Submerged Membrane Bioreactor with Chitosan Bead Addition and Optimization of Operational Parameters

Maneerat Tiranuntakul

Division of Chemical Engineering, Faculty of Engineering,

Rajamangala University of Technology Krungthep, Bangkok 10120 Thailand

Tel. and Fax. 02-2879600 ext. 1210, E-mail: maneefrat.t@rmutk.ac.th

Abstract

In the present study the influence of suction flux, chitosan bead addition and aeration intensity on fouling was investigated using 2^3 factorial designs. Maximum and minimum values for suction flux (4–8 L/m^2.h), chitosan bead addition (0.25–0.5 g/g MLSS) and aeration intensity (0.3–0.6 m^3/m^2.h) were adopted as the base of membrane bioreactor operation for synthetic wastewater treatment. Concerning the fouling ability of the three factors, suction flux was observed to have the largest effect on resistance increase followed by aeration intensity and chitosan bead addition. The best recommendation of the system operation was performed at low suction flux with high aeration intensity and high chitosan bead addition.

1. Introduction

Over the last decades, a modification of the conventional activated sludge process using submerged membranes technology called submerged membrane bioreactor (SMBR) has been used to separate of the effluent, replacing sedimentation, which reduces the plant size due to the absence of settling tanks. Although their several advantages are well recognized, the SMBR process also has as its principal limitation on membrane fouling, which causes permeate flux decline and necessitates frequent cleaning and/or replacement of membranes.

One of the strategies to reduce fouling in SMBR is to adding antifouling agent such as diatomaceous earth (DE) [1], perlite (natural form of glass, i.e. siliceous rock) [2], and fibrous materials (plant and wood fibres). DE which is conventionally used for filtration of beer and sugar beet, can cause health hazards while its waste disposal can be troublesome [3]. Furthermore, while it is known that if the DE dose is increased the average cake resistance decreases [4], it was shown that a coating on a membrane often does not form properly resulting in the formation of cracks and defects [2]. Perlite, on the other hand, has been used safely for over 50 years in a variety of applications, but since it is a dust it also acts as an irritant, which can result in temporary physical irritation, discomfort and impaired vision [5]. In brief, both DE and perlite have disadvantages because of their hazards and membrane defects.

Chitosan is a polycationic polysaccharide that is produced by the thermochemical alkaline deacetylation of chitin [6]. Chitosan is inexpensive, environmentally benign (non-toxic), harmless to humans and biodegradable [6]. Therefore, one of the possible ideal materials which can mitigate SMBR fouling and causes no harm to health and environment

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is chitosan. It is the aim of this study to examine the impact of chitosan beads as an antifouling agent in a membrane bioreactor. A detailed evaluation of fouling influenced by suction flux, chitosan bead addition and aeration intensity was performed. The behavior of the filtration process in a submerged MBR under varying operational conditions was investigated in the first step. The influence of these factors on fouling was then analyzed. By this means optimum operational conditions were identified.

2. Experimental Materials and Method

2.1 Experimental Facility

A pilot scale SMBR used in this study was consisted of a 60 liter aerobic unit fitted with a submerged flat-sheet membranes. The membrane material is chlorinated polyethylene with nominal pore size 0.4 µm. Permeate was removed using a pump passing through permeate line. Pressure gauge was also located on the permeate line. The aeration process was conducted using a blower and controlled using air rota-meter.

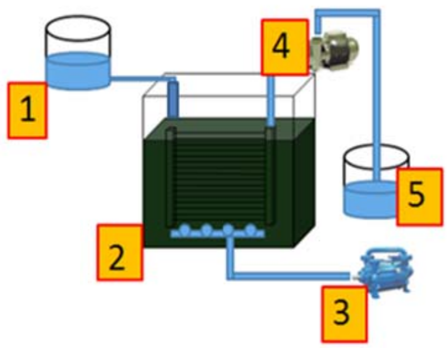

Figure 1 Schematic diagram of the system: (1) feed tank, (2) submerged membrane bioreactor, (3) blower, (4) suction pump, (5) Permeate tank

Schematic diagram of the system was shown in Figure 1 The components and quality of synthetic wastewater in the study was also showed in table 1.

