# Performance evaluation of three different membrane types in a pilot scale SMBR system

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***Abstract***

Membrane bioreactors (MBRs) have nowadays an increasing use, in municipal and industrial wastewater treatment for the advantages they present, with respect to the conventional treatment methods. An interesting question which arises in the MBR process is, "which are the criteria that somebody can be based on, to choose the appropriate type of membrane"? The objective of this preliminary study is to compare the working behavior of three different commercial membrane opened and closed modules, consisting of three identical flat sheet membrane filters each, based on some performance evaluation criteria. The membrane modules used in this work were working continuously for 137 d period in a pilot plant submerged bioreactor (SMBR) system, treating synthetic municipal wastewater. During this period several chemical cleanings of all the membrane modules was performed at the time, when a prescribed trans-membrane pressure (TMP) value of 200 mbar is developed first, in one of the three membrane modules. An experimental cycle is corresponded to the time period (days) between two successive chemical membrane cleanings. Performance evaluation of these membrane types in this experimental work were based on the following applied criteria: the period of time (in days) required, after each cleaning process, to raise the TMP at each membrane module to the selected fixed values of 50, 100 and 150 mbar; the mean % flux decrement observed at a selected TMP value of 100 mbar in relation to the flux value just after each cleaning process in each membrane module; the effluent's mean % turbidity improvement and the % mean chlorides decrement in each membrane module with respect to the corresponding ones of the clarified effluent (after precipitation for 2 hours) in the biomass. It was found that the examined filter membranes presented differentiations with each other, with respect only to the first of the above established efficiency criteria whereas slightly modification in performance efficiency, were found using the other three criteria. It was also found that the membrane of the same type presented better efficiency, based on above criteria, when they were working in closed factory modules.

***Keywords***

SMBR, membranes, synthetic wastewater, flat sheet membranes, filter modules, efficiency criteria, performance, open module, closed module.

## *1. Introduction*

Membrane bioreactor (MBR) is the combination of a membrane process like microfiltration or ultra-filtration with a suspended growth bioreactor, and is now widely used for municipal and industrial wastewater treatment with plant sizes up to 80,000 population equivalent (i.e. 48 million liters per day). MBR processes can produce effluent of high quality enough to be discharged to coastal, surface or brackish waterways or to be reclaimed for urban irrigation. Other advantages of MBRs over conventional processes include small footprint, easy retrofit and upgrade of old wastewater treatment plants. It is possible to operate MBR processes at higher mixed liquor suspended solids (MLSS) concentrations compared to conventional settlement separation systems, thus reducing the reactor volume to achieve the same loading rate. Recent technical innovation and significant membrane cost reduction have enabled MBRs to become an established process option to treat wastewaters [1]. As a result, the MBR process has now become an attractive option for the treatment and reuse of industrial and municipal wastewaters, as evidenced by their constantly rising numbers and capacity. The current MBR market has been estimated to value around US$216 million in 2006 and to rise to US$363 million by 2010 [2].The global MBR operation is expected to grow from 3,879 thousand cubic meters/day in 2011 to 12,344 thousand cubic meters/day by 2017, at an estimated Compound Annual Growth Rate (CAGR) of 20.8% for the period 2012 to 2017. As of year 2011, Asia-Pacific leads MBR market with a share of 41.2% in terms of value followed by Europe and N. America [3].There is no doubt that advanced wastewater treatment processes using MBR, have a variety of advantages over conventional biological processes including smaller plant size [4]. Despite that, rapid fouling tendency in a high solid content wastewater remains the most critical problem in the successful application and cost-efficient operation of SMBRs, thus the control of fouling is the key to the stable operation of SMBRs. Membrane fouling is a process whereby a solution or a particle is deposited on a membrane surface or in membrane pores in a process such as in a Membrane bioreactor [5], so that the membrane's performance is degraded. Membrane bioreactors can be used to reduce the footprint of an activated sludge sewage treatment system by removing some of the liquid component of the mixed liquor. This leaves a concentrated waste product that is then treated using the activated sludge process. Fouling can be divided into reversible and irreversible fouling based on the attachment strength of particles to the membrane surface. Reversible fouling can be removed by a strong shear force or backwashing. Formation of a strong matrix of fouling layer during a continuous filtration process will result in reversible fouling being transformed into an irreversible fouling layer. Irreversible fouling is the strong attachment of particles which cannot be removed by physical cleaning. Some of the factors that affect membrane fouling are: Membrane pore size, hydrophobicity, pore size distribution and membrane material, operating conditions such as pH, temperature, flow rate and pressure. Some antifouling methods are: the following intermittent permeation, membrane backwashing, air backwashing use of proprietary anti-fouling products, such as Nalco's membrane performance enhancer technology. In addition, different types of chemical cleaning may also be recommended such us: chemically enhanced backwash (daily), maintenance cleaning with higher chemical concentration (weekly), intensive chemical cleaning (once or twice a year).

