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Performance of an Ultrafiltration Membrane Pilot System for Treatment of Waste Stabilization Lagoon Effluent

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Abstract: Bali Tourism Development Corporation's lagoon (BTDC lagoon) has been used for treating wastewaters that come from all facilities available in the Nusa Dua Resort tourist area. Reuse of the lagoon effluent is limited for some applications due to salt and suspended solid contents. Application of an integrated membrane system for improving the water quality of the lagoon effluent which is suitable for various uses is under consideration. In this work an ultrafiltration (UF) pilot performance for possible pretreatment of Reverse Osmosis **(**RO**)** was investigated. The results showed that permeate quality was stable (less than 0.5 NTU), regardless of concentrating and diluting retentate in each cycle and fouling for a long duration of operation. However, the water quality obtained with this membrane was not enough to be directly used. The permeate quality obtained from the UF system fulfils the requirement for the optimal operation of reverse osmosis. Moreover, appropriate intermittent-backwash operation was fairly effective to maintain the fluxes at a reasonable level.

Key words: Lagoon, ultrafiltration, wastewater treatment, water reuse.

1. Introduction

The Nusa Dua Resort tourists area is one of truly wonderful tourist destinations in Bali. This area has international quality facilities, such as five star hotels with 4,000 rooms, Bali International Convention Center (BICC), Galleria Nusa Dua shopping center, Bali Golf & Country Club, Amphitheatre, etc. Wastewaters that come from those facilities are treated in a waste stabilization pond, well known as BTDC lagoon. The lagoon was built in 1976 with capacity 10,000 m^3/day and was operated since 1980. The lagoon effluent has been partly utilized on site for watering the area. The increase of water price in recent years (domestic water price in 2010 = IDR 11,500/m^3 that correspond to USD 1.27/m^3) has led to a complete re-thinking of total water recycling.

In general, lagoon effluent contains salts, soluble organic substances and particles especially algae cells [1, 2]. These components inhibit the use of lagoon effluent for other applications. For improving the water quality of the lagoon effluent, membrane processes could be used because of their excellent effectiveness as barriers against a wide range of contaminants including particles, turbidity, cysts, bacteria, viruses, color, organic carbon, disinfection by-product (DBP) precursors, and dissolved solids. Additionally, the relative costs of membrane systems have decreased due to technological advancements. For these reasons, the use of membrane technologies have been steadily growing and playing an increasing important role in water treatment [3-6] and wastewater reuse [7-9]. Concerning the wastewater reuse, reverse osmosis (RO) is usually used to treat such effluents with a high salts content like lagoon effluent.

Effective pretreatment is the key success for the application of RO [10]. One or more pretreatment processes such as

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coagulation–flocculation–sedimentation, sand or multimedia filtration, chlorination/ozonation, flotation, activated carbon adsorption and other low-pressure membrane processes such as microfiltration (MF) and ultrafiltration (UF) have an important role to guarantee good and consistent performance of RO systems [11-13]. The parameters taken into account for the water quality characterization are the suspended solids, turbidity, fouling tendency, organic matters and algae content [11]. UF membranes, which have being proven in a wide range of much more difficult liquid environments such as municipal and industrial wastewaters, have become the preferred pretreatment solution [14].

There is a considerable potential for using of MF and UF for algae removal from water [15-17]. However, membrane fouling is still an inevitable problem. During algae bloom, trans-membrane pressure seriously increases or flux significantly decreases [18]. The cells attach to the membrane and then start to release secretion and produce extracellular polymeric substances (EPS), which accumulate on the surface and cause the flux decline [19]. Moreover, lagoon effluent contains particles, colloids, salts, natural organic matter (NOM) and soluble microbial products (SMP) derived from biological wastewater treatment processes, these constituents can be adsorbed and deposited on the membrane surface [17]. The cleaning with the either of NaOH or NaOCl was effective to restore membrane performance [13, 14]. There was also an evidence that combining permanganate and chlorine could reduce the rate of UF membrane fouling [20]. Nevertheless, membrane system must be precisely selected and designed to meet quality goals at the reasonable cost. So far, study on treatment of lagoon effluent was just in laboratory scale [2, 17]. Technological innovation developed in this study is an effort to apply the UF membrane pilot system for treatment of BTDC lagoon effluent. The objective of this study was to evaluate the UF membrane pilot performance which respect to the flux and water quality.

