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Effluent reuse potential of a dual-stage ceramic MBR coupled with RO treatment for textile wastewater

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ABSTRACT

The objective of this study was to investigate textile wastewater treatment using pilot-scale dual-stage ceramic membrane bioreactor (MBR) and subsequent reverse osmosis (RO) system. Performance tests were carried out for 2 months using wastewater obtained from a local textile plant. Three different filtration periods (15, 30, and 45 min) with three back flushes (4, 8, and 12 s) were tested to observe flux and removal efficiencies of color, chemical oxygen demand (COD), ammonium (NH_4^+–N), and phosphate (PO_4^{3-}–P). MBR plant was operated at 500 mbar suction pressure. Mixed liquor suspended solids in the reactor was about 6.3 g/L. COD and color removal efficiencies in MBR were ranging from 83.2% to 89.1% and from 83.2% to 95.6 %, respectively. Moreover, NH_4^+–N, PO_4^{3-}–P and sulfate (SO_4^{2-}) removal efficiencies in the MBR system were about 44.4%–81.7%, 60.0%–85.3%, and 21.2%–54.9%, respectively. Carbohydrate and protein concentrations of soluble microbial products and extracellular polymeric substances in the reactor were also measured. The complete removal efficiency of color, PO_4^{3-}–P, and SO_4^{2-} was achieved with the RO system integrated into ceramic MBR. In addition, higher than 95% of conductivity, COD and NH_4^+–N, were removed from wastewater. The permeate quality was so high that the water could be recycled for reuse in the dying process.

Keywords: Ceramic-membrane bioreactor; Reverse osmosis; Textile wastewater treatment; Water reuse; Fabric dyeing

1. Introduction

Industrialization and growing population have increased the demand for clean water and produced large quantities of wastewater which have caused significant environmental problems [1]. The textile industry, which produces a large volume of wastewater, is one of the most rapidly growing industries in the world, especially in Turkey [2,3]. From 20 to 350 m^3 of freshwater is consumed for each ton of the product [4]. The content of textile wastewater is variable depending on the process. The textile wastewater includes high amounts of chemical oxygen demand (COD), biological oxygen demand, color, and salinity which can change based on the type of product [5].

The uncontrolled discharge of textile effluents into the receiving media affects the aquatic ecosystem adversely due to its toxic impact on living organisms [6]. They also negatively impact receiving media aesthetically due to the release

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of color. In recent years, more restricted discharge limits are required for the treatment of textile wastewater. Therefore, recycling of wastewater in the textile industry is becoming increasingly important not only because of the requirement of large amounts of water during the process but also because of more stringent discharge standards [7]. There are many treatment methods for the treatment of textile wastewater including coagulation, flocculation, adsorption, ion exchange, advanced oxidation, membrane filtration processes, and biologic treatment technologies [8–10]. Adsorption, coagulation/flocculation, and ion exchange processes just change the phase of pollutants and therefore, new problems arise. Advanced oxidation processes are potentially useful, but they are too expensive for at large scale applications. The biological treatment processes are the most economical and beneficial technology for the treatment of textile wastewater [11,12]. However, a conventional biological treatment process cannot provide sufficient water quality for the reuse of wastewater in the process. On the other hand, membrane bioreactors (MBRs), which combine microfiltration (MF)/ultrafiltration (UF) and biological treatment, possess significant advantages over conventional biological treatment systems including higher removal efficiency, high solid content, and small footprint [4].

Orhon et al. [13] developed a super-fast membrane bioreactor (SFMBR) which was based on extremely high rate system operation at sludge ages between 0.5 and 2.0 d. The results showed that SFMBR proved capable of securing complete removal of soluble biodegradable COD, even at extremely high concentrations of 1,000 mg/L. It also generated much lower soluble microbial products (SMPs) compared to traditional MBR [13]. Sözen et al. [14] investigated the effect of sludge age on substrate utilization kinetics, SMP generation, and composition of the microbial community sustained in the SFMBR. The reactor was operated under different operating conditions and SFMBR was able to secure complete removal of available soluble/readily biodegradable substrate.

Ceramic membranes offer unique advantages over polymeric membranes due to their robustness, higher permeate flux, flexibility in chemical cleaning, inert, non-biodegradable, longer service life, and ease of use. On the other hand, their higher cost has limited its use [15]. Ceramic MBRs have been tested in the treatment of industrial and municipal wastewater. For example, the treatment of simulated municipal wastewater was carried out as a pilot-scale ceramic MBR system [16]. The ceramic membrane (KO1-X, TECH-SEP KERASEP, France) consisted of the ceramic support (Al_2O_3–TiO_2) and the membrane active layer (ZrO_2). The relationship between the introduction of excess phosphorus to the bioreactor and deterioration of the membrane filtration performance was investigated. It was reported that the introduction of excess phosphorus leads to the production of inorganic precipitants such as calcium and magnesium complexes which caused abrasion of the membrane active filtration layer with extensive membrane fouling of the inorganic membrane [16]. A submerged tubular ceramic MBR was tested for the treatment of high strength wastewater [17]. The ceramic membrane enhanced as high as 98% COD removal efficiency with significant soluble nutrient rejection. The performance of a tubular ceramic MBR was operated for phenol removal with varying phenol concentrations under varying hydraulic retention times (HRT) at 30 d of sludge retention time (SRT) [18]. The tubular ceramic membrane was operated with a mode of 15 min of filtration followed by 15 s of permeate backwashing. The results indicated that the MBR could be operated safely up to 600 mg/L of phenol at 2–4 h HRT and 30 d SRT. Moreover, COD and phenol removal efficiencies were greater than 88% at 100 mg/L of phenol. Olive mill wastewater (OMW) was treated using an external ceramic MBR with biomass especially acclimated to phenol [19]. The reactor supplied high permeate flux (92 L//m^2/h) with zero phenolic compounds. Moreover, fouling problems did not occur during all the experiments. They concluded that the OMW treatment in the MBR could be used as a pre-treatment stage, basically for phenolic compounds removal before a conventional biological process.

