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Reuse feasibility of pre-treated grey water and domestic wastewater with a compact household reverse osmosis system

G. Onkal Engin*, B. Sinmaz Ucar, E. Senturk

Gebze Institute of Technology, Department of Environmental Engineering, Gebze, Kocaeli, 41400 Turkey
Tel. +90 (262) 6053210; Fax +90 (262) 6053210; email: guleda@gyte.edu.tr

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ABSTRACT

Many countries in the Mediterranean basin are facing water shortage issues. Since water is becoming a rare resource, grey water and domestic wastewater reuse arises as a sustainable solution to reduce the overall water demand. In this study, a compact household reverse osmosis unit was used in order to determine the feasibility of pre-treated grey water and domestic wastewater reuse. The preliminary studies revealed that the compact system used was able to treat the wastewaters studied with quite high organic matter and nutrient removal efficiencies. For pre-treated grey water, the COD and BOD removal rates were around 80%. For pre-treated domestic wastewater, the organic matter removal rates were higher. In addition, soluble nutrients, such as nitrate and phosphate were also studied. The conductivity of permeate was reduced to 15 μS/cm and 55 μS/cm for grey water and domestic wastewater, respectively, within 15 min. The permeate obtained was free of suspended solids and had an excellent physical appearance. The overall results indicated that the product can be used for gardening, fire hydrants, field irrigation, or alternatively for toilet flushing after disinfection.

Keywords: Reverse osmosis; Grey water; Domestic wastewater; Reuse

1. Introduction

In most developing countries, water supply, wastewater treatment and disposal are, still, a matter of concern that needs to be addressed. The prospects for economic and social development and the priorities for industrial investments are the main obstacles in making decisions on public water supply and wastewater facilities.

Some new water supply and sanitation concepts, especially for remote regions and villages, have emerged over the past two decades, especially in the arid and semi-arid regions of the Mediterranean basin. Projects including urine separation [1], grey water collection [2] and other sanitation systems, such as vacuum systems [3] have been implemented in some developed countries. Furthermore, developing countries also show an increasing interest in these new sanitation applications, such as reuse of treated wastewater [4]. The reasons for gaining interest in these concepts are water shortage, rise in population, growing urbanization, climate change, environmental and economic considerations. Grey water reuse, especially, attracted some attention, since the characteristics is of importance [2]. Grey water is proved to be less polluted compared to domestic wastewater [5]. It was previously

* Corresponding author.

reported that approximately 1/3 of the total household water consumption can be reduced by reusing grey water for flushing purposes [2].

When evaluating the possibilities for reuse of domestic wastewater, the need for pre-treatment should also be evaluated thoroughly. In this regard, there are two important points that should be addressed. The first is that wastewater disposal must be managed effectively to safeguard public health, and protect freshwaters from pollution. Secondly, treated wastewater must be reintegrated safely in the water cycle and reclaimed water should contribute considerably to household water budget and/or agricultural applications, especially in countries with limited water resources [6].

Different technologies were successfully applied to treat grey water and domestic wastewater for reuse purposes, including coagulation, adsorption, filtration and biological treatment [7–10]. The use of reverse osmosis for grey water and wastewater reuse is a relatively new area [11–13]. In order to keep the removal efficiency high and extend the life of reverse osmosis systems, it is important to carry out pre-treatment prior to introduction to a reverse osmosis system. With the selection of appropriate pre-treatment, fouling, co-precipitation and concentration polarization can be minimized. Consequently, the permeate flux, removal efficiency, recovery rates and operating costs are optimized.

The onsite reuse of grey water and wastewater are practiced in some countries as a sustainable solution to reduce the overall water demand. Despite considerable research effort undertaken on the issue, the use of such systems still need to be promoted in Turkey. The main objective of this study is to determine the feasibility of using a compact household reverse osmosis unit to treat pre-treated grey water and domestic wastewater for further use.

2. Materials and methods

A commercially available reverse osmosis system was used in order to determine the treatment and reuse efficiencies of pre-treated grey water and domestic wastewater. The characteristics of wastewaters and the membrane system used are given below.