In this study the efficiency of three commercial different flat sheet membrane modules was compared with respect to the fouling progress presented, in a time period of 137 days of continuous operation in an SMBR pilot unit, treating synthetic waste water. Seven experimental cycles, have taken place during the above period. At the end of each experimental cycle (when one of the three membrane modules reached a pressure of 200 mbar), chemical cleaning was performed on all the modules and the process begins again in a new experimental cycle. Performance evaluation of these membrane types in this experimental work were based on the following applied criteria: the meantime (in days) required, after each cleaning process, to raise the TMP at each membrane module to three selected fixed values of 50, 100 and 150 mbar; the mean % flux difference observed at a selected TMP value of 100 mbar with respect to the flux value just after each cleaning process in each membrane module; the effluent mean % turbidity improvement and the effluent mean % chlorides decrement in each membrane module with respect to the corresponding ones of the clarified effluent (after precipitation for 2 hours) in the biomass; Finally a comparison was made between the operation of closed and open filter modules of the same type, based on the above applied criteria.

## *2. Materials and methods*

### 2.1. Synthetic Wastewater

For the operating needs of the pilot SMBR unit, it was chosen to develop biomass using a new strong, in terms of organic load, SWW. The components for preparing the new SWW are shown in Table 1 [6].

**Table 1.** SWW components

| Material * | Chemical Formula | Concentration in SWW (mg/L) |
|---|---|---|
| D(+)-Glucose | $C_6H_{12}O_6\ H_2O$ | 400±10 |
| Peptone A | Peptone from soybean | 50±2 |
| Peptone B | Peptone from gelatin | 150±5 |
| Urea | $CO(NH_2)_2$ | 50±2 |
| Ammonium Sulfate | $(NH_4)_2\ SO_4$ | 50±2 |
| Ammonium chloride | $NH_4Cl$ | 50±2 |
| Potassium dihydrogenphosphate | $KH_2\ PO_4$ | 15±1 |

* The synthesis of SWW supplemented with minerals and trace elements [6].

### 2.2. Membrane module's properties

Three commercial flat sheet membrane modules were used (Type 1/ Type 2/ Type 3) and their specifications are presented in Tab. 2.

**Table 2.** Specifications of membranes

| Membrane | Type1 | Type 2 | Type 3 |
|---|---|---|---|
| Membrane Type | FS | FS | FS |
| Filtration Type | MF | UF | UF |
| Membrane Material | CPE | PVDF | PES |
| Pore Size (μm) | 0.4 | 0.1 | 0.04 |
| Membrane Area (m2) | 0.10 | 0.11 | 0.113 |
| Dimensions (mm) | 316x226x6 | 320x220x6 | 250x225x1, 5 |
| Max Flux ($m^3/m^2d$) | 1.2 | 1.2-1.8 | 1, 4 |