2. Materials and Methods

2.1 Membrane Characteristic

An ultrafiltration membrane made from polysulfone with 50 kDa MWCO was used. The membrane was supplied by GDP Filter with the characteristics as shown in Table 1.

2.2 Feed Characteristic

BTDC lagoon covers 30 hectares of land surface, 17 hectares of which have been used for the installations and pumps. It consists of 2 installations; water treatment facilities (cell 1, 2a, 2b and 3), another is irrigation processing facilities (aerator pool, sedimentation and filtration pool). The characteristics of BTDC lagoon effluent were presented in Table 2. Total hardness in lagoon effluent is 348 mg/L as $CaCO_3$, while the turbidity and TDS are 5.85 NTU and 878 mg/L, respectively.

2.3 Pilot Scale

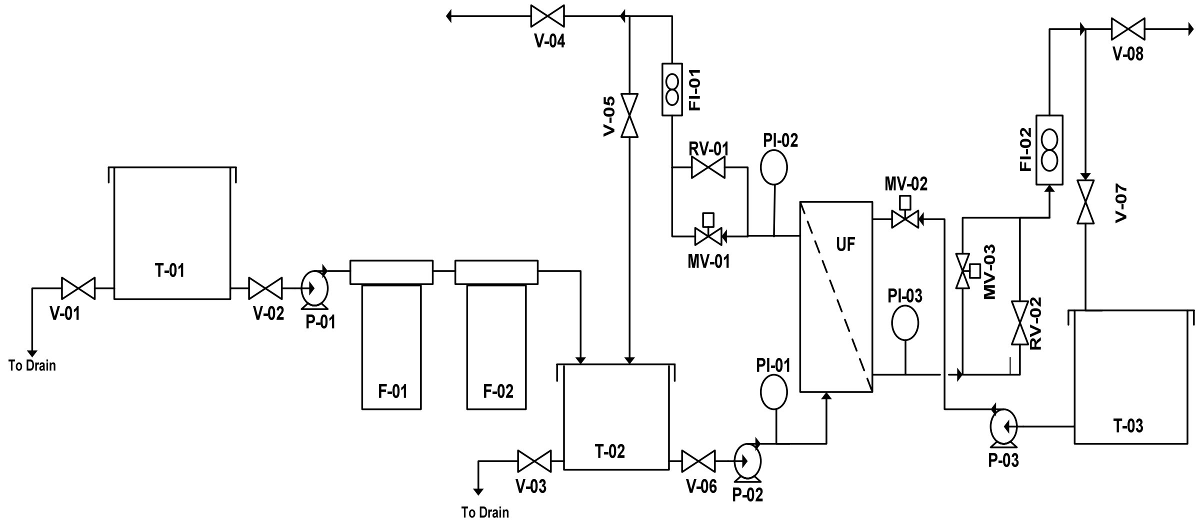
Treatment of BTDC lagoon effluent was carried out using the pilot scale which is depicted in Fig. 1. In

Table 1 Characteristics of membrane module from GDP filter.

Parameter	Description
Model	S-640
Type	Hollow fiber
Material	Polysulfone
Dimension	Dia. 6 inch × L 40 inch

Table 2 Average characteristics of BTDC lagoon effluent.

Parameter (units)	Value
Total hardness (as mg/L $CaCO_3$)	348
Calcium (as mg/L Ca^{2+})	64.8
Magnesium (as mg/L Mg^{2+})	44.64
SO_4 (mg/L)	83.87
NO_3 (mg/L)	0.2
NO_2 (mg/L)	0.62
NH_3 (mg/L)	0
TOC_{KMnO_4} (mg/L)	26.95
pH	7.5
TDS (mg/L)	878
Cl (mg/L)	532.59
Turbidity (NTU)	5.85



T-01: Feed Tank
T-02: UF Feed Tank
T-03: Backwash Tank
P-01: Pretreatment Pump
P-02: UF Feed Pump
P-03: Backwash Pump
F-01: Cartridge Filter 10μ
F-02: Cartridge Filter 5μ
PI: Pressure Indicator
FI: Flow Indicator
V: Ball Valve
MV: Motorized Valve
RV: Bypass Valve

Fig. 1 Schematic diagram of the UF membrane pilot system for treatment of BTDC lagoon effluent.

