Tecnología y Ciencias del Agua

DOI:10.24850/j-tyca-2018-05-08

Articles

Elimination of pesticides with a membrane bioreactor and two different sludge retention times

Abstract

This research evaluated the efficiency of a membrane bioreactor (MBR) to eliminate pesticides. It also demonstrated that the presence of pesticides did not influence the efficiency of elimination of organic matter. Sixteen pesticides were studied, which were used to dope a synthetic urban residual water. The research was carried out in a pilot scale MBR plant, operated at a sludge retention time (SRT) of 30 and 60 days, with a mass loading of 0.23 $kgCOD \cdot kgVSS^{-1} \cdot d^{-1}$ and average flow of 5.44 $L \cdot m^{-2} h^{-1}$. The results showed that triazines and linuron have a lower degree of elimination, with the best results being 60 days TRC with values between 73% and 82%, while organochlorines were reduced in the order of 90% and 99%. This technology can result in an excellent effluent quality, allowing it to be reused and contributing to maintain the good ecological state of the receiving environment.

Keywords: Membrane bioreactor, chemical oxygen demand, micropollutants, pesticides, sludge retention time, heterotrophic biomass.

Received: 13/08/2017

Accepted: 16/03/2018

Introduction

Currently, the treatment of urban wastewater generally does not include the elimination of some organic compounds in low concentrations, also called micropollutants (MPs). This problem may involve the contamination of surface and groundwater by some toxic MPs (surfactants, pharmaceutical waste, personal care products, various household chemical products, and pesticides) (Margot, Rossi, Barry, & Holliger, 2015). In addition, the presence of these compounds in the effluents of wastewater treatment plants (WWTP) limits the possibility of reusing the effluents. The presence of these MPs in the aquatic environment has become a global problem, and one of growing environmental concern (Luo *et al*., 2014). This problem is due to its daily introduction into the environment in very low concentrations, mainly through effluents from WWTPs. Current WWTPs are not designed to eliminate or degrade MPs, therefore, many of these MPs pass through the wastewater treatment processes because of their persistence and/or continuous introduction into the environment (Bolong, Ismail, Salim, & Matsuura, 2009; Luo *et al*., 2014).

Studies on the presence and behavior of pesticides in WWTPs are few (Buttiglieri, Migliorisi, & Malpei, 2011), because these substances have generally been considered more for agriculture rather than as having an urban origin (Köck-Schulmeyer *et al*., 2013). The presence of pesticides in urban WWTPs is mainly due to non-agricultural uses. The list of uses includes the management of the grass, the control of vegetation in industries and non-agricultural crops, such as commercial forestry and horticulture.

The negative effects that MPs can generate include aquatic toxicity, endocrine alterations, genotoxicity and increased resistance of pathogenic bacteria (H(Halling-Sørensen *et al*., 1998; Kümmerer, 2004). These effects have generated growing concern in the scientific community, and therefore physical-chemical and biological technologies are sought to mineralize or degrade these substances in wastewater.

Membrane bioreactors (MBR) combine biological treatment (usually aerobic) with membrane filtration to produce clarified and largely disinfected effluents (Judd, 2016). MBRs have become a state-of-the-art technology that can be used as an alternative to conventional wastewater treatment processes (Aslam, Charfi, Lesage, Heran, & Kim, 2017). The MBR can be used when the quality of treated water needs to be high for its reuse, and where space is limited (Aslam *et al*., 2017; Judd, 2016). MBRs can efficiently remove many MPs that include compounds that are resistant to the activated sludge process ((Luo *et al*., 2014). In addition, the MBR has high biodegradation capacity and efficiency, low sludge production, low cost and simplicity of construction (Karaolia *et al*., 2017).