**Table 3.** Suggested membranes conditions

| Membrane | Type1 | Type 2 | Type 3 |
|---|---|---|---|
| Used Time (min) | 9 | 8 | 8 |
| Relaxing Time (min) | 1 | 2 | 2 |
| Suggested pH | (1-10) | (3-12) | (1-12) |
| Bubble | Coarse | Coarse | Fine |
| Suggested Module Air (Lt/m) | 21-45 | 21-27 | 4.5 |
| Max TMP (mbar) | 200 | 250 | 300 |
| Membrane Spacing mm | 14 | 14 | 11.5 |
| Suggested MLSS | 3,500-12,000 | 8000-12,000 | <12,000 |
| Suggested Temperature | 5-40 | 5-40 | 5-40 |

The operating conditions suggested by manufactures for membrane modules are presented in Tab. 3. It should be noticed that the modules of type1 and 2 were made as an open frame modules whilst type 3 is a factory closed module. This operative condition occurred in the first 5 cycles, then we replaced type 1 and type 2 with closed module too.

### 2.3 Pilot Unit

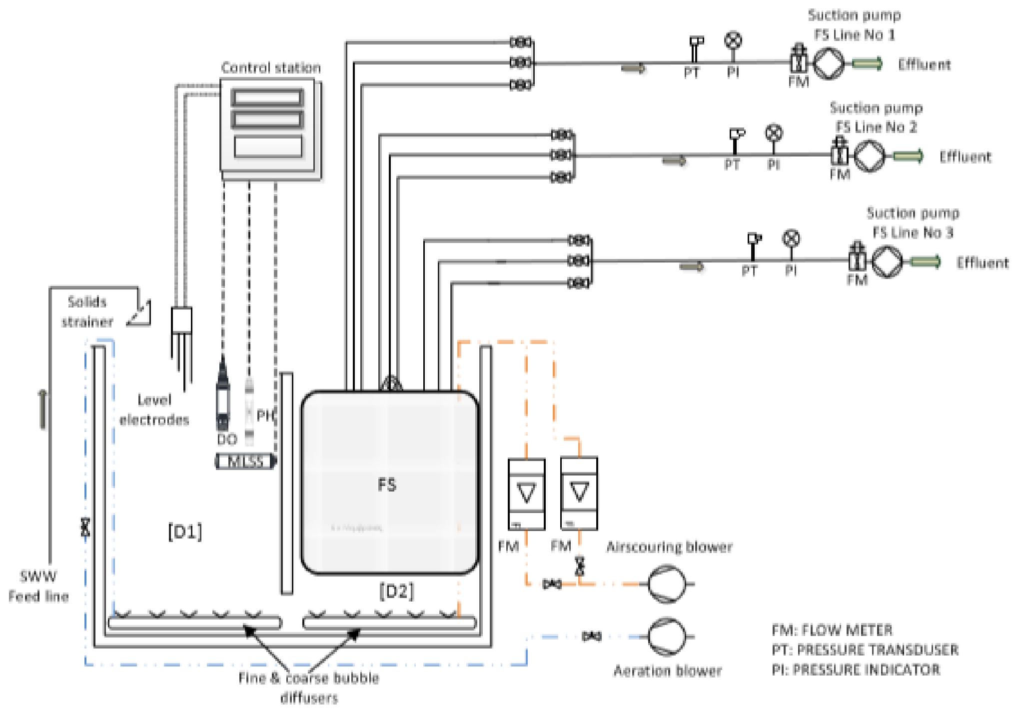


Fig. 1. Schematic overview of the SMBR pilot-plant.

As shown in Fig. 1, the main body of the pilot unit consists of an amphoteric (D1) and an aerobic (D2) compartment. The effective volume of each compartment is 37 L and 150 L, respectively. In the first compartment (D1), for the on-line monitoring of the characteristics of biomass, a pH meter, a DO meter and an MLSS meter are used. The necessary amount of air for the biological process to D1 could supply either by tubular medium size bubble diffuser or by air stone fine bubble diffusers, fed from a diaphragm type blower. In the second compartment (D2), three flat sheet modules were placed. A variable speed peristaltic suction pump is installed in each effluent module line (suction line). Operating and shutdown time of the suction pumps as well as the operating pressure of the line were adjusted and monitoring from the control station according to the manufacturer instructions for membrane protection reasons. Finally each suction line was provided with a flow meter.

