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Procedia CIRP 40 (2016) 419 – 424

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13th Global Conference on Sustainable Manufacturing - Decoupling Growth from Resource Use

Membrane bioreactor and promising application for textile industry in Vietnam

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Abstract

A pilot-scale membrane bioreactor (MBR) was developed in order to run two membrane modules in parallel for the treatment of model textile wastewater (MTDW). Two independently operated commercially available ultrafiltration membrane modules called UP150 from Microdyn-Nadir where tested in the same activated sludge tank over a period of 70 days for their removal efficiency of the MTDW. In general the results of both membrane modules are in very good agreement. The water permeability ranged between 20 – 50 L/(m^2.h.bar). Typically, the chemical oxygen demand (COD) removal efficiency indicated good biodegradation performance above 95%. The nitrification rate depended on the food to microorganism (F/M) ratio i.e. below 0.2 kg COD/(kg MLSS.d) the system showed complete nitrification. However, the color rejection for the model dyes was only around 20% to 60% what can be attributed to the low biodegradability of these chemicals. The next step is to run the MBR with novel nanostructured membranes in parallel with the commercially available membrane to compare their performances. This study contributes to sustainable development in the textile industry by improving water quality of treated textile wastewater what helps to reduce fresh water consumption and pollutant discharge.

Peer-review under responsibility of the International Scientific Committee of the 13th Global Conference on Sustainable Manufacturing

Keywords: Wastewater treatment; textile industry; membrane bioreactor (MBR); ultrafiltration;

1. Introduction

Vietnam's textile and garment sector has seen fast and sustainable growth over the past years, playing an important role in national socio-economic development. Demand for labor in the sector is huge. Every year, the sector gives employment for 2.2 million people [1].

Wastewater treatment process has become a significant issue for operation and environment especially in the industrial textile sector. Sustainable development can be more effective by making use of water reuse systems. The processes in textile and laundry industries can be considered as very water intensive and therefore this sector discharge every day a high amount of wastewater. Membrane technology has been recently applied in wastewater treatment as an efficient alternative to conventional treatment. Hence membrane technology can be regarded as a promising technology for waste treatment and reuse in textile and laundry industries [2].

Membrane bioreactor (MBR) technology is a combination of the conventional biological sludge process, a wastewater treatment process characterized by the suspended growth of biomass, with a micro- or ultrafiltration membrane system [3]. The advantage of MBR technology is its ability to biodegrade the waste compounds and separate the treated water from the mixed liquor due to the small pore diameter of the membrane. The bacteria and suspended solids can be kept out of the effluent since the membranes typically have a pore diameter from 0.01 to 0.1μm.

Nomenclature

ASP	Active sludge process
BOD	Biochemical oxygen demand

Peer-review under responsibility of the International Scientific Committee of the 13th Global Conference on Sustainable Manufacturing
doi:10.1016/j.procir.2016.01.083

COD	Chemical oxygen demand
DI	Distilled water
DO	Dissolved oxygen
F/M	Food to microorganisms
HRT	Hydraulic residence time
MBR	Membrane bioreactor
MLSS	Mixed liquor suspended solids
MTDW	Model textile dye wastewater
MWCO	Molecular Weight Cut-Off
OLR	Organic loading rate
PES	Polyethersulfone
PET	Polyethylene terephthalate
TMP	Transmembrane pressure
TN	Total Nitrogen
UF	Ultrafiltration
WP	Water permeability

2. Materials and Methods

2.1. Model textile dye wastewater (MTDW)

The quality of wastewater is an important factor in the biological degradation process. The model textile dye wastewater (MTDW) for this study was developed in a previous work [4] and it is mainly based on a blue anthrachinone reactive dye (Remazol Brilliant Blue R) and on a red azo dye (Acid Red 4) which represent typical industrial dyes widely applied in textile industry (Fig. 1). Besides, glucose was added as C-source, a typical industrial detergent (Albatex DBC) was used along with the following salts: NaCl, $NaHCO_3$ and NH_4Cl (N-source). The composition of MTDW is given in Table 1 and the measured characteristics are listed in Table 2.