During the last decade, interest in the potential of MBRs to eliminate MPs has increased. The research conducted with MBR is based mainly on the elimination or degradation of drugs and personal care products (Bo, Urase, & Wang, 2009; Kantiani *et al*., 2008; Kim, Cho, Kim, Vanderford, & Snyder, 2007; Kimura, Hara, & Watanabe, 2005). However, some investigations refer to pesticides in general (Ghoshdastidar & Tong, 2013; Navaratna *et al*., 2012; Trinh *et al*., 2016). The MBR is usually operated with a long sludge retention time (SRT). Long SRTs can improve the removal of some MPs by adsorption in sludge and subsequent biodegradation. In addition, long SRT can also help the proliferation of slow-growing bacteria, thereby improving the microbial diversity in the reactor and achieving a better biodegradation of the MPs (Navaratna *et al*., 2012; Radjenović, Petrović, & Barceló, 2009; Reif, Suárez, Omil, & Lema, 2008). The mechanisms for eliminating MPs by MBR are complex and include biotransformation, biomass adsorption, volatilization, membrane adsorption and physical retention by the membrane (Trinh *et al*., 2016).

Accordingly, this paper presents a study of the influence of sludge retention time on the efficiency of a laboratory-scale MBR under normal operating conditions, in order to evaluate the elimination of pesticides, the heterotrophic performance of biomass and the oxidation of organic matter.

Materials and methods

The MBR system at laboratory scale (Figura 4) consists of a 90 liter reactor with an internal submerged membrane module, microfiltration hollow fiber, Porous Fibers Micronet R, polyvinylidene fluoride (PVDF) with a pore size of 0.4 µm, a filtering surface of 1 m^2 and a feeding and a permeate tank. Feeding and permeate extraction through the membranes is carried out with Dosiper C1R and Watson-Marlow model 323 U/D peristaltic pumps, respectively.

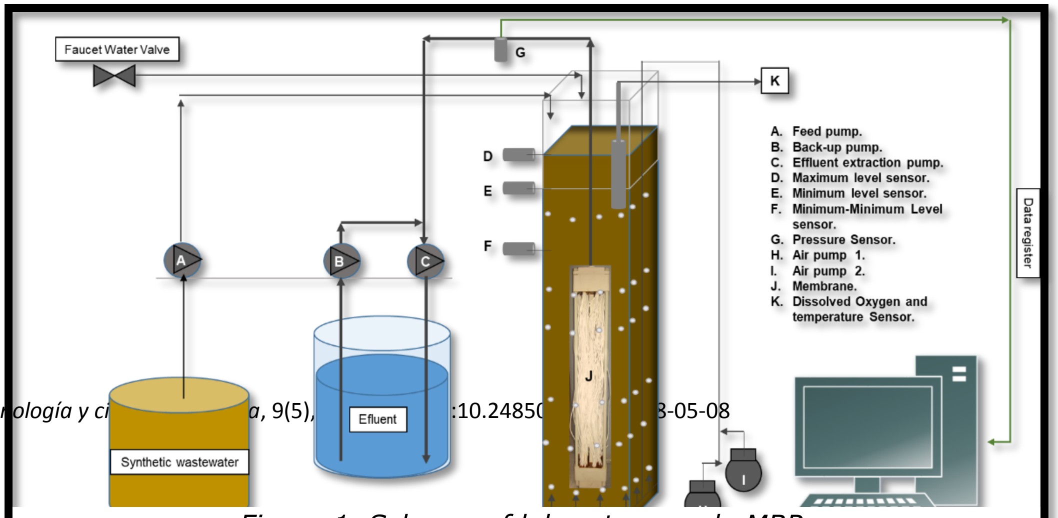

Figura 1. Scheme of laboratory-scale MBR.

The main operating variables are monitored online and graphically in a computer coupled to the system. To maintain the different operations of the automated plant, the software executes orders based on signals received from the liquid level sensors (Endress + Hauser, model Liquiphant T FTL260), the pressure transmitter (Cerabar T PMP131), the pumps, the aeration blowers (Aqua Medic model Mistral 4000) and the (Endress + Hauser, model Oxymax COS61) dissolved oxygen (DO) and temperature sensors.

The filtration is carried out from outside to inside of the membranes (out-in direction), in a period of 10 minutes. A portion of this permeate is stored in a tank to be used in the backwashes of the membranes, which are performed for 30 seconds as physical cleaning.