**2.4 Experiment Procedure**

The experimental operating conditions are shown in Tab. 4. Bioreactor operates on MLSS between 6,000 and 9,000 mg/Lt, pH between 7 and 8 and DO 2-3 the air which supplied for the membrane air scouring was 12 ml / min for membrane modules without frame (type 1, 2) while it was 10ml/min for lab closed module unit. In the case of type 3 the air scouring was stable 8ml/min

**Table 4** Experimental conditions

| Membrane | Type 1 | Type 2 | Type 3 |
|---|---|---|---|
| Used Time (min) | 8 | 8 | 8 |
| Relaxing Time (min) | 2 | 2 | 2 |
| pH | 7-8 | 7-8 | 7-8 |
| MLSS | 6,000-8,000 | 6,000-8,000 | 6,000-8,000 |
| Air (Lt/min) (1-5 cycles) | 14 | 14 | 8 |
| Air (Lt/min) (6, 7 cycles) | 10 | 10 | 8 |
| Membrane Spacing (mm) | 20 | 20 | 11.5 |

**Note: During the experiments three different pumps (one for each suction line) of the same type were used.**

Dissolved oxygen (DO) in the bioreactor was stable by using low aeration conditions (2-3 Lt/min). Chemical cleaning of all the membrane modules was performed at the time, when a prescribed trans-membrane pressure (TMP) value of 200 mbar is developed first, in one of the three filter modules. For chemical cleaning Nalco of 1% concentration and citric acid of 1% concentration were used. An experimental cycle is corresponded to the time period (days) between two successive chemical membrane cleanings. The experimental data were collected during seven experimental cycles during the working period. During each experimental cycle flux and TMP of each membrane were measured twice a day. During the fifth experimental cycle the parameters of turbidity and the concentration of chlorides in effluents of each module were measured and compared with those of biomass clarified effluent. The above two parameters were chosen for the relative stability that they present with time. The last two experimental cycles include the operation of all the membrane types in closed factory modules. SMBR operating characteristics (TMP, Flux, HRT (hydraulic retention times), pH, DO, T, and MLSS) together with activated sludge characteristics (TS, TSS, VSS, and sludge volume index (SVI)) were also recorded during the overall experimental procedure. Effluent chemical analysis on other parameters was also done.

### *3. Results and Discussion*

Experimental data of the resulting TMP and flux values of membrane modules versus time, during the 7 experimental cycles are presented in Fig. 2, 3 respectively. It should be noticed that before of each experimental cycle a chemical cleaning procedure is performed in each membrane module. Also the MLSS range of the bioreactor is presented in each operating cycle.