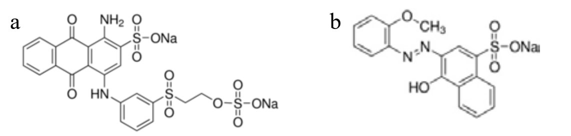

Fig.1. Chemical structure of a) Remazol Brilliant Blue R and b) Acid Red 4

Table 1. Composition of the model textile dye wastewater.

No.	Dyestuff & chemicals	Concentration (*mg/L*)
1	Remazol Brilliant Blue R	50
2	Acid Red 4	50
3	NaCl	2500
4	$NaHCO_3$	1000
5	Glucose	2000
6	Albatex DBC (Detergent)	50
7	NH_4Cl	300

Table 2. Characteristics of the model textile dye wastewater

Parameter	Unit	MTDW[a]
pH	-----	7.5 ± 0.5
COD	mg/L	2367 ± 125
BOD_5	mg/L	731 ± 80
Total - N	mg/L	78 ± 8
Conductivity	mS/cm	6.6 ±0.15

[a] Average values and standard deviation

2.2. Lab-scale MBR

A polyvinyl chloride (PVC) tank was used as activated sludge tank with a total volume around 60L. The hydraulic volume is 47L after having submerged the housing with the membrane modules. The membrane housing was fitted with two three envelope flat ultrafiltration (UF) membranes supplied by the company Microdyn-Nadir (0,33m^2 membrane area, each, characteristics see Table 3) [5]. Each of the two three envelope stacks was connected to a feed and suction pump and hence can be operated independently (Fig. 2). Consequently in future work the performance of different membrane materials can be compared in the same activated sludge tank. Besides the membrane module as well as feed and suction pump the plant consists of an air compressor and a variety of sensors such as level sensor, differential pressure sensor flow sensor, pH sensor, temperature sensor, conductivity sensor, dissolved oxygen (DO) sensor and air flow meter (see Fig. 2). The data were acquired by LabVIEW program from National Instruments.

Table 3. Characteristics of the UF membrane (UP150) [5]

UP150	Value
Active layer	PES
Support layer	PET
MWCO	150 kDa
Pore size	0,04 µm
Water permeability	> 280 (L/(m^2.h bar))

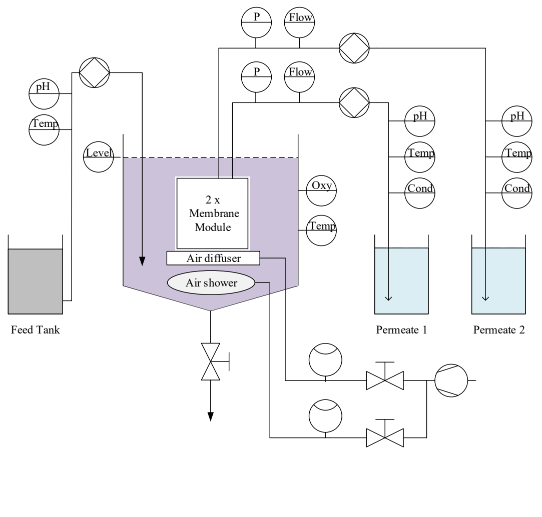

Fig. 2. Schematic diagram of membrane bioreactor

2.3 Spectrophotometer method

The concentration of the red and the blue dyes, in the feed and in the permeate solution were analyzed by use of spectrophotometer UV-1800 from Shimadzu (Japan). The wavelength of maximum absorbance for the red and the blue dyes were found at 505 and 595 nm, respectively. A calibration routine based on Beer´s Law was used to calculate concentration from absorbance.

2.4 COD measurement

All COD values were analyzed with COD cell tests (Method 1.14541) from Merck KGaA (Germany), where the range of measurement is 25-1500 mg/L of COD. According to the COD product brochure the coefficient of variation (% standard deviation) is supposed to be ±0.68% [6].