The blower pumps were operating permanently, maintaining by bubbling the tangential cleaning of the membranes. In parallel, through oxygenation, the biomass is supplied with the concentration of dissolved oxygen (DO) needed for its growth and it is maintained in suspension.

The plant was operated at a SRT of 30 and 60 days, with a temperature between 20 and 29 ° C, oxygen concentrations of 5 ± 1 $mg \cdot l^{-1}$, average organic load of 0.23 $kgCOD \cdot kgVSS^{-1}d^{-1}$, pH between 6.8 and 7.5, hydraulic retention time (HRT) of 20 h, average flow of 5.44 $L \cdot m^{-2}h^{-1}$ and an increase in transmembrane pressure of 0.83 $kPa \cdot d^{-1}$, 0.38 $kPa \cdot d^{-1}$ and 0.37 $kPa \cdot d^{-1}$ during the stabilization period, SRT of 30 d and SRT of 60 d, respectively.

The influent is simulated using synthetic water, prepared with a concentrate based on the synthetic food composition recommended by (DIN 38 412-L24) and used by Holler and Trösch (2001), with a reference COD of 3 038 $mgO_2 \cdot l^{-1}$, as detailed in **¡Error! No se encuentra el origen de la referencia.**.

Table 1.Synthetic wastewater composition.

Compound	**COD reference**	**Simulated COD**
	3 038 $mgO_2 \cdot l^{-1}$	**13 500 $mgO_2 \cdot l^{-1}$**
	1 l	**30 l**
Casein Peptone /g	1.6	177.75
Meat extract /g	1.1	122.20
Urea /g	0.3	33.33
$MgSO_4 \cdot 7 H_2O$ /g	0.02	2.22
KH_2PO_4 /g	0.28	31.11
$CaCl_2 \cdot 2 H_2O$ /g	0.04	4.44
NaCl /g	0.07	7.78
$NaHCO_3$ /g	3.038	13.50

In this study, the micropollutants shown in **¡Error! No se encuentra el origen de la referencia.** were added to the synthetic water (influent). All MPs belong to the triazine and organochlorine groups.

Table 2. Micropollutants doping of the influent.

ORGANOCHLORINES						
Micropollutants	**CAS - Number**	**Formula**		**Microcontaminant**	**CAS - Number**	**Formula**
alachlor	15972-60-8	$C_{14}H_{20}ClNO_2$		α-endosulfan	959-98-8	$C_9H_6Cl_6O_3S$
lindane	58-89-9	$C_6H_6Cl_6$		β-endosulfan	33213-65-9	$C_9H_6Cl_6O_3S$
heptachlor	76-44-8	$C_{10}H_5Cl_7$		dieldrin	60-57-1	$C_{12}H_8Cl_6O$
heptachlor epoxide	1024-57-3	$C_{10}H_5Cl_7O$		Endrin	72-20-8	$C_{12}H_8Cl_6O$

Isodrine	465-73-6	$C_{12}H_8Cl_6$	trifluralin	1582-09-8	$C1_3H_{16}F_3N_3O_4$
p,p-DDD	72-54-8	$C_{14}H_{10}Cl_4$	Linuron	330-55-2	$C_9H_{10}Cl_2N_2O_2$
o,p-DDD	53-19-0	$C_{14}H_{10}Cl_4$			
TRIAZINES					
Simazine	122-34-9	$C_7H_{12}N_5Cl$	Terbutilazine	5915-41-3	$C_9H_{16}ClN_5$
Atrazine	1912-24-9	$C_8H_{14}ClN_5$			

The initial concentration of these micropollutants was determined by toxicity tests with the method used by Prieto-Rodríguez *et al*. (2013). This test was applied to inoculum sludge from the Rincón de León Wastewater Treatment Plant (Alicante, Spain). The results obtained indicated that a concentration of 10 $\mu g \cdot L^{-1}$ did not inhibit microbial activity. This concentration is similar to that found in urban wastewater (Robles-Molina, Gilbert-López, García-Reyes, & Molina-Díaz, 2014), therefore, this initial concentration was selected, of 10 $\mu g \cdot L^{-1}$ of each compound. To add the pesticides to the synthetic wastewater, a period of stabilization of the MBR system of 41 days was carried out.

