Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2018.22215

110 (2018) 100–108
April

Treatment of greywater in single households aiming at its reuse

Taísa Machado de Oliveira*, Cláudia Telles Benatti, Célia Regina Granhen Tavares

Department of Chemical Engineering, State University of Maringa, UEM, Avenue Gastao Vidigal 2431, CEP 87053-310, Maringa, Parana, Brazil, emails: taisamachadooliveira@hotmail.com (T.M. de Oliveira), ctbenatti@gmail.br (C.T. Benatti), crgtavares@uem.br (C.R.G. Tavares)

Received 29 November 2017; Accepted 16 March 2018

ABSTRACT

The operational performance of a submerged microfiltration (MF) membrane system for greywater treatment was evaluated. The tests were conducted on bench scale for the treatment of real greywater from a single household. The influence of transmembrane pressure (0.08, 0.10 and 0.15 bar), different packing densities membrane (500, 800 and 1,000 $m^2 m^{-3}$) and aeration (without aeration, 30 and 50 L h^{-1}) on cumulative permeate flux decline was investigated. For the range of operational conditions considered in this study, the optimum parameters turned out to be MF membrane modules with packing densities of 500 and 800 $m^2 m^{-3}$, as well as, the presence of aeration and low pressures (below 0.1 bar). The treatment was efficient at the removal of apparent color, turbidity and total suspended solids. It was also observed that the absence for fecal coliforms counting in the treated samples. However, for the reuse that demands direct contact with the user, such as car washing and toilet flushing, it would be necessary to polish the permeate for the parameters to meet the most strict guidelines for domestic reuse, including the removal of organic matter, surfactant and total dissolved solids.

Keywords: Greywater; Membrane; Microfiltration; Reuse; Treatment

1. Introduction

The priority for Latin America is to consolidate the progress achieved in providing drinking water and sanitation services, ensuring the full realization of the human right to water and sanitation and considering the post-2015 development agenda [1]. Therefore, sustainable water management is an important goal and a key element of sustainable urban development [2].

In this context, new ways to save water begin to emerge for Brazilian single-family houses, including the division of domestic effluent in greywater and black water. Greywater is the wastewater from washing machines, laundry tubs, showers, basins, baths and kitchen. It does not include wastewater from toilets, urinals or bidets. This is referred to as black water (water containing human excrement) [3].

The greywater return factor (proportion of water consumption that is converted to greywater) varies from 65% to 95 %, making it a good source for water reuse [4,5]. Qualitatively, greywater might include some chemicals and several millions of pathogenic bacteria per 100 mL, which can cause a health hazard if this water is reused without proper treatment [6]. Therefore, the greywater should undergo certain treatments to be ready for reuse. The treated greywater should fulfill the water reuse guidelines which may vary from one country to another [6]. During the last decade, the United States Environmental Protection Agency [7] and the World Health Organization [8] have formulated guidelines for water reuse, including greywater. These guidelines define a 5-d biochemical oxygen demand (BOD_5) ≤ 10 mg L^{-1}, total suspended solid (TSS) ≤ 10 mg L^{-1} and fecal coliforms (FCs) ≤ 10 CFU per 100 mL for the greywater reuse in toilet flushing and car washing. An important objective of these guidelines was to ensure the designing, installing and maintaining of greywater systems in a manner that aims to protect human health, plants, soil and the environment [9].

There are no particular norms and regulations for greywater reuse in Brazil since the concept of greywater reuse

* Corresponding author.

is recent and still restricted. The legislation that indicates general water quality standards for reuse in Brazil is NBR 13,969/1997 [10]. It discusses the reuse of treated domestic sewage, indicating its uses and a requirement of non-potable and sanitary quality, establishing a turbidity < 10 NTU and FC < 500 MPN/100 mL for a class 3 reuse, in toilet flushing. Some Brazilian municipalities have implemented more specific laws to regulate the water reuse. For example, Niteroi (RJ), municipal law 2856/2011 establishes that treated greywater should obey the following parameters: turbidity ≤ 5 NTU, color ≤ 15 UNITS PtCo, total dissolved solid (TDS) ≤ 200 mg L^{-1} and the absence of FC, for the greywater reuse in toilet flushing, agricultural purposes and sidewalks washing [11].

It can be seen from literature review that different treatment technologies have been studied for greywater treatment, depending on the required quality standard for reuse applications. Among the different treatment methods, the membrane separation process (MSP) seems to be an attractive solution for the treatment and reuse of greywater in single-family houses. The membranes are a physical barrier to a wide range of pollutants including microorganisms; require a small footprint for their implementation, low necessity of chemical products to conduct the treatment and lower production of residues [2,12–14]. The MSP has confirmed a high performance achieved by high pressure membranes with effluents containing very low turbidity and undetectable levels of TSS and FC that meet some of the most stringent standards for greywater reuse [15–18]. Expectedly, such high performances were also reported for nanofiltration and reverse osmosis membranes [16,17].

Although, MSP shows a great number of applications and advantages, they also have several drawbacks. One of the principal limitations is the decrease of permeate flux with time, which is mainly due to membrane fouling [14]. This is one of the most critical issues in membrane separation technology as it contributes to higher production cost and energy consumption [19]. Permeate flux decline in membrane is mainly caused by two phenomena: the formation of a gel layer on the membrane surface and the obstruction of membrane pores [20]. Moreover, other physical or chemical mechanisms that contribute to membrane fouling can also take place, such as physical adsorption, deposition or conglomeration of particles, colloids or macromolecules on the membrane surface, interactions between different solutes in the feed stream, formation of complexed species [21,22].