2.5 Total-N

The total-N has been determined by TOC-L CHP/CPN analyser (Shimadzu, Japan).

2.6 NH_4^+-N

All NH_4^+-N analyses have been conducted with cell tests (Method: 1.14558) from Merck KGaA (Germany). The measuring range of this method is 0.2 – 8 mg/L. The standard deviation is ± 1.0% [6].

3. Experimental results and discussions

It is the purpose of this experimental work to compare the performance of two similar commercial UF membrane modules as a first step so that in a follow up work two membrane modules consisting of different membrane materials can be compared in the activated sludge tank under same conditions. The MBR tank was initially filled with activated sludge from a municipal sewage treatment plant and kept at 20°C over the entire experimental period. The starting mixed liquor suspended solids (MLSS) was around 4 g/L and increased in the course of the experimental period to around 14 g/L. The food to microorganisms (F/M) ratio ranged between 0.1 – 0.25 kg COD/ kg MLSS.d and the organic loading rate (OLR) 0.8 – 2.0 kg COD/m^3.d.

3.1. Flux and TMP

Fig. 3 shows the flux and transmembrane pressure (TMP) of the two separate commercial UF membrane modules (denoted as Com1 and Com2) over a period of 70 days. In the acclimation phase, the fluxes of both membranes were kept around 1.2 L/m^2.h. Subsequently they were increased to 2.0 - 2.5 L/m^2.h. However, it was impossible to exactly adjust the same flux for both modules, which was shown by trying to set the different pump speed on day 27 (Fig. 3). As can be seen in Fig. 3 the TMP was almost constant around 40 – 60 mbar despite increase of the water flux.

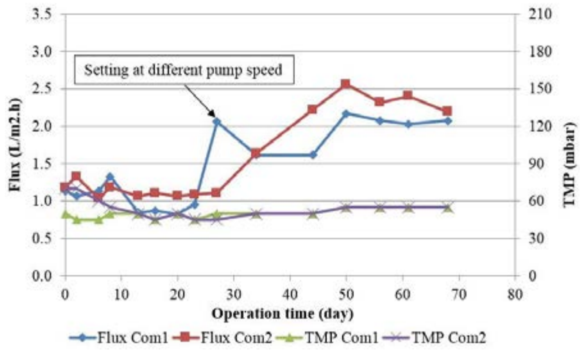

Fig. 3. Flux and TMP of the MBR experiments

3.2. Water permeability

The water permeability (WP) of the experimental series is shown in Fig. 4. In the first part until day 20 the WP of Com1 and Com2 fluctuated around 20 L/m^2.h.bar. After having increased the water flux on day 27, the flux of the membrane modules was between 30 and 45 L/m^2.h.bar. When comparing WP with the values of water flux it is notable that the WP rises with increasing water flux and hence WP is not independent of the TMP (Fig. 3, Fig. 4). This needs to be studied in further work.

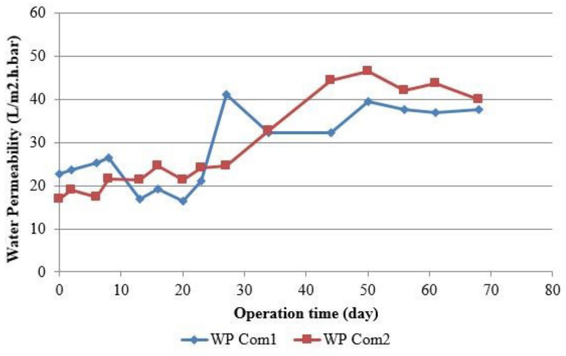

Fig. 4. Water permeability of the MBR experiments

3.3. Hydraulic Residence Time (HRT)

Fig. 5 shows the HRT of the carried out experiments. The HRT fluctuated between 55h and 70h until day 27. Subsequently, the HRT dropped down to 30h due to the increase of water flux and remained stable at around 30h from day 50.