Analytical methods

- The COD was quantified by photometric determination of the concentration of chromium (III) after oxidation for two hours with $K_2Cr_2O_7/H_2SO_4/Ag_2SO_4$ at 148 ° C using MACHEREY-NAGEL digestion vial test and Nanocolor 500D spectrophotometer.
- The respirometry tests were carried out using a batch type respirometer (Spanjers, Vanrolleghem, Olsson, & Dold, 1996). The respirometer used was a Surcis S.L. model BM-T. This analyzer can measure the dynamic rate of oxygen absorption, RS ($mgO_2 \cdot l^{-1}h^{-1}$), oxygen absorption rate, OUR ($mgO_2 \cdot l^{-1}h^{-1}$), oxygen consumption, OC ($mg\ O_2 \cdot l^{-1}$) and other parameters.

The respirometry tests were performed with a one-liter sample of the mixed liquor MBR. To this sample, aeration was applied using an air pump for 24 h to reach the endogenous conditions prior to starting the experiment, and a nitrification inhibitor (Allil Tiourea, 3 $mg \cdot g\ MLVSS^{-1}$) was added 30 minutes before starting the test.

The biomass decomposition coefficient (kd) was evaluated based on the endogenous oxygen uptake rate and the total concentration of mixed liquor volatile suspended solids (MLVSS) based on Ramalho (1990), with the following equation:

$$K_d = \frac{OUR_{end}}{1.42\ [MLVSS]}$$

To determine the coefficient of yield of the heterotrophic biomass (Y_H), a stock solution of sodium acetate (500 $mg \cdot l^{-1}$) was made. From this solution, at least three more dilutions of COD 100, 200 and 400 $mg \cdot l^{-1}$ were prepared and the total COD value of the dilutions (COD_{act}) were obtained using a vial test. After this, an RS test was performed on the mixed liquor with 50 ml of each dilution, to obtain the oxygen consumption (OC). In this way, Y_H can be estimated based on the substrate concentration andOC. In order to evaluate Y_H, it was necessary to consider the conversion factor *fcv*, with a value of 1.48 $mgCOD \cdot mg\ MLVSS^{-1}$, performing the calculations according to Leyva-Díaz *et al*. (2013):

$Y_{H,COD} = 1 - \frac{OC_{act}}{COD_{act}}$ (coefficient of yield of the heterotrophic biomass relative to the chemical oxygen demand) and

$Y_H = \frac{Y_{H,COD}}{1.48}$ (coefficient of yield of the heterotrophic biomass relative to the concentration of microorganisms).

The generation and visualization of the data was done using BM-Advance software, which generated the respirograms corresponding to the different experiments.

- To determine the MP concentrations, the following compounds were analyzed: alachlor, lindane, heptachlor, heptachlor epoxide, α-endosulfan, β-endosulfan, dieldrin, endrin, isodrine, pp-DDD, op-DDD, trifluralin, linuron (organochlorines) and simazine, atrazine and terbuthylazine (triazines).
  For the quantification and analysis of these micropollutants, MBR effluent samples were taken in 500 ml sterilized bottles. The conditioning of the samples consisted of filtration by means of 0.7 µm fiberglass filters (Millipore), and solid phase extraction was carried out with Dionex Auto Trace 280 (Thermo Scientific) equipment, using Oasis HLB 6cc / 200 mg cartridges and HPLC quality solvents (dichloromethane, acetonitrile and water from Sigma Aldrich) according to De-Almeida-Azevedo, Lacorte, Vinhas, Viana and Barceló (2000). To improve the retention of compounds with a lower log k_{ow} coefficient, the samples were brought to a pH of 4 with

sulfuric acid. The extract collected in each tube was dried with N_2 flow, and once the volume was reduced, the sample was transferred to an "insert" of 200 µl where the process was continued until total drying. The sample was then reconstituted with 200 µl of internal standard solution (500 $\mu g \cdot l^{-1}$ in triphenyl phosphate and atrazine-d5). The samples were analyzed by gas chromatography coupled to mass spectrometry using an Agilent 7890A chromatograph and Agilent model 5975C quadrupole mass spectrometer. The column used was the Agilent 19091S-433 HP-5MS (5% diphenyl-95% dimethylpolysiloxane) capillary column (30 m × 0.25 mm ID, df = 0.25 µm). A helium mobile phase (1.3 $ml \cdot min^{-1}$) was used and the SIM mode was used (quantification with main ion and identification with confirmation ions).