Table 1 synthetic wastewater used in the study (mg/L)

Components	Concentration
glucose	360
Protein	80
$NaHCO_3$	24
KH_2PO_4	14
NH_4Cl	60
$CaCl_2$	18
$MgSO_4.7H_2O$	24
COD	300

2.2 Preparation of chitosan beads

Chitosan solution was prepared by dissolving 20 g of dry flake chitosan (degree of deacetylation, 85 DD%) into 1 liter of 2.0 %v/v of acetic acid solution. It was stirred by mechanical motor stirrer at room temperature till dissolved all. Chitosan solution was dropped into 1 M NaOH to form chitosan beads. The chitosan beads were washed by DI water several times till pH of washed waster become 7.

2.3 Experimental Design

The influence of suction flux, chitosan bead addition and aeration intensity on fouling was investigated at maximum and minimum level, yielding a 2^3 factorial design as shown in table 2. Maximum (+) and minimum (-) values for suction flux (4–8 $L/m^2.h$), chitosan addition (0.25–0.5 g/g MLSS) and aeration intensity (0.3–0.6 $m^3/m^2.h$) were adopted as the base of membrane operation. Experimental period in each run was fixed at 100 hours.

Membrane cleaning was performed at the end of each experiment. During chemical cleaning operations, membrane was removed from the activated sludge reactor. The membrane module was flushed with tape water in order to remove the visible cake layer and then immerged for 60 min in a solution containing 500 ppm sodium hypochlorite and 0.5% (v/v) detergent [7]. Tap water permeability was consecutively determined by using a filtration test at increasing fluxes.

Table 2 Assignment of operational parameters in the 2^3 factorial design

Run	Suction flux	Chitosan bead addition	Aeration intensity
1	-	-	-
2	-	-	+
3	-	+	-
4	-	+	+
5	+	_	-
6	+	_	+
7	+	+	-
8	+	+	+

To determine the influence on fouling of the selected operational parameters, the increasing rate of filtration resistance (k) was determined as responding value as calculated in equation 1 and 2.

From Darcy's Law:

$$J = \frac{\Delta P}{\mu R} \quad (1)$$

and

$$k = \frac{\Delta R}{\Delta t} \quad (2)$$

where J is the permeate flux, ΔP the trans-membrane pressure (TMP), μ the viscosity, R the filtration resistance (1/m), k the filtration resistance rate (1/m.hr).

3. Results and Discussion

3.1 Membrane fouling rate

In this study, the changing course of flux was monitored over each experiment. The membrane filtration resistance increased with time in all the experiments as shown in Figure 2 (where experimental run no. 3 is shown as example). For the most part of the experiment a linear progress of resistance was observed. The increasing rate of resistance (k) was therefore assessed as slope of the increasing resistance during this period ($\Delta R/\Delta t$) as a good linear fit was obtained (R^2 = 0.81). The initial portion of the curve is not linear and was therefore eliminated for calculation of k.

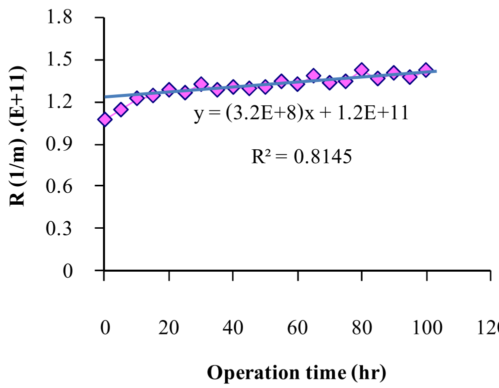

Figure 2 The changing course of filtration resistance (R) over an experiment. The linear regression slope was taken as the increasing rate of resistance k.