In this context, the performance evaluation of the MSP technology treating real greywater is required for contributing to existing knowledge on greywater treatment. During this study, the efficiency of a submerged microfiltration (MF) membrane system in treating real greywater from a single household was examined. The tests were conducted on bench scale under the influence of different factors, such as different packing densities membranes and predetermined hydrodynamic conditions (transmembrane pressure [TMP] and aeration). Moreover, this work investigated the permeate flux decline during MF membrane treatment, to allow to select the best operating conditions and the analyses of effluent quality for non-potable reuse.

2. Methods

2.1. Experimental setup

To develop this research, a medium single household was chosen (useful area of 390 m^2), located in the northwest of Parana (Brazil). Four-people were living in the household: two children and two adults, as well as an employee who worked there during the day.

The samples of greywater were obtained from the inspection chamber of the sewage collection system for the studied household. The collection counted with the immobilization of the toilet, always in the period between 8 am and 2 pm. The sampling followed the greywater production in the residence during the day, for a 6-month period. The collections were conducted every hour in order to obtain a compound sample for the analysis. The greywater included wastewater from baths, showers, wash basins, washing machines and dishwashers.

A schematic diagram of the greywater treatment system is shown in Fig. 1. It was constituted of a supply reservoir, supported on a semi-analytical balance (Q510-3200C) with the submerged MF membrane module. A vacuum pump was applied to pump permeate through the permeate collection channel.

2.2. Microfiltration membrane modules

The hollow fibers MF membrane modules were provided by the Brazilian Company PAM-Membranes Ltd. These fibers were made of polyimide material, distributed vertically and fixed in the extremities of the modules. The upper extremity received the aperture of filtering fibers for the permeate exit. The transportation through the MF membrane was the cross-flux filtration, with the permeation occurring perpendicularly to the flux direction to the submerged membrane module. Details on the membrane modules are listed in Table 1.

2.3. Study of the permeate flux for predetermined hydrodynamic conditions

Before the beginning of each experimental test, the MF of the deionized water was carried out at a pressure equal to or slightly higher than the work pressure (0.20 bar) during 0.25 h period required for the compaction of the membrane modules.

The experiments were performed at a constant temperature of 25°C. Permeate flux was gravimetrically measured at different time intervals. Each run was stopped after 100 min of operation, when a quasi-stationary permeate flux was reached. The experiments were performed at three different TMPs 0.08, 0.10 and 0.15 bar. Every minute, the value of the permeate mass and the filtration times were rated to establish the permeate flux (J_p) represented by Eq. (1):

$$J_p = \frac{\Delta m_p \times 60}{A \times \Delta t \times \mu} \tag{1}$$

where J_p is permeate flux (L h^{-1} m^{-2}), Δm_p is permeate mass flux variation (g), A is membrane module area (m^2), Δt is time variation (min) and μ is permeate volumetric density (g L^{-1}).

Therefore, the data of permeate flux and time for each pressure and each membrane module studied enabled the observation of the flux behavior.

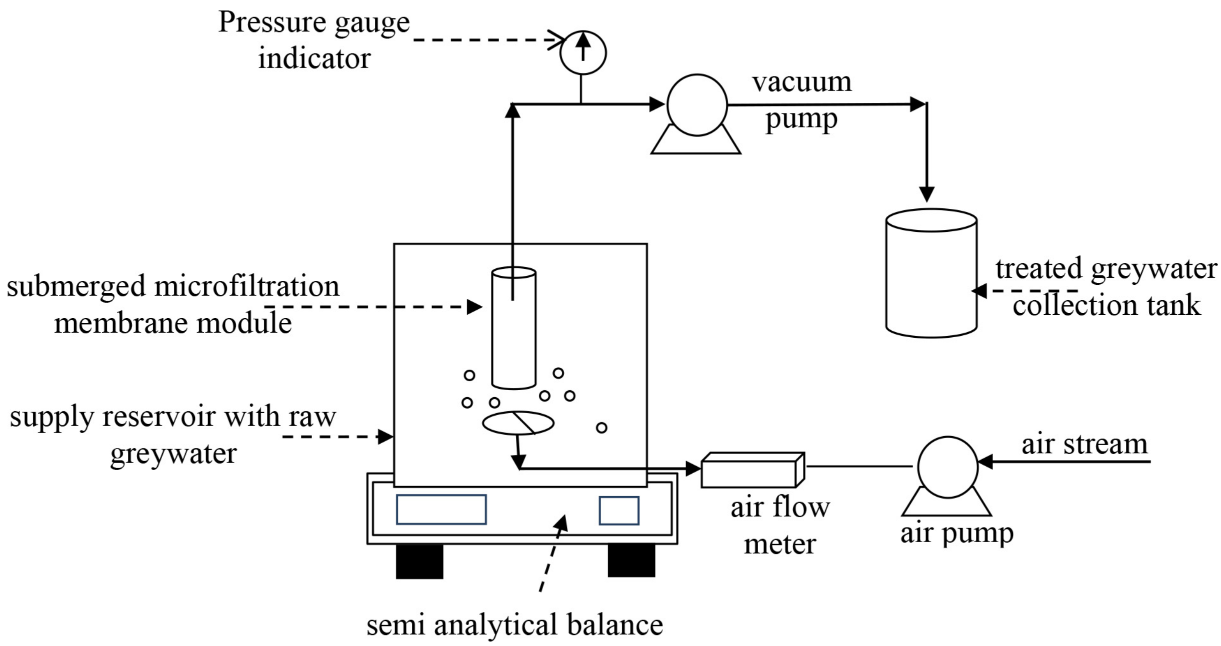

Fig. 1. Schematic representation of the bench-scale experiment with real greywater.