Results and discussion

Biomass Activity

The respirometry tests enabled measuring the activity of the heterotrophic biomass during the experimental period. **¡Error! No se encuentra el origen de la referencia.** shows the average values of the biokinetic parameters evaluated from the information obtained in the respirograms.

Table 3. Mean values of the biokinetic parameters.

Endogenous conditions				
Parameter	**OUR ($mg\ O_2 \cdot l^{-1}h^{-1}$)**	**SOUR ($mgO_2 \cdot gMLVSS^{-1}h^{-1}$)**	***Kd* (d^{-1})**	**Y_H ($mgMLVSS \cdot mg\ COD^{-1}$)**
SRT = 30 d	2.932	1.215	0.021	0.373
SRT = 60 d	2.982	0.866	0.015	0.339

The biological activity of the sludge has been studied in endogenous conditions based on oxygen absorption (OUR) and the specific rate of oxygen absorption (SOUR). OUR is directly associated with the elimination of the substrate, while SOUR is associated with the elimination of substrate and with the production of biomass, so it is a better indicator of the biological activity of the sludge.

The suspended solids in the mixed liquor (MLSS) showed an average concentration of 3.07 and 2.13 $g \cdot l^{-1}$ for SRT of 60 and 30 d, respectively, as a result of operating the pilot plant with a low organic loading rate (OLR) of 0.23 $kgCOD \cdot kgVSS^{-1} \cdot d^{-1}$. This statement can be verified by the low values of biomass production obtained (Y_H = 0.34-0.37) as shown in **¡Error! No se encuentra el origen de la referencia.**. In this sense, Leyva Díaz (2015) reported a Y_H (mg $MLVSS \cdot mgCOD^{-1}$) = 0.5040 in MBR, values that are commonly determined in MBR. In low OLRs, the growth of microorganisms is generally limited by the supply of nutrients, which implies a lower production of sludge. The literature reports that with increased SRT, the characteristics of the bioactivity of the sludge decrease in the MBR (Ouyang & Liu, 2009).

The results showed a proportional relationship between OUR and SOUR for the two sludge retention times (SRT) studied. This is because the concentrations of MLSS were very similar. The SOUR was slightly higher for SRT= 30 d than for SRT= 60 d. This means that the SOUR decreases with the increase in SRT. These results confirm that the biomass is more active with shorter SRT. Long SRT involve lower energy requirements, since the sludge is increasingly endogenous and the energy is used mainly for cellular maintenance and not for bacterial growth. The endogenous decomposition constant (kd) remained similar for the two SRT studied (kd = 0.021-0.015 d^{-1}).

Reduction of Micropollutants

The concentration of each compound in the MBR influent was maintained at a concentration of 10 $\mu g \cdot l^{-1}$ throughout the investigation period (representative of real urban wastewater). **¡Error! No se encuentra el origen de la referencia.** presents the average concentrations found in the MBR effluent for the compounds studied, at sludge retention times of 30 and 60 days:

Table 4. Average concentration of pesticides in the effluent.