2.1. Wastewater specifications

2.1.1. Grey water

Grey water was collected from bathroom sink, shower and kitchen sink of a household. The grey water was collected by gravity in an underground sump and then pumped into a holding tank. Samples were either used immediately or stored at 4±1°C and analysed within 8 h. The samples were subjected to coagulation prior to introduction to the reverse osmosis system in order to protect the membranes. The optimum dosages of coagulant and flocculant were determined by jar test. Consequently, the optimum dosages for dehydrated $Al_2(SO_4)_3$ and polyelectrolyte was found to be 1.5 g/L and 3 mL/L, respectively. Each experiment was conducted with 30 L of grey water sample.

2.1.2. Synthetic wastewater

The working solution (30 L) was prepared by dissolving organic matters and inorganic compounds that normally exist in domestic wastewater. The synthetic wastewater was prepared according to the recipe given in ISO 11733: 2004 Water Quality — Determination of the elimination biodegradability of organic compounds in an aqueous medium-Activated sludge simulation test. The organic and inorganic wastewater constituents are listed in Table 1. All the chemicals (Merck) used were of analytical reagent grade and tap water was used during the preparation of synthetic wastewater. Since all individual components of synthetic wastewater cannot be separately analyzed, a surrogate quantity, COD, was used in measuring the concentration of the solution.

Table 1
Synthetic wastewater constituents

Compounds	Concentration, mg/L
Peptone	38.4
Glucose	141.8
NH_4Cl	4.6
K_2HPO_4	3.2
$Na_2HPO_4.7H_2O$	6.4
$NaHCO_3$	58.8
NaCI	80.0

2.1.3. Domestic wastewater

Domestic wastewater was collected from sedimentation tank effluent of a large wastewater treatment plant located in Istanbul, Turkey. 30 L samples were taken and the samples were either used immediately or stored at 4±1°C and analysed within 8 h. The samples were introduced to the reverse osmosis system without any further treatment.

2.2. Equipment, instrumentation and operational procedure

The scheme of the experimental set-up is given in Fig. 1. The set-up used in this study consisted of a raw wastewater tank made up of polyethylene (40 L), feeding pump (Predo Water Pump), a commercially available compact household reverse osmosis unit (Filmtec Corporation, CSM RE2012-100) and a permeate collection tank (10 L). The sediment filters (C and E) were used to protect the membrane from particulate matter entering the system. The block carbon filter (D) was used for partial

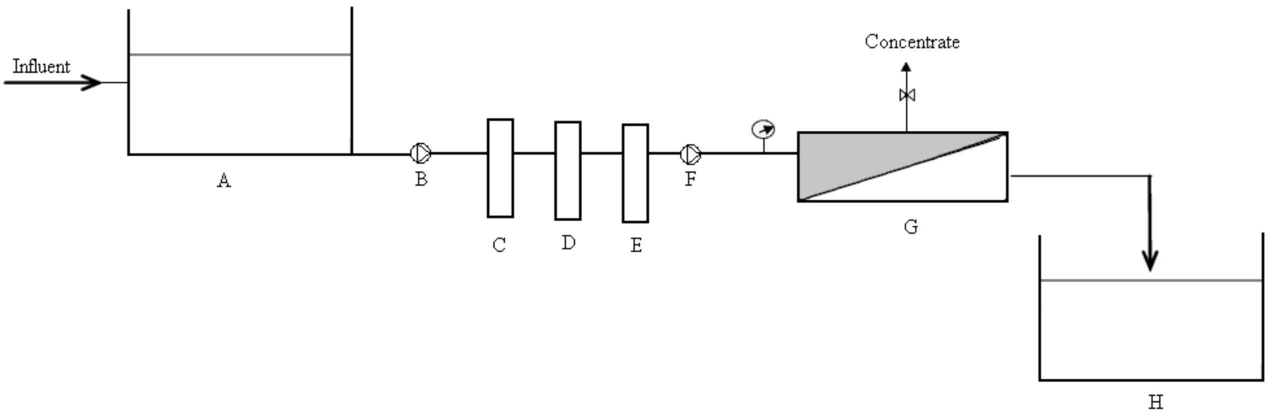

Fig. 1. The diagram of the experimental set-up (A) feed tank, (B and F) pump, (C and E) sediment filters, (D) block carbon filter, (G) reverse osmosis unit and (H) permeate tank.

