Desalination and Water Treatment
www.deswater.com

35 (2011) 101–109
November

1944-3994/1944-3986
doi: 10/5004/dwt.2011.3136

Comparative study between activated sludge versus membrane bioreactor for textile wastewater

Salazar Lorena[a,*], Crespi Martì[b], Salazar Roberto[c]

[a]*Department of Environmental Engineering, Mariana University, Street 18 # 34 – 104 Pasto - Nariño*
Tel 0927+7314923; email: losaga00yahoo.com
[b]*Institute of Textile Research and Industrial Cooperation of Terrassa (INTEXTER), Laboratory of Environmental Pollution Control, Politécnical University of Catalonia, Barcelona, Spain*
[c]*Department of Civil Engineering, Nariño University, Torobajo, Pasto – Nariño*

Received 24 September 2010; Accepted 6 July 2011

ABSTRACT

The aim of this experimental work was to evaluate the carbonaceous constituents in textile wastewater, and the influence of slowly biodegradable products, also to compare two processes: Membrane bioreactor (MBR) and activated sludge (AS) for treating textile wastewater. The MBR pilot plant includes an aerobic reactor of 50 l, and membranes of micro and ultra filtration, the AS pilot plant has an aerobic reactor of 4 l. The processes were run 3 times over 244 d, with the same relative F/M and SRT. Respirometry was carried out to find the carbonaceous constituents in the wastewater, and also the Ultimate BOD, the mixed liquor suspended solids (MLSS) to evaluate the sludge, and different analysis: chemical oxygen demand and color removal, in order to evaluate process performance. The results show that the range of reduction of COD emissions using the MBR was 89–92%, and using AS was 54–70%, the color removal using MBR was 70% with MF membranes, and 72–73% with UF membranes, and 28% using AS. These results demonstrated that the textile wastewater could be treated by biological treatment but with high SRT, and also that the MBR is more efficient and stable that a conventional activated sludge process for treating textile wastewater.

Keywords: Membrane bioreactor; Textile wastewater; Active Sludge Process; Color Removal; Carbonaceous constituent; Respirometry; Ultimate BOD

1. Introduction

Textile wastewater is an important pollution source that contains high concentrations of inorganic and organic chemicals, and it is also highly colored from residual dyestuffs [1]. This wastewater is known to have a strong color, large amounts of suspended solids (TSS), broadly fluctuating pH, high temperature, and high chemical oxygen demand (COD) concentration [2]. Previous studies have shown that many of the dyes are carcinogenic, mutagenic, and detrimental to the environment [3].

The effluent generated contains a wide range of contaminants, such as salts, enzymes, surfactants, oxidizing and reducing agents. In environmental terms, these contaminants mean suspended solids, COD, BOD, as well as high, pH and strong color. Biological treatment, chemical precipitation, membrane technology, activated carbon adsorption and evaporation are the common wastewater treatment techniques of textile industry effluents [4–6]. A membrane bioreactor (MBR), is a combination process of biological reactor coupled

*Corresponding author.

with a membrane separation device, that is commonly regarded to be an innovative technology for wastewater treatment and reclamation.

The aerobic membrane bioreactor process has successfully treated effluents from a wide range of industrial wastewaters, including cosmetics, pharmaceuticals, textiles, abattoirs, metal fabrication, paper and pulp, rendering and chemical manufacture. The membrane bioreactor process operates in a considerably different range of parameters that the conventional activated sludge process. While solid retention time (SRT) falls in the range of 5–30 d for a conventional system, SRT values frequently exceed 30 d for the MBR [7,8]. The loading rate or Food/Microorganisms (F/M) ratio falls in the range of 0.05–1.5/d for a conventional system, but is usually 0.1/d for a MBR. The low F/M occurs due to the high mixed liquor suspended solids (MLSS) in the bioreactor, which typically range from 5,000 to 20,000 mg/l for MBR, and 2000 mg/l in conventional processes.

The most common biological process to treat textile wastewater is the activated sludge process (AS) [4]. This process involves the production and maintenance of microbial population in aerobic conditions. These microorganisms consume the biodegradable substrate, and solid separation is carried out by a secondary clarifier. The main problem of the activated sludge process is bulking sludge, and *Nocardia* foam.

However, this process has several difficulties in order to remove the slowly biodegradable substrate, non biodegradable substrate, as well as virus and bacteria [10,11], colloidal suspended solids. All these facts do not allow the reuse or recycling the effluent.