In some instances, even MBR processes cannot provide adequate quality of water for the reuse [5]. Recently, reverse osmosis (RO) coupled MBR has become one of the most promising technologies for the reuse of textile wastewater due to the ability of RO membranes for the removal of both color and dissolved ions [6,20,21]. Even though there are several studies on the treatment and reuse of textile wastewater by MBR and/or membrane filtration systems, there is still a lack of studies on a pilot scale using real textile wastewater. Jager et. al. studied on the treatment of textile wastewater by pilot-scale MBR and RO systems in which the color of textile wastewater was decreased from an average of 660 American dye manufacture index (ADMI units) to 12 ADMI that was lower than potable watercolor (17 ADMI) and they reported that treated wastewater was convenient for the reuse in dyeing processes [6]. Malpei et al. [22] studied on the treatment of textile wastewater by pilot-scale MBR with hollow fiber membrane and they observed that the effluent of recommended treatment plant could be used as feed water in the further treatment process by NF/RO membranes for the reuse of wastewater in any textile processes. In another study, it was determined that the use of the MBR pilot plant for the removal of organics and nitrogen from textile wastewater enhanced satisfactory results in which the removal efficiencies of COD and total nitrogen (TN) were about 87% and 55%, respectively. Also, it was reported that only 20 types of organic compounds were found in the effluent [11].

In this study, pilot-scale dual-stage ceramic MBR and subsequent RO system was used for textile wastewater treatment and recovered water was tested for the fabric dyeing process. The removal efficiencies of COD, ammonia (NH_4^+), phosphate (PO_4^{3-}), sulfate (SO_4^{2-}), conductivity, and color were monitored for the long term operated pilot-scale MBR-RO system while the effect of operating conditions on both permeate flux and permeate quality were investigated.

2. Materials and methods

2.1. Design of pilot-scale dual-stage ceramic MBR and subsequent RO system

The pilot-scale MBR-RO system had a volume of 1.25 m^3. The MBR system is shown in Fig. 1 was composed of three compartments: anoxic tank (1 unit), aerobic tank (1 unit), and MBR tank (1 unit). The anoxic, aerobic, and MBR tanks had