Compound	**Log K_{OW}**	**SRT= 30 days**		**SRT= 60 days**	
		N	**Average concentration ($\mu g \cdot l^{-1}$)**	**N**	**Average concentration ($\mu g \cdot l^{-1}$)**
Trifluralin	5.34 (a)	7	< 0.025	17	< 0.025
Simazine	2.18 (a)	7	4.275	17	2.690
Atrazine	2.61 (a)	7	4.726	17	2.240
Lindane	3.72 (a)	7	0.845	17	0.035
Terbutilazine	3.21 (a)	7	3.667	17	1.767
Heptachlor	6.10 (a)	7	< 0.025	17	< 0.025
Alachlor	3.52 (a)	7	0.978	17	0.161
Linuron	3.20 (a)	7	4.833	17	1.795
Isodrine	6.75 (a)	7	< 0.025	17	< 0.025
Heptachlor epoxide	4.98 (a)	7	< 0.025	17	< 0.025
α-endosulfan	3.83 (a)	7	0.061	17	< 0.025
Dieldrin	5.40 (a)	7	< 0.025	17	< 0.025
p,p-DDD	6.02 (a)	7	< 0.050	17	< 0.050
Endrin	5.20 (a)	7	< 0.025	17	< 0.025
β-endosulfan	3.83 (a)	7	0.036	17	< 0.025
o,p-DDD	5.87 (a)	7	0.090	17	< 0.050

(a) http://www.chemspider.com/ (Royal Society of Chemistry, 2018); N= number of samples analyzed.

According to the results obtained in this study, different elimination efficiencies were obtained in the MBR, depending on the properties of each compound. Some compounds were poorly eliminated, such as simazine, atrazine, terbutilazine and linuron; others moderately eliminated, such as lindane and alachlor; and others, highly eliminated, such as trifluralin, heptachlor, isodrine, heptachlor epoxide, α-endosulfan, dieldrin, endrin, β-endosulfan, or, p-DDD and p, p-DDD.

The degree of elimination of the micropollutants studied is related, among other factors, to the hydrophobicity coefficients (defined as log K_{OW}) of all the compounds studied, as shown in **¡Error! No se encuentra el origen de la referencia.**, obtained from the Royal Society of Chemistry (2018).

According to Jones, Voulvoulis and Lester (2005), if a chemical product is more hydrophobic, the greater the amount that accumulates in the solid phase (for example, biosolids), and the more hydrophilic it is, the greater the amount that will remain in the aqueous phase. Depending on the sorption potential, three ranges can be distinguished:

- Log K_{ow} < 2.5 low sorption potential
- Log K_{ow} > 2.5 and < 4.0 medium sorption potential
- Log K_{ow} > 4.0 high sorption potential

Figure shows the elimination efficiency obtained for the compounds with SRT of 30 and 60 days in the MBR, and is related to the hydrophobicity of the compounds (log K_{OW}).

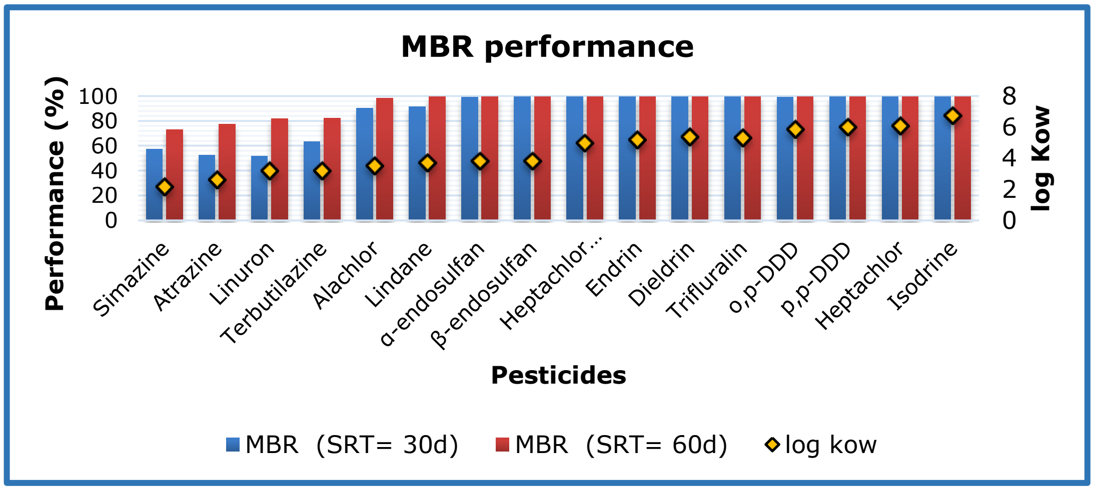

Figure 2. Average elimination of pesticides.