removal of organic matter and chloride ions present in wastewater. A solenoid valve which takes signals from low pressure and high pressure switches also protected the membrane. The specifications and operational conditions of the reverse osmosis membrane can be found in Table 2.

Table 2
Specifications and operational limits of the household membrane used

Specifications	Description
Membrane type	Thin-film composite
Membrane material	PA (polyamide)
Membrane surface charge	Negative
Configuration	Spiral-wound, tape wrapping
Permeate flow rate[1], L/d	379
Salt rejection[2], %	96
Operating limits	
Max. operating pressure, MPa	0.86
Max. feed flow rate, m^3/h	0.45
Max. operating temperature, °C	45
Operating pH range	3.0–10.0
Max. turbidity, NTU	1.0
Max. SDI[3] (15 min)	5.0
Max. free chlorine concentration, mg/L	0.1

[1]Permeate flow rate is based on standard test conditions and may vary depending on feed water quality. Individual element's permeate flow may vary within 15%.
[2]The stated performance is initial data taken after 30 min of operation based on the following conditions: 250 mg/L NaCl solution at 413.69 kPa applied pressure, 15% recovery, 25°C and pH 6.5~7.0.
[3]SDI: Silt Density Index

In order to test the membrane pressure and the equipment, the reverse osmosis system was run for 5 h using tap water prior to the experiments carried out. All the experiments were conducted for 35 min. Upon completion of the experimental work, the membrane unit was kept in sodium metabisulphide solution in an air tight container. Before starting a new set of experiments, the system was rinsed with tap water for 1 h to completely wash off the sodium metabisulphide solution.

2.3. Analytical methods

All the analytical methods, which were used in order to monitor the performance of the system, were carried out using the methods given in the Standard Methods [14]. The chemical and biochemical oxygen demand (COD and BOD_5) analyses were performed according to the STM 5220 C and STM 5210 B methods, respectively [14]. The nitrate and phosphate analyses were also performed using the STM 4500 Nitrate-B and STM 4500-P methods, respectively [14]. The pH, conductivity and temperature measurements were carried out using a hand-held multimeter (WTW). All the chemicals used were of analytical reagent grade and laboratory distilled water was used during the experiments.

3. Results and discussion

As it is known, numerous parameters are used to define reuse water quality for a selection of different purposes, to assess salinity hazards, and to determine appropriate management strategies. The total concentration of soluble salts is one of the most important parameters in the determination of water quality for gardening and field irrigation. The amount of soluble salts defines the suitability of water for irrigation and the potential for plant toxicity. Water salinity is usually measured by the TDS (total dissolved solids) or the EC (electrical conductivity). In addition, the BOD_5, NO_3^- and PO_4^{3-} and pH are among the important parameters in the determination of reuse possibilities of wastewaters. During the following sections, the removal of such parameters from grey water, synthetic wastewater and raw wastewater was discussed.

3.1. Contaminant removal in grey water

In order to determine the reuse possibilities of grey water, the processed grey water sample was introduced to the system and the COD, BOD_5, TDS, NO_3^- and PO_4^{3-} analyses of the raw grey water, pre-treatment and composite permeate were carried out. In Table 3, the processes applied and the results obtained can be seen.

It was observed that the coagulation process was effective in reducing the organic matter, as well as nutrients. The increase in total dissolved solids was thought to be due to the coagulant used. The results of reverse osmosis system were satisfactory both from the point of organic matter (80%) and nutrients (~50%) removal. The TDS values were also satisfactorily removed from the grey water by a percentage of 95.7.