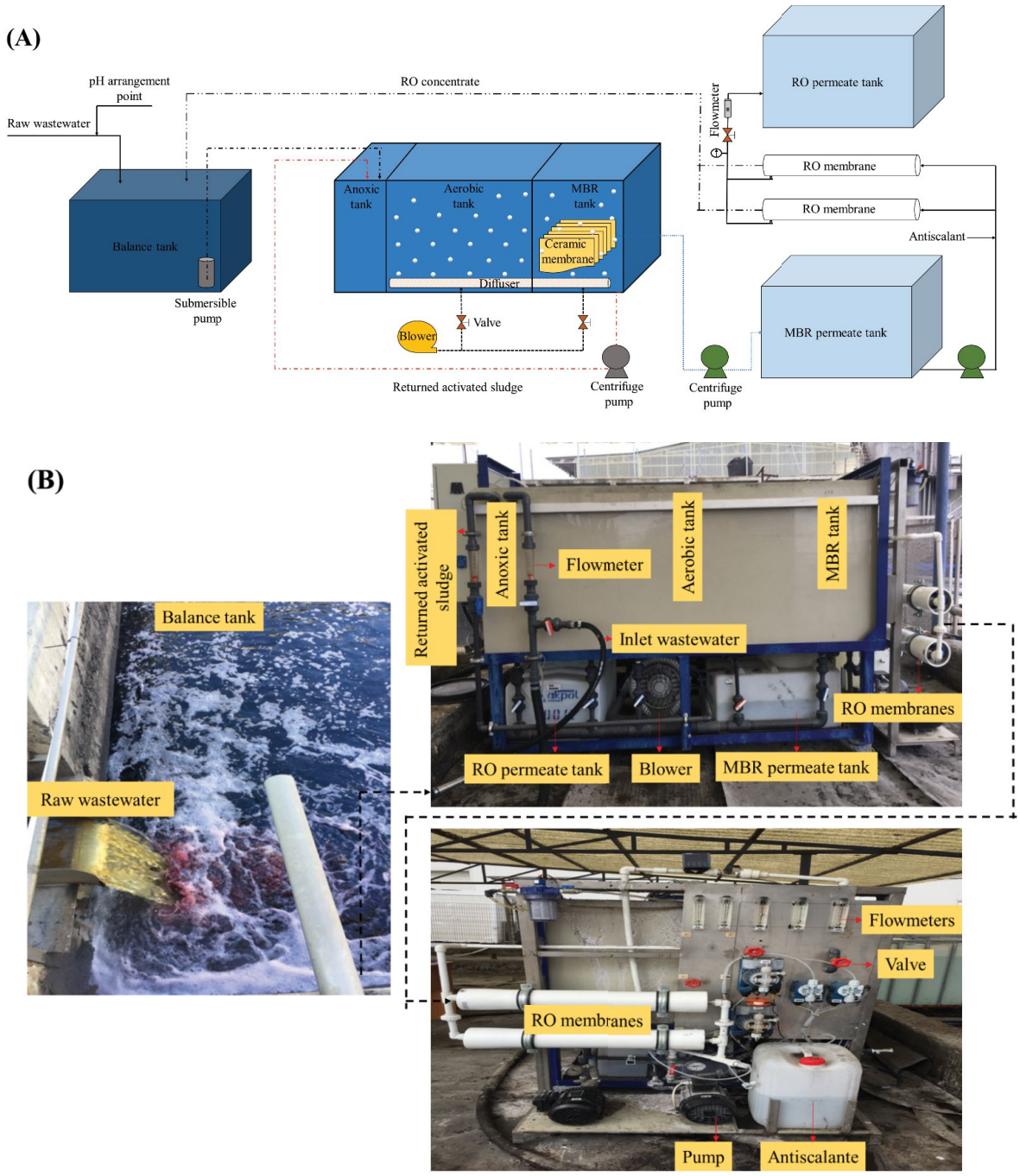

Fig. 1. (a) Schematic diagram of pilot-scale dual-stage ceramic MBR and subsequent RO system and (b) Photographs of the system.

a volume of 0.15, 0.85, and 0.25 m^3, respectively. Pipe type diffusers were installed into the bottom of the aerobic and MBR tanks and aerated with a blower which had a capacity of 1 m^3/h. Silicon carbide flat sheet ceramic membranes (SICFM-6040-DO-T-520) was used in the pilot system and provided from Cembrane company (Germany). The flat sheet membranes are individually mounted in a module. Each module was encapsulated in an SS316L frame providing a rigid structure ensuring the modules could be easily stacked on top of each other to form a tower depending on capacity needs. The detailed specifications of the ceramic membrane are given in Table 1.

2.2. Inoculation and operation of pilot MBR system

The anoxic and aerobic tanks were inoculated with 2,500 mg/L activated sludge obtained from the aeration tank of Kıvanc Textile Wastewater Treatment Plant. The characterization of textile wastewater is given in Table 2. The color of wastewater could change at any time. The wastewater

Table 1
Specifications of the silicon carbide flat sheet ceramic membrane

Module housing material	SS316
O-ring material	Viton/EPDM/NBR (NSF61)
Pipe material	Polypropylene
No. of single ceramic plates	7
Nominal pore size, μm	0.1
Avg. distance between ceramic plates, mm	5.7
Active membrane surface, m^2	1.06
Max. permeate flow, m^3/h	1
Max. filtration pressure, m bar	700
Max. back-flush pressure, bar	3.0
Temperature operating range, °C	5–60
Cleaning methods	Back-flush/Ozone/High pressure jet/Chemical cleaning
Field of application	Drinking water/wastewater/industrial
Special features	Multi ceramic plate configuration with exchangeable single ceramic plates compact design ensuring low foot-print

Table 2
Characterization of textile wastewater

Parameter	Value
COD, mg/L	900 ± 51
NH_4^+–N, mg/L	22.4 ± 4.3
PO_4^{3-}–P, mg/L	2.7 ± 0.6
SO_4^{2-}, mg/L	398 ± 65
Color, Pt/Co	205 ± 49
Conductivity, mS/cm	3.4 ± 0.3
pH	7.96 ± 0.65

was fed directly from the balance tank to the MBR system. The influent pump was controlled by a water level sensor to maintain a constant water level in the bioreactor over the experimental period. The UF ceramic MBR system was operated with a feed flow rate of 50 L/h into the anoxic tank. The corresponding average HRT for the MBR system was 3 h (anoxic tank) and 21 h (aerobic tank) with sludge age (θ_c) of 20 d. The dissolved oxygen (DO) concentration was about 2 to 4 mg/L in the aerated zone of the bioreactor. In this pilot system, the HRT of each biological stage was remained constant, therefore, the only parameter changing during this study was the feed composition of the textile wastewater fed into the MBR system. The membrane-filtered effluent was obtained by suction using a pump connected to the ceramic module. The effluent flow rate and the transmembrane pressure (TMP) were monitored by a digital water meter and a digital pressure gauge, respectively. Five samples were collected from the system from the point of inlet wastewater tank, aerobic MBR tank, MBR permeate tank, RO permeate tank, and RO concentrate tank during a month. Filtration performance of the pilot-scale MBR was conducted with the constant flux about 25 $L/m^2/h$ (LMH). Intermittent filtration (15–45 min filtration, 30 s relaxation, and 4–12 s back-flush with permeate) was also optimized. The cross-flow velocity (CFV) along the membrane surfaces was maintained at 0.2–0.4 m/s by air scouring.