For the atrazine, simazine, terbuthylazine and linuron compounds at SRT of 30 d, the average elimination percentages were 52.7%, 57.2%, 63.3% and 51.7%, respectively, however at SRT of 60 d, the average elimination percentages increased with respect to SRT of 30 days, with 77.6%, 76.1%, 82.3% and 82.1%, respectively. Figure also shows that these compounds have low hydrophobicity coefficients, which indicates their marked hydrophilic characteristic. In addition, in their molecular structure, these compounds have electron acceptor functional groups (chlorides and the s-triazines ring for triazines), which by their nature have low biodegradability (Tadkaew, Hai, McDonald, Khan, & Nghiem, 2011). All these characteristics make them refractory to the MBR treatment, remaining in the aqueous phase. Bernhard, Müller and Knepper (2006) corroborate that simazine and atrazine are poorly eliminated in biological systems because they have low hydrophobicity and limited biodegradability. However, with the increase in sludge retention time, an increase in the efficiency of elimination of these pesticides can be observed.

In the literature, other authors report lower performance with the MBR operation, including Wijekoon *et al*. (2013) with a 36% reduction in atrazine using ceramic membranes and Tadkaew *et al*. (2011) with a 21% reduction in linuron using hollow fiber ultrafiltration membrane modules.

The averages for the elimination of alachlor were 90.2% and 98.4% at 30 and 60 days of sludge retention, respectively. The averages for the elimination of lindane were 91.6% and 99.7% at 30 and 60 days of sludge retention, respectively. Although in their molecular structure alachlor and lindane have electron-winning functional groups (chlorides), they also have a moderate hydrophobic character (log K_{OW} of 3.52 and 3.72), and adsorption in sludge can be their main elimination mechanism.

In general, the more hydrophobic compounds, such as α-endosulfan, β-endosulfan, heptachlor epoxide, endrin, dieldrin, trifluralin, o,p-DDD, p, p-DDD, heptachlor and isodrine, resulted in an average elimination greater than 99% with both sludge retention times. Absorption in biosolids and biodegradation contributed to their elimination, due to their high hydrophobicity coefficients.

The sludge retention time of 60 d can improve the elimination efficiency of the compounds studied in the aqueous phase, with respect to the retention time of sludge of 30 d, because a prolonged SRT can induce the proliferation of slow growth bacteria, thus improving the microbial diversity in the reactor and achieving a better biodegradation of the MPs. Adsorption and biodegradation can be the main mechanism for the elimination of micropollutants when treated with a MBR. Boonyaroj, Chiemchaisri, Chiemchaisri, Theepharaksapan y Yamamoto, (2012), and De-Gusseme, Vanhaecke, Verstraete and Boon (2011) found that the elimination of organic micropollutants improved under conditions of higher sludge retention times. However, the presence of some compounds in the effluent is an indicator of the need to add a tertiary treatment to complete the elimination/mineralization of pesticides.

Reduction of Organic Matter

This investigation was carried out at an average organic load rate of 0.23 $kgCOD \cdot kgVSS^{-1}d^{-1}$ with an average chemical oxygen demand of 363 $mgO_2 \cdot l^{-1}$, obtaining reductions in organic matter as shown in Figure 3, which presents the data on the evolution of the COD according to the sludge retention times, for both the influent and the effluent.

