DESALINATION

Desalination 222 (2008) 38–49

www.elsevier.com/locate/desal

Chlorination and coagulation as pretreatments for greywater desalination

Eran Friedler*, Ilan Katz, Carlos G. Dosoretz

Faculty of Civil and Environmental Engineering, Grand Water Research Institute,
Technion — Israel Institute of Technology, Haifa, Israel
Tel. +972-4-8292633; Fax +972-4-8228898; email: eranf@tx.technion.ac.il

Received 20 January 2007; accepted 30 January 2007

Abstract

On-site greywater reclamation is thought to enhance water usage efficiency and decrease urban water demand. Direct membrane filtration is an attractive approach for treatment of greywater in residential areas due to its small footprint and high reliability, as product quality is insensitive to fluctuations in inflow quality. The research evaluated coagulation or chlorination as possible pretreatments for ultrafiltration followed by RO desalination. The system was fed with “light” greywater (avg. TOC, TN and P — 24.9, 4.6 and 0.7 mg L^{-1}; turbidity — 34 NTU). Direct filtration, without pretreatment, resulted in sharp decrease of the UF permeability, due to organic fouling and biofouling. The RO membrane was suspected for phosphate salt scaling. To overcome these drawbacks, coagulation and chlorination were evaluated as pretreatment options prior to UF. Chlorine demand of the greywater was 10–20 mg L^{-1}. Applying this dose and controlling residual chlorine in the UF feed, lowered the fouling rate by 33%. Mass balances calculations indicated that chlorination inhibited microbial activity in the UF system. The partial oxidation of the organic matter, achieved by the chlorination pretreatment, may have changed the properties of the organic matter and thus its reactivity with the UF and RO membranes. Next, ferric chloride was tested as a coagulant. Dosing 50 mg L^{-1} ferric chloride reduced the UF flux decline rate by 43%, mainly due to a 38% decrease of the organic load. After coagulation, larger particles with narrower size distribution were observed in the feed (average size ~0.5 μm). This upward shift resulted in a more porous filtration cake buildup on the UF membrane, a finding which supports the enhanced performance. Greywater desalination demonstrated the ability to produce high quality effluents and the RO sensitivity to different parameters. Although a positive synergistic effect could be anticipated, the combined coagulation-chlorination process increased fouling rate probably due to the increase in the concentration polarization phenomenon, as a result of a rise in the concentrations of counter ions associated with the pretreatment reactants and possible surplus of the latter. The results indicate that greywater pretreatment is a prerequisite to hamper UF membrane biofouling. Coagulation was found to be superior to chlorination for the UF. Effluents produced by each of the membranal steps were of excellent

---

*Corresponding author.

Presented at the conference on Desalination and the Environment. Sponsored by the European Desalination Society and Center for Research and Technology Hellas (CERTH), Sani Resort, Halkidiki, Greece, April 22–25, 2007.

doi:10.1016/j.desal.0000.00.000

quality that can be used for various purposes, being low in organic content, suspended matter and colloids (UF), or desalinated (RO).

Keywords: Greywater; Desalination; Direct membrane filtration; Pretreatment; Coagulation; Chlorination; UF; RO

1. Introduction

Traditional approach for municipal wastewater treatment was a centralised one, in which municipal sewage is conveyed through a sewer network to a central wastewater treatment plant. This approach was supported by economy of scale by the better ability to employ skilled professionals in a large wastewater treatment plant. Decentralised systems were generally conceptualised as costly, poorly controlled systems that often produce low quality effluent. Today, due to continuous urbanisation and urban sprawl (and the reduction of funds available for public infrastructure), it becomes harder to maintain and develop centralised systems which often lag behind urban development.

Decentralised/on-site treatment and reuse options are investigated in many countries around the world (EU, Japan, Australia, USA, Israel, etc.). These on-site systems either serve as an alternative to traditional systems, or augment existing systems by alleviating the hydraulic and organic loads from them. Greywater, which is composed of domestic wastewater other than toilet flashing, is a main target source for wastewater decentralised treatment and reuse. On-site reclamation of greywater is thought to enhance water usage efficiency and decrease the urban demand of potable water. Indeed on-site greywater reuse can reduce urban water demand by up to 10–25% [1]. For example, Ref. [1] demonstrated that in Israel, with 30% of houses having greywater reuse systems, $35\text{–}50 \times 10^6\,\mathrm{m}^3\,\mathrm{y}^{-1}$ of potable water would be saved in 2023 (anticipated population 10×10^6). Further, Ref. [2] have shown that in many cases on-site reuse of greywater maybe also economically feasible to the individual consumer.

In contrast with common perception, greywater may be polluted, with COD concentrations of up to several hundred mg L^{-1}, turbidity up to 70–100 NTU, faecal coliforms about 10^4–10^6 cfu $(100\ \mathrm{mL})^{-1}$, and significant concentration of detergents, B, Na, etc. Thus, if not treated to a high standard, they may cause health risk and negative aesthetic and environmental effects [3–5]. Thus, Ref. [6] suggested where possible to reuse only light greywater (e.g. greywater originating from the bath, shower and washbasin) in order to minimise treatment costs and possible adverse effects.