The conductivity and TDS values of the grey water permeate were investigated as a function of time and presented in Fig. 2. As can be seen from Fig. 2, both the conductivity and TDS values decreased dramatically within the first 5 min. Although the system was run for 35 min, it was observed that a period of 15 min is sufficient to reach the minimum value.

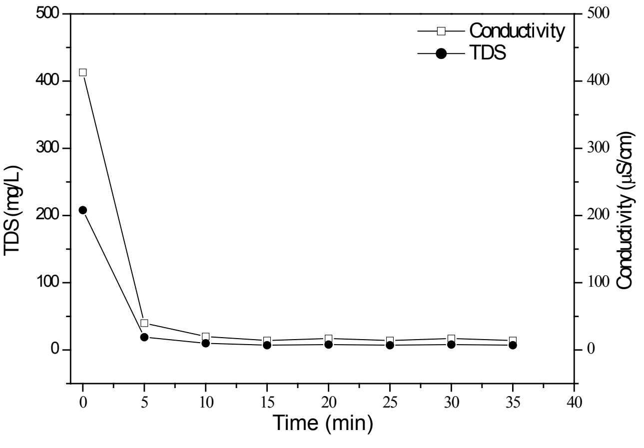

Fig. 2. The conductivity and TDS values of the grey water permeate as a function of time.

The authors did not encounter any study treating grey water using reverse osmosis systems. However, there are a number of papers reporting ultrafiltration (UF) and nanofiltration (NF) membrane systems treating grey water. In a recent study conducted by Li et al. [15] the performance of nutrient oriented decentralized grey water treatment system which uses a direct UF membrane filtration system was evaluated. The results indicated that the organic matter removal rate was 81.6%. However, it was also reported in the same study that the soluble nutrients remained in the permeate. In an earlier study, low load grey water, collected from a sports center's public showers, for on site reuse with UF and NF membranes was treated [16]. It was found out that permeate produced by nanofiltration was of high quality compared to UF membrane unit. The soluble organic matter and ionic species removal rates with NF were around 90% and 50%, respectively. It was also reported that the organic matter removal rate for UF membrane was as low as 45–70%. In another study [17] aiming to treat and recover the resources present in the grey water using a submerged spiral-wound UF membrane module, it was shown that, TOC was reduced from the influent value of 161–28.6 mg/L in the permeate, with an average elimination rate of 83.4%. The total nitrogen and total phosphorus in the permeate were reported to be 16.7 and 6.7 mg/L, respectively.

3.2. Contaminant removal in synthetic wastewater

The results obtained with grey water were promising and therefore as a second approach, synthetic wastewater was prepared and introduced to the reverse osmosis system. The COD, BOD_5, TDS, NO_3^- and PO_4^{3-} analyses of the raw wastewater and composite permeate were given in Table 4.

In this part of the study, the results obtained were also satisfactory. The removal rates of both COD and BOD_5 were found to be 96%. From the point of nutrients removal, the obtained values were much better. The removal efficiency for NO_3^- was 87% and PO_4^{3-} was 94%. In a previous study with a reverse osmosis system, it was found that the ammonium and nitrate removal efficiencies were 80 and 90%, respectively [18]. Since, there were no suspended solids in the prepared wastewater, better results were obtained with the synthetic wastewater

Table 3
Contaminant removal results for pre-treated grey water

Sample	COD, mg/L	BOD_5, mg/L	NO_3^-, mg/L	PO_4^{3-}, mg/L	TDS, mg/L	pH
Raw grey water	338.00	219.70	0.90	0.63	185.12	7.60
Effluent coagulation	120.00	78.00	<0.50	0.20	208.00	7.84
Permeate	24.00	15.60	<0.50	0.10	9.00	6.67

Table 4
Contaminant removal results for synthetic wastewater

Sample	COD, mg/L	BOD_5, mg/L	NO_3^-, mg/L	PO_4^{3-}, mg/L	TDS, mg/L	pH
Synthetic wastewater	293.00	190.45	3.80	1.60	423	7.82
Permeate	13.00	8.45	<0.5	0.10	25	6.95

samples. The TDS values were also satisfactorily removed from the synthetic wastewater by a percentage of 94.