Table 1
Technical information on the MF modules

Characteristic	Module A	Module B	Module C
Packing density, $m^2\ m^{-3}$	500	800	1,000
Module functional length, mm	120	120	120
Hydraulic permeability, $L\ h^{-1}\ m^{-2}\ bar^{-1}$	140.9	134.3	118.5
Permeation area, m^2	0.091	0.146	0.182
Amount of fibers	255	408	509
Hydraulic diameter of pores, μm	0.41	0.40	0.38
Fiber inside diameter, mm	0.40	0.40	0.40
Fiber outside diameter, mm	0.95	0.95	0.95

The MF was also operated with turbulence promoters. The air blower (Boyu, SC-7500) was used for aeration of the membrane fibers. Air was introduced intermittently through a fine bubble membrane diffuser installed directly below the membrane module in order to provide an uplifting flow of bubbles which scour the membrane surface to prevent the membrane from fouling. For this purpose, the process worked with two different aeration conditions, 30 and 50 L h^{-1}, for each TMP. The same methodology presented previously was repeated for each chosen TMP and aeration.

2.4. Statistical analysis

The analysis of variance (ANOVA) is a powerful statistical technique which studies the effects of a set of factors on the mean of one variable. ANOVA decomposes the total variability of the response variable in the effects of each factor of study and their possible interactions plus a residual part related to the uncontrolled factors and variability occurred by chance. By means of this technique, the purpose of the statistical study was to analyze the effect of the operating conditions on flux decline. The response variable chosen for this purpose was the cumulative permeate flux decline (SFD) which is defined by the following Eq. (2):

$$\mathrm{SFD} = \sum_{i=1}^{N} \frac{J_p(0) - J_p(i)}{J_p(0)} \tag{2}$$

where N is the point corresponding to the end of the experiment, when the quasi-stationary flux is achieved; $J_p(0)$ is the initial permeate flux and $J_p(i)$ is the permeate flux at different operating times.

This parameter summarizes the information on the evolution of permeate flux with time throughout the experiment (and not only for one specific time). Therefore, by means of this parameter flux decline can be characterized. Then, the greater the SFD is the faster and more noticeable the flux decline is, thus indicating that membrane fouling is more severe.

The combined variation of the three factors selected for the study consisted of packing density membrane (x_1), TMP (x_2) and aeration (x_3) and all the combinations of factor levels were investigated. In this way, the experiment had $3^3 = 27$ treatments and each treatment was conducted in duplicate.

The significant results of ANOVA were analyzed using Tukey's test. It is a single-step multiple comparison procedure and statistical test. It was used in conjunction with an ANOVA (post hoc analysis) to find means that are significantly different from each other.

2.5. Cleaning procedure

After each experiment, the membranes modules were cleaned with deionized water, at a TMP slightly higher than 0.1 bar, with 1-min backwashing. This was sufficient to remove the particles adhered to the membrane fibers. After the cleaning, the water permeability was checked with deionized water at 25°C and a TMP of 0.2 bar.

In case of the permeability recovery had not been achieved through backwashing, the chemical cleaning of the membrane module would have been carried out using domestic chemical products (sodium hypochlorite diluted to 0.1% v/v in water).

2.6. Analytical procedures

The pH was measured using a DIGIMED Equipment, Analytical Instrumentation. Physical parameters were determined using the methodology described by the Standard Methods for the Examination of Water and Wastewater [23]. Apparent color was determined using Platinum–Cobalt method; turbidity was determined using the spectrophotometric method and set of solids (suspended and dissolved) were determined using the gravimetric method. BOD_5 was determined using the BODTrak™ II methodology described by the HACH equipment, with accuracy of ±1.0 mg L^{-1}, and the results were expressed in milligrams of oxygen consumed per liter of sample during 5 d of incubation at 20°C. Anionic surfactants were determined through the spectrophotometric method of methylene blue, methodology described by the NBR 10,738/89 [24]. FC was quantified through plates for FCs counting by 3M Petrifilm, according to the methods AOAC (991.14).

2.7. Pollutants removal efficiency of the membrane modules and determination of the treated greywater quality

In the end of each test, the raw and treated greywater were collected and followed to the Laboratory of Environment Management, Control, and Conservation of the Department of Chemical Engineering of the State University of Maringa. The conditions of sampling, conservation and analysis followed the recommendations of the Standard Methods for the Examination of Water and Wastewater [23]. The physical, chemical and biological parameters were assessed, such as apparent color, turbidity, TSS and TDS, BOD_5, surfactant and FC.

Parameter used to quantify the efficiency of MF was solute removal (*R*). It is calculated as indicated in Eq. (3), where C_i and C_f are feed and permeate concentrations at the time of measurement, respectively.

$$R(\%) = \frac{C_i - C_f}{C_i} \times 100 \tag{3}$$

3. Results and discussion

3.1. Study of the permeate flux in predetermined hydrodynamic conditions

The experimental data of permeate flux were plotted vs. time (Figs. 2–4) per membrane module in predetermined hydrodynamic conditions.

It could be observed from Figs. 2–4 that the obtained curves, that represent the evolution of permeate flux with time, showed a shape composed by two regions: the first one where the permeate flux declined very sharply, and a second region where the permeate flux declined more slowly until a quasi-stationary permeate flux was reached. It was a natural consequence of the membrane selectivity and the physical, chemical interactions of the particles accumulated on the surface, called concentration polarization [21]. 15 min later, the permeate flux decreased gradually towards the stationary state, which, it occurred due to the blocking of the pores by the adsorption of particles inside the membrane pores, hampering the permeate passage and generating the fouling in the membrane modules [25].