2.3. Subsequent RO treatment

The pilot-scale ceramic MBR permeate was continuously fed into a holding tank (100 L) and was coupled with the RO system. During this section of the study, two spiral wound RO membranes (SW30XHR-2540) were used. The UF permeate was fed to the RO system at an average flow rate of 1.0 m^3/h, with an average feed pressure of 10 bar, 1 bar differential pressure, a CFV of 3.25 m/s and an average flux of 10 $L/m^2/h$.

2.4. Analysis of the samples

COD, mixed liquor suspended solids (MLSS), mixed liquor volatile suspended solids (MLVSS), SMP and extracellular polymeric substances (EPS) of sludge were measured a couple of days. Measurements of COD, NH_4^+–N, PO_4^{3-}–P, SO_4^{2-}, MLSS, and MLVSS were performed as defined in the standard method [23]. The pH and conductivity of the samples was directly measured with a multimeter (WTW Multi 340i, USA) The activated sludge was filtered through 0.45 μm membranes and soluble COD, NH_4^+–N, PO_4^{3-}–P, SO_4^{2-} measurements were performed. Measurement of color was performed according to the single-wavelength method using the HACH DR5000 UV–vis laboratory spectrophotometer (Germany). Lowry method was used for the measurement of protein content by using a UV-vis spectrophotometer (GBC, Cintra-20, USA) at the wavelength of 660 nm [24]. Bovine serum albumin (BSA) was used as a standard and the results expressed in mg equivalent of BSA per liter. Dubois method was used for the measurement of carbohydrate content at 490 nm [25]. Glucose was used as a standard and the results expressed in mg equivalent of glucose per liter. Triplicate experiments were performed for all membrane filtration. The removal efficiency of COD and SMP fractions (SMP_c and SMP_p) were calculated.

The recovered water from the textile industry wastewater was tested on the quality of the dyeing process in comparison with the conventional RO treated brackish water (normally used in the wet dyeing laboratory of the selected facility). Testing has been performed according to the standard of the German Institute for Standardization, (DIN 5033). The detailed procedure for fabric dyeing is given elsewhere [26]. Key steps involved in dyeing with recovered water as follows:

- pH was adjusted in the range of 6.5–7.0 after treatment if the pH was out of range.
- Reactive dyeing with the exhaust method was used at elevated temperature (90°C) for 2.5–3 h. Dyes, salts, partial alkalis, and other auxiliaries were added to the dye bath at 25°C ± 1°C. Dye bath was heated to 60°C for 60 min and then the rest alkali was added and kept running the process for the next 90 min.
- The samples were washed off with normal groundwater and let them dry in the oven for 5 min at 100°C.
- The color variation was analyzed between the samples by comparing them with standard RO treated groundwater using a spectrophotometer (HiTech, Data Color, 600, Switzerland).

Spectrophotometer directly provides the final result of the ΔE report which determines whether the sample is yellower, redder, bluer, greener, and the depth of value, chroma, the hue of lab dip. ΔE value can change from 0 to 100; however, acceptable ΔE value for textile is 1.00. If ΔE value is found ≤1, it means that not visible by human eyes. ΔE value is found between 1–2, it means that visible through very close observation by the standard observer.

3. Results and discussion

3.1. Characterization of the activated sludge in the MBR

MBR was operated for 2 months between 10th February and 10th April 2019. The changes in sludge concentration, temperature, SMP, and EPS in the MBR during the whole experiment are shown in Fig. 2. From day 1 to day 30, at days of SRT 20, the growth of biomass in the MBR was occurred after seeding the sludge and feeding wastewater, and a steady-state with MLSS concentration 6.0–6.5 g/L achieved at the end of this period (Fig. 2a). The reason for the insufficient growth of biomass might be due to the decline of the sludge yield coefficient at such low temperatures and the decrease of food to microorganism ratio (F/M) [27]. Wu et al. [27] reported that the decline of sludge biomass was observed when the temperature of mixed liquor was in a range of 8°C–10°C. Moreover, a steady-state concentration with 14 g MLSS/L was reached for SRT 20 d [27]. The temperature