Mean while the MBR process allows: better control of biological activity, longer sludge retention time, independent of the hydraulic retention time, complete removal of solids and nearly complete removal of effluent microorganisms, smaller footprint, high removal ratios for most contaminants, reduce sludge production and rapid start-up of biological process [12–18]. Membrane bioreactor (MBR) technology is advancing rapidly around the world both in research and commercial applications, the MBR systems have mostly been used to treat industrial wastewater, domestic wastewater and specific municipal wastewater [19]. However, important parts of this process need to be researched, particularly for example in the area of textile waste water [20]. To design an activated sludge treatment process properly, characterization of the wastewater is perhaps the most critical step in the process. For biological nutrient-removal processes, wastewater characterization is essential for predicting performance. Wastewater characterization is an important element in the evaluation of existing facilities for optimizing performance and available treatment capacity. Without comprehensive wastewater characterization, facilities may either be under-or overdesigned, resulting in inadequate or inefficient treatment.

Carbonaceous constituents measured by BOD or COD analyses are critical to the activated-sludge process design. Higher concentrations of degradable COD or BOD result in (1) a larger aeration basin volume, (2) more oxygen transfer needs, and (3) greater sludge production [21].

The aim of this experimental work was evaluate the carbonaceous constituents in textile wastewater, the influence of slowly biodegradable products, and to compare the two processes: The Membrane bioreactor (MBR) and the activated sludge (AS), for treating textile wastewater.

2. Materials and methods

Two pilot plants were used in this study, one for the MBR and the second one for active sludge. The influent was textile wastewater elaborated in laboratory conditions. The experiment was run three times during a period of 244 d.

2.1. Textile effluent

The case study was performed at the Institut de Investigaciò Textil i Cooperaciò Industrial de Terrassa (Barcelona, Spain). The sector of the textile industry selected was the sector of dyeing and finishing of cotton knit, it is a big consumer of water, and their effluent has a high COD [24]. Furthermore this sector produces 50% of the production and exportations of Spanish textile industry [25].

The effluent of this industry is composed by series of effluents of wet processes, such as scouring, desizing, dyeing, rinsing, washing and softening. The most contaminant wet process is the scouring and desizing with a 50–70% of the COD [26].

The wastewater treated was elaborated in laboratory conditions in order to reproduce the effluent produced by the industry of dyeing and finishing of cotton knit. This are regarded as the major pollutants in textile waste water [2,22]. Two kinds of textile effluent were elaborated to evaluate the biodegradable constituents, one of them has slowly biodegradable substrate (WSBP) typical for the textile wastewater, as polyvinyl alcohol (200 mg/l), starch (100 mg/l), and fatty alcohol ethoxlate (FINDET 1618, 50 mg/l), and the other without slowly biodegradable products (WOSBP). The characteristics of textile wastewater is shown in Table 1.

2.2. Membrane bioreactor (MBR)

The MBR used in this study was a pilot plant, composed of an aerobic reactor connected to an external tank with submerged UF membranes. The aerobic reactor had a working volume of 50 l. The influent was pumped directly from a raw wastewater tank, mixed completely

Table 1
Characteristics textile wastewater

Parameter	Unit	Dyeing	Desizing and scouring	Washing	Softening	Textile effluent WSBP	Textile effluent WOSBP
Ph		11	11	8	8	8	10
Cond.	mS/m	701	684	155	154	1,382	1382
T	°C	20	20	20	20	20	20
TOC	mg/L	154	3,563	28	160	650	617
COD	mg/l	511	13,812	24	40	1457	1500
BOD_5	mg/l	3	4,281	7	23	215	464
TSS	mg/l	197	415	18	69	119	119
Color	Hazen	10,000	625	0	0	1,17	1,17
Phosphorus	mg/l	–	–	–	–	1,6	1,6
Nitrogen (Kjendahl)	mg/l	0	402	0	0	24	24
Biodegradability	%	0	31	30	27	31	1280

with activated sludge and purified by a series of metabolic microorganism reactions. The submerged UF membranes were connected to a suction pump. The effluent passed through the membrane separation unit with a flow velocity of 0.7–0.4 l/h, and trans-membrane pressure (TMP) of –0.1 bar. The reactor was aerated by a membrane diffuser in the bioreactor's base, the dissolved oxygen concentration in the aerobic reactor was higher than 2 mgO_2/l. The reactor was coupled to an ultra filtration module of (POLYMEM – France) with submerged hollow fibers. The MBR pilot plant used in this work is shown in the Fig. 1.

Three membrane external modules were employed in this study, the characteristics are shown in the Table 2.

The evaluation of the backwashing time, gave a result after 60 min of operation. When the trans-membrane pressure (TMP) went beyond 75 kPa, the membrane needs to be cleaned. The cleaning procedure was a back wash with filtered effluent mixed with cleaning solution to remove the fouling.