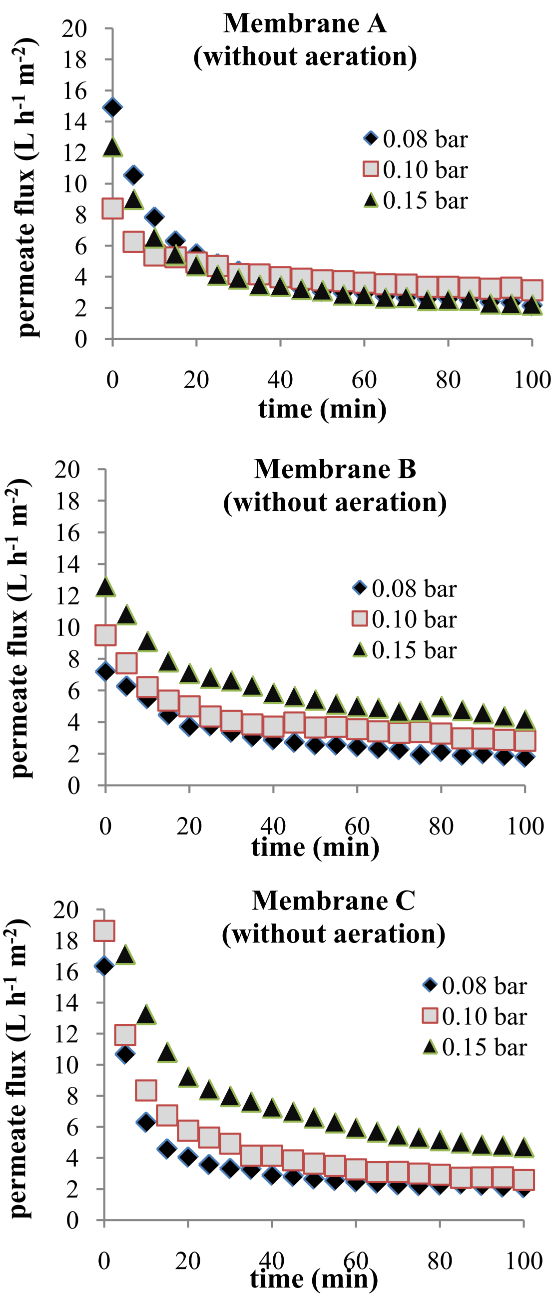

Fig. 2. Experimental data for permeate flux for the membranes modules at different TMPs without aeration.

The tests without aeration indicated the following values of permeate flux decrease: module A (packing density 500 m^2 m^{-3}) 80%, 50% and 77%; module B (packing density 800 m^2 m^{-3}), 71%, 64% and 63%, and module C (packing density 1,000 m^2 m^{-3}) 82%, 80% and 74%, for pressures 0.08, 0.10 and 0.15 bar, respectively.

New tests were carried out with aeration of 30 and 50 L h^{-1} for each preset pressure to verify the existence of alterations in the permeate flux decrease during the 100 min of operation. The air supply in the lower part of the membrane modules caused transient turbulence on the membrane surface, increasing the phenomenon of particles transportation to the center of the reactor.

Figs. 3 and 4 indicate that even with aeration in the membrane fibers, the permeate flux decrease occurred due to the characteristics of the raw greywater as well as the physical properties of the membrane module, such as the distribution of the pores in the membrane fibers, justifying the permeate flux variability.

Another relevant factor was the formation of foam in the moment of aeration in some of the experimental tests acting