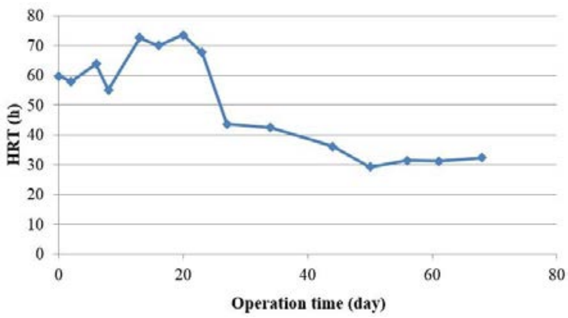

Fig. 5. HRT of the MBR experiments

3.4. Permeate COD and COD removal efficiency

Fig. 6 represents the COD removal efficiency for the entire duration of the experimental study. The result demonstrates very good agreement of COD removal ability for both membrane modules (Com1, Com2). The average feed COD was around 2367 mg/L (Table 2). Typically, COD removal efficiency indicates good performance above 95%. There were some instances when the efficiency slightly dropped most notably on day 6, day 16 and day 23 due to overflow of the MBR tank because of strong foaming. On day 23 the volume of reactor tank was half emptied and subsequently refilled which new sludge resulting in a slight drop of MLSS (drop < 1g/L).

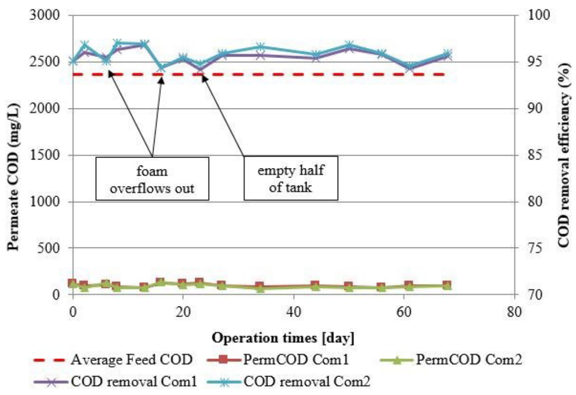

Fig. 6. COD removal efficiency

3.5. Effect of HRT on COD removal efficiency

Fig. 7 indicates that COD rejection was independent of HRT. The COD removal efficiency fluctuated at around 95% even when the HRT dropped down from 70h to 30h. It can be concluded that for the entire experimental period there was no dependency between HRT and COD removal.

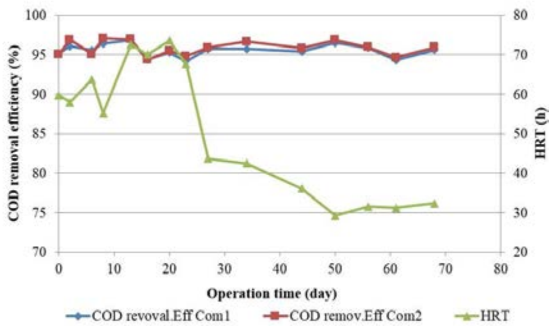

Fig. 7. COD removal efficiency

3.6. Dye removal efficiency in permeate

Since the membrane that was used in the MBR module had a molecular weight cut off (MWCO) of 150 kDa the red and blue dyes with molecular weight of 380.4 g/mol and 626.5 g/mol respectively should be allowed to pass through the membrane. In contrast, Fig. 8 shows a rejection for the red dye between 15-70% and for the blue dye between 30-80% respectively. It could be explained that the applied dyes are negatively charged and the MBR module is also negatively charged. Therefore, it could be a charged exclusion mechanism, which might have resulted in dye rejections [4]. In addition the dyes were partly degraded by biological process [4].

The result shows both UF membrane modules (Com1, Com2) had similar color rejection (Fig. 8). Whereby the red dye removal efficiency was generally lower than rejection of the blue dye. This can be attributed to the fact that the red dye is an azo dye which show typically low biodegradability under aerobic condition [7]. In general efficiency of biodegradation is higher during the first phase (until day 23) compared to second phase which can be attributed to higher HRT.

