Journal of Membrane Science 320 (2008) 57–64

Contents lists available at ScienceDirect

Journal of Membrane Science

journal homepage: www.elsevier.com/locate/memsci

Effects of several different flux enhancing chemicals on filterability and fouling reduction of membrane bioreactor (MBR) mixed liquors

H. Koseoglu[a], N.O. Yigit[a], V. Iversen[b], A. Drews[b], M. Kitis[a], B. Lesjean[c], M. Kraume[b,*]

[a] Department of Environmental Engineering, Suleyman Demirel University, 32260 Isparta, Turkey
[b] Chair of Chemical Engineering, Technische Universität Berlin, Straße des 17, Juni 136, MA 5-7, 10623 Berlin, Germany
[c] Berlin Centre of Competence for Water, Cicerostr. 24, 10709 Berlin, Germany

ARTICLE INFO

Article history:
Received 11 January 2008
Received in revised form 6 March 2008
Accepted 7 March 2008
Available online 8 April 2008

Keywords:
Critical flux
Flux enhancing chemicals
Fouling
MBR
Permeability
SMP

ABSTRACT

The main objective of this work was to determine the effectiveness of various chemicals on filterability and fouling reduction in MBR mixed liquors. Different lab-scale experiments were conducted with a total of 7 different additives (3 cationic polymers (MPL30, MPE50, KD452), a biopolymer (Chit), a starch (Sta), and 2 metal salts ($FeCl_3$, PACl)). Initially, batch shaker tests were performed for each additive to determine the optimum dosages in terms of soluble microbial products (SMP) removal. Then, short-term filtration trials and critical flux tests were performed. All tested additives were able to remove SMP, but at different extent; 33, 45, 51, 36, 38, 54, and 56% for MPL30, MPE50, KD452, $FeCl_3$, PACl, Chit, and Sta, respectively. The cationic polymer KD452 exhibited the best performance in terms of the extent of SMP removal and the required dosage. All tested cationic polymers, starch and chitosan significantly reduced fouling rates and increased permeability values. At their optimum dosages, the cationic polymers MPE50, MPL30 and KD452 provided 96, 80 and 74% reductions in fouling rates, respectively. The enhancements in critical flux achieved by MPL30, MPE50, KD452, $FeCl_3$, PACl, Chit, and Sta were 38, 46, 38, 14, 14, 0, and 22% in comparison with raw mixed liquor. Cationic polymers increased critical flux values to levels above 50 L m^{-2} h^{-1}. SMP removal from MBR mixed liquors and further improvement in filtration performance and fouling control did not always correlate. Overall, based on the lab-scale tests conducted, cationic polymeric additives were found to be favorable over the other additives due to their steady and successful performance in fouling control. The performance of cationic polymers was independent of small variations in dosing, while for other additives over- or under-dosing showed detrimental effects on filterability.

1. Introduction

The membrane assisted activated sludge process in a membrane bioreactor (MBR) is a biological wastewater treatment process which employs micro- or ultrafiltration instead of a clarifier to separate biomass from the treated water. Because of its effective retention of biomass in the reactor and the complete removal of particulate impurities from the effluent, the MBR is deemed to be the leading wastewater treatment technology where high quality effluent is required [1–4]. However, membrane fouling is still the major limitation to the wide-spread application of the MBR process with cost effective filtration fluxes since membrane filtration of biosuspensions is a challenging task [5–8]. Various publications indicated that the characteristics of the mixed liquor affect membrane filterability, such as viscosity [7,9–13], extracellular polymeric substances, EPS [7,10,14,15], floc size [7,16–18], colloidal and soluble organic substances [7,19–25]. EPS and SMP (soluble microbial products) have been identified as major foulants in many experimental studies [10,20,26–29] although one study showed contradicting results [30]. The removal of soluble foulants like SMP in the activated sludge is very important since they may potentially cause internal fouling of membranes, and thus decreased membrane filterability [31].

Traditional strategies for fouling prevention mostly try to remedy the effects of fouling by optimization of hydrodynamics and air scour [32]. A new and promising method is to coagulate/flocculate the activated sludge by adding chemicals and thereby to bind colloids and other mixed liquor components in flocs [33,34]. The enhanced filterability in MBR with the addition of fouling reducers was attributed to an increase in floc size and to a decrease in concentration of soluble foulants in the bulk phase [31]. Various different additives including synthetic or natural polymers, metal salts, resins, granular or powder activated carbon have been tested for fouling control in MBRs [7,33–43]. Cationic polymers were found to be promising as they influence EPS aggregation [40]. Yoon et al. [39] indicated that total solids in bioreactor could be raised

* Corresponding author. Tel.: +49 30 31423701; fax: +49 30 31421134.
E-mail address: matthias.kraume@tu-berlin.de (M. Kraume).

0376-7388/$ – see front matter © 2008 Published by Elsevier B.V.
doi:10.1016/j.memsci.2008.03.053

to 50,000 mg L^{-1} without immediate membrane fouling with the addition of 2200 mg L^{-1} of a cationic polymer. Similarly, addition of a cationic polymer increased the critical flux in a pilot-scale MBR [34]. After testing a total of 30 different additives, Iversen et al. [41] have shown that some of the tested additives were able to significantly reduce the concentrations of SMP. Furthermore, they indicated that the additives may also affect the porosity of the cake through formation of larger flocs. Similarly, Hwang et al. [42] reported that the cake in the reactor dosed with polymeric additive exhibited a 1.3 times greater porosity than that in the control reactor. Most of the studies have focused on minimizing cake layer formation and related issues, because the cake is considered to be a major factor in resistance to permeate flux in MBR [27,42,43]. Fang et al. [33] investigated the use of activated carbon to control fouling in activated sludge filtration and found that virgin activated carbon reduced the film filtration resistance by 22%. Wu et al. [7] investigated the effects of polymeric (aluminum chloride and ferric sulfate) and monomeric ($Al_2(SO_4)_3$ and $FeCl_3$) coagulants on the mixed liquor properties and fouling control in MBRs. They found that polymeric coagulants were more effective for filterability improvement due to larger flocs formed by charge neutralization mechanism and decreased supernatant organic fractions. Alum or zeolite addition to MBRs retarded the rising rate of the suction pressure and reduced the specific filtration resistance [35].