Most treatment units reported in the literature consist of filtration followed by disinfection. Experience has shown however that these systems fail to produce effluent suitable for on-site reuse. In order to overcome this deficiency, more current treatment units incorporate biological treatment as well [4,7–9]. In recent years the use of membrane embedded wastewater treatment processes have become more common due to the significant reduction in their unit cost and the significant improvement of their performance which makes them very reliable processes. Of these, direct membrane filtration is especially attractive for on-site greywater treatment and reuse in urban areas (which are usually densely populated) due to its small footprint, ease of operation and maintenance, and fundamentally, its high reliability as the quality of the product is insensitive to operational conditions and fluctuations in inflow quality (which can be significant when on-site treatment is considered). Nevertheless, direct membrane filtration units suffer from rapid decline of permeate flux especially when the feed water contains considerable concentrations of organic matter, suspended solids and nutrients as in the case of domestic greywater.

The goal of this work is to study the performance of direct membrane filtration system for on-site greywater treatment, and to evaluate the effects of two possible pretreatments, namely: chlorination and coagulation followed by sedimentation, on reducing the decline rate of the permeate flux and thus on enhancing the performance of the suggested treatment.

2. Materials and methods

2.1. Source of raw greywater

Light greywater served as the raw water in all experiments. The plumbing of 14 flats in a seven storey high building located in the Technion campus that accommodates married students (some with young children) was retrofitted in order to separately convey light greywater by a gravity collector to the basement of the building (for more details see Ref. [10]). Raw greywater was taken from an equalisation basin that was installed in the basement and transported to the direct-membrane filtration experimental set-up.

2.2. Description of the treatment system

A two-phase membrane system for the treatment of greywater was constructed. The system consisted of an optional pretreatment stage followed by ultra filtration module and an RO module in series (Fig. 1).

- The pretreatment stage contained four options:
  (1) No treatment — This option served as the baseline case.
  (2) Pre-chlorination — The goal of this pretreatment was twofold: to significantly reduce the number of microorganisms, and to partially oxidise the organic matter present in the raw greywater. It was envisaged that significant reduction of microorganisms in the feed will lead to a considerable decrease of the biofouling rate on the UF membrane, and that the partial oxidation of organic matter will add to this effect.
  (3) Coagulation + sedimentation — This pretreatment option aimed at reducing suspended matter, biodegradable organics and nutrients (nitrogen and phosphorus compounds) in the feed. It was believed that some removal of microorganisms will be achieved by this pretreatment too.
  (4) Combined pretreatment — Coagulation (3) followed by chlorination (4).
- The ultra filtration membrane unit (FP100 membrane, PCI) consisted of 18 tubular PVDF membranes in parallel with total surface area of 0.88 m^2. The molecular weight cut off the membranes is 100 kDa. The UF was operated in crossflow mode with 10 sec backwash every 30 min, controlled by industrial controller and data logger (M90, Unitronics, Israel).

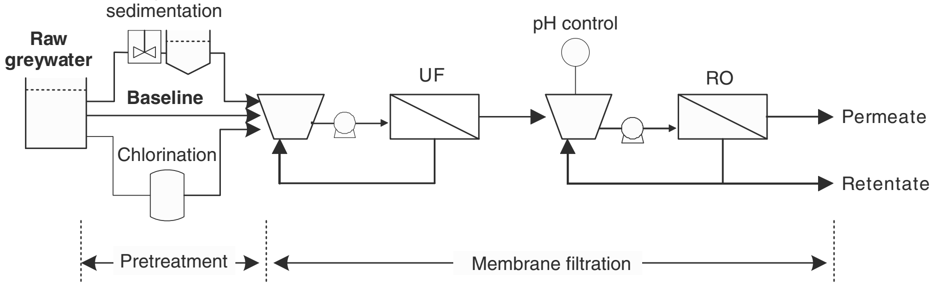


Fig. 1. General scheme of the experimental treatment train.

The unit was operated at a constant TMP of 1 bar at batch mode, with full recirculation of all streams to the feed tank.

- The RO system was based on 2.5" module (model XLE-2521, FilmTec) has an active area of 1.2 m^2, and salt rejection ability of 99%. The system includes heat exchanger and operated at TMP of 5 bar, 50% recovery ratio and batch mode. The pH of the feed to the RO system was controlled by a pH controller (HI8710E, Hanna) and kept at 6.5.

2.3. Experimental

In the first stage, side experiments were conducted in order to assess the required chlorine and coagulant doses to be used in the second stage continuous.