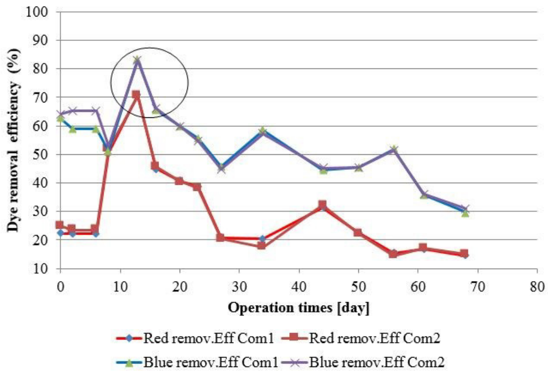

Fig. 8. Red and Blue dye removal efficiency

3.7. N-Balance

The source of total-N (TN) depends on the chemicals used for MTDW. In this work, the main sources of nitrogen (N) were the red dye, blue dye, and NH_4Cl.

Fig. 9 shows the N-balance during the experimental period regarding TN, N-NO_3^- and NH_4^+ in the permeate. Firstly it can be seen that the TN concentration in the permeate is significantly lower than the TN concentration in the feed solution (78 mg/L, Table 2) which might be attributed to an N-uptake into the activated sludge since the MLSS increased from around 4 g/L to 14 g/L during the entire experimental period.

As for the other experimental parameters also TN, NO_3^- and NH_4^+ in the permeate of both membrane modules are in very good agreement. After a short initial period the system showed complete nitrification (Fig. 9) since the NH_4^+ was entirely converted into NO_3^-. This can be attributed to sufficient DO (6–8 mg/L) and high sludge age. It is known from literature that generally MBRs exhibit high nitrification rates due to high sludge age [3, 8]. Decrease of nitrification rate from day 45 can be explained by decrease of HRT and therefore higher food to microorganism (F/M) ratio (> 0.2 kg COD/kg MLSS.d).

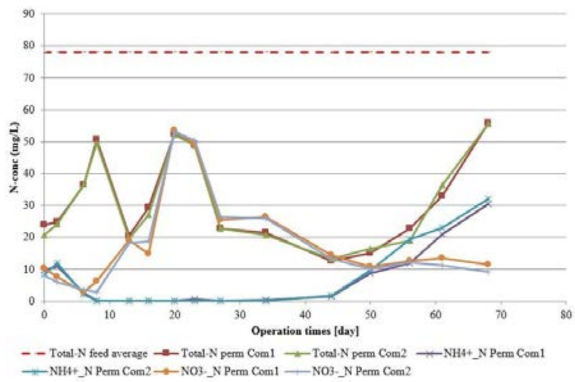

Fig. 9. N – Balance

4. Conclusion and Outlook

Within this experimental work a laboratory-scale membrane bioreactor (MBR) pilot plant has been developed which allows to test two small membrane modules (membrane area 0,33 m^2, each) independently in the same activated sludge tank (60 L). Performance of two commercial UF membranes from Microdyn-Nadir have been analyzed with a model textile dye wastewater (MTDW). Both membrane modules showed good agreement for all tested parameters such as e.g. COD, dye removal, total-N (TN), N-NO_3^- and N-NH_4^+ removal efficiency. The MBR showed high COD removal efficiency (>95%) which was independent from HRT (30-70 h). The MBR had complete nitrification below F/M ratio of 0.2 kg COD/(kg MLSS.d). However, the color rejection for the model dyes was generally only around 20% to 60% and showed a trend to lower values with shorter HRT what can be attributed to the low biodegradability of these chemicals. The next step is to run the MBR with novel nanostructured membranes in parallel with the commercially available membrane to compare their performances. This study contributes to sustainable development in the textile industry by improving water quality of treated textile wastewater what helps to reduce fresh water consumption and pollutant discharge.

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