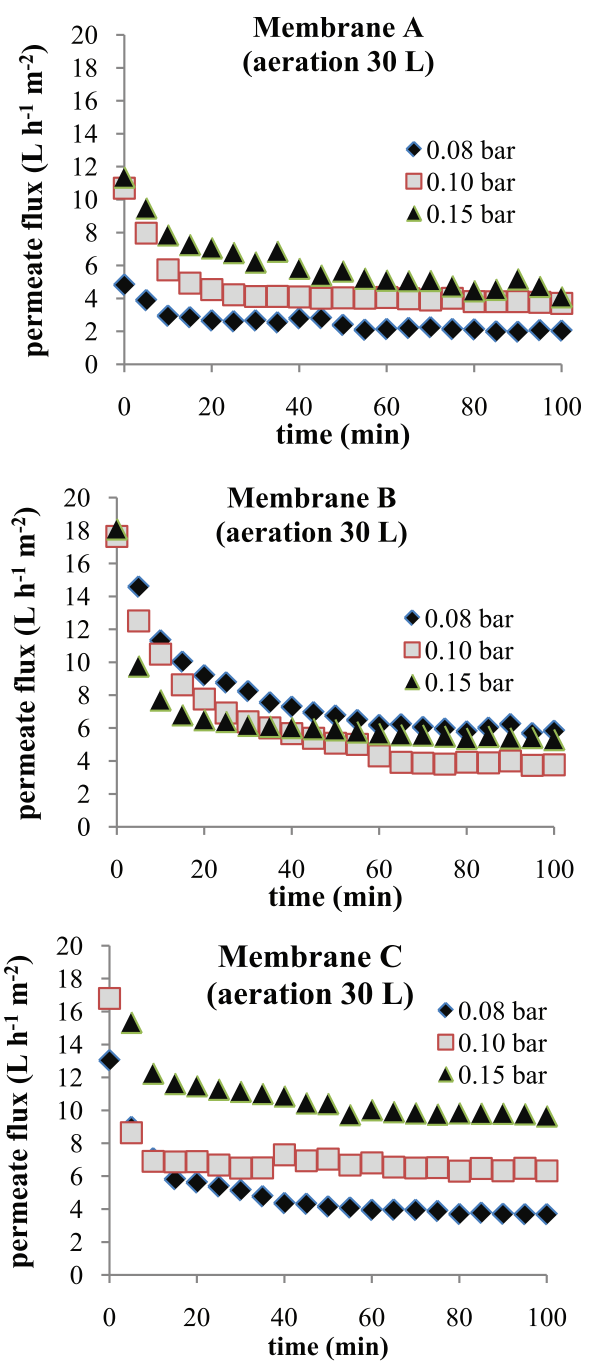

Fig. 3. Experimental data for permeate flux for the membranes modules at different TMPs and aeration of 30 L h^{-1}.

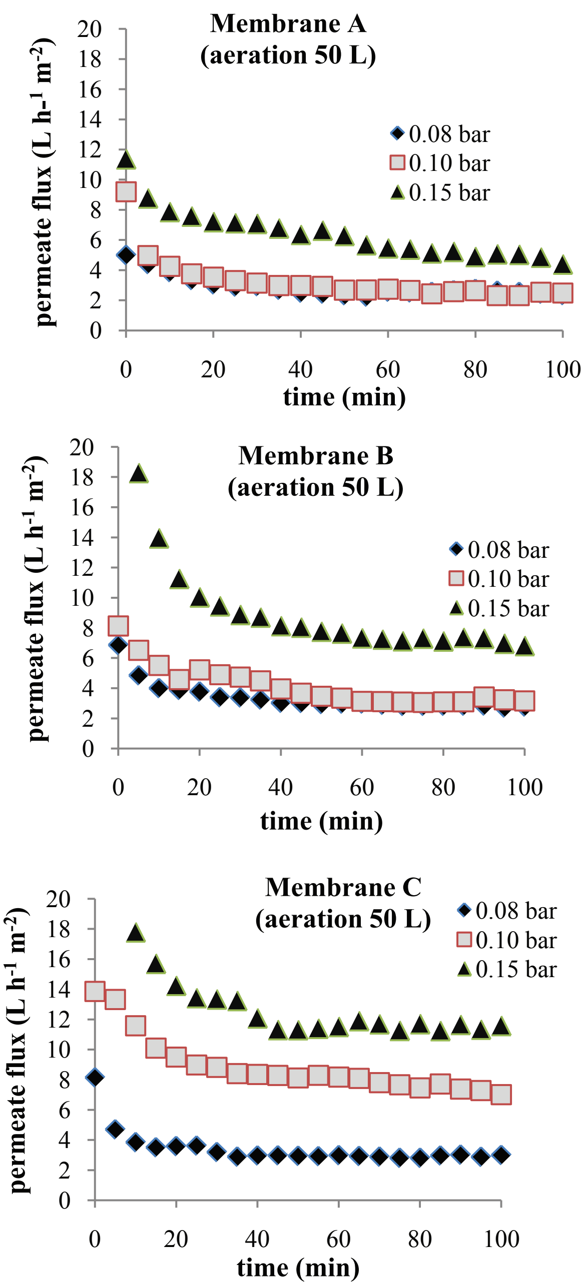

Fig. 4. Experimental data for permeate flux for the membrane module C at different TMPs and aeration of 50 L h^{-1}.

as a source of random errors. The aeration in the experiments reduced minimally the permeate flux decrease.

Testes conducted with membrane module A revealed that the aeration was more favorable for the experiments with pressures of 0.08 and 0.15 bar. The permeate flux decreased from 8.8 to 1.9 and 2.1 L h^{-1} m^{-2} as well as from 7.5 to 4.9 and 4.7 L h^{-1} m^{-2} for pressures (0.08 and 0.15 bar) and aeration 30 and 50 L h^{-1}, respectively, if compared with the tests without aeration in the same pressure conditions. However, for pressure of 0.10 bar, the aeration did not minimize the permeate flux decrease, which reached 3.2, 4.7 and 3.2 L h^{-1} m^{-2} for the tests without aeration and with aeration of 30 and 50 L h^{-1}, respectively.

Membrane module B, at the pressure of 0.08 bar, had a permeate flux decrease of 4.4, 8.8 and 2.2 L h^{-1} m^{-2} for the tests without aeration and with aeration of 30 and 50 L h^{-1}, respectively. The pressure of 0.10 bar presented 5.2, 10.1 and 3.6 L h^{-1} m^{-2} for the tests without aeration and with aeration of 30 and 50 L h^{-1}, respectively. For pressure of 0.15 bar, the value was 13.6, 6.6 and 15.1 L h^{-1} m^{-2} for the tests without aeration and with aeration of 30 and 50 L h^{-1}, respectively. Considering these results, it is possible to conclude that a divergence of results occurred since the values do not indicate a relationship among pressure, aeration and permeate flux decrease. It could have occurred due to greywater variability, such as the concentration of suspended solids in the greywater, which may have affected the feed solution diffusivity causing a higher variation of both the initial and the final fluxes.

In membrane module C, the aeration in the membrane fibers decreased the thickness of the polarized layer, which did not benefit the permeate flux decrease in the experiments conducted with predetermined conditions, such as occurred in the experiments with pressures of 0.08 and 0.10 bar. Moreover, the experiments with a pressure of 0.10 and 0.15 bar and an aeration of 30 L h^{-1} presented a decrease of 42% (10.6 at 3.9 L h^{-1} m^{-2}) and 34% (13.6 at 6.6 L h^{-1} m^{-2}), respectively, compared with the tests without aeration using the same pressures.