- Chlorination was performed by adding hypochlorite solution to the sample in various concentrations: In the first experiment hypochlorite doses were set to satisfy a chlorine dose of 0 to 30 mg L^{-1} with 10 mg L^{-1} intervals; Following the knowledge gained during the first experiment, in the following ones chlorine doses were set at 0 and from 5 to 20 mg L^{-1} at 2.5 mg L^{-1} intervals. In each of the above samples residual chlorine, and heterotrophic plate count (HPC) were determined after 30 and 60 min contact time.
- The optimal dose ferric chloride ($FeCl_3$) as a flocculant was determined by a jar test. The test was performed in a standard flocculator (RAE Motor Corp. six paddle stirrer) equipped with standard rotating blades, and six identical 2 L circular flasks. The test was conducted at the following manner: addition of the flocculant, rapid mixing (100 rpm) for 5 min, gentle mixing (25 rpm) for 30 min, and sedimentation (0 rpm) 30 min. Samples of the raw greywater and the flocculated-settled samples were taken for analysis of pH, EC, turbidity, TOC, alkalinity TN, dissolved P, K, Na, Ca and Mg.

Experiments in the second stage were conducted on the two phase membrane system. Here, chlorination was performed by adding hypochlorite solution to the UF feed tank where the raw greywater was stored. Due to the vulnerability of the RO membrane to residual chlorine, permeate of the UF sub-unit was dechlorinated prior to its introduction to the RO sub-unit, using the thiosulfate method [11]. Coagulation–sedimentation in this stage was performed in a batch mode, with the following procedure: 100 L of raw greywater were placed in a sedimentation tank; flocculant was added; rapid mixing was applied for 5 min followed by 25 min of gentle mixing and 30 min of settling; then, settled sludge was emptied from the bottom of the tank and the supernatant was transferred to the UF feed tank.

The UF and RO sub-systems were operated separately, while using a batch of UF permeate to initiate the RO sub-system. In each sub-system all streams were circulated into the feed tank and once a day that batch wash replaced by a new batch of greywater (for the UF unit) and UF permeate (for the RO unit). The RO unit was operated while simulating 50% recovery, meaning that after new batch was introduced to the system, 50% of its volume was discharged as permeate. The remaining volume in the RO system was about double in concentration, simulating the rejected stream of RO system working at 50% recovery.

2.4. Analysis methods

During the preliminary batch experiments residual chlorine was analysed by the DPD colorimetric method (4500-Cl G, [12]), while during the continuous experiments in the membrane system it was determined on-site by Free & Total Chlorine Test Kit (CN-66, Hach). HPC was by spread plate method (9215-C, [12]), TSS by 2540-D method [12] and VSS by 2540-E method [12], Alkalinity by Gran method [13]. pH and EC were measured with Cyberscan electrodes (PC-300, Eutech), turbidity with Digital Direct Reading Turbidimeter (Orbeco-Hellige). TOC and TN (total nitrogen) were analysed by Multi N/C 2000 apparatus (Analytik-Jena). Dissolved P, Na, K, Ca and Mg were measured by ICP-AES (Optima 300 DV, Perkin-Elmer). Particle size distribution (by number and volume) was calculated using a Coulter LS 230- LS particle size analyzer.

3. Results and discussion

3.1. Raw greywater characteristics and preliminary experiments

During the study period the quality of the raw greywater was monitored regularly and exhibited quite high variability. Average concentrations of major pollutants were: TSS — 61.3 mg L^{-1} (STD 36.5 mg L^{-1}), VSS — 49.7 mg L^{-1} (STD 26.5 mg L^{-1}), BOD — 104 mg L^{-1} (STD 32.5 mg L^{-1}), turbidity — 34 NTU (STD 25 NTU), and HPC 2.0×10^7 cfu mL^{-1} (STD 2.1×10^7 cfu mL^{-1}). These values fall within the range reported in the literature for greywater from similar sources [6,14].

The breakpoint in the chlorination experiments ranged from 10 to less than 20 mg L^{-1} (Fig. 2A). This was much lower than data reported by Ref. [15]. HPC counts in the greywater declined significantly from about 10^7 cfu mL^{-1} in the non-chlorinated greywater to about 10^3 cfu mL^{-1} even after a minimal chlorine dose of 5 mg L^{-1} (~4 logs removal) and declined very moderately with increase of the dose (Fig. 2B). Chlorine residual declined only slightly after 60 min contact time while HPC counts did not exhibit any distinct change between 30 and 60 min contact time (data not shown). Following these results, the chlorine dose for the continuous experiments was set at 20 mg L^{-1}.

Fig. 3 shows that the optimal dose of ferric chloride, as revealed by the preliminary experiments, ranged between 40 and 50 mg L^{-1}. With this dose it was possible to remove 94% of the turbidity, 60% of the TOC, 49% of the total nitrogen and about 100% of the phosphorus from the greywater. Hence the ferric chloride dose for the membrane filtration pre-treatment was set at 50 mg L^{-1}. This dosage resembled the finding of [16] working with high quality domestic effluent, however it is much lower than reported values [17] for average wastewater coagulation as the greywater possesses lower contamination value compared with domestic sewage.