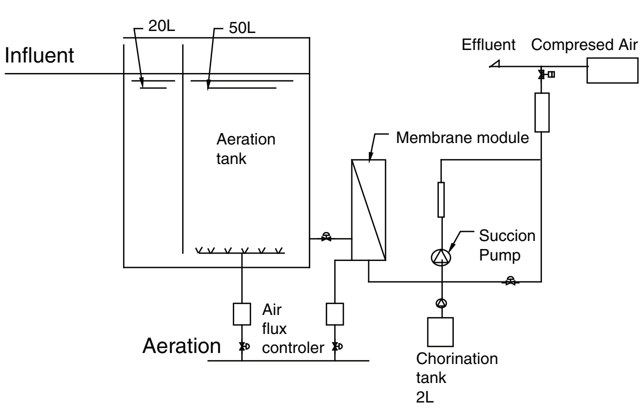

Fig. 1. Flux diagram membrane bioreactor.

Table 2
Characteristics membrane modules

Characteristics	Module		
	UF10S	UF10S3	UF10S2
Filtration	Microfiltration	Ultrafiltration	Ultrafiltration
Material	Polysulfone	Polysulfone	Polysulfone
Geometry	Tubular	Tubular	Tubular
Filter area (m^2)	0.2	0.2	0.2
Pore size (µm)	0.2	0.08	0.01
Permeability l/(h m^2 kPa)	8	4	2.2

2.3. Active sludge unit

The active sludge (AS) pilot plant, is composed of an aerobic reactor (volume 4 l), connected to a sedimentation tank. The flux diagram is shown in Fig. 2.

2.4. Analyses

2.4.1. Physical analysis

The measured water properties are: Temperature, mixed liquor suspended solids (MLSS), turbidity, pH, conductivity, dissolved oxygen, nitrogen (Kjendahl), as well as the color, which were measured by determining the spectral adsorption coefficient of 0.45 µm filtered samples at 490 nm using a SHIMADZU UV spectrometer [22].

2.4.2. Bio – chemical analysis

BOD_5, COD, TOC were determined as prescribed in Standard Methods 20th edition.

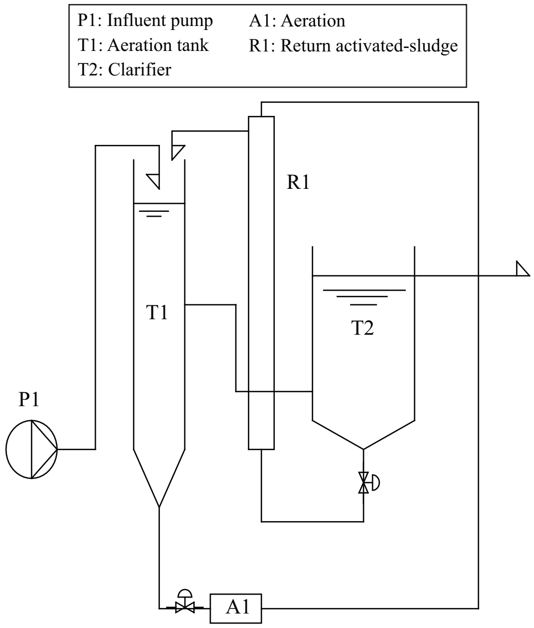

Fig. 2. Flux diagram sludge activated pilot plant.

2.4.3. Respirometric determination of BOD - Ultimate BOD

The value of k is needed if the BOD_5 is to be used to obtain UBOD, the ultimate or 20 d BOD. There are several ways of determining $k1$ and UBOD from the results of a series of BOD measurements, including the methods of least squares, the methods of moments, etc. the least- squares method involves fitting a curve through a set of data points, so that the sum of the squares of the residuals must be a minimum. For a time series of BOD measurements on the same sample, the following equation may be written for each of the various n data points [9]:

$$\frac{dy}{dt}\Big|_{t=n} = k1(\mathrm{UBOD} - y)$$

If simplifying and sum of the squares residuals R is to be a minimum, the following set of equations result:

$$na + b\sum y - \sum y' = 0$$
$$a\sum y + b\sum y^2 - \sum yy' = 0$$

where n = number of data points
$a = -b\mathrm{UBOD}$
$b = -k1$ (base e)
$\mathrm{UBOD} = -a/b$
$y = y_t$, mg/l

$$y' = y_{n+1} - y_{n-1}/2\Delta t$$

Solve both equations is possible to obtain the rate of BOD oxidation (k), and the UBOD.

For more feasibility the BOD measurements, were performed according to the Electrolytic Respirometer Bioscience manual, using an Electrolytic Respirometer (BI – 1000, Bioscience Inc).