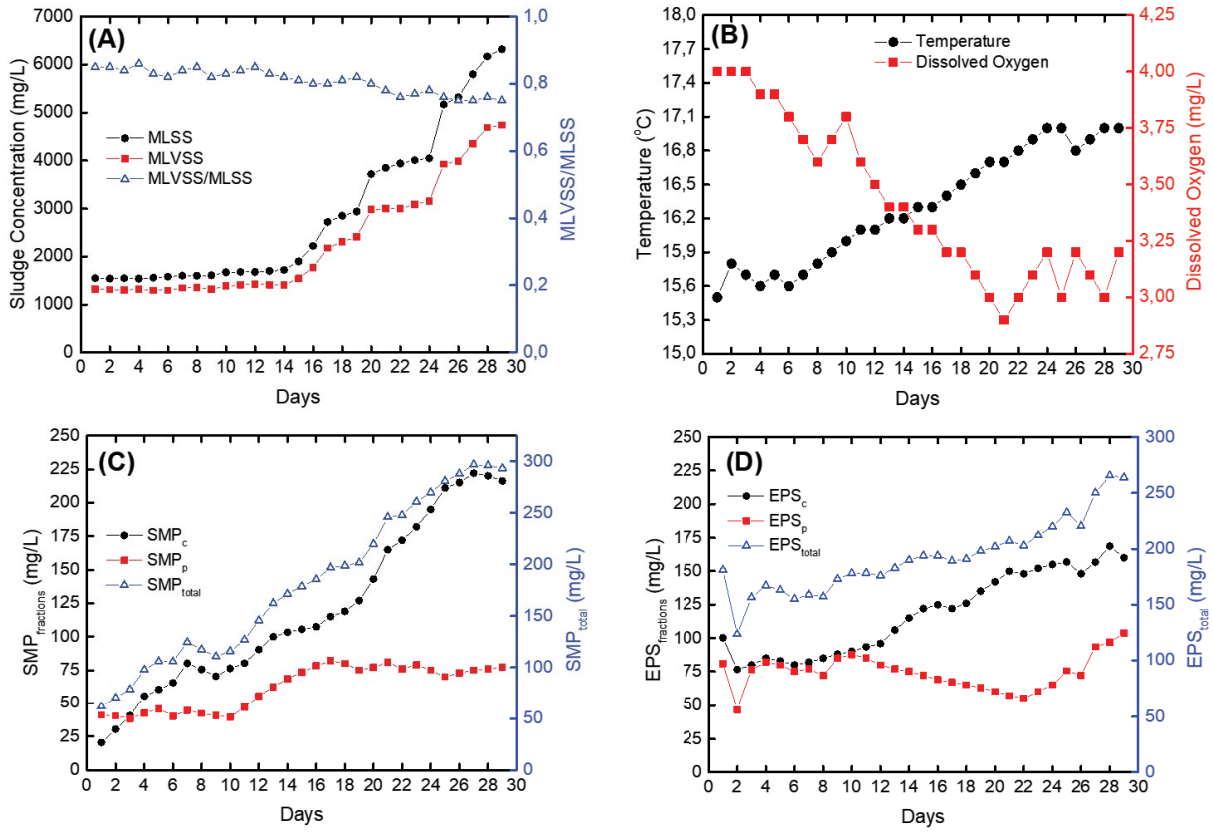

Fig. 2. Variations of (a) MLSS and MLVSS concentrations with operation time, (b) temperature and dissolved oxygen of mixed liquor with operation time, (c) SMP fractions concentration with operation time, and (d) EPS fractions concentration with operation time (SMP_c: carbohydrate concentration of soluble microbial products; SMP_p: protein concentration of soluble microbial products; EPS_c: carbohydrate concentration of extracellular polymeric substances; EPS_p: protein concentration of extracellular polymeric substances).

and DO of the MBR was 16.3°C ± 0.5°C and 3.4 ± 0.4 mg/L, respectively (Fig. 2b). SMP and EPS fractions such as carbohydrate and protein were also measured in the MBR and were presented in Figs. 2c and 2d, respectively. The soluble and bound carbohydrate was higher than soluble and bound protein during the whole experiment. However, soluble carbohydrate (SMP_c) was higher than bound carbohydrate (EPS_c) (Fig. 2c). But unlike carbohydrate, soluble protein (SMP_p) was lower than bound protein (EPS_p) (Fig. 2d). At the beginning of the MBR operation, SMP_c and SMP_p were 20.4 and 41.0 mg/L, respectively. However, at the end of the MBR operation, SMP_c and SMP_p were 216.2 and 77.2 mg/L, respectively. It can be noticed that when MLSS concentration increased over time SMP fractions also increased, especially carbohydrates. Increasing MLSS might decrease the F/M ratio and increase microorganism lysis due to starving and stress. EPS showed a similar result with SMP. EPS_c and EPS_p increased from 100.2 and 81.0 mg/L to 160 and 103.8 mg/L, respectively (Fig. 2d).

3.2. Optimization of MBR operating parameters

The MBR was operated with doing some trials to find optimum operation conditions such as suction time and back-flush time. First, the MBR plant was operated with tap water for 2 h. All the equipment and instruments were checked if they were functioning properly. After running several trials of MBR with tap water with reproducible results, the plant was tested for 2 months with real textile wastewater. During this trial period, different types of chemicals and washing agents were used by the textile industry. Thus, inlet wastewater qualities changed daily. The MBR was operated with a constant TMP of 500 mbar. In the first step, suction time was optimized to obtain the highest flux. In the second step, optimum back-flush time was determined according to the first step. Three different filtration time (15, 30, and 45 min), 30 s relaxation, and 4 s back-flush with permeate were tested. Fluxes were measured 24.5, 23.3, and 19.6 LMH for 15, 30, and 45 min filtration time, respectively (Fig. 3a). In this study, 30 min filtration time was chosen as the optimum suction time because the flux was close with 15 min filtration time. In the second step, three different back-flush times (4, 8, and 12 s) were optimized with constant filtration time (30 min). Fluxes were measured 23.3, 26.2, and 27.1 LMH for 4, 8, and 12 s back-flush time (Fig. 3b). The optimum operating parameters of MBR were chosen 30 min filtration time, 30 s relaxation, and 8 s back-flush with permeate.