3.2. Greywater ultrafiltration

Direct filtration, without any pretreatment (the baseline runs) resulted in a sharp decrease

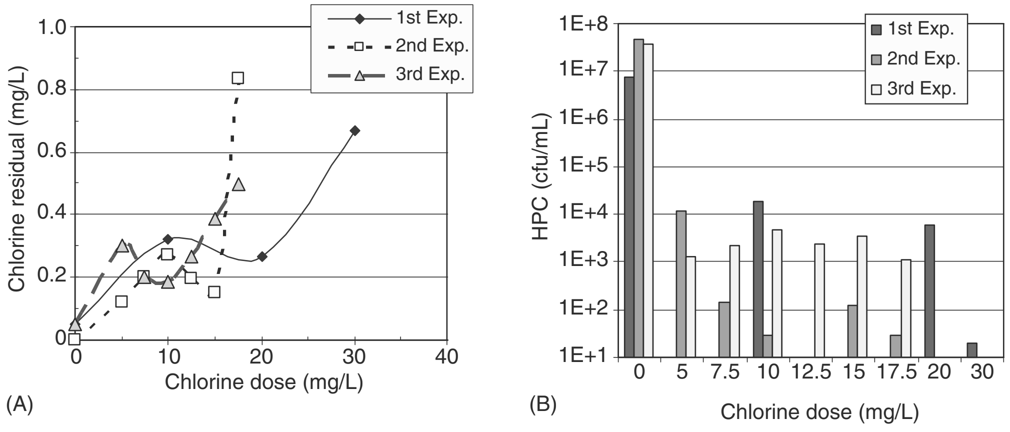
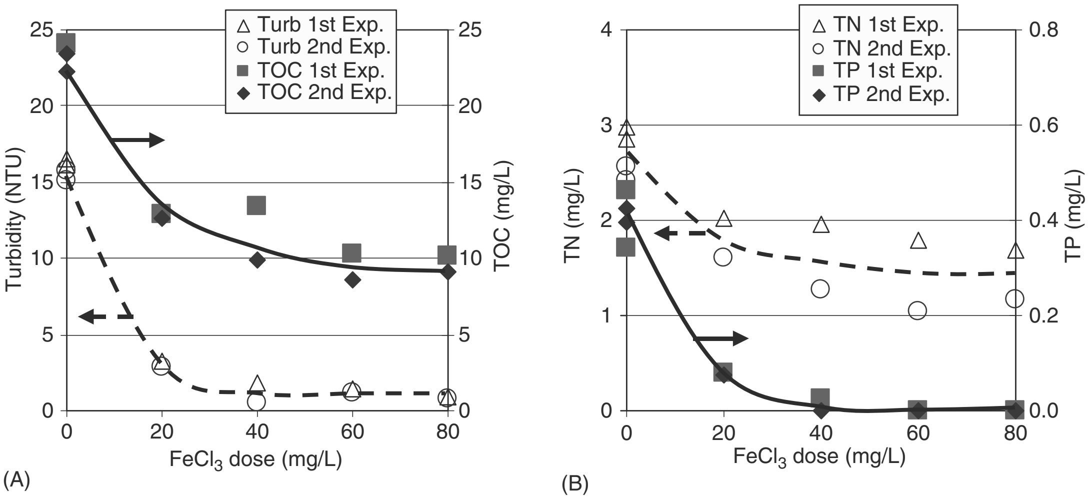


Fig. 2. Residual chlorine (A) and HPC (B) vs. chlorine dose (after 30 min contact time).



(A) (B)

Fig. 3. Turbidity (A), TOC (A), TN (B) and TP (B) as function of ferric chloride dose.

of the UF permeability, to about 20% of its initial value after three days of continuous operation (Fig. 4). This was a result of organic fouling followed by biofouling.

Coagulation by 50 mg L^{-1} ferric chloride resulted in the reduction of greywater turbidity from 24 to 11 NTU (55%) as well as reduction of TOC, TN, dissolved P and alkalinity by 35%,

