Effect of Organic Loading Rate on the Performance of a Membrane Bioreactor (MBR) Treating Textile Wastewater

Wimonmas Boonyungyuen, Watcharapol Wonglertarak, and Boonchai Wichitsathian

***Abstract*—**The paper aims at studying the effect of organic loading rate on the performance and degradation of a membrane bioreactor (MBR) treating textile wastewater, which contaminated Reactive Red141 operated at organic loading rate 1 kg/m^3•d. under the textile wastewater treatment by anaerobic digestion. Effect of organic loading rate (OLR), MBR at low OLR can operate longer than MBR at high OLR. because of dissolved and colloid organic concentration accumulated on membrane surface. This causes external fouling, mainly membrane fouling. However, MBR at 0.13-0.52 kg/m^3.d showed organic matter removal in BOD at 78.5–89.8%. MBR effluences remain few, readily biodegradable organic matters, and have similar organic matter removal because the membrane can collect enough microorganism within system to degrade organic matter.

***Keywords*—** Organic loading rate (OLR), membrane bioreactor (MBR), biodegradation, filtration performance.

I. Introduction

TEXTILE industry is one of the greatest generators of liquid effluent wastewater. The effluents from these industries are complex, containing a wide variety of products, such as dyes, detergents, humectants, oxidants, etc. Colored effluents into rivers reduced dissolved oxygen concentration and created toxic effect on the germination rates of biomass. Several methods are used to achieve decolourization of textile effluents such as physicochemical and biological. Physicochemical are effective but they are expensive and create a secondary disposal problem [1]. Biological processes are ecofriendly microbial decolorization and detoxification and more cost-effective. However, textile effluents have low biodegradability, toxicity and color issues. Recently, application of a membrane bioreactor (MBR) has been widely recognized for innovation of wastewater treatment processes [2]. MBR has more advantages than conventional treatment methods, such as having stable and better effluent quality, high volumetric load and less surplus sludge production [3]-[4]. Limitation of MBR system is that organic loading affects microorganism growth and degradation capability and creates some problem for membrane performance. In order to develop better treatment of textile wastewater, the objective of this work was to study the effect of organic loading rate on the performance and degradation of a submerged membrane bioreactor (MBR) treating textile wastewater, which contaminated Reactive Red141.

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II. Materials And Method

A. Synthetic textile wastewater

Synthetic textile wastewater was prepared by desizing, scouring bleaching, mercerizing, dyeing and finishing process in textile industry. The components of the synthetic dyeing wastewater containing 100 mg/L reactive red 141 dye used in this study were obtained from DyStar Thai Co., Ltd. Thailand., 900 mg/L starch, 150 mg/L polyvinyl alcohol (PVA), 50 mg/L polyarcylic acid and 110 mg/L NaOH, nutrients: 67 mg/L KH_2PO_4, 26 mg/L $CaCl_2$•$2H_2O$, 28 mg/L $MgSO_4$•$7H_2O$ and 6 mg/L $FeCl_3$•$6H_2O$ and 1 ml/L of a trace element solution containing 5000 mg/L $FeSO_4$•$7H_2O$, 392 mg/L $CuSO_4$•$7H_2O$, 248 mg/L $Co(NO_3)2$•$6H_2O$, 177 mg/L NaB_4O_7•$10H_2O$, 100 $MnCl_2$•$4H_2O$, 25 mg/L NiCl7•$6H_2O$ and 11 mg/L $ZnSO_4$•$7H_2O$.

B. Experimental setup

The experimental setup used for this study is shown in Fig. 1. The two-stage system consisted of an anaerobic digestion and an aerobic MBR. The anaerobic system contained a 20 L and organic loading 1 kg/m3•d. The aerobic MBR part used had a working volume of 10 L and contained a hollow fiber membrane (0.9 m^2 membrane surface area, 0.4 µm pore size and polycrylonitrile). The effluent stream was controlled by peristaltic pump at the flow rate based on HRT 24, 12 and 6 h (OLR 0.13, 0.26 and 0.52 kg/m^3.d).