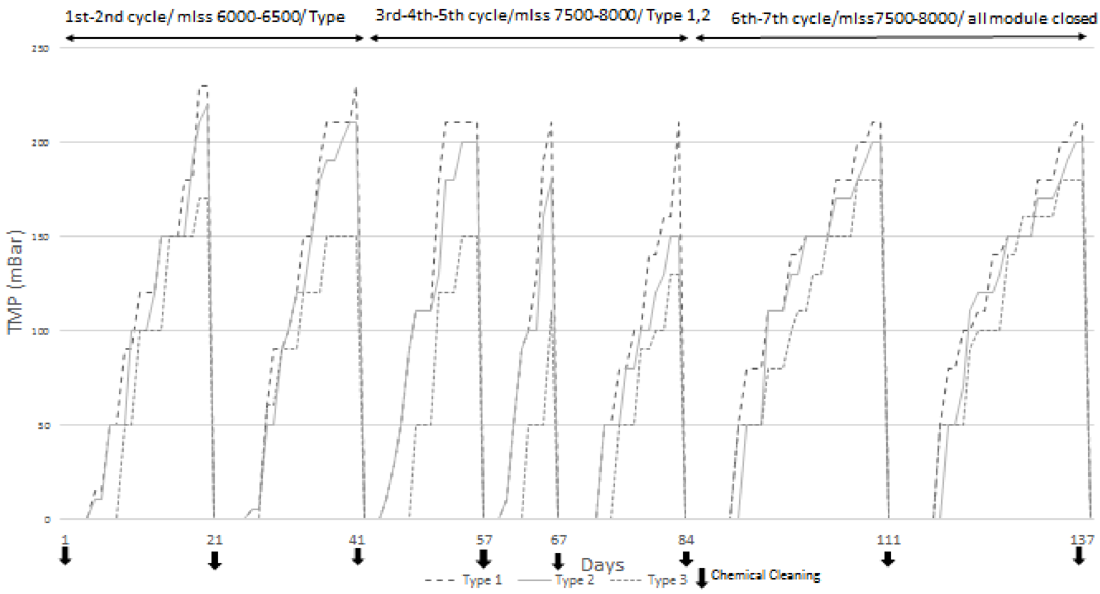


Fig. 2. TMP readings of the membrane modules during the seven experimental cycles.

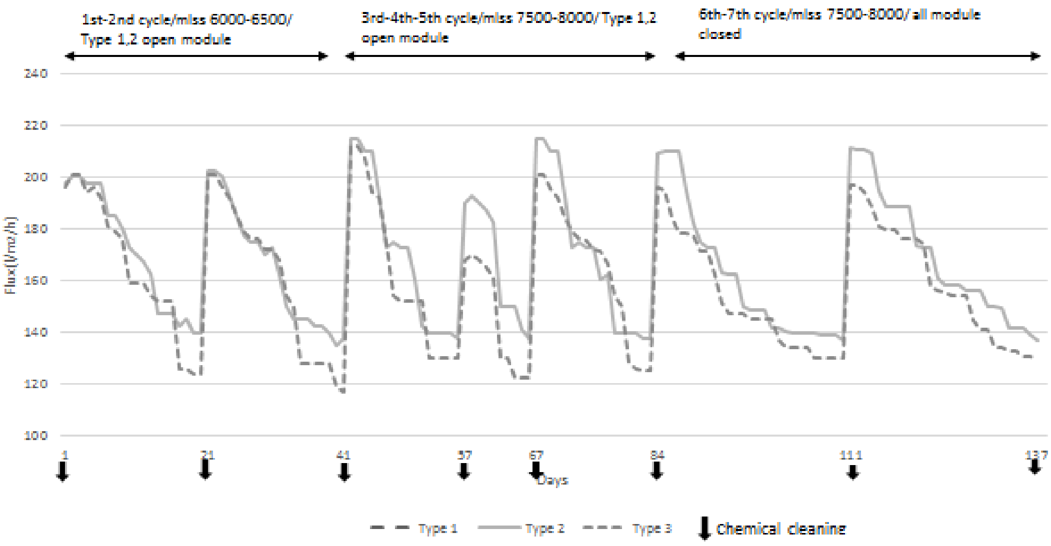


Fig. 3. Flux readings of the membrane modules during the seven experimental cycles.

It should be noticed that a temporarily variation in the TMP and flux values are depicted in the 4$^{th}$ cycle (Fig. 2, 3).