3.3. Treated wastewater quality for dual-stage MBR and subsequent RO system

Five samples were collected from the point of inlet wastewater (balance tank), aerobic MBR, MBR permeate, RO permeate, and RO concentrate every other day. Conductivity, color, soluble COD, NH_4^+–N, PO_4^{3-}–P, SO_4^{2-} were measured at each sample. Conductivity did not change after ceramic membrane filtration because of MF properties of the membrane. However, results showed that subsequent RO system enhanced salt rejection higher than 95% (Fig. 4a). It was clear that the respective biological treatment stages (anoxic and aerobic) exhibited some degree of dye removal and hence a reduction in color was between 79.2% and 94.3%, in MBR tank, 83.2% and 95.6% in MBR permeate, and 100% in RO permeate (Fig. 4b). The color removal in MBR permeate was higher than in the MBR tank. The reason might be the formation of biofilm on the ceramic membrane could act as a primary bio-based membrane and some color could be degraded by the biofilm. Barredo-Damas et al. [28] reported similar results and significant removal of color (between 82% and 98%) was obtained using tubular ceramic membranes with a support layer of TiO_2 and an active layer of ZrO_2. They explained the terms of pollutant retention as cake layer formation on the membrane surface together with pore blocking caused further color and COD retention.

The COD removal efficiency was between 83.5% and 89.0% in the MBR permeate. In a conventional activated sludge system, COD removal efficiency was around 81.9% since it only worked by microorganisms in aerobic conditions. Moreover, COD removal efficiency was around 96.4% in RO permeate (Fig. 4c). In the MBR system, physical separation of permeate also happened along with biological degradation in aerobic conditions which increased the efficiency of

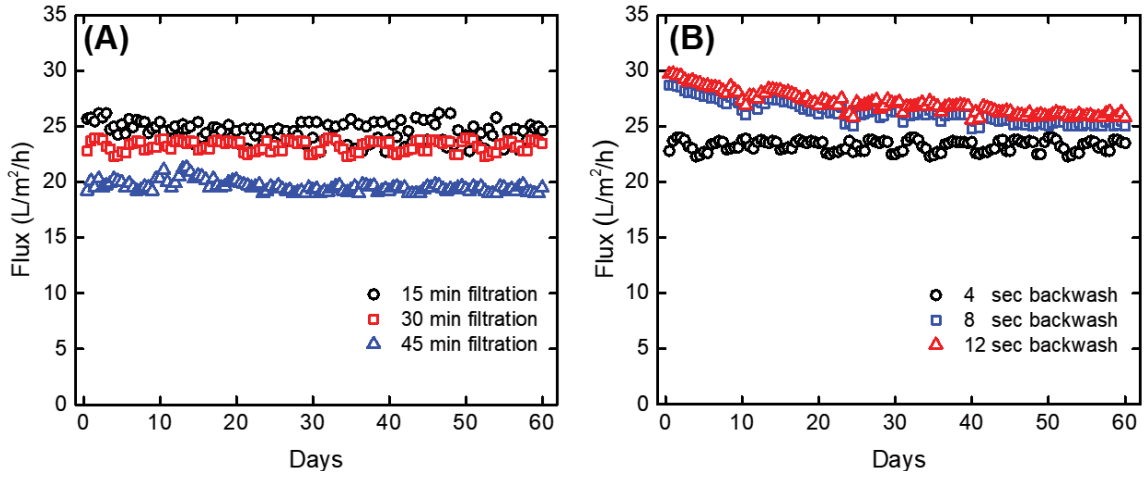

Fig. 3. Optimization of (a) filtration time and (b) back-flush time (experimental conditions: TMP: 500 mbar, θ_c: 20 d, and MLSS: 6 g/L).