Fractionation of COD: The fractionation of COD is shown in Fig. 3, this method was determined by the Metcalf & Eddy Method [7]. The Filtration methods, such as a 0.45 µm filter, were used to determine the soluble COD (sCOD) and the particulate COD (pCOD). The IWA Task Group model was used to obtain readily biodegradable soluble COD (rbCOD), where the ultimate biochemical oxygen demand (UBOD) is the rbCOD. Respirometry was used to determine the UBOD [23].

2.5. Operation variables

Three experiments were conducted for membrane bioreactor and active sludge. The operation variables during the long –term pilot experiment are listed in Table 3, as we can see in the Table 3, the COD influent,

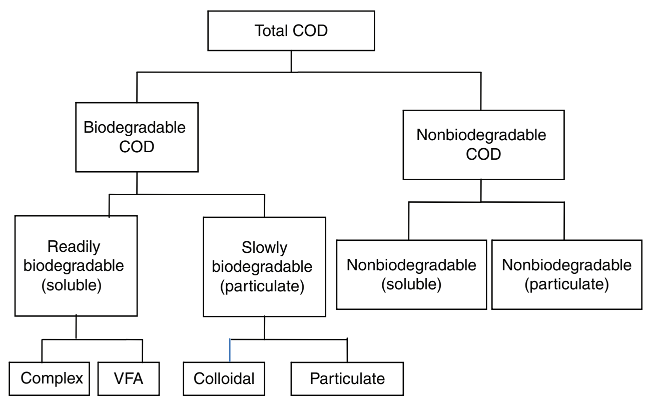

Fig. 3. Fractionation of COD wastewater.

Table 3
Operation variables

Items process	AS	MBR
COD (mg/l)	1500	1500
MLSS (mg/l)	3401	840
Qe (l/d)	2	6
HRT (d)	2	9
V (l)	4	40
F/M (kgCOD/kgMLSS.d)	0.2	0.2
Membrane flux (l/m² h)	–	3.5
SRT (d)	48	45

the relation F/M, and also the SRT, were constant for the three experiments and for both processes during a period of 165 d each one. The control parameter for the design and the operation was the food microorganisms ratio F/M, for both process, this ratio is usually evaluated for systems that were designed based on SRT, to provide a reference point to previous activated sludge design and operation performance [9]. The HRT is not the control parameter for both process, due to both pilot plants have different biological volume tanks, and the wastewater was elaborated in laboratory conditions, these facts difficult the experimental work.

3. Results and discussion

3.1. Case description

The case study was performed at the Institut de Investigaciò Textil i Cooperaciò Industrial de Terrassa (Barcelona, Spain), with two pilot plants. One MBR and the other active sludge, evaluating in parallel with the same affluent, textile wastewater, and relation food/microorganism as an operational control parameter.

3.2. Fractionation of COD

The characterization of the wastewater is perhaps the most critical step in the process to understand the differences in both processes, this fact is also important to evaluate the design characteristics [7]. Physic chemical, biochemical and respirometric techniques were applied for the water characterization. The evaluation of carbonaceous constituents, the fractionation of COD, was used in order to analyze the capacity of biodegradation of biodegradable products, and non biodegradable products, in both process.

3.2.1. COD biodegradable and nonbiodegradable

The respirometic determination of BOD, was evaluated with an effluent with slowly biodegradable products (WSBP) and without slowly biodegradable products (WOSBP) [23].

The influence of slowly biodegradable products is shown in the Fig. 4.

BOD measurements were used to obtain the UBOD, with respirometric techniques. And then it was necessary to apply the least squares method to determinate the rate of BOD oxidation (*k*), and the UBOD. The results of the analyses of BOD_5, COD, UBOD, and UBOD/COD for both effluents are presented in Table 4.

The effects of the influence of slowly biodegradable products (EWSBP) and also without slowly biodegradable products (EWOSBP), are illustrated in the Table 4, the value of the UBOD and the rate of BOD oxidation

Table 4
Results of BOD, COD and UBOD evaluation

	BOD5 mgO_2/l	COD mg/l	UBOD mgO_2/l	k (base e)	UBOD/COD
EWOSBP	325	1500	428	0.23	0.30
EWSBP	215	1500	310	0.20	0.29

are greater for EWOSBP than for an effluent with them (EWSBP). The rate of BOD oxidation (*k*) are 0.23/d and 0.20/d, these values are typical for *k*, due to this both effluent could be treated using a biological process [9]. Certainly the most biodegradable wastewater is the effluent without slowly biodegradable products, for this reason it is important to research in the elimination of non biodegradable products like softeners, dispersants, dyes, in the wastewater treatment of textile industry.