general, the UF membrane pilot system consists of two main parts: cartridge filter and the UF membrane module with backwash facility. A commercially available hollow fiber membrane module (S-640) supplied by GDP Filter was used. It was operated with a single module at constant TMP during 8 hours every day and has two primary phases of operation: filtration and backwash. When in the filtration phase, feed water was pumped to the bottom of the membrane module and entered the membrane channels. Filtration was conducted in a cross-flow configuration. The filtrate was partly used as backwash at the end of filtration phase. The backwash interval and duration were adjusted with a diaphragm pump (Puricom UP-8000, maximum flow rate of 3 lpm, maximum pressure of 80 psi, motor 48VDC/2A/50hz), flow rate indicators (FI), and pressure indicators (PI). During the backwash, a certain of pressure was applied for 10 s. The back pressure removes accumulated solids on the membrane surface, and was followed by an air blow process that flushes the solids from the membrane channels. Following the air blow, the feed and filtrate sides of the membrane were rinsed before further filtration was done.

2.4 Experimental Procedure

In this study, a total recycle mode was used, i.e., both permeate and retentate were returned to the feed tank to maintain the feed characteristic relatively constant. To avoid the effect of membrane compaction, deionized water was recirculated at TMP of 3 bars for 8 h prior to the operation of the lagoon effluent. The cross flow velocity was regulated by an adjustable DC power supply. The TMP was adjusted by needle valves on the feed and permeate side of the membrane module. The pressures were measured before (P_{in}) and after (P_{out}) the membrane module and on the permeate side (P_{perm}). The TMP is given by:

$$\mathrm{TMP} = \frac{P_{in} + P_{out}}{2} - P_{perm} \qquad (1)$$

For evaluating the effect of membrane fouling to the hydraulic resistance, the pure water fluxes were measured under the following conditions: (1) for a new membrane; (2) for a membrane which had been fouled by static adsorption; (3) for a membrane which had been fouled by permeation of the lagoon effluent. Additionally, the permeate fluxes under a given set of operating conditions were measured. After each experiment, the membrane was cleaned by either aqueous NaOH solution (0.5% w/v) or by aqueous NaOCl solution (100 mg/L). The flux of pure water was measured after the membrane cleaning to evaluate the irreversible membrane fouling.

2.5 Analysis of Hydrodinamic Resistance

Any attempt to control membrane fouling requires an understanding of the mechanisms and their contribution. A series resistance model [21] was used to analyze the hydraulic resistances:

$$J = \frac{TMP}{\mu R_t} \tag{2}$$

Where, J_{ss} is the steady state flux, TMP is the trans-membrane pressure, and μ is the viscosity of solution. The total hydraulic resistance, R_t, is accounted by a number of resistances:

$$R_t = R_m + R_a + R_{pp} + R_{cp} \tag{3}$$

Where, R_m, R_a, R_{pp} and R_{cp} refer to the intrinsic membrane resistance, adsorptive fouling, pore blocking and concentration polarization, respectively.

Firstly, the membrane resistance, R_m, was determined by ultrafiltration of deionized water through the clean membrane. From the pure water flux the membrane resistance could be calculated as:

$$R_m = \frac{1}{J}\frac{TMP}{\mu_{water}} \tag{4}$$

Secondly, the deionized water was then replaced by the feed without applying trans-membrane pressure (no flux across the membrane). After the membrane was rinsed by deionized water, ultrafiltration of deionized water through the fouled membrane was carried out to determine resistance R_1, which is the sum of R_m and R_a.

$$R_1 = R_a + R_m = \frac{1}{J}\frac{TMP}{\mu_{water}} \tag{5}$$

Thirdly, feed water was filtered at TMP 0.6 bar to determine the total membrane resistance, R_t.

$$R_t = R_m + R_a + R_{pp} + R_{cp} = \frac{1}{J}\frac{TMP}{\mu_{permeate}} \tag{6}$$

Fourthly, the membrane was then rinsed by deionized water to remove all removable foulants, particularly those of the polarization layer. After cleaning the apparatus, deionized water was filtered through the rinsed membrane under the same conditions. This test was used to determined resistance R_2, which is the sum of R_m, R_a and R_{pp}:

$$R_2 = R_m + R_a + R_{pp} = \frac{1}{J}\frac{TMP}{\mu_{water}} \tag{7}$$

The resistance of concentration polarization, R_{cp}, was calculated by subtraction of R_t and R_2:

$$R_{cp} = R_t - R_2 \tag{8}$$

The resistance of pore blocking, R_{pp}, was calculated by subtraction of R_2 and R_1:

$$R_{pp} = R_2 - R_1 \tag{9}$$

3. Results and Discussion

3.1 Flux Behaviour

To know the performance of the pilot system, the behavior of permeate flux was firstly investigated. The results are presented in Fig. 2. It was observed that the flux decreases sharply in the first 20 minutes and then decreases gradually to about 50-60% of the initial permeate flux. After one hour filtration, the permeate flux seems to be constant. The reason for this flux decline is concentration polarization and fouling. Stopping the filtration for some times and then restarted filtration could not bring back the permeate flux to the initial value. This phenomenon suggests that the fouling is the dominant effect. In the early minutes of filtration, the accumulation of material on the membrane surface leads to gel layer formation and