The conductivity and TDS values of the synthetic wastewater permeate as a function of time were of similar trend with the ones obtained using the grey water samples. As can be seen from Fig. 3, the conductivity and TDS values decreased instantaneously. It was also observed that a period of 15 min was sufficient to reach the minimum value.

3.3. Contaminant removal in raw domestic wastewater

After completion of the synthetic wastewater experiments, domestic wastewater obtained from sedimentation tank effluent of a large wastewater treatment plant was introduced to the reverse osmosis system. The results of COD, BOD_5, TDS, NO_3^- and PO_4^{3-} analyses of the pretreated domestic wastewater and composite permeate are presented in Table 5.

The removal rates of both COD and BOD_5 for this part of the study were also found to be around 94%. The obtained values for the removal of nutrients were slightly lower compared to studies conducted with grey water and synthetic wastewater. The removal efficiencies for NO_3^- and PO_4^{3-} were 92% and 91%, respectively. The TDS values were also satisfactorily removed from the synthetic wastewater by a percentage of 95. Although, the overall results of raw wastewater were lower compared to the studies with grey water and synthetic wastewater, it can be concluded that the system used in this study is capable of removing contaminants from wastewater for reuse purposes.

The conductivity and TDS values of the raw wastewater permeate as a function of time were given in Fig. 4. The results indicated that a period of 15 min was sufficient to reach the minimum value for both conductivity and TDS, irrespective of the wastewater type used in the system.

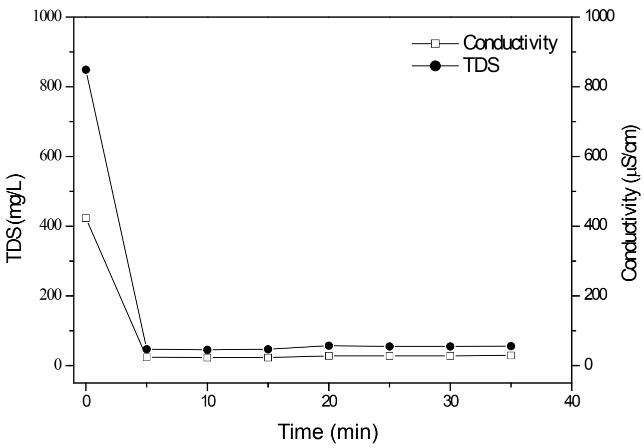

Fig. 3. The conductivity and TDS values of the synthetic wastewater permeate as a function of time.

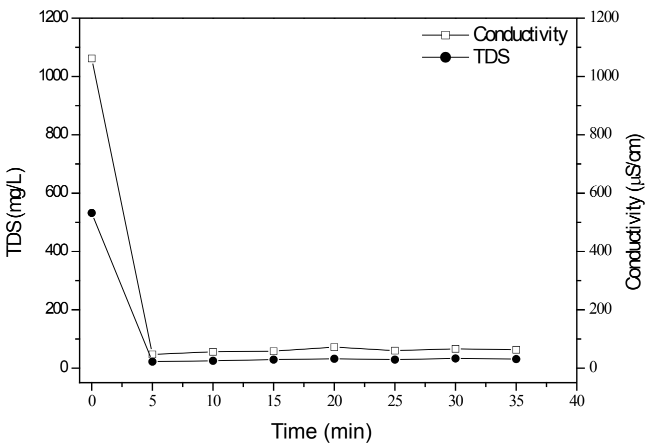

Fig. 4. The conductivity and TDS values of the raw wastewater permeate as a function of time.