The difference between the influent and the effluent of the biological reactor in the AS pilot plant was used to obtain the total biodegradable COD (bCOD) [7], the UBOD was used to obtain the readily biodegradable rbCOD. The effluent of the MBR process was used to obtain the nonbiodegradable soluble COD (nbsCOD), and the difference is the non biodegradable particulate of nbpCOD. These evaluations were done with two influents, one of them with slowly biodedegradable (WSBP) products and other without them (WOSBP). The results are shown Fig. 5.

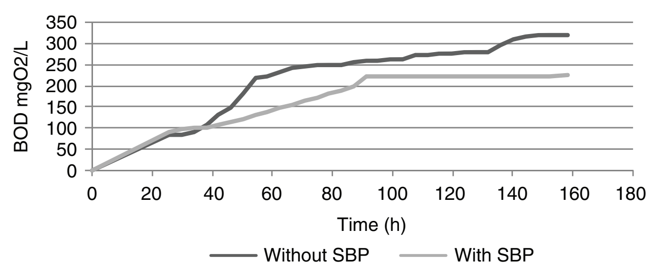

Fig. 4. BOD measurements, with and without slowly biodegradable products (SBP).

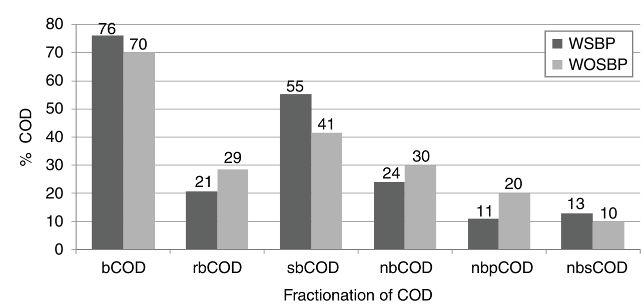

Fig. 5. Evaluation of the fractionation of COD.

Approximately 70–76% COD from the textile effluent is biodegradable (bCOD), this means that it could be assimilated by the biological process. Approximately 20–30% of this biodegradable portion is readily biodegradable soluble chemical oxygen demand (rbCOD). This is the portion that could be quickly assimilated by the biomass. This fact is important because it helps to select an adequate solid retention time (SRT) and also to select a hydraulic retention time (HRT) in the biological process.

The other 41–55% COD, is slowly biodegradable (sbCOD). The sbCOD must be hydrolyzed and then assimilated at slower rates. For this reason it is important to have longer SRT and HRT, in biological process. For the nonbiodegradable portion 24–30% nbCOD, approximately 11–20% is nonbiodegradable particulate COD (nbpCOD). This portion will contribute to the sludge production, in the active-sludge process.

The nonbiodegradable particulate COD (nbpCOD) in MBR, is the portion that could be retained for filtration systems. This is one of the advantages of the MBR system. For the final portion 10–13% nonbiodegradable soluble COD (nbsCOD), is the portion that will be found in the activated-sludge effluent. This probably means, that for textile wastewater is a necessary design installation with, longer sludge retention times, and also longer hydraulics retention time, for this reason the installation area for the biological process will be bigger.

3.3. Process performance

3.3.1. Variation of COD and sludge concentration with time

The variations of the COD in the affluent and effluent of MBR and AS with time during the three experiments are illustrated in Fig. 6. It shows the variability of the effluent of the active sludge process, and the stability of the MBR.

The Table 5, show the average of the three experiments, of the COD effluent, and demonstrate the stability of the MBR process with slow standard deviation, and the variability of the AS.

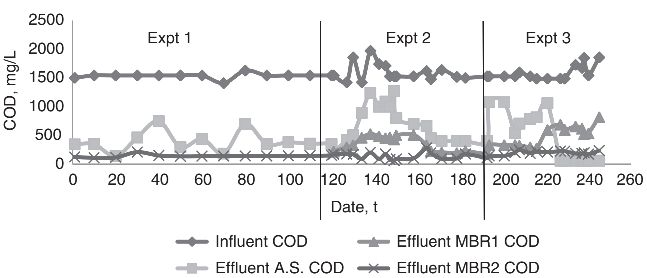

Fig. 6. Variation of COD with time.

Table 5
Statistical values of the AS and MBR COD effluent

	AV SA	SD FA	AV B MBR	SD B MBR	AV MBR	SD MBR
1EXP	39100	171.89			142.08	23.69
2EXP	695.94	332.37	353.18	128.51	138.24	58.84
3EXP	462.57	441.77	492.64	492.64	198.14	31.68
AV	516.50	315.34	422.91	310.58	159.49	38.07
DS	159.46	135.74	98.62	257.48	33.53	18.42

The affluent COD remains at about 1500 mg/l, the average effluent COD of activated sludge process (effluent A.S.), in the three experiments, was 516 mg/l, which fluctuated from 391–695.9 mg/l, and standard deviation 159 mg/l, the average efficiency in COD removal was 71%. The COD from the biological MBR reactor was average 422.91 mg/l, which fluctuated from 353–492 mg/l. Standard deviation was 257.6 mg/l, and the efficiency was 78%. This demonstrate the efficiency and stability of the biological process of MBR, the MBR process is able to work whit high SRT, independent to the HRT, this is optimal for the textile wastewater like we see in the fractionation of COD, because help to biodegrade the slowly biodegradable products.