3.2 Calculation of main effects

In table 3, k-values for each run within the experimental design are given. Runs 5 and 2 exhibit highest and lowest fouling and therefore represent fouling benchmarks within the range of operational parameters investigated in this study.

Table 3 Experimental results of resistance increase (k)

Run	Suction flux	Chitosan addition	Aeration intensity	k (1/m.hr)
1	-	-	-	4.3E+8
2	-	-	+	2.0E+8
3	-	+	-	3.2E+8
4	-	+	+	2.4E+8
5	+	_	-	17.5E+8
6	+	_	+	5.8E+8
7	+	+	-	7.3E+8
8	+	+	+	4.4E+8

From table 3, the influence of suction time on fouling is clearly visible. All experiments operated at low suction flux showed decidedly lower fouling. To define more precisely the relative effect of each operating parameter, the main effects as well as the two and three factor interactions were calculated according to the method prescribed in [8].

As shown in Figure 3, suction flux was observed to have the largest effect on resistance increase. Cake layer formation strongly depends on the membrane filtered volume due to convective transport of dispersed particles, colloids and molecules [7]. Thus, a reduction of permeate suction enhances back transport of cake layer particles, mainly caused by aeration induced shear stress forces as well as chitosan bead scouring on membrane surface [7]. Similar results of suction flux were published in [7, 9, 10]. In this study, the influence of suction flux, aeration intensity and addition of chitosan beads on TMP-increase were investigated. At given flux and MLSS (4,300 mg/L), magnitude of suction flux was found to have strongest influence on fouling.

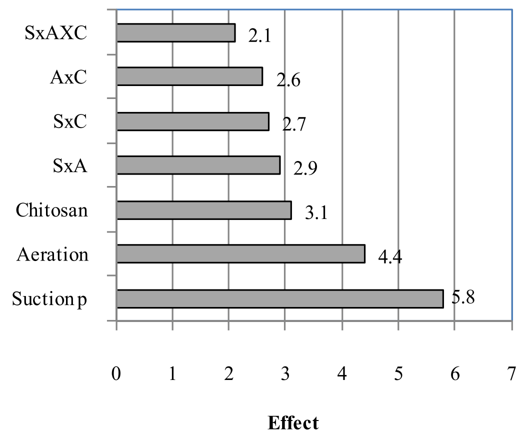

Figure 3 Main effects of the operational parameters on resistance increase and interactions.

The efficiency of air induced crossflow to remove or at least reduce the fouling layer on the membrane surface has been extensively reported [7, 9, 11]. Confirming previous studies, aeration intensity was also very effective in hindering fouling. Addition of chitosan beads contributed to cake layer removal at a smaller level than aeration intensity. A change in amount of chitosan bead adding from low to high resulted in an average decrease of k by 3.1, while the main effect of aeration intensity was 4.4. For the removal of pore clogging, which is assumed to be a substantial part of total resistance in this study, aeration and chitosan bead addition was effective. However, a sustainable reduction of fouling to its initial suction value has not been much observed. This result corresponded to findings obtained by Le Rouxa et al. [10] who studied the effect of flake chitosan on membrane fouling and found that one gram chitosan per biomass of yeast helped to reduce filtration resistance of 57%.

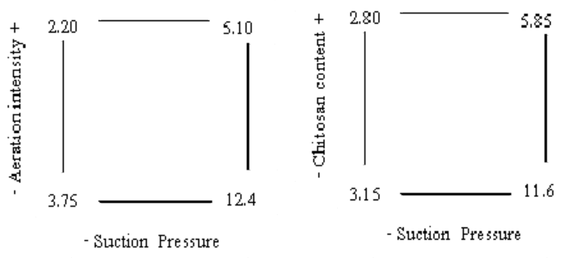

Figure 4 two-way tables for aeration intensity–suction flux and chitosan addition–suction flux interactions

Both, aeration intensity and chitosan bead addition exhibited significant interactions with suction flux. These interactions can be best considered using the two-way table (Figure 4). Because of the general symmetry of the experiment, two sets of measures for each combination of aeration intensity, chitosan bead addition and suction flux are available. The two-way table is obtained by calculating the average of the two measures for each combination [8].