Although many studies investigated the impacts of various additives on fouling control in MBRs, the majority of such studies were conducted at irregular intervals under different experimental conditions, which may limit side-by-side comparison of additives for fouling control. In this study, a total of 7 different additives (3 cationic polymers, a biopolymer, a starch, and 2 metal salts) were tested and compared in lab-scale trials for their SMP elimination and fouling control potential in MBR mixed liquors. Unlike many other studies, all additives were tested under the uniformly designed experimental scheme, e.g., using mixed liquors from the same pilot-scale MBR and relatively short test periods to minimize the variations in the characteristics of mixed liquors. Even so, changes in mixed liquor properties cannot be ruled out completely which is why a reference run was always conducted. Furthermore, all necessary adjustments were made in the lab-scale membrane test unit to best simulate hydrodynamic conditions in submerged flatsheet modules. Initially, batch shaker tests were performed for each additive to determine the optimum dosages in terms of SMP removal. Short-term filtration and critical flux tests were conducted to determine the impacts of additives and their dosages on filterability performance and fouling control of the MBR mixed liquors.

2. Materials and methods

The tested additives included three different cationic polymers, a biopolymer, a starch, and two metal salts (Table 1). Batch shaker tests were conducted for each additive at various dosages to determine the extent of SMP removals. The dosage which provided the highest degree of SMP removal or above which no further improvement was achieved was chosen as the optimum dosage for each additive. The MBR mixed liquor samples were obtained from a pilot-scale MBR (with immersed flat-sheet membrane modules) aerobically treating domestic wastewater in the City of Berlin. Fresh MBR mixed liquor samples were taken from the pilot unit about 2 h before the start of a batch test. SMP concentrations were measured for each raw mixed liquor sample. The mixed liquor suspended solids (MLSS) concentrations of the samples ranged between 8 and 10 g L^{-1}. The stock solutions of the additives were prepared in deionized water right before the batch tests, except for the chitosan solution which was prepared about 12 h before dosing to beakers. This duration was necessary to activate the chitosan. The stock solutions of all additives were mixed about 1 h for homogenization before batch tests. The stock solutions of starch and chitosan were also heated during mixing. After preparation of the additive stock solutions, the batch tests were immediately started. Raw or additive-dosed mixed liquor samples (200 mL) were mixed in 500-mL glass beakers in a reciprocating shaker (GFL 1083) for 1 h, at $20 \pm 0.5\,^{\circ}C$ temperature and a frequency of 130 min^{-1}. The shaker was provided with a thermo-stated bath in which a mobile tray with adjustable speed permits the mixing of the beakers. After contact with the additive for 1 h, mixed liquor samples were filtered (Whatman, black ribbon) prior to SMP analysis. Concentrations of protein and polysaccharide fractions of SMP were determined based on the methods reported by Lowry et al. [44] and Dubois et al. [45], respectively. Total SMP concentrations reported are the sum of the concentrations of protein and polysaccharide fractions. SMP measurements were conducted in duplicate.

In the second phase of the work, short-term (2 h) mixed liquor filtration tests were conducted in constant flux mode (27 L m^{-2} h^{-1}) to investigate the influence of additive concentration on short-term fouling/filterability and to prove if the optimum dosage in terms of SMP removal is equal to the optimum dosage in terms of filterability improvement, in which case it could be established as a quick test for the determination of the required additive dosage for a given mixed liquor. For each additive, three different dosages were employed in filtration tests: optimum dosage (found from the batch tests), one-step lower and one-step higher dosage (as employed in batch tests) than the optimum dosage. Furthermore, filtration tests were also conducted with raw mixed liquor samples taken on the same day to compare the results with those of mixed liquor samples spiked with additives. Similar to batch SMP removal tests, mixed liquor samples were obtained from the same pilot MBR unit with MLSS concentrations of about 8–9 g L^{-1}. The short-term mixed liquor filtration tests were conducted in a cross-flow lab-scale MBR test unit (Fig. 1). All necessary adjustments (i.e., using a channel height of 5 mm, introducing air at a representative superficial gas

Table 1
Tested additives and their optimal dosages for SMP removal

Category	Supplier	Abbreviation	Product	Optimal dosage found in this work (mg L^{-1})	Optimal dosage found in the previous work[a] (mg L^{-1})	Other information
Metal salt	Merck	$FeCl_3$	–	85	NA[b]	Ferro chloride
	Ciba	PACl	Magnasol 5108	100	100	Alum polymer
Biopolymer (chitosan)	France Chitine	Chit	Chitosan 221	250	200	Flakes
Polymer	Nalco	MPE50	MPE-50	500	500	Cationic
	Kurita	MPL30	MP L 30	600	500	Cationic
	Adipap	KD452	Adifloc KD 452	70	70	Cationic
Starch	Tate & Lyle	Sta	Mylbond 168	1500	1500	Corn starch

[a] Different raw MBR mixed liquor samples were tested in the previous work [48].
[b] Not tested.