C. Analytical methods

The performances of the reactors were analyzed for COD, BOD, TKN, TP and MLVSS were determined according to the Standard Method [5]. The carbonaceous material characterizations measured in terms of the COD parameter were subdivided into a number of fractions following [6]. The

flux was measured using a calibrated cylinder and a stopwatch. A transmembrane pressure (TMP) was measured using vacuum gauge with monitoring pressure difference across the membrane module.

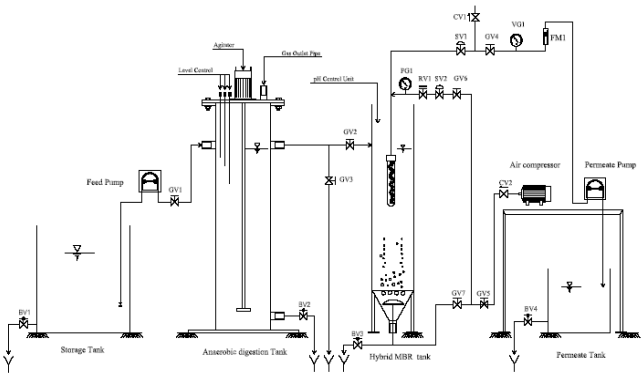

Fig. 1 Scheme of the experimental plant.

III. Results and Discussion

A. Effect of different organic loading rate on filtration operation

The filtration operations were terminated for MBR system when the TMP reached and permeable flow decreased. It is shown in figure 2 a. b. and c. which is the change in TMP and flux over time for the experiments in MBR system. MBR system was maintained at OLR 0.13, 0.26 and 0.52 kg/m^3.d. At OLR 0.13 kg/m^3.d could be lagged for about 1.67 and 6.25 times compared to the MBR system at OLR 0.26 and 0.52 kg/m^3.d, respectively.

Fouling can be classified into 2 parts shown in the table 1, which are irreversible fouling and irrecoverable fouling. Irreversible fouling at OLR 0.13, 0.26 and 0.52 kg/m^3.d was 6.35×10^{-3}, 8.43×10^{-3} and 1.18×10^{-1} mbar/min, respectively.

TABLE 1
FOULING TYPE OF MBR

OLR (kg/m^3.d)	Fouling Type	
	Irreversible fouling (mbar/min)	Irrecoverable fouling (mbar/min)
0.13	6.35×10^{-3}	4.72×10^{-5}
0.26	8.43×10^{-3}	1.94×10^{-4}
0.52	1.18×10^{-1}	-

High OLR shows higher irreversible fouling than low OLR. Because irreversible fouling arisen from interactions of some dissolved and colloid matter on membrane could be removed by physical and chemical cleaning with external fouling rate, it is mainly fouling, whereas irrecoverable fouling is clogging in membrane pore, which cannot be removed by chemical cleaning. MBR at OLR 0.13 and 0.26 kg/m^3.d has irrecoverable fouling at 4.72×10^{-5} and 1.94×10^{-4} mbar/min, respectively. OLR at 0.52 kg/m^3.d did not show irrecoverable fouling because the flow direction is dead-end filtration, which is high concentration of polarization. As a result, mainly fouling type is external fouling, which has effects on cake layer and prolong operation.