Table 5
Contaminant removal results for raw wastewater

Sample	COD, mg/L	BOD_5, mg/L	NO_3^-, mg/L	PO_4^{3-}, mg/L	TDS, mg/L	pH
Raw wastewater	470.00	305.50	6.30	2.20	532	7.86
Permeate	29.98	22.56	<0.50	0.20	39	6.92

There are a number of studies conducted in the area of wastewater treatment using reverse osmosis membranes [6,12,19,20]. An interesting one was from Korea [12]. The idea behind the study was to reuse treated wastewater for irrigational purposes in an island in Korea, and, in the mean time, to protect groundwater which is the sole water source. For this purpose, a pilot-scale integrated membrane system (MF–RO) was evaluated for domestic wastewater reuse. The results presented indicated that with such an integrated membrane system organic matter removal rates as high as 93% were achieved. Similarly, the conductivity, which was selected to be one of the most significant parameters, was reduced by a percentage of 99%. The authors concluded that the treated water quality satisfied the drinking water standards and was comparable to those of groundwater.

As expected, removal efficiency for RO membrane was high for all the parameters (both organic matter and nutrients removal) measured, in this study. The results were quite satisfactory and comparable to the results presented in the literature. The results obtained did not show significant difference between different types of wastewater treated. In addition, the quality of processed waters was indicated that it can be reused for some applications such as flushing or irrigation gardening, fire hydrants, field irrigation, or alternatively for toilet flushing after disinfection.

4. Conclusions

At least half of the water is used for applications where drinking water quality is not required. Grey water and wastewater generated from households can be processed within a few hours using a compact household reverse osmosis unit for reuse possibilities. There is a couple of problems associated with grey water and wastewater reuse. One of them is that grey water composition might vary significantly due to the variations in water consumption. Concentration variability of grey water produced would not constrain grey water treatment and reuse, even when using small on-site grey water treatment systems. However, the levels of grey water production could be affected. Secondly, oxygen depletion due to degradation of organic matter during storage could be another risk for sulphide production. In order to prevent this problem, storage times should be kept to a minimum. The system used in this study, with a feed flow rate of 0.45 m^3/h and a permeate production capacity of 379 L/d would cope with these kind of changes in both grey water quality and quantity.

Reverse osmosis treatment of the selected wastewaters was carried out until 90–95% water recovery was achieved. The COD and BOD_5 values of processed water were found to be lower than 30 mg/L. The conductivity of permeate was lower than 50 μS/cm for synthetic wastewater and raw wastewater. However, the conductivity of grey water permeate was even lower reaching a value of 14 μS/cm. The quality of processed waters indicated that it can be reused for the some applications such as gardening, fire hydrants, field/parks irrigation, or alternatively for toilet flushing after disinfection. Although, it is very well known that reverse osmosis systems are capable of removing microorganisms present in wastewater, a further polishing step might be required. In this study, the microorganisms present in permeate could not be detected. Therefore, in future studies, the microorganism detection should also be considered. Considering the health, environmental and agricultural production issues, the treated effluent has to meet high quality standards determined by the associated standards. In this study, it was shown that membrane treatment is an efficient process and that membrane technology can be implemented after the removal of the suspended matter. It is foreseen that in future, the membrane technology will be the predominant process in further treatment of domestic and/or industrial wastewaters for reuse.

The energy requirement of the system was also calculated and found to be less than 0.3 USD for the treatment of 1 m^3 wastewater. It is well known that the most significant costs associated with reverse osmosis systems, aside from the capital cost, are the costs of energy consumption and the membrane replacement. The cost of fresh water in Istanbul, Turkey is approximately 0.2 USD/m^3. Therefore, it can be concluded that the treatment of wastewater with a compact household reverse osmosis system with rudimentary pre-treatment can be cost effective. It is also expected that the increasing use of novel systems designed to work with renewable energy would reduce the unit cost of wastewater treatment.

The main advantages of such a system can, therefore, be concluded as: (i) easy operation and maintenance, (ii) no requirement for a skilled operator and (iii) less consumables. Although the removal efficiency using a compact household reverse osmosis unit used in this work was quite satisfactory, pre-treatment was required depending on the nature of wastewater. It was found that reverse osmosis combined with a pre-treatment unit would be a reliable technology for reuse.

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