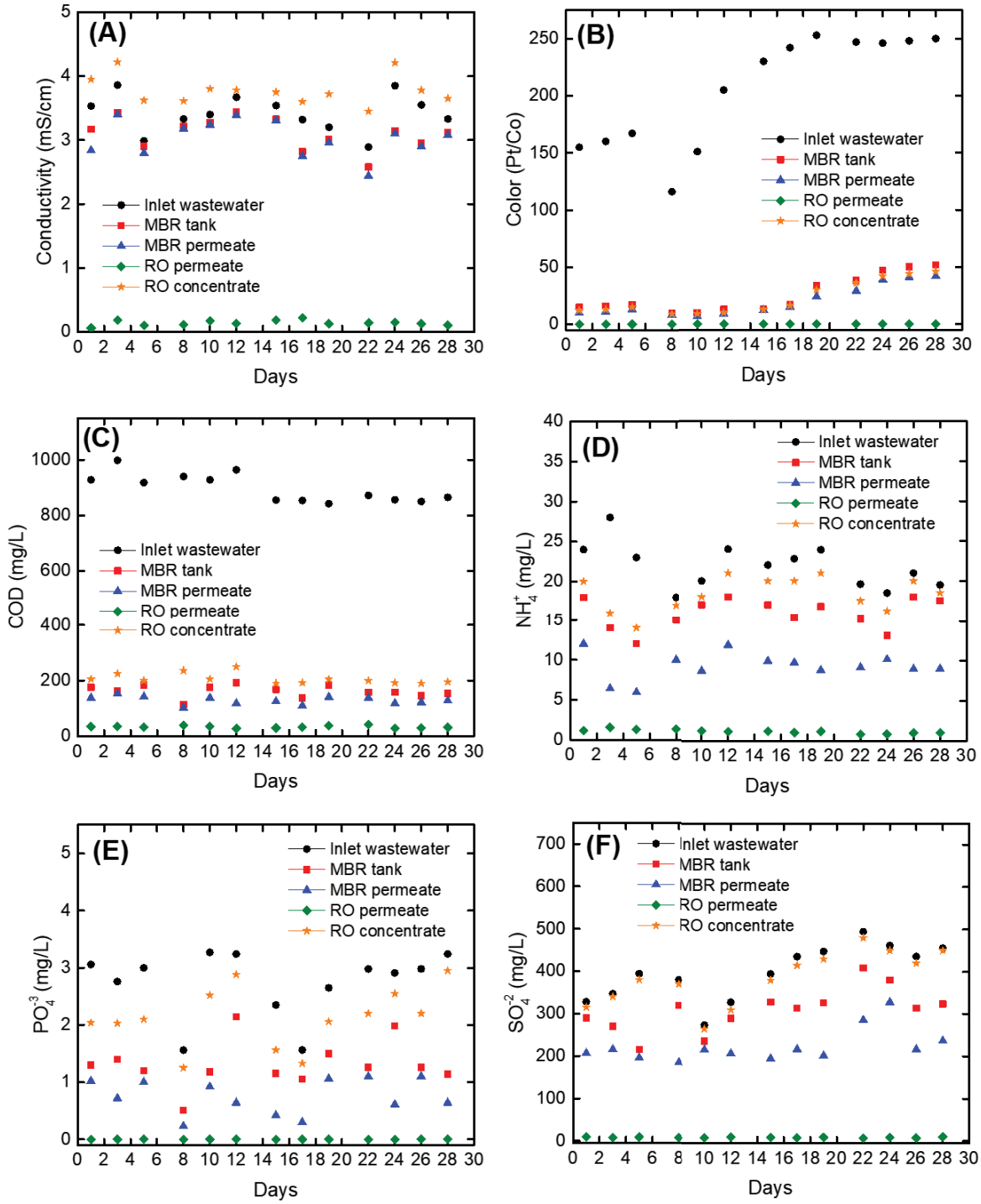

Fig. 4. Variations of parameters of pilot-scale dual-stage ceramic MBR and subsequent RO system for (a) conductivity, (b) color, (c) COD, (d) NH_4^+–N, (e) PO_4^{3-}–P, and (f) SO_4^{2-}.

the overall wastewater treatment system [29]. Considerable reductions of COD (79%) were also achieved by [28] using commercial ceramic membranes with molecular weight cut-offs of 30 kDa at 3 m/s cross-flow velocity.

The NH_4^+–N removal efficiency was between 44.4% and 77.1% in the MBR permeate. In a conventional activated sludge system, NH_4^+–N removal efficiency was around 26.9%. Moreover, NH_4^+–N removal efficiency was around 94.7% in RO permeate (Fig. 4d). Kitanou et al. [30] reported that the influent TN mean concentration was 54 mg/L, decreasing to 24.5 mg/L in the ASP and to 4 mg/L in the MBR permeate. This reduction in the nitrogen content throughout the operation of the MBR could be due to both the hydrolysis of the accumulated particulate organic matter and the cell disintegration.

This occurs during the nitrification and denitrification process [31]. We also obtained a high NH_4^+–N removal efficiency in our study and this indicated the nitrification and denitrification process occurred in anoxic and aerobic stages.

Fig. 4e shows that there was a significant difference in the average between the PO_4^{3-}–P concentrations in the influent and in the MBR permeate. The PO_4^{3-}–P removal efficiency was between 60.0% and 85.3% in the MBR permeate. In a conventional activated sludge system, PO_4^{3-}–P removal efficiency was around 51.6%. Moreover, PO_4^{3-}–P removal efficiency was 100% in RO permeate (Fig. 4e). Kitanou et al. [30] investigated total phosphorus (TP) removal in the MBR pilot and the activated sludge process (ASP). The mean value of the TP concentration in the influent was 8.3 mg/L, which decreased to 2.6 mg/L at the outlet of the ASP treatment. Also, a significant decrease in TP concentration from 9.2 to 1.6 mg/L was recorded in the MBR permeate [30].

The SO_4^{2-} removal efficiency was between 21.2% and 54.9% in the MBR. In a conventional activated sludge system, SO_4^{2-} removal efficiency was around 21.8%. Moreover, SO_4^{2-} removal efficiency was 97.8% in RO permeate (Fig. 4f).

Jeong et al. [32] reported a study including preparation, characterization, and application of low-cost pyrophyllite-alumina composite ceramic membranes for treating low-strength domestic wastewater. The pilot-scale system was operated at SRT of 15 d and an HRT of 4 h. During short-term ceramic MBR operations, the permeate flux was set to a constant value of 15 LMH over 10 d of operation without fouling control, except for membrane relaxation strategies. After 10 d, the membrane flux was increased to a constant operating flux of 20 LMH for the last 20 d of operation. A high COD removal efficiency of over 90% was obtained without fouling control and the soluble COD concentration in the membrane permeate was decreased from 197.0 ± 62.9 to 16.3 ± 5.5 mg/L, with an average COD removal rate of 91.6% ± 3.5%. Moreover, an excellent NH_4^+–N removal efficiency of 93.2% ± 9.3%, with an average influent and effluent NH_4^+–N concentration of 23.0 and 2.1 mg/L, respectively was achieved.

