to be related to the presence of simpler compounds in RGW. As shown in Table 1, although different chemical substances and commercial products are used to make synthetic greywater based on the past studies, some of them may not be present in RGW. For example, as mentioned, the measured value of COD in a dormitory complex at Shiraz University was only 80 mg/L (39).

In another study, integrated fixed-film activated sludge system was used to remove LAS from synthetic greywater, which its organic load was 0.11-1.3 gCOD/L.d. The removal efficiency for LAS has varied at different organic loads (83%-94%) (7). As the organic load in this system was much lower than that reported in the present study (6.1-18.3 gCOD/L.d), it seems that the system used in the present study had a higher ability to remove LAS at high organic loads.

In another study on the removal of surfactants from greywater by a membrane bioreactor (MBR) system, the removal efficiency of surfactants was 97%. The higher levels of efficiency could be the result of the better aerobic conditions in the MBR system (43). Using higher aeration can also expect higher efficiencies in the treatment system used in the present study. Furthermore, due to the higher cost of MBR and the almost equal efficiency of both systems in LAS removal, O_3/BAC/UF treatment system seems to be an effective process for greywater treatment.

Under aerobic conditions, LAS breaks into shorter chains, and eventually, transforms into carbon dioxide and water (7). Because of the presence of dissolved oxygen, high biodegradability of LAS, and the formation of a bacterial consortium consisting of resistant bacteria to environmental conditions, as well as the capability of degrading organic matter, a high percentage of LAS was removed.

Hybrid multi-layer slow sand filter microfiltration and ultrafiltration system was used to remove LAS from synthetic greywater in another study (6). The results showed that the above-mentioned system has a high ability to remove LAS (about 95%). However, with the increase of organic load, the system's ability decreased. The leading cause of LAS removal was the biological layer located on the surface of the slow sand filter. Although the above-mentioned study has a high ability to remove LAS, due to the application of two sequential membrane processes (microfiltration and ultrafiltration), it has a higher cost compared to the system used in the present study.

In a study in China, an oxygen-based membrane biofilm reactor was used to remove large amounts of LAS from synthetic greywater. *Pseudomonas* and *Zoogloea* were the main agents of LAS removal in biofilm. A high amount of oxygen provided for the biofilm resulted in the removal of about 95% of LAS (44). *Pseudomonas* was used in the bacterial consortium of the present study as in this study. *Pseudomonas* has a great ability to remove contaminants. Although the cost of the above-mentioned treatment system seems to be less than the treatment system in the present study, the study in China was performed only on synthetic greywater and its operation can be somewhat complicated.

Conclusion

In this study, the efficiency of O_3/BAC/UF processes on synthetic greywater treatment (at low, medium, and high organic loads) and RGW samples taken from a residential complex in Shiraz, Iran, was investigated. The results show that the efficiency of this system is sufficient for RGW and synthetic greywater treatment meets the standards of wastewater usage for agricultural and irrigation purposes, disposal to absorbent wells, as well as discharge into surface water. Therefore, because this treatment process is environmentally friendly and mainly uses physical and biological processes, it can be used as a greywater treatment method in Iran. Wastewater reuse can alleviate the problem of freshwater shortage.

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Ethical issues

This research project was approved by the Research Committee of Shahid Sadoughi University of Medical Sciences, Yazd, Iran (Ethical code: IR.SSU.SPH.REC.1398.137). The authors certify that this manuscript is the original work of the authors and all data collected during the study are as presented in this manuscript, and no data from the study will be published separately.

Competing interests

The authors declare that they have no conflict of interests.

Authors' contributions

Conceptualization: Ebrahim Shahsavani, Ali Asghar Ebrahimi, Mohammad Reza Samaei, Ehsan Abouee Mehrizi.
Data curation: Ebrahim Shahsavani, Mohammad Reza Samaei, Farzan Madadizadeh, Alireza Abbasi.
Formal Analysis: Ebrahim Shahsavani, Mohammad Reza Samaei, Farzan Madadizadeh.
Funding acquisition: Mohammad Hassan Ehrampoush
Investigation: Ali Asghar Ebrahimi, Mohammad Hassan Ehrampoush, Mohammad Reza Samaei, Ehsan Abouee Mehrizi, Farzan Madadizadeh.
Methodology: Ebrahim Shahsavani, Ali Asghar Ebrahimi, Mohammad Reza Samaei, Ehsan Abouee Mehrizi, Farzan Madadizadeh, Alireza Abbasi, Parvaneh Talebi.
Project administration: Ali Asghar Ebrahimi, Mohammad Hassan Ehrampoush, Mohammad Reza Samaei, Ehsan Abouee Mehrizi, Farzan Madadizadeh.
Resources: Ebrahim Shahsavani, Mohammad Reza SamaeiSoftware: Ebrahim Shahsavani, Mohammad Reza Samaei, Farzan Madadizadeh, Alireza Abbasi, Amin Mohammadpour.
Supervision: Ali Asghar Ebrahimi, Mohammad Hassan Ehrampoush, Mohammad Reza Samaei, Ehsan Abouee Mehrizi, Farzan Madadizadeh.
Validation: Ebrahim Shahsavani, Ali Asghar Ebrahimi,

Mohammad Hassan Ehrampoush, Mohammad Reza Samaei, Ehsan Abouee Mehrizi, Farzan Madadizadeh, Alireza Abbasi, Parvaneh Talebi, Amin Mohammadpour.
Visualization: Ebrahim Shahsavani, Ali Asghar Ebrahimi, Mohammad Reza Samaei.
Writing – original draft: Ebrahim Shahsavani, Mohammad Reza Samaei.
Writing – review & editing: Ebrahim Shahsavani, Ali Asghar Ebrahimi, Mohammad Hassan Ehrampoush, Mohammad Reza Samaei, Ehsan Abouee Mehrizi, Farzan Madadizadeh, Alireza Abbasi, Parvaneh Talebi, Amin Mohammadpour.

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