Considering these results for permeate flux decrease, the membrane system restriction was verified, which may interfere on the operational performance of the treatment and the permeate quality [26]. Therefore, in order to restitute the permeate flux, backwashing pulses (1 min) were interchanged after each 100 min experiment. This is the most common physical cleaning method to remove membrane fouling [27].

Thus, due to these divergences in the results a statistical analysis was performed to quantify the effect of the operating conditions on SFD.

3.2. Statistical assessment of the SFD regarding the predetermined conditions

The ANOVA analysis was conducted to verify the occurrence of significant differences among the averages of the treatments. To corroborate the assumption of homoscedasticity, a logarithmic function was applied in the response variable. Table 2 shows the obtained ANOVA table.

Table 2 shows that all the factors (packing density, TMP and aeration) had significant influence on SFD, because their *P* values were lower than 0.05. However, their coupled effects presented a *P* value higher than 0.05, so they did not have remarkable influence on the response variable. Thus, the variables independent of packing density membrane, TMP and aeration were considered significant.

The regression equation obtained from the experimental data considering main effects among factors for MF is represented in Eq. (4).

$$\text{SFD} = \exp\left(0.6312 + 0.0013 \times x_1 + 8.988 \times x_2 - 0.0104 \times x_3\right) \tag{4}$$

where 500 ≤ x_1 ≤ 1,000 m^2 m^{-3}, 0.08 ≤ x_2 ≤ 0.15 bar and 0 ≤ x_3 ≤ 50 L h^{-1}.

From Eq. (4), it can also be observed from the sign of the standardized effect that the SFD increases with TMP and packing densities membrane, while it decreased with aeration.

However, the highest interference on the SFD, due to the fouling membranes, occurred through the driving force (TMP) applied to the module for the raw treated greywater suction. Comparing with pressure, the characteristics of the membrane modules and aeration had very low interference, actually insignificant.

For the identification of the factor levels that interfered on SFD, a Tukey's test was carried out at 5% significance represented in Table 3.

The different letters in Table 3 reveal the occurrence of differences among the levels. The level for packing density membrane 1,000 m^2 m^{-3} was significantly different from packing density membrane 500 m^2 m^{-3}, presenting, in average, the lowest difference permeate flux. However, it was not significantly different from packing 800 m^2 m^{-3}.

In the experiments using a pressure of 0.15 bar, a higher permeate flux difference occurred; 0.08 bar indicated the lowest permeate flux difference. However, no significant difference occurred for the pressure of 0.10 bar.

Table 2
ANOVA table for average SFD in the membrane modules (R^2 = 97.31%; R^2_{adj} = 95.89%), level of significance: 2.45

Factors	Sum of squares	Degrees of freedom	Mean square	*F* ratio	*P* value
x_1: packing density	3.87	2	1.94	5.74	0.01
x_2: TMP	3.78	2	1.89	5.61	0.01
x_3: aeration	2.88	2	1.44	4.28	0.02
x_1x_2	2.68	4	0.67	1.99	0.13
x_1x_3	0.31	4	0.08	0.23	0.92
x_2x_3	0.42	4	0.11	0.31	0.87
$x_1x_2x_3$	0.50	8	0.06	0.18	0.99
Residues	9.10	27	0.34	–	–

Regarding aeration, the value of 50 L h^{-1} presented the lowest permeate flux difference; however, it was not significantly different from the aeration of 30 L h^{-1}.

3.3. Pollutants removal efficiency of the membrane modules and determination of the treated greywater quality

By assessing the results of these parameters in the different predetermined hydrodynamic conditions (pressure and aeration), it was not observed significant differences or any premises in the removal efficiency of physical, chemical parameters, pressure and aeration. Thus, the removal efficiencies of studied parameters were assessed regarding the characteristics of the packing densities of the MF membrane modules. Table 4 presents the average and the standard deviation for the characteristics of the raw and treated greywater as well as the removal efficiencies of assessed parameters in the three MF membrane modules studied.

Table 3
Tukey's test at 5% significance

	Factor level	Average	Group
Packing densities	1,000	14.34	a
	800	10.02	ab
	500	7.45	b
Pressure	0.15	14.67	a
	0.10	9.33	ab
	0.08	7.83	b
Aeration	0	12.90	a
	30	11.12	ab
	50	7.46	b

The MF was efficient at the removal of apparent color, turbidity and TSS. The average removal for membrane modules A, B and C was, respectively, 97% ± 2%, 93% ± 8% and 95% ± 3% for apparent color; 99% ± 2%, 94% ± 8% and 97% ± 5% for turbidity, and 98% ± 5%, 90% ± 9% and 94% ± 8% for suspended solids total. Therefore, the permeate quality for modules A, B and C was 11 ± 13, 26 ± 24 and 19 ± 12 UNITS PtCo APHA for apparent color; 2 ± 2, 5 ± 5 and 2 ± 3 NTU for turbidity; and 1 ± 3, 4 ± 4 and 2 ± 3 mg L^{-1} for TSS, respectively. It was also observed considerable number of FCs in the raw greywater indicating a potential for the presence of pathogens from the digestive tract. After the MF, complete removal of pathogenic organisms was achieved. Contaminants removal for hollow fibers MF membranes were similar to the work detailed by Guilbaud et al. [16], Venkatesh and Senthilmurugan [17] and Dey et al. [18].