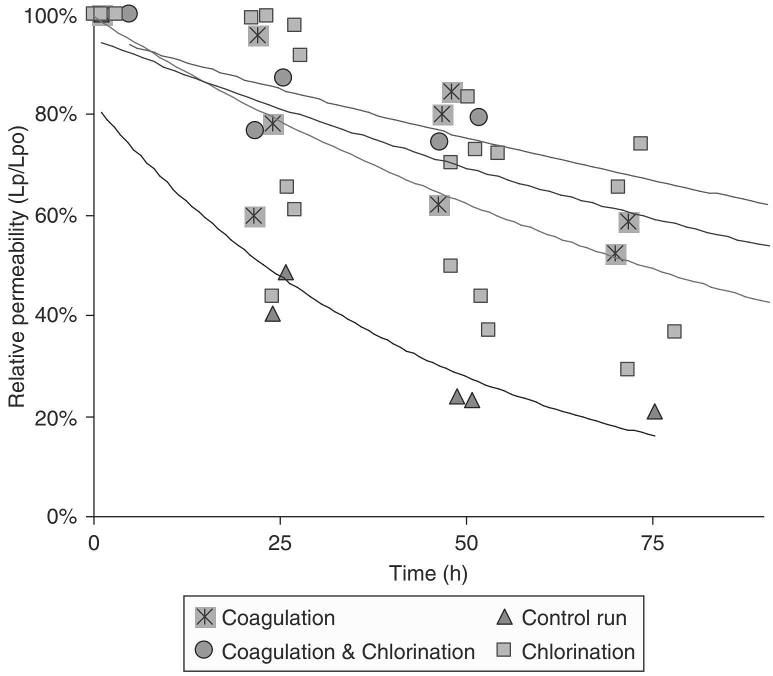


Fig. 4. Greywater ultrafiltration — relative membrane permeability at the four treatment pathways.

14%, 80% and 18% to 16.3, 4.9, and 0.1 mg L^{-1} respectively. Greywater coagulation resulted in a much lower decline rate of the UF flux (43% lower than the decline rate in the baseline runs after 3 days of continuous operation, Fig. 4), retaining 60% of the initial flux. This was mainly due to a decrease of the organic load and an upward shift of the particle size distribution. Coagulation changed the particles size volumetric distribution, after coagulation, larger particles with narrower distribution were observed, with an average size above 0.5 μm (Fig. 5), as compared with 0.064 μm before coagulation. The significant shift in the particle size distribution resulted in a more porous filtration cake buildup over the UF membrane, a finding which supports the enhanced performance observed.

Chlorination treatment required continuous hypochlorite dosing to the UF system, due to decline in residual chlorine concentration by volatilisation and internal chlorine demand, probably by fouled surfaces, mainly on the membrane. Hypochlorite solution was continuously fed to the UF feed tank in order to keep residual chlorine concentration above 1 mg L^{-1}. The fouling rate of UF runs with this pretreatment was 33% lower than the fouling rate of the baseline runs, retaining 50% of the initial flux (after three days of continuous operation). It should be noted that UF runs with chlorination pretreatment showed much higher variability than all other runs.

HPC counts in the feed tank were four orders of magnitude lower than in the baseline runs, with about 5×10^3 cfu mL^{-1}. TOC and TN analyses did not show significant oxidation of the organic matter and consequently the organic load on the UF system was not reduced. Nevertheless, TOC, TN and P mass balances revealed that bacterial activity in the UF system was markedly inhibited as presented by lower consumption of substrate and nutrients within the system: TOC, TN and P consumption during the baseline runs stood at 45%, 27%, 37% (respectively), while their consumption during the chlorination treatment runs was only 36%, 1% and 8% (respectively), probably due to lower biological activity in the UF system under the oxidative conditions.

The combined treatment (coagulation & chlorination) exhibited similar decline of the UF membrane permeability as the coagulation treatment (~25% vs. ~30% after 50 h of continuous operation). The combined process succeeded to remove 67% of the turbidity producing a feed of 9.1 NTU as well as reduction of 24% of the TOC, 2% TN,

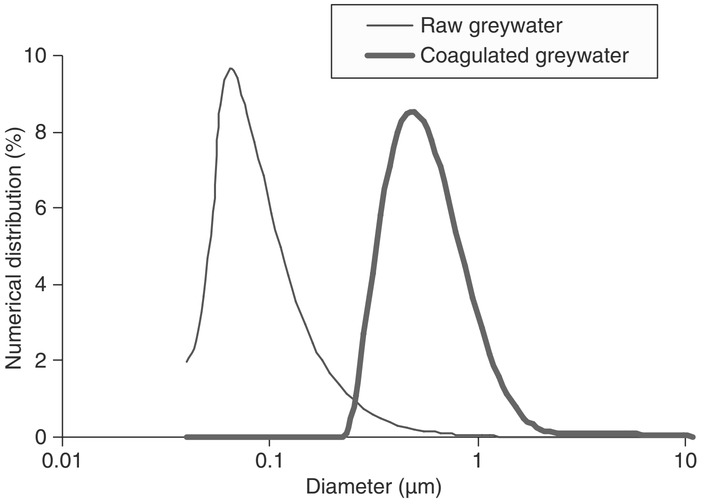


Fig. 5. Particles size volumetric distribution of raw greywater and after coagulation by 50 mg L^{-1} ferric chloride.