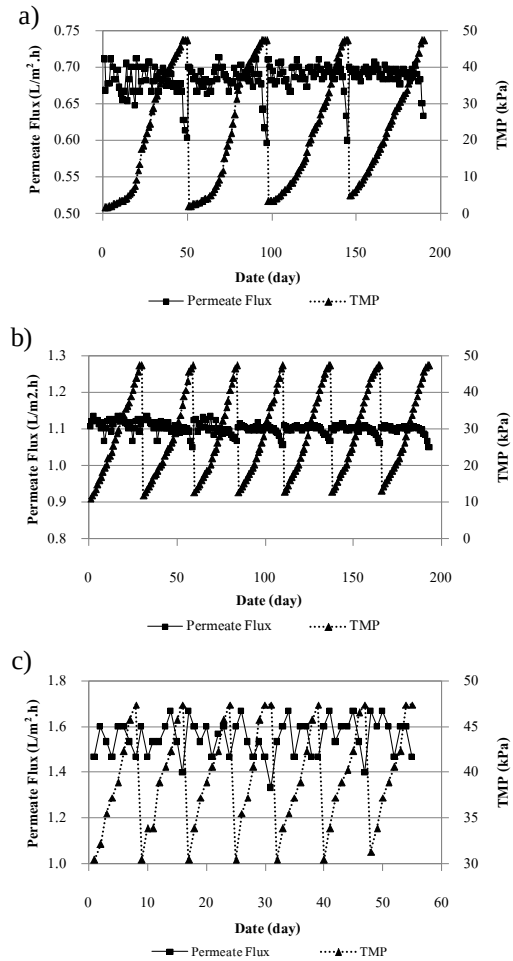

Fig. 2 Permeate Flux and TMP profile
a) OLR 0.13 kg/m^3.d (HRT 24 hr);
b) OLR 0.26 kg/m^3.d (HRT 12 hr);
c) OLR 0.52 kg/m^3.d (HRT 6 hr)

B. Effect of different organic loading rate on organic matter removal

The anaerobic digestion and MBR was continuously operated for 380 d. MBR system maintained MLVSS concentration at about 10 g/L. Table 1 shows the average water quality of the influent wastewater, anaerobic and MBR effluent, and summarizes the average efficiency of treatment system. The anaerobic digestion can remove soluble organic matter in SCOD and SBOD at 82.8% and 51.1%, respectively,

TABLE II
WATER QUALITY AND EFFICIENCY OF TEXTILE WASTEWATER TREATED BY ANAEROBIC DIGESTION AND MBR

parameter	Textile Wastewater	Anaerobic Effluent		MBR Effluent					
				OLR 0.13 kg/m^3.d (HRT 24 hr)		OLR 0.26 kg/m^3.d (HRT 12 hr)		OLR 0.52 kg/m^3.d (HRT 6 hr)	
	(mg/L)	(mg/L)	% removal	(mg/L)	% removal	(mg/L)	% removal	(mg/L)	% removal
TCOD (mg/L)	1,000.0±58.0	256.5±27.1	69.2±1.7	84.4±10.2	67.1±1.9	109.8±5.0	57.2±2.1	132.0±4.3	48.5±4.4
SCOD (mg/L)	714.0±41.0	122.7±11.0	82.8±0.7						
$TBOD_{20}$ (mg/L)	150.1±5.9	109.6±5.0	27.0±0.2	11.2±0.3	89.8±0.2	19.7±2.0	82.0±0.4	23.6±1.2	78.5±0.7
$SBOD_{20}$ (mg/L)	107.2±1.5	52.4±6.7	51.1±0.8						
TKN (mg/L)	8.8±1.3	6.9±0.3	20.8±7.2	2.5±1.2	63.6±17.2	2.6±0.3	62.3±7.4	3.2±0.2	53.6±2.3
TP (mg/L)	5.0±0.2	2.2±0.03	55.4±0.6	0.9±0.1	59.2±2.2	1.1±0.06	50.0±2.7	0.98±0.02	55.5±1.6
Color (ADMI)	2,179.7±88.0	1,240.7±81.8	43.1±1.5	93.5±11.5	92.8±4.3	153.7±20.4	87.0±8.5	163.4±12.2	86.8±1.9

TABLE III
COD FRACTIONS AND BOD/COD RATIO OF THE INFLUENT AND EFFLUENT ANAEROBIC AND MBR PROCESS.