The concentration of BOD_5 in raw greywater was 165 ± 50, 200 ± 122 and 184 ± 128 mg L^{-1}; after the MF, the values were 64 ± 21, 113 ± 94 and 86 ± 50 mg L^{-1} for modules A, B and C, respectively. The concentrations of surfactant found in greywater varied from 23 to 39 mg L^{-1}. The MF enabled permeates with average concentrations of 18.2 ± 5.5, 21.6 ± 2.1 and 18.6 ± 4.3 for modules A, B and C, respectively. Finally, the concentration of TDS varied from 209 to 2,212 mg L^{-1} in raw greywater and between 76 and 916 mg L^{-1} in the treated greywater.

Regarding the last three parameters discussed, the greywater treatment removed 58% ± 18%, 46% ± 21%

Table 4
Averages[a] of the assessed parameters for raw and treated greywater in the membrane modules

Module A			Module B			Module C		
Packing of 500 m^2 m^{-3}			Packing of 800 m^2 m^{-3}			Packing of 1,000 m^2 m^{-3}		
Raw	Treated	Removal (%)	Raw	Treated	Removal (%)	Raw	Treated	Removal (%)
Apparent color (UNITS PtCo APHA)								
363 ± 216	11 ± 13	97 ± 2	560 ± 353	26 ± 24	93 ± 8	487 ± 345	19 ± 12	95 ± 3
Turbidity (NTU)								
78 ± 30	2 ± 2	99 ± 2	127 ± 99	5 ± 5	94 ± 8	123 ± 103	2 ± 3	97 ± 5
TSS (mg L^{-1})								
48 ± 16	1 ± 3	98 ± 5	51 ± 21	4 ± 4	90 ± 9	55 ± 25	2 ± 3	94 ± 8
Fecal coliforms (CFU per mL)								
272 ± 82	ND[b]	>99.9	221 ± 132	ND	>99.9	233 ± 103	ND	>99.9
BOD_5 (mg L^{-1})								
165 ± 50	64 ± 21	58 ± 18	200 ± 122	113 ± 94	46 ± 21	184 ± 128	86 ± 50	49 ± 18
Surfactant (mg L^{-1})								
30.0 ± 5.9	18.2 ± 5.5	36.4 ± 22.6	28.4 ± 2.3	21.6 ± 2.1	23.8 ± 5.8	26.3 ± 5.3	18.6 ± 4.3	28.8 ± 10.7
TDS (mg L^{-1})								
603 ± 360	436 ± 305	33 ± 13	855 ± 460	587 ± 223	27 ± 15	505 ± 339	371 ± 315	31 ± 14

[a]Average of nine samples.
[b]ND, not detectable in the used method.

and 49% ± 18% of BOD_5; 36.4% ± 22.6%, 23.8% ± 5.8% and 28.8% ± 10.7% of surfactant; and 33% ± 13%, 27% ± 15% and 31% ± 14% of TDS for MF modules A, B and C, respectively. The removal efficiencies of these parameters were lower when compared with the physical parameters, as expected, since the MF membrane's pore size is 0.4 μm, which would not be selective to those parameters [21]. Thus, the pore sizes of the membranes have an important impact on the organic removal efficiency [28].

This study was in agreement with the results obtained by Mizzouri et al. [29], who demonstrated that the MF membrane system had removal of suspended solids, turbidity and FCs excellently, however, remove the organics poorly. Appropriate alternative to MF is to use this process as a pretreatment option for greywater treatment. The MF treated greywater could be further purified by reverse osmosis membrane for surfactant [17] and organic matter removal.

4. Conclusions

Facing the imminent perspective of lack of water, it is essential to reuse urban effluent. It is an alternative that assures not only prosperity and quality of life to the humankind, but also benefits the conservation of the natural resources available in the planet, corroborating with the proposition of an efficient sustainability.

Among the analyzed factors, the highest interference in the cumulative permeate flux decline, due to the fouling in the MF membrane, occurred through the TMP. The aeration and the packing density of the membrane module had insignificant interference on the minimization of the cumulative permeate flux decline. Therefore, the MF membrane modules with packing densities of 500 and 800 $m^2 m^{-3}$, as well as, the presence of aeration and low pressures (below 0.1 bar) presented the most satisfactory results regarding the SFD.

This work verified that the treatment of greywater using MSP of submerged MF was efficient at removing the physical and microbiological parameters of the domestic effluent. The most significant result of this study was that the MF treatment produces average effluent values of FCs and TSS that satisfy the United States Environmental Protection Agency and the World Health Organization guidelines for reuse for non-potable applications (TSS ≤ 10 mg L^{-1} and FC ≤ 10 CFU per 100 mL). However, for the reuse that demands direct contact with the user, such as car washing and toilet flushing, it would be also necessary to polish the permeate to obtain a treated greywater with a final organic matter BOD_5 ≤ 10 mg L^{-1}. Also, according to the Brazilian municipal law 2,856/2011 for reuse, the treated greywater obtained in this work could be reused to toilet flushing, agricultural purposes and sidewalks washing.

Finally, domestic reuse is currently an important alternative. Measures such as the preservation and improvement of consumption efficiency, as well as reuse itself, delay the upcoming scarcity and enable a sustainable development.

Acknowledgments

Financial support provided by Coordenação de Aperfeiçoamento de Pessoal do Nível Superior (CAPES) and the Financiadora de Estudos e Projetos (FINEP) were greatly appreciated.