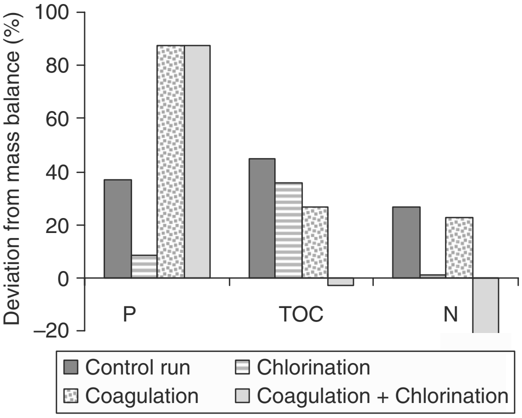


Fig. 6. Greywater UF — mass balance calculations, displayed as deviation from balance (positive values indicate deposition and/or degradation).

80% P and 14% alkalinity. At these low feed concentrations TOC and TN calculations displayed a complete mass balance without decomposition of organic matter in the UF system by microbial activity. As stated above, inhibition of microbial activity in the system was obtained by continuous hypochlorite solution addition that kept residual chlorine of 8.9 (STD 6.4) mg L^{-1} in the UF feed tank. Phosphorus mass balance followed the coagulation pattern, and 82% of it was precipitated out of the flow probably due to continuation of the coagulation process in the UF (Fig. 6).

Greywater ultrafiltration permeate quality shall be evaluated in regard to two aspects: its optional utilization for in-situ direct reuse, and its compatibility for RO post-treatment. The four UF treatments resulted in high quality permeates that can be directly reused for various purposes (such as toilet flushing, garden irrigation, etc.) with no health risk and marginal (if any) environmental effects. The four permeates were characterized by low concentrations of organic matter, nutrients (N, P) and turbidity (Table 1), and were free of suspended matter and pathogens. In regard to the permeate quality, the difference between the treatments were not significant for direct reuse, however for subsequent desalination the elevated pH alkalinity and TDS should be considered to avoid scaling on the RO membrane as well as TOC concentrations that can donate for organic and biological fouling. The elevated TOC at the chlorination and the combined treatment can be explained by detachment of organic fouling (due to chlorination) from the system and may be considered as an artifact. Acceptable and sustainable phosphorous levels were obtained only by coagulation.

3.3. Greywater desalination

The baseline RO run (direct UF filtration followed by RO) operated steadily and scaling was

Table 1
Greywater ultrafiltration — permeate characteristics

	Units	Baseline run	Chlorination	Coagulation	Coagulation & Chlorination
pH	–	7.5	8.4	7.9	9.0
Turbidity	NTU	<1	1.2	<1	<1
Alkalinity	mg L^{-1} (as $CaCo_3$)	120.5	214.6	149.0	179.0
P	mg L^{-1}	0.2	0.5	0.0	0.1
Mg^{2+}	mg L^{-1}	32.3	32.7	32.6	33.0
Ca^{2+}	mg L^{-1}	51.4	69.6	58.3	59.8
TOC	mg L^{-1}	7.9	14.0	8.4	14.0
TN	mg L^{-1}	3.3	5.2	3.6	1.1

not recorded, as it was operated under a pH control and low phosphate influent (the RO system was operated at 50% recovery and the pH was adjusted to 6.5). The two other pretreatments (i.e. chlorination and coagulation) displayed a less steady operation. Nevertheless, no reduction in the average membrane permeability was observed (Fig. 7). The noisy data followed the UF performances, and are probably due to the daily replacement of feed batches, as well as the variation in the feed's substances concentrations, resulted from the small scale of the contributing population. However the runs with the combined pretreatment (coagulation plus chlorination) exhibited lower flux and a reduction in the membrane permeability with time. The lower RO performances can be due to elevated feed's solute concentration, as was detected by the electrical conductivity. The combined pretreatment was apparently affected by the rise of counter ions concentrations (Cl^- and Na^+) which was an indirect result of the addition of ferric chloride ($FeCl_3$, flocculation), sodium hypochlorite (NaHOCl, chlorination) and sodium thiosulfate ($Na_2S_2O_3$, de-chlorination prior to RO) and possible residual concentrations of Fe_3^+, and SO_4^- resulting from incomplete reactions or surplus of these species. This probably augmented the concentration polarization layer and therefore enhanced the solute transportation rate towards the membrane surface, and thus the fouling rate. The feed electrical conductivity and the average fluxes appeared to have a statistically significant negative correlation ($r^2 = 0.673$, $p<0.05$), that supports our findings (Fig. 8) .

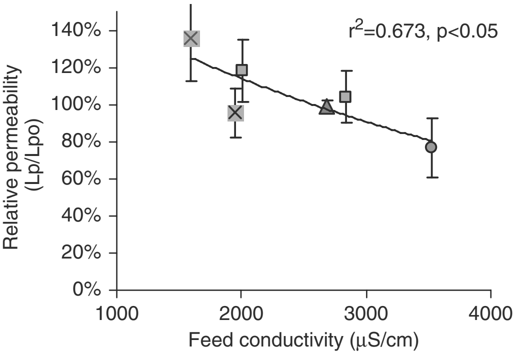


Fig. 8. Greywater desalination – relative membrane permeability as a function of the feed electrical conductivity.