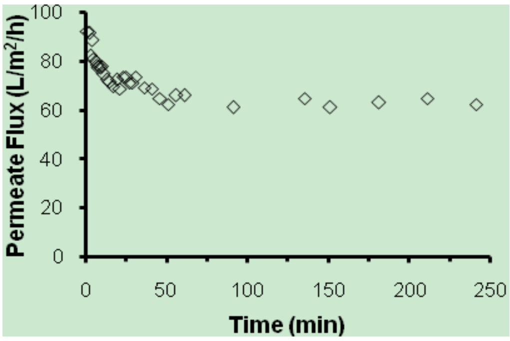


Fig. 2 Permeate flux behavior during ultrafiltration of lagoon effluent at TMP = 2 bar.

eventually to cake formation. Initially, the effect of solid deposition on membrane surface on flux decline is significant. As the filtration time was increased the transport of solute (micro algae) to the membrane surface decreases. Consequently, its effect on flux decline becomes smaller. Apparently, the fouling mechanism is cake layer formation. The slow decrease in the permeate flux after one hour of filtration may be due to the maintenance of the cake at a constant thickness. This phenomenon was well explained by Bowen et al. [22]. Ahn and Song [23] found similar results during their study on treatment of wastewater from a hotel building by UF and MF membranes.

3.2 Effect of Backwash on Permeate Flux

It was clearly seen that fouling reduced the membrane performance, i.e., permeate flux. Therefore, fouling should be minimized. In this work, the effect of backwashing for control of fouling was investigated. Two conditions for the backwash were compared. The results are presented in Fig. 3. It is clearly seen that backwashing increased the permeate flux significantly. Nevertheless, the effectiveness of backwash for minimizing the flux decline is influenced by its conditions. The backwash pressure is the most important parameter. The backwash interval and duration did not significantly influence the effectiveness of backwash for increasing the flux. With the backwash pressure of 1 bar, the permeate flux could be maintained within the range 85-95% of initial flux.

3.3 Membrane Rejection

Membrane rejection is another performance indicator for the membrane processes. In order to know the membrane rejection, the evolution of feed concentration and permeate quality were investigated.

3.3.1 Feed Turbidity Evolution

The removal of microalgae can be traced by the feed concentration evolution (note that the experiments were done in circulation mode). Fig. 4 shows the feed turbidity profile as function of filtration time. It is shown that decrease in feed turbidity was taken place for both ultra-filtration with and without backwash. This phenomenon supports the previous explanation, namely deposition of solid matter on the membrane surface and or membrane pores occurred. No significant difference in feed turbidity between UF with and without backwash implies that backwash can only control the permeate flux. It could not increase the permeate quality. Further, this result suggests that membrane cleaning is needed to maintain the membrane performance.

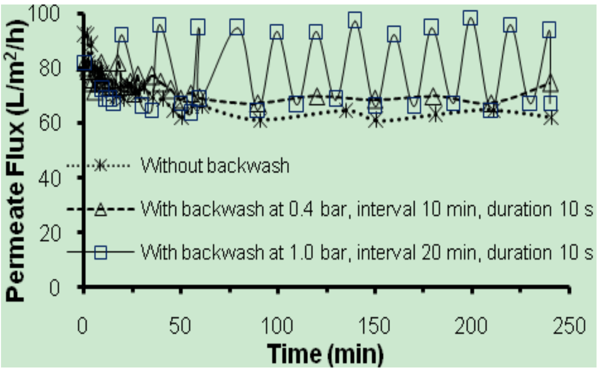


Fig. 3 The effect of backwash on permeate flux behavior.