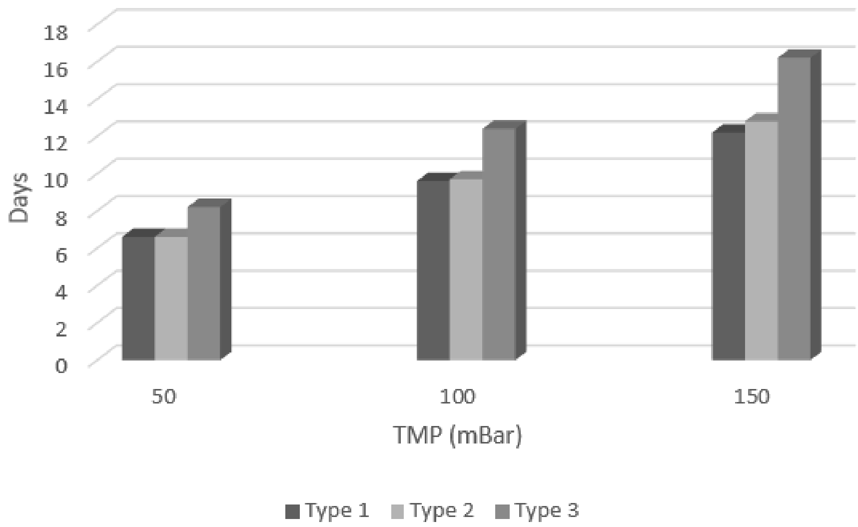


Fig. 4. Mean days needed for each membrane module to reach the prescribed TMP values of 50, 100, 150 mbar for the first 5 experimental cycles.

In Figure 4 the days to reach the prescribed values of 50,100,150 mbar of each membrane module type used, after the cleaning procedure are presented for the first 5 experimental cycles. It is observed that Type 3 module was exhibited better performance in all the above TMP values with respect to the other two membrane modules which presented almost the same behavior. The above can be mainly due to the fact that membrane module of type 3 is a factory made closed lab unit, whereas the other membrane modules of types 1 and 2 were open ones .

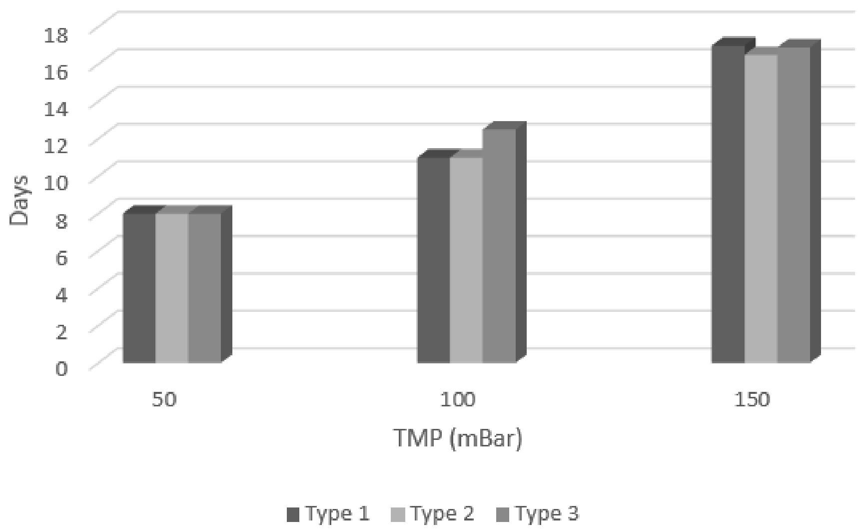


Fig. 5. Mean days needed for each closed membrane module to reach the prescribed TMP values of 50, 100, 150 mbar for the last 2 experimental cycles (6-7 cycles).

In Figure 5 the days to reach the prescribed TMP values of 50, 100, 150 mbar of each membrane module type used, after the cleaning procedure are presented for the 2 last experimental cycles where all the working modules are factory made closed lab units. It is observed that the type 3 module was exhibited better performance only in at TMP value of

100 mbar with respect to the other two membrane modules which presented almost the same performance in all cases.