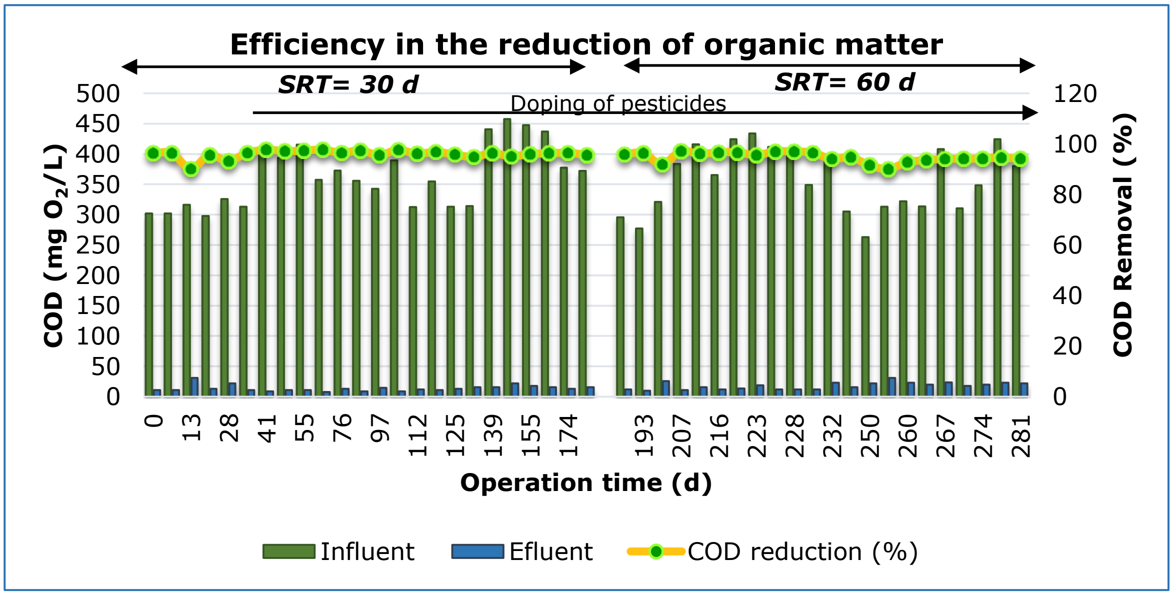

Figure 3. Reduction in organic matter.

The results obtained show that the elimination efficiency for the two retention times studied was excellent, obtaining an average elimination in organic matter of 96%. The reduction in organic matter was not affected by doping the micropollutants, as shown in Figure , specifically, the doping of the pesticides in the influent began on day 41 of the investigation, resulting in a reduction in organic matter within the average range.

This satisfactory performance of the MBR technology is compared with that found by Neoh, Noor, Mutamim and Lim (2016), who report a high yield when using the MBR to eliminate organic matter and that it is an attractive alternative for water reuse. Domínguez (2010) also conducted studies of MBR yields, where 97% and 98% of the organic matter was eliminated. And Rodríguez *et al*. (2011) found yields higher than 90%. All this demonstrates the robustness and capacity of this type of technology to treat wastewater.

Conclusions

For the family of organochlorines, excellent elimination yields were obtained, with values between 90 and 99% for the two sludge retention times studied.

For the triazine family (simazine, atrazine and terbuthylazine) and linuron, a SRT of 60 d resulted in an average elimination increment of 20%, with values close to 80% yield. With the MBR operation, the increase in sludge retention time increased the elimination of some MPs from the water.

Through the MBR system, hydrophobic compounds can achieve elimination greater than 90%, whereas electron acceptor compounds (persistent) with low hydrophobicity can obtain elimination below 60%.

The heterotrophic growth coefficients showed low values because they operated at a low load. However, efficiencies of 96% were achieved in the reduction in COD, which shows that the presence of MPs in the influent does not affect the MBR yields in terms of the elimination of organic matter.

These results demonstrate the efficiency of MBR systems in the elimination or degradation of some pesticides. To improve the efficiency in the elimination of the micropollutants, future research can explore using the MBR as a first barrier, followed by post-treatment (advanced oxidation processes and/or other membrane processes) to improve the quality of the effluent in terms of the presence of these more refractory substances.

Acknowledgments

This research was developed at the Institute of Water and Environmental Sciences of the University of Alicante within the framework of the project CTM 2013-46669: Eliminación y/o degradacion de contaminantes emergentes en aguas mediante tratamientos combinados, of the Ministerio de Economía e Competitividad de España and also with the help of the Subprograma de Ayuda Económica Complementaria N° 08-2014-074 del Instituto para la Formación y Aprovechamiento de Recursos Humanos (IFARHU)-Universidad Tecnológica de Panamá, República de Panamá.