The effluent of MBR (effluent MBR2 COD) had an average of 158 mg/l which fluctuated from 60–280 mg/l and had a standard deviation of 50 mg/l, the efficiency was 91%. The activated sludge process had a high variability and a lower efficiency. The MBR biological process is 7% more efficient and stable than an activated sludge process, the MBR is 17% more efficient for the COD removal, than the active sludge process at similar operative parameters. It can be concluded that the removal efficiency of organic pollutants was high and stable when the MBR was applied to textile wastewater treatment.

The formation of sludge during the experiment is shown in Fig. 7. The behavior of the sludge concentration

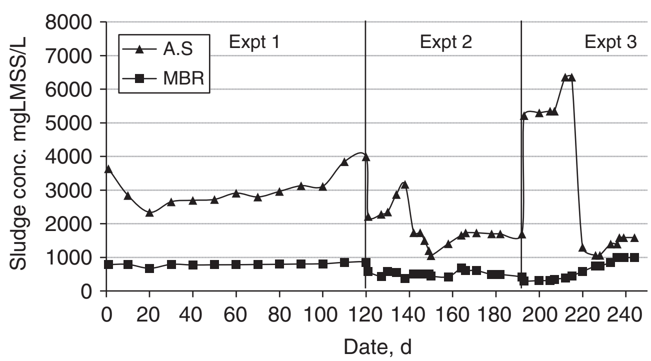

Fig. 7. The variation of sludge concentration with time.

in active sludge process could be describe in three stages: At the first one there was an increasing concentration, then there was a decreasing concentration of the sludge produced by a formation of a cake layer in the sedimentation tank, called *bulking*, after the *bulking* there was an increased of the concentration of sludge [25]. Meanwhile, the behavior of the sludge concentration in MBR is stable in all of the three studies, and they did not have increasing or decreasing rates. The kinetic analysis can help to explain this behavior [4].

The Table 6, indicated the elevated variation of the sludge concentration in the biological reactor in active-sludge process, generated by the bulking of the sludge, this behavior was reply in the three experiments. Meanwhile in MBR the concentration of MLSS was stable in all the process due to the membrane.

3.3.2. Color removal

The evaluation of color removal was made in three effluents, the first one in the effluent of activated sludge (EAS) pilot plant, in the supernatant of MBR (SMBR) and the effluent MBR (EMBR) pilot plant, which works with microfiltration membrane (MF) with a pore size 0.2 μm, for a period of 100 d. The evaluation method was determined by the spectral adsorption coefficient of 0.45 μm with filtered samples at 490 nm. The results are illustrated in Fig. 8.

Table 6
Statistical values of the MLSS evaluation

	Average SA	SD FA	Average MBR	SD MBR
1EXP	3047.38	492.32	791.54	42.44
2EXP	1865.65	553.12	512.82	82.45
3EXP	3207.07	2230.86	644.00	290.03

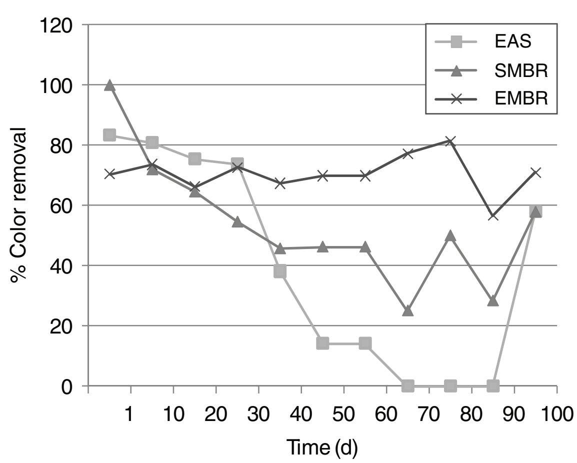

Fig. 8. Evaluation of color removal.

Table 7
Estatistical values in evaluation of color removal

	Ef FA1 % Rem	Sup MBR % Rem	Ef MBR % Rem
AV	28	53	70
SD	11.66	20.06	6.11

Table 8
Evaluation of color removal with different membranes

	MFS % Rem	UFS3 % Rem	UFS2 % Rem
AV	70	72	73
SD	3	13	9

The Fig. 8, shows the stability and the efficiency on color removal of the biological process in MBR, and the instability of the active sludge process.