3.4. Lab scale dyeing results

The reusability of the RO membrane permeates obtained treatment of ceramic MBR effluent (Fig. 5a) was confirmed by laboratory-scale dyeing process and compared quality of reclaimed water dyeing with standard water dyeing using spectrophotometer. Spectrophotometric results (ΔE) were found 0.99 which was under acceptable limit. Spectrophotometer directly gives the final result of the ΔE report which determines whether the sample is yellower, redder, bluer, greener, and the depth of value, chroma, the hue of labdip. ΔE value can change from 0–100; however, acceptable ΔE value for textile is 1.00 [26]. In our study, the treated textile industry wastewater was suitable for reuse into the wet fabric dyeing processes because of enhanced required water quality for fabric dyeing (Fig. 5b).

4. Conclusion

In this work, commercially available a silicon carbide ceramic flat sheet MF membrane was applied to the pilot-scale

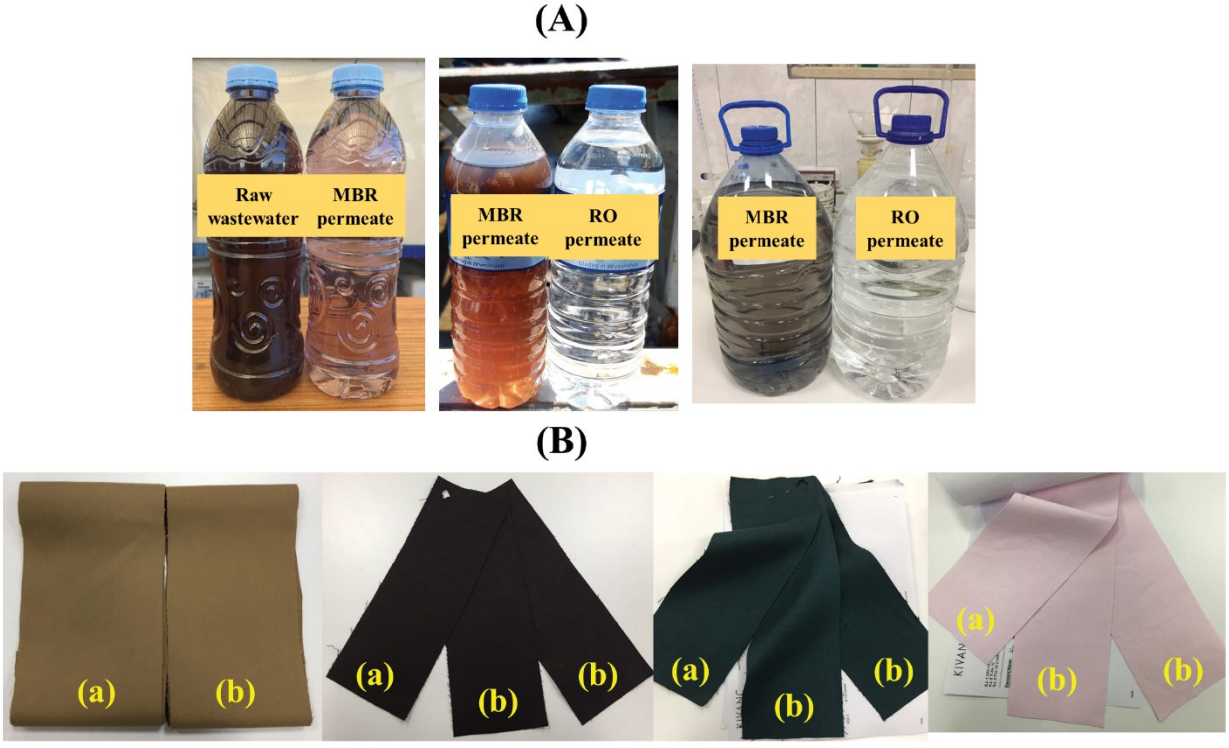

Fig. 5. (a) Photographs of MBR and RO permeates recovered from textile industry wastewater and (b) dyed fabrics (a and b show dyed fabrics with standard and recovered water, respectively).

dual-stage MBR and subsequent RO system and was used for treating textile wastewater treatment as well as reusability of wastewater for the dyeing process. The ceramic membrane successfully removed color, COD, NH_4^+–N, and PO_4^{3-}–P in the pilot-scale MBR from real textile wastewater. Moreover, the RO membrane system was integrated into the MBR system to improve water effluent quality. The subsequent RO system successfully removed conductivity and SO_4^{2-} ions.

The physicochemical sludge properties, especially the ratio of carbohydrates to proteins both in SMP and EPS, were affected when the MLSS was increased. SMP_c and SMP_p increased from 20.4 to 216.2 mg/L and from 41.0 to 77.2 mg/L, respectively. EPS_c and EPS_p increased from 100.2 to 160.0 mg/L and from 81.0 to 103.8 mg/L, respectively.

Ceramic membrane operating parameters were also investigated and the optimum operating parameters of MBR were chosen 30 min filtration, 30 s relaxation, and 8 s backflush. The results indicated that dual-stage ceramic MBR and subsequent RO system could be a very competitive candidate for membrane-based treatment of high-strength textile wastewater. Although the composition of the feed wastewater was continuously changing during the study, consistent reduction of the color and the other parameters measured in the incoming wastewater was evident in the composition of the ceramic MF and RO permeates.

The results suggested that RO coupled with ceramic MBR is an effective process to produce a high water quality for reuse in dyeing processes.

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