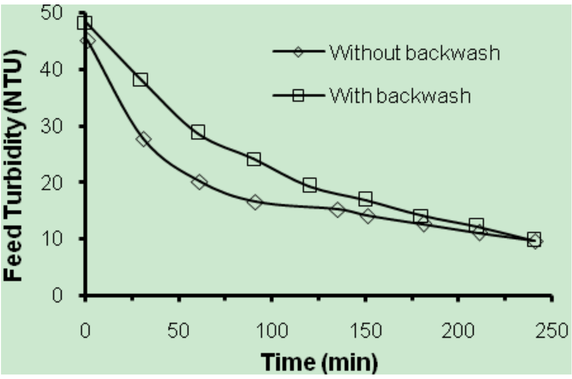


Fig. 4 The variation of feed turbidity during ultrafiltration (circulation mode filtration).

3.3.2 Permeate Quality

Table 3 shows the average concentration of lagoon effluent and UF permeate. It is observed that high rejection, i.e. more than 90% was obtained in the case of turbidity. The rejection of TOC_{KMnO_4} was of 70% whereas pH was slightly increased. However, no rejection on total hardness, mono and divalent ions were observed. These results suggest that the permeate quality obtained from the UF system meets the requirement for optimal operation of reverse osmosis

Table 3 Average water quality of lagoon effluent, membrane permeate, and percent rejection.

Parameter (units)	Lagoon effluent	UF permeate	Rejection (%)
Total hardness (as mg/L $CaCO_3$)	348	348	0
Calcium (as mg/L Ca^{2+})	64.8	64.8	0
Magnesium (as mg/L Mg^{2+})	44.64	44.64	0
SO_4 (mg/L)	83.87	79.33	5
NO_3 (mg/L)	0.2	0.34	
NO_2 (mg/L)	0.62	0.43	31
NH_3 (mg/L)	0	0	
TOC_{KMnO_4} (mg/L)	26.95	7.86	71
pH	7.5	8.1	
TDS	878	1050	
Cl	532.59	524.58	2
Turbidity	5.85	0.4	93
Cu	0.0037	0.0022	41
Pb	0.0254	-0.1101	
Zn	0.0068	0.0051	25
Cr	0.7018	0.614	12

but it was not enough to be directly recycled.

3.4 Long-term Operation

In order to know the real application, long term experiments were done. The pilot system was continuously operated for almost 4 weeks. The operation condition of the membrane was kept at a TMP of 2 bars and temperature of 20 ± 3 °C, 1 bar backwash pressure, 20 minutes backwash interval, and 10 second duration. Fig. 5 summarizes the long-term performance data of the UF membrane filtering waste stabilization lagoon effluent. The specific flux decline was recorded over time.

As shown in Fig. 5, the pilot system demonstrated stable performance within the first ten days of operation as the TMP was well maintained in the range of 2 bars at 20 °C. After 10 days of operation, a sudden specific flux drop was observed. Accordingly, the specific flux gradually decreased to about 85 L/m^2 h at 20 °C by the closure of the testing after 22 days of operation.

3.5 Membrane Hydraulic Resistance

To further analyst the fouling behavior, a series resistance model was applied. Fig. 6 shows the resistance toward fouling in short and long-term operation. Rm indicates the resistance caused by the intrinsic membrane, and Rpp indicates the resistance

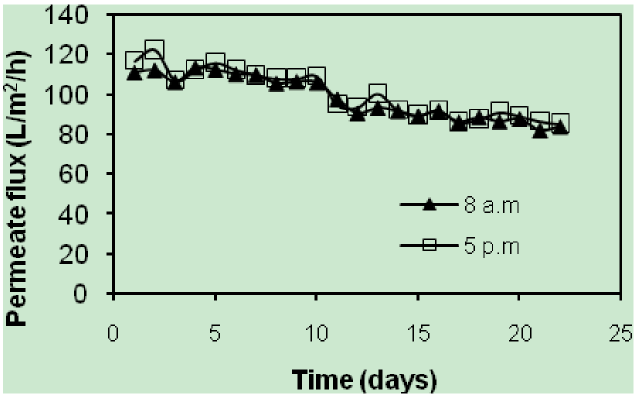


Fig. 5 Permeate flux pattern in long-term operation.