The Table 7, show the percentages of color removal of each process, the active sludge has 28% of color removal, the biological process an 53%, and 70% in MBR.

Is clear that the instability of the activated sludge process. The biological process in MBR is 25% more efficient than AS, in the color removal. The implementation of membranes filtration contributes whit 17%, in the color removal. Finally the MBR process retains 42% more color particles than a conventional process of AS.

Three different membranes were evaluated in this study for the MBR, one microfiltration (MFS) 0.2 μm of pore size, the second 0.08 μm (UFS3) ultra filtration membrane, and the third ultra filtration membrane of 0.01 μm pore size (UFS2). The results are illustrated in Table 8.

The color removal for the MFS membranes was 70%, for UFS3 was 72%, and for UFS2 was 73%. The difference between membranes of microfiltration and ultra filtration is not so representative however is necessary a cost study and a deeper research in the membrane efficiency.

4. Conclusions

The textile wastewater has high values of readily biodegradable soluble COD (rbsCOD 41–55%), this value affects the design of the biological process for the AS and MBR, in (1) a larger aeration basin volume, (2) more oxygen transfer needs, and (3) greater sludge production.

The COD efficiency removal for the AS process was in average of 71%, for the supernatant of MBR was 78%, and for MBR was 91%. The non biodegradable COD portion (nbCOD) of the textile effluent was 24–30%. The membranes of microfiltration retain 11−20% of non biodegradable COD (nbCOD). These results suggest that influence of microfiltration membranes in a biological process increases the process efficiency approximately in 20%. Besides this offers effluent quality as well as effluent stability.

One of the principal factors that affect the efficiency of COD removal, in the activated sludge process(AS), was due to the bulking sludge phenomena produced by the filamentous bacteria (*Nocardia amarae*). This result in an evacuation of biomass in the secondary settle thank, which affects the stability and efficiency of the process. Meanwhile the closed box configuration of the MBR makes that all the biomass maintains in the biological thank, which offers stability to the process.

The colloidal particles are the biggest problem for the textile wastewater. The percentage of color removal for the AS process was 28% and for MBR process was of 70%, with microfiltration membranes and 73% with ultra filtration membranes. For this reason for AS process is necessary to add tertiary treatments to remove the colloidal particles, which increases the cost of the treatment system.

Symbols

MBR	—	Membrane bioreactor
AS	—	Activated sludge process
BOD	—	biological oxygen demand (mg O_2/l)
COD	—	chemical oxygen demand (mg O_2/l)
k	—	Rate of BOD oxidation
UBOD	—	Ultimate biochemical oxygen demand
bCOD	—	biodegradable chemical oxygen demand
pCOD	—	particulate chemical oxygen demand
sCOD	—	soluble chemical oxygen demand
nbCOD	—	non biodegradable chemical oxygen demand
rbCOD	—	readily biodegradable soluble chemical oxygen demand.
bsCOD	—	biodegradable soluble chemical oxygen demand
sbCOD	—	Slowly biodegradable chemical oxygen demand
bpCOD	—	biodegradable particulate chemical oxygen demand
nbpCOD	—	nonbiodegradable chemical oxygen demand
nbsCOD	—	nonbiodegrdable soluble chemical oxygen demand
TOC	—	total organic carbon (mg/l)
MLSS	—	mixed liquor solid suspended
Qe	—	effluent flux
V	—	volume of the biological reactor
MF	—	Microfiltration
MFS	—	Microfiltration membranes
UFS3	—	Ultrafiltration membranes (0.08 µm)
UFS2	—	Ultrafiltration membranes of (0.01 µm)
Effluent MBR1 COD	—	effluent of the biological process in MBR
Effluent MBR2 COD	—	effluent of all the MBR process

References

[1] Z. Badani, H. Ait-Amar, A. Si-Salah, M. Brik and W. Fuchs, Treatment of textile waste wáter by membrane bioreactor and reuse, Desalination, 185 (2005) 411−417.

[2] L. Salazar, In: "Estudio de la depuración de efluentes de la industria textil, mediante un biorreactor de membrana", Research work, Universitat Politécnica de Catalunya (UPC), Barcelona, 2005, pp 250.

[3] T. Kim, Ch. Park., J. Lee., E. Shin and S. Kim. Pilot scaled treatment of textile wastewater by combined process (fluidized biofilm process – chemical coagulation–electrochemical oxidation), Water Res., 36 (2002) 3979–3988.