References

[1] WWAP (United Nations World Water Assessment Programme) The United Nations World Water Development Report, Water for a Sustainable World, UNESCO, Paris, France, 2015.
[2] P. Holt, E. James, Wastewater Reuse in the Urban Environment: Selection of Technologies, Ecological Engineering, Landcom WSUD Strategy, Parramatta, New South Wales, Australia, 2006.
[3] RMIT University, Urban Greywater Design and Installation Handbook, RMIT University and National Water Commission, Australian Government, Canberra, 2008.
[4] E. Friedler, M. Hadari, Economic feasibility of on-site greywater reuse in multistory buildings, Desalination, 190 (2006) 221–223.
[5] L.A. Abu Ghunmi, G. Zeeman, M. Fayyad, J.B. Van Lier, Greywater treatment systems: a review, Crit. Rev. Environ. Sci. Technol., 41 (2011) 657–698.
[6] K. Bani-Melhem, Z. Al-Qodah, M. Al-Shannag, A. Qasaimeh, M.R. Qtaishat, M. Alkasrawi, On the performance of real grey water treatment using a submerged membrane bioreactor system, J. Membr. Sci., 476 (2015) 40–49.
[7] United State Environmental Protection Agency USEPA, Guidelines for Water Reuse, Washington, D.C., USA, 2004.
[8] World Health Organization, Progress on Drinking Water and Sanitation, Joint Monitoring Programme for Water Supply and Sanitation, WHO, UNICEF, 2012.
[9] F.A. Memon, S. Ward, Alternative Water Supply Systems, IWA Publishing, London, 2015.
[10] ABNT – 13,969/1997 – Tanques sépticos – Unidades de tratamento complementar e disposição final dos efluentes líquidos – Projeto, construção e operação, Rio de Janeiro, 1989.
[11] Lei municipal n° 2.856, Institui Mecanismos de Estimulo à Instalação de Sistema de Coleta e Reutilização de Águas Servidas em Edificações Públicas e Privadas, Niterói (RJ), 2011.
[12] M. Pidou, Membrane Processes for Greywater Recycling, Chapter 12, Alternative Water Supply Systems, IWA Publishing, London, 2015.
[13] F. Li, K. Wichmann, R. Otterpohl, Review of the technological approaches for grey water treatment and reuses, Sci. Total Environ., 407 (2009) 3439–3449.
[14] T. Peters, Membrane technology for water treatment, Rev. Chem. Eng. Technol., 33 (2010) 1233–1244.
[15] F. Hourlier, A. Masse, P. Jaouen, A. Lakel, C. Gerente, C. Faur, P. Le Cloirec, Formulation of synthetic greywater as an evaluation tool for wastewater recycling technologies, J. Environ. Technol., 31 (2010) 215–223.
[16] J. Guilbaud, A. Masséa, Y. Andrès, F. Combe, P. Jaouena, Laundry water recycling in ship by direct nanofiltration with tubular membranes, Resour. Conserv. Recycl., 55 (2010) 148–154.
[17] T. Venkatesh, S. Senthilmurugan, Greywater treatment and simultaneous surfactant recovery using UF and RO process, Separ. Sci. Technol., 52 (2017) 2262–2273.
[18] S. Dey, P. Bhattacharya, S. Bandyopadhyay, S.N. Roy, S. Majumdar, G.C. Sahoo, Single step preparation of zirconia ultrafiltration membrane over clay-alumina based multichannel ceramic support for wastewater treatment, J. Membr. Sci. Res., 4 (2018) 28–33.
[19] M.-C. Martí-Calatayud, M.-C. Vincent-Vela, S. Álvarez-Blanco, J. Lora-García, E. Bergantiños-Rodríguez, Analysis and optimization of the influence of operating conditions in the ultrafiltration of macromolecules using a response surface methodological approach, Chem. Eng. J., 156 (2010) 337–346.
[20] M.N. Abu Seman, M. Khayet, Z.I. Bin Ali, N. Hilal, J. Membr. Sci., 355 (2010) 133–141.
[21] R.W. Baker, Membrane Technology and Applications, Reduction of nanofiltration membrane fouling by UV-initiated graft polymerization technique, J. Membr. Sci., 2nd ed., John Wiley & Sons Ltd, California, 2004.
[22] A.G.F. Norman, N. Li, W.S. Winston Ho, T. Matsuura, Advanced Membrane Technology and Applications, John Wiley & Sons, Inc., New Jersey, 2008.
[23] APHA, AWWA and WEF, Standard Methods for the Examination of Water and Wastewater, American Public Health Association, American Water Works Association and Water Environment Federation Publication, 21st ed., Washington, D.C., USA, 2005.

[24] ABNT – NBR 10738 – Água – Determinação de surfactantes aniônicos pelo método espectrofotométrico do azul-de-metileno, Rio de Janeiro, 1989.
[25] J. Orantes, C. Wisniewski, M. Heran, A. Grasmick, The influence of operating conditions on permeability changes in a submerged membrane bioreactor, Sep. Purif. Technol., 52 (2006) 60–66.
[26] S. Judd, The MBR Book: Principles and Applications of Membrane Bioreactors for Water and Wastewater Treatment, Butterworth-Heinemenn, Oxford, 2010.
[27] S.H.D. Silalahi, T. Leiknes, High frequency back-pulsing for fouling development control in ceramic microfiltration for treatment of produced water, Desal. Wat. Treat., 28 (2011) 137–152.
[28] G. Ramon, M. Green, R. Semiat, C. Dosoretz, Low strength greywater characterization and treatment by direct membrane filtration, Desalination, 170 (2004) 241–250.
[29] N.S. Mizzouri, M.M.J. Algabban, H.M. Hassan, Assessment of grey water disposal and different treatment options for Domiz camp in Duhok city, J. Duhok Univ., 20 (2017) 184–195.