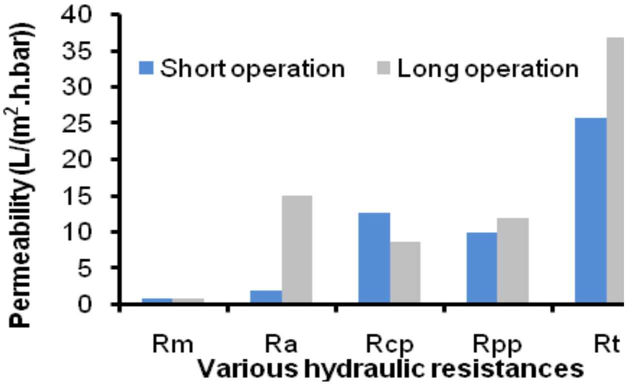


Fig. 6 Various hydraulic resistances of membrane.

mostly caused by solutes adsorbed within the inner pore fibers. Rcp is the resistance caused by the filtration cake on the membrane surface or the polarization concentration. In general, Rvalue in long-term operation was larger than in short-term one. However, the Rcp in long-term operation was smaller than in short-term operation. This phenomenon indicates that in the long-term operation, polarization concentration shifts to more permanent condition leading to fouling.

3.6 Membrane Cleaning

As discussed above, foulants accumulated on the membrane surface and/or membrane pores caused a significant loss of membrane performance during filtration. This condition occurs continuously throughout the process. Hence, the foulants must be periodically removed from the membrane structure using an appropriate cleaning procedure to restore the membrane performance. Cleaning is intended as a tool to clean un-removable foulants during rinsing. Thus the membrane permeability can be brought back close to the initial value. The development of an appropriate cleaning strategy requires an understanding of the physical and chemical characteristics of the key foulants, the membrane polymer and module, and the various cleaning solutions so that the cleaning procedure must effectively remove and/or dissolve the foulants while not exceeding the mechanical or chemical limits of the membrane polymer [24].

In this experiment chemical cleaning procedures were performed at the end of each experiment. Cleaning solution (400 ppm) was fed to the membrane from the feed-side, in order to reduce fouling formation. Two cleaning agents were exmined in various time of cleaning: NaOH with cleaning time 30 and 240 min and NaOCl with cleaning time 30, 60, 90, 120, 150 and 240 min. All cleaning processes were carried out at ambient temperature. The permeability of UF membrane during the testing period is shown as CWF (clean water flux) measurements. Fig. 7 shows the CWF recovered after the membrane was cleaned at various cleaning time. NaOCl is proved to be inadequate cleaning solution to maintain the membrane permeability at acceptable CWF during discontinuous testing periods. As can be seen, a significant CWF could be achieved after internal cleaning with NaOCl solution. On the contrary, cleaning with NaOH solution did not improve water flux significantly in both cleaning time of 30 and 240 min.

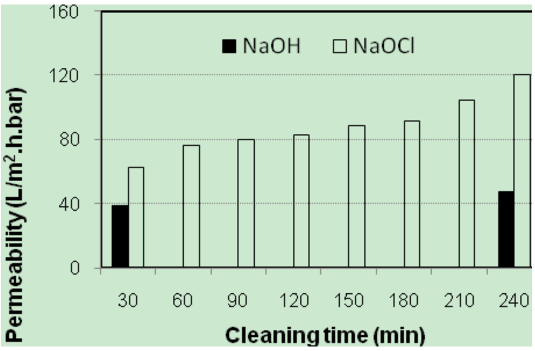


Fig. 7 Membrane permeability in various cleaning times using NaOH and NaOCl.

The permeability of membrane was restored to about 120 L/m^2·h·bar, when the nominal CWF of the clean membrane is 140 L/m^2·h·bar. The membrane performance could be restored approximately 90% compared to its initial performance as shown in Fig. 7. This finding was supported by several previous studies by other researchers [7, 25]. Nevertheless one should note that NaOCl can degrade sulfone polymer leading to membrane pore enlargment as reported by Rouaix [26]. Therefore, the NaOCl dose has to be considered.

4. Conclusions

The performance of an ultrafiltration pilot system for treatment of lagoon effluent was investigated for possible pretreatment of RO. The results showed that permeate turbidity was quite stable (less than 0.5 NTU), regardless of concentrating and diluting retentate in each cycle and fouling for a long duration of operation. The permeate quality obtained from the UF system fulfils the requirement for optimal operation of reverse osmosis. Moreover, appropriate intermittent backwash operation was fairly effective to maintain fluxes at a reasonable level. The backwash pressure was the key parameter during backwashing operation.

Evaluation of hydraulic resistance indicated that the polarization concentration and pore blocking constituted the main parts of the total mass transfer resistance with fouling is the most dominant effect. Concentration polarization and pore blocking were beyond approximately 40% and 30% of the total filtration resistance, respectively. Finally, the developed cleaning procedure NaOCl solution could restore membrane performance approximately 90% of the initial performance.

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