parameter	Textile Wastewater		Anaerobic Effluent		MBR Effluent					
					OLR 0.13 kg/m^3.d (HRT 24 hr)		OLR 0.26 kg/m^3.d (HRT 12 hr)		OLR 0.52 kg/m^3.d (HRT 6 hr)	
	COD (mg/L)	% of TCOD	COD (mg/L)	% of TCOD	COD (mg/L)	% of TCOD	COD (mg/L)	% of TCOD	COD (mg/L)	% of TCOD
Readily biodegradable (S_s)	107.20	10.72	52.40	20.43	11.20	19.27	19.70	17.95	23.60	17.88
Slowly biodegradable (X_s)	42.90	4.29	57.20	22.30	-	-	-	-	-	-
Soluble inert (S_i)	606.80	60.68	70.30	27.41	73.20	86.73	90.06	82.05	108.40	82.12
particulate inert (X_i)	243.10	24.31	76.60	29.86	-	-	-	-		-
BOD_{20}/COD	0.150		0.448		0.133		0.179		0.179	

which is higher than particulate organic matter removal because anaerobic process can absorb soluble matter on microorganism surface and/or dead cell composition [7]. The average TKN removal is limited because organic nitrogen transfers to nitrogen gas under anaerobic condition. Colors can be removed by cleavaging of azo dye linkages. Anaerobic effluent has characteristics that cannot be discharged to environment.

Therefore, using MBR to treat anaerobic effluent under organic loading rate (OLR) of 0.13, 0.26 and 0.52 kg/m^3.d, different OLR has similar organic matter removal, it shows organic matter removal in BOD at 89.8%, 82.0% and 78.5%, respectively because membrane can filtrate microorganisms within system, which can degrade higher organic matter than the system that has the F/M ratio of 0.26-0.50 d^{-1}. However, TKN and TP removal could be enhanced under low OLR operation, because carbon source was limited. MBR system under aerobic condition can remove colors at OLR 0.13 kg/m^3.d higher than 0.26 and 0.52 kg/m^3.d by about 5-6%, which is slightly different because oxygen inhibition can affect color removal. So, retention time for degradation supports color removal [8].

Low OLR can remove organic matter higher than high OLR because the membrane can filtrate microorganisms within system, which can degrade higher organic matter than the system that has the F/M ratio of 0.26-0.5 d^{-1}. MBR system under aerobic condition can remove colors at OLR 0.13 kg/m^3.d higher than 0.26 and 0.52 kg/m^3.d by about 5-6%, which is also slightly different because oxygen inhibition affects color removal. So, retention time for degradation can support color removal [8]. However, TKN and TP removal could be enhanced under low OLR operation because carbon source was limited.

C. Biodegradation analysis

The biodegradation was monitored by COD fraction and BOD/COD ratio. COD fraction of textile wastewater, anaerobic digestion and MBR effluent at organic loading rate 0.13, 0.26 and 0.52 kg/m^3.d were shown in Table 3. Textile wastewater has low BOD/COD ratio of 0.15 and high soluble inert (S_I) ratio of 60.7% of TCOD, which is hardly biodegradable. This caused azo dyes high dissolution capability in water solution, thus meets at high SCOD, and structure of azo dyes is more complex and has larger molecules, which have low biodegradability by heterotroph bacteria. However, anaerobic digestion can hydrolyze restricted biodegradable matter and absorb on microorganism surface and/or dead cell composition [7].

This causes S_I to reduce to 93.5%. Anaerobic effluent has the BOD/COD ratio of 0.43, higher than wastewater influent, but which has high hardly biodegradable ratio. However, MBR can collect microorganism in order to support high volumetric load than conventional system. The MBR effluent at OLR 0.13 kg/m^3.d has readily biodegradable ratio less than MBR at other OLR by about 4.6 - 4.7%, which confirms that the BOD/COD ratio of MBR at OLR 0.13

kg/m^3.d is lower than MBR at high OLR, because microorganism can degrade suitable organic content and the prolonged contact time between the organic matter and the biomass [9]-[10]. In particulate part including slowly biodegradable and particulate inert, the membrane can completely filtrate in this part.

IV. Conclusions

On the effect of organic loading rate (OLR), MBR can operate longer than MBR at high OLR. Because dissolved and colloid organic concentration accumulates on the membrane surface. It causes external fouling, mainly membrane fouling. However, MBR at 0.13-0.52 kg/m^3.d shows organic matter removal in COD at 48-67%. MBR effluences remain few readily biodegradable organic matters and show similar organic matter removal because the membrane can collect enough microorganism within system to degrade organic matter.

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