The pH control in the RO system seemed to inhibit inorganic scaling as demonstrated by the mass balance calculation (Fig. 9), while TOC and total nitrogen found out not to fulfill a closed mass balance, this was probably due to their settling on the membrane surface and subsequent decomposition by microorganisms in the system. The chlorination treatment appeared to enhance organic matter deposition over the membrane

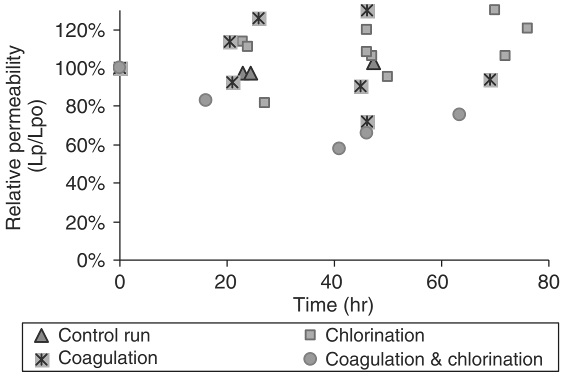


Fig. 7. Greywater desalination — relative membrane permeability at the four treatment.

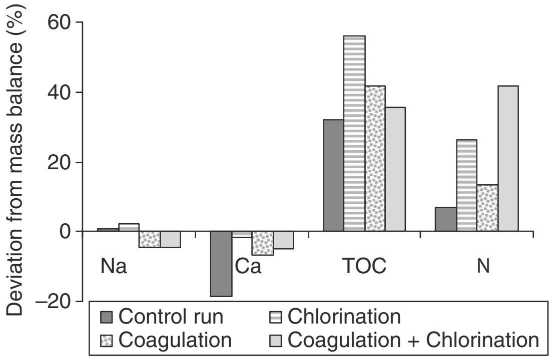


Fig. 9. Greywater desalination — rejection percentage of selected substances.

Table 2
Greywater desalination — permeate characteristics

	Units	Baseline run	Chlorination	Coagulation	Coagulation & Chlorination
pH	–	7.1	6.5	6.9	6.6
Turbidity	NTU	<1	<1	<1	<1
Ec	μS cm^{-1}	85	75	76	128
Alk	mg L^{-1} (as $CaCo_3$)	2.9	3.0	2.9	0.5
P	mg L^{-1}	0.0	0.0	0.0	0.0
Mg^{2+}	mg L^{-1}	0.2	0.2	0.2	0.1
Ca^{2+}	mg L^{-1}	1.1	1.3	0.9	0.7
TOC	mg L^{-1}	1.4	1.4	1.6	0.9
TN	mg L^{-1}	0.7	2.6	1.5	0.3

and/or its degradation on the membrane surface. These two phenomena can be explained partial oxidation of organic matter by the hypochlorous acid. This partial oxidation may have changed the properties of the organic matter (and thus its reactivity with the RO membrane), and may have increased its bioavailability.

Desalinated greywater was found to be of premium quality for any reclamation purposes, (Table 2) as a result of the RO rejection (Fig. 10). The common scaling obstacles of effluent desalination has been overcome by the low concentration of phosphate ions in the feed (achieved by partial scaling on the UF membrane and by precipitation by the coagulation pretreatment) and by setting a low pH value (6.5) to inhibit carbonate scaling. At these conditions the organic matter decomposition attributed for the membrane fouling and flux decline.

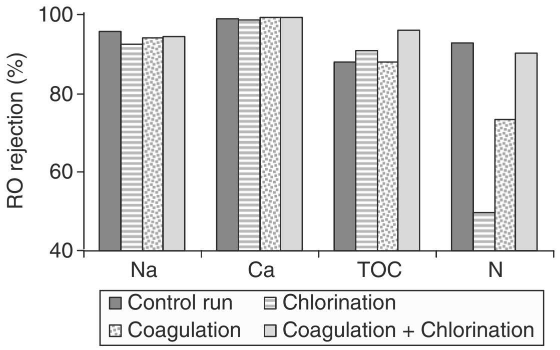


Fig. 10. Greywater desalination — rejection percentage of selected substances.

Greywater, compared with wastewater effluent, contains less hardness and alkalinity as well as lower phosphate levels. Consequently, under proper pretreatment, steady desalination process can be achieved with grater success.

4. Conclusions

This work evaluated the use of coagulation or chlorination as chemical pretreatment for treatment of greywater by two step membrane filtration, i.e. ultrafiltration followed by RO desalination. The system was fed with “light” greywater (originating from bath, shower and washbasin) which were collected from 14 flats that were retrofitted to separately collect the greywater. Average concentrations in the raw greywater were: turbidity of 34 NTU, 24.9 mg/L TOC, 4.6 mg/L TN & 0.7 mg/L TP.