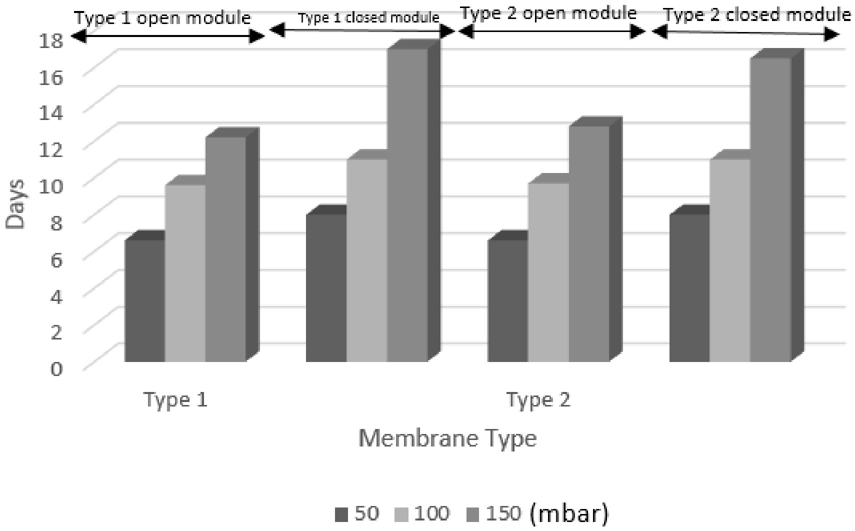


Fig. 6. Mean days needed for open membrane and close module (Type1 and 2) to reach the prescribed TMP values of 50, 100, 150 mbar.

In Fig. 6 the days needed to reach the prescribed TMP values (50, 100 and 150 mbar) for open and closed modules (type 1 and 2) are presented and compared. It was observed that the closed modules showed a better behavior for all the prescribed TMP values of 50, 100, 150 mbar with respect to the open ones. That might be happened due to the reason that the external membranes of each module.

**Table 5.** Other examined parameters for the performance evaluation of the used membrane types 1, 2, 3.

| Membrane Type | Mean percentage flux difference (flux at 0 mbar minus flux at 100 mbar) of the first 5 experimental cycles of the three membrane modules | Mean percentage turbidity improvement in effluent versus the one of the clarified effluent, during the 5th experimental cycle | Mean percentage chloride concentration decrement in effluent versus the one in the clarified effluent, during the 5th experimental cycle |
|---|---|---|---|
| Type1 | 80 % | 98.51% | 86.40% |
| Type 2 | 78 % | 98.39% | 87.36% |
| Type 3 | 74 % | 98.52% | 87.96% |

In table 5 the mean % flux difference observed at a selected TMP value of 100 mbar with respect to the flux value just after each cleaning process in each membrane module is presented for the first five cycles in which type 1, 2 modules were opened and type was a closed one. In this case a better performance of type 3 was observed with respect to the other types. Further experiments on the above parameter using all the membrane modules as closed ones (6, 7 experimental cycles) showed the following results: type 1: 77.61%; Type 2 76.8 %; Type 3 73.9%. So in both cases of opened and closed membrane modules the type 3 presented better performance at the mean percentage fluxes difference with respect to the other two. In order to examine the mean percentage turbidity improvement and the mean percentage chloride concentration decrement, of the effluent with respect to the clarified effluent, seven measurements during the fifth experimental cycle at each membrane module were done. In this case all the examined membrane types (open and closed) were presented similar behavior.

***Conclusions***

The objective of this preliminary study is to compare the working behavior of three different commercial flat sheet membrane modules, based on the following applied criteria: the meantime (in days) required, after each cleaning process, to raise the TMP at each membrane module to three selected values of 50, 100 and 150 mbar; the mean % flux difference observed at a selected TMP value of 100 mbar with respect to the flux value just after each cleaning process in each membrane module; the effluent's mean % turbidity improvement and the % mean chlorides decrement in each membrane module. It is observed that for the first five cycles Type 3 module (closed) was exhibited better performance in all the prescribed TMP values with respect to the other two membrane modules (opened) which presented almost the same behavior. For the 2 last experimental cycles where all the working modules are factory closed, it is observed that the type 3 module was exhibited better performance only in at TMP value of 100 mbar with respect to the other two membrane modules which presented almost the same performance in all cases. As regards the criterion of percentage flux difference, it is observed that type 3 in both cases, either open or closed module present better results with respect to the other two. In the cases of the mean percentage turbidity improvement and the mean percentage chloride concentration decrements, between the effluent and the clarified effluent, all the examined membrane types (open and closed) were presented similar behavior).

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