In Figure 4, aeration intensity/chitosan bead addition by suction flux interactions evidently arise from a difference in sensitivity to suction flux for both operational parameters. With suction flux at (-), a change in aeration intensity and chitosan addition affected resistance increase by 1.55 and 0.35, respectively. This is implied that the increase of chitosan bead addition from 0.25 g/gMLSS to 0.5 g/gMLSS showed little benefit in fouling reduction at low suction force. At high suction flux (+), an increase of aeration intensity or chitosan bead addition affected fouling decidedly stronger as a decrease in k of 7.3 and 5.75, respectively has been observed. Obviously, aeration intensity and addition of chitosan bead outbalanced enhanced cake layer formation due to enlarged suction flux. Compared to chitosan bead addition, aeration intensity seems to be more effective at both low and high suction flux. However, the combined application between aeration intensity and chitosan bead addition showed great efficiency in hindering fouling.

4. Conclusions

The influence of variation of suction flux (4–8 $L/m^2.h$), chitosan bead addition (0.25–0.5 g/g MLSS) and aeration intensity (0.3–0.6 $m^3/m^2.h$) on the rate of resistance increase was investigated. The 2^3 factorial design proved to be a very valuable tool to evaluate fouling effects. The major conclusions which can be drawn are:

Suction flux strongly affected resistance increase, followed by aeration intensity and chitosan bead addition. Both, aeration intensity and chitosan bead addition strongly affected fouling at high suction flux.

The requirements in case of fouling can be best met when the system was operated at low suction flux by using high aeration intensity and high chitosan bead addition.

In order to kept minimum energy consumption from aeration (low aeration intensity), chitosan bead addition is a positive option to reduce fouling.

5. Acknowledgement

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6. References

[1] V. Palacios, et al., “Comparative study of crossflow microfiltration with conventional filtration of sherry wine”, J. Food Eng., Vol. 54, 2002, pp. 95–102.

[2] G. Meindersma, et al., “Separation of a biocatalyst with ultrafiltration or filtration after bioconversion”, J. Membr. Sci., Vol.125, 1997, pp. 333–349.

[3] Anon, “Leading filtration companies aim to improve beer and wine filtration”, Membr. Technol., Vol. 3, 2003, p 1.

[4] F. Kar and N. Arslan, “Filtration of sugar-beet pulp pectin extract and flow properties of pectin solutions”, J. Food Eng., Vol. 36, 1998, pp. 113–122.

[5] The Perlite Institute, Health Effects of Perlite, http://www.perlite.org/health.htm.

[6] H. Ping, et al., “Chitosan microspheres prepared by spray drying method”, Eur. J. Pharm. Sci., Vol. 4, 1996, pp. 173-185.

[7] P Schoeberl, et al., “Optimization of operational parameters for a submerged membrane bioreactor treating dyehouse wastewater”, Sep. and Purif. Technol., Vol. 44, 2005, pp. 61–68.

[8] G. Box, et al., Statistics For Experimenters, Wiley, New York, 1978.

[9] P. Gui, et al., “Effect of operational parameters on sludge accumulation on membrane surfaces in a submerged membrane bioreactor”, Desalination, Vol. 151, No. 2, 2003, pp. 185–194.

[10] I. le Rouxa, et al., “Use of chitosan as an antifouling agent in a membrane bioreactor”, J. Membr. Sci., Vol. 248, 2005, pp. 127–136

[11] R. Liu, et al., “Hydrodynamic effect on sludge accumulation over membrane surfaces in a submerged membrane

Bioreactor”, Process Biochem., Vol. 39, No. 2, 2003, pp. 157–163.