Direct filtration, without any pretreatment resulted in sharp decrease of the UF permeability to about 20% of the original flux after three days of operation. This resulted from organic fouling followed by biofouling. The RO membrane permeability was suspected to decrease due to inorganic scaling (phosphate and carbonate). To overcome these drawbacks, coagulation and chlorination were evaluated as pretreatments prior to the UF.

The chlorine demand of the greywater, as determined by batch experiments, was 10–20 mg L^{-1}. Dosing 20 mg L^{-1} chlorine while controlling the residual chlorine concentration in the UF feed, lowered the UF fouling rate by 33% (after three days of operation). Chlorination inhibited microbial activity in the UF system as indicated by a mass balances calculations of organic matter, nitrogen and phosphate in the system. Chlorinated effluents behaved differently in the UF and RO membrane systems, compared to non chlorinated effluents, probably due to the partial oxidation and a change in the organic matter reactivity with the membranes.

Ferric chloride was tested as a coagulant, and its required dose was evaluated by a Jar test analysis. A dose of 50 mg L^{-1} reduced the UF flux decline by 43% after tree days of operation (retaining 60% of the initial flux). This was mainly due to 38% decrease of the organic load. After coagulation, larger particle sizes with narrower distribution were observed in the greywater, with an average size of about 0.5 μm. This shift in the particle size distribution resulted in a more porous filtration cake buildup on the UF membrane. A finding which supports the enhanced performance observed.

Greywater desalination demonstrated the ability to produced high quality effluents. The experiments depicted the sensitivity of the RO treatment to different parameters, and although a positive synergistic effect could be anticipated, the combined coagulation-chlorination process increased fouling rate probably due to the increase in the concentration polarization phenomenon, as a result of a rise in the concentrations of counter ions associated with the pretreatment reactants and possible surplus of the latter.

In conclusion, the results of the present research indicate that greywater pretreatment is a prerequisite to hamper UF membrane biofouling for steady operation. Coagulation was found to be the preferred technique over chlorination for ultrafiltration. Further, in contrast with chlorination that should be followed by de-chlorination prior the RO stage, coagulation was found to be compatible with the reverse osmosis stage. Nonetheless, chlorination, or other form of disinfection should be applied to prevent bacterial regrowth in permeate lines.

Effluents produced by each of the membranal steps were of excellent quality that can be used for various purposes according to required criteria for “unrestricted reuse”. The effluents were either low in organic content, suspended matter and colloids (UF), or desalinated effluent (RO).

Acknowledgement

The financial support of the Grand Water Research Institute (Technion) is greatly appreciated.

References

[1] E. Friedler and N.I. Galil, in: C. Maksimovich, D. Butler and F.A. Memon, (Eds.), Advances in Water Supply Management, Balkema Publishers, Lisse, The Netherlands, 2003, pp. 535–544.

[2] E. Friedler and M. Hadari, Desalination, 190 (2006) 221–234.

[3] M.C. Almeida, D. Butler and E. Friedler, Urban Water, 1 (1999) 49–55.

[4] C. Diaper, A. Dixon, D. Butler, A. Fewkes, S.A. Parsons, T. Stephenson, M. Strathern and J. Strutt, Water Sci. Tech., 43 (10) (2001) 83–90.

[5] A. Dixon, D. Butler and A. Fewkes, J. Inst. Water Environ. Manag., 13 (1999) 322–326.

[6] E. Friedler, Environ. Tech., 25 (9) (2004) 423–431.

[7] V. Lazarova, S. Hills and R. Birks, Water Sci. Tech. Water Supp., 3 (4) (2003) 69–77.

[8] E. A. Gardner, Water Sci. Tech. Wat. Supp., 3 (4) (2003) 21–23.

[9] B. Jefferson, A.L. Laine, T. Stephenson and S.J. Judd, Water Sci. Tech., 43 (10) (2001) 211–218.

[10] E. Friedler, R. Kovalio and A. Ben-Zvi, Environ. Tech., 27 (6) (2006) 653–663.

[11] G.C. White, The Handbook of Chlorination and Alternative Disinfectants, Wiley, NY, 1999, pp. 1064–1066.

[12] Standard Methods for the Examination of Water and Wastewater, Online Edition, APHA, AWWA, WEF, 2006, http://www.standardmethods.org/.

[13] O. Lahav, B.E. Morgan and R.E. Lowenthal, Water SA, 27 (4) (2001) 423–431.

[14] G. Ramon, M. Green, R. Semiat and C.G. Dosoretz, Desalination, 170 (3) (2004) 241–250.

[15] J.G. March, M. Gual and F. Orozco, Desalination, 164 (2004) 241–247.

[16] Y. Soffer, R. BEN Aim and A. Adin, Water Sci. Tech., 51 (6–7) (2005) 123–134.

[17] D. Abdessemed and G. Nezzal, Desalination, 152 (2002) 367–373.