[4] L. Salazar and M. Crespi, Evaluation of kinetic coefficients using membrane bioreactor and active sludge process treating textile wastewater, Desalin. Water Treat., 13 (2010) 471–478.

[5] S. Ghoreischi and R. Haghighi, Chemical catalytic reaction and biological oxidation for treatment non-biodegradable textile effluent, Chem. Eng. J., 95 (2003) 163−169.

[6] S. Baunmgarten, H.Fr. Schöder and J. Pinnekamp, Performance of membrane bioreactors used for the treatment of wastewater from the chemical and textile industries, Water Sci. Technol., 53(9) (2006) 61−67.

[7] T. Stephenson, S. Judd, B. Jefferson, K. Brindle, Membrane bioreactors for wastewater treatment. IWA Publishing and the authors, London., (2002) pp. 175.

[8] S. Adham, P. Gagliardo, L. Boulos, J. Oppenhelmerand R. Trussel, Feasibility of the membranebioreactor process for water reclamation,Water Sci. Technol., 43(10) (2001) 203−209.

[9] Metcalf & Eddy, Inc., Wastewater Engineering: Treatment and Reuse, 4th Ed. McGraw-Hill, New York (2003).

[10] R. Bai and H. Leow, Microfiltration of activated sludge wastewater- the effect of system operation parameters, Sep. Purif. Technol., 29 (2002) 183.

[11] Y. Tsang, S. Sin and H. Chua, Nocardia foaming control in activated sludge process treating domestic wastewater, Bioresour. Technol.., 99 (2008) 3381−3388.

[12] J. Manem and R. Sanderson, Biorreactores de membrana. En: Tratamiento de Agua por procesos de membrana. Principios, procesos y aplicaciones. American Water Works Asocciation Research Fundation, McGrawHill (1998) 757–787.

[13] P. Merlo, S. Adhams, P. Gagliardo and R. Trusell, Application of membrane bioreactor (MBR) technology for water reclamation, Water Environment Federation (2000) pp. 40.

[14] N. Cicek, J. Franco, M. Suidan, V. Urbain and J. Manem, Characterization and comparison of a membrane bioreactor and conventional activated-sludge system in the treatment of wastewater containing high-molecular–weight compounds, Wat. Environ. Res., 71 (1990) 64–70.

[15] S. Adham, J. De Carolis, Jude Grounds and L. Waseserman, Bill. Pearce, MBR. Performance, Pilot-scale test show membrane bioreactor can treat raw wastewater or advanced primary system effluent, Water Environ. Technol., 74 (2004) 33−39.

[16] H. Van der Roest, A. Van Bentem and D. Lawrence, MBR-technology in municipal wastewater treatment: challenging the traditional treatment technologies, Water Sci. Technol., 46–45 (2002) 273–280.

[17] B. Lesjejan, S. Rosenberger and J. Schrotter, Membrane–aided biologicalwastewater treatment–an overview of applied systems, Membrane Technology, August (2004).
[18] N. Cicek, A review of membrane bioreactors and their potential application in the treatment of agricultural wastewater, Can. Biosyst. Eng., 45 (2003) 639−646.
[19] Pearce Graeme, Introduction to membranes: An introduction to membrane bioreactors, Filtr. Sep., January/February (2008).
[20] W. Yang, N. Cicek and J. Ilg, State-of-the-art of membrane bioreactors: Worldwide research and commercial applications in North America, J. Membr. Sci., 270 (2006) 201–211.
[21] H. Boursier, F. Béline, Y.E. Paul, Piggery wastewater characterization for biological nitrogen removal process design, Bioresour. Technol., 96 (2005) 351–358.
[22] APHA, AWWA and WEF, Standard Methods for the Examination of Wastewater, 20th Edition, United States of America, 1998.
[23] IWA Task Group on Mathematical Modeling for design and operation of biological Wastewater treatment, IWA publishing, London, England (2000).
[24] European Commission DG JRC, Integrated pollution prevention and control (IPPC), Reference document on best available techniques for the textile industry, http:// eippcb.jrc.es (2002).
[25] Asociacion Industrial textile del Proceso Algodonero (AITPA), El sector textile del proceso algodonero presenta sus resultados a la asambela general.AITPA. Barcelona, http//www.aitpa.es/industria/tex-mundo.htm, 19/11/02.
[26] INIPSA. Problemática contaminante del sector de la industria textil y medidas aplicables para la adeguada gestión medioambiental de la actividad. Memoria documento Ii. MOPT. Secretaría de estado para las políticas del agua y del medio ambiente. Madrid (1992).
[27] M. Richard, Activated sludge microbiology problems and their control, Conference presented at the 20th Annual USEPA National Operator Trainers conference, Buffalo, NY (2003).