Separation and Purification Technology 169 (2016) 43–49

Contents lists available at ScienceDirect

Separation and Purification Technology

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

Influence of different biofilm carriers on the operation and membrane fouling of submerged membrane bioreactors

Tokihiro Kurita, Takuma Mogi, Katsuki Kimura *

Division of Environmental Engineering, Hokkaido University, N13W8, Kita-ku, Sapporo 060-8628, Japan

ARTICLE INFO

Article history:
Received 27 October 2015
Received in revised form 25 May 2016
Accepted 26 May 2016
Available online 27 May 2016

Keywords:
Membrane bioreactor (MBR)
Biofilm carrier
Membrane fouling
Filterability of mixed liquor suspensions

ABSTRACT

It has been reported that the combination process of biofilm and submerged membrane bioreactors (MBRs) can mitigate membrane fouling. In this study, the influence of using three different biofilm carriers (fixed rope carrier, moving granular carrier and moving sponge carrier) on the operation and membrane fouling of MBRs was investigated. Using rope or sponge carriers with MBR processes improved the removal efficiency of nitrogen via the creation of an anoxic part inside the carriers. However, membrane fouling became very severe when rope carriers were used. Using granular or sponge carriers effectively mitigated membrane fouling because they mechanically cleaned the membrane surface. The cake/gel layer on the membrane surface was perfectly removed by granular or sponge carriers. However, the deterioration of the filterability of the mixed liquor suspensions was significant with granular carriers, leading to the evolution of physically irreversible fouling, whereas such deterioration was insignificant with the sponge carrier. The characteristics of the soluble microbial products (SMP) significantly varied depending on the types of carriers used, which could influence the filterability of mixed liquor suspensions and the development of irreversible membrane fouling.

1. Introduction

Introducing granular or sponge materials into submerged membrane bioreactors (MBRs) can mitigate membrane fouling and bring about a stable operation because of their mechanical cleaning effect on the membrane surface [1,2]. Some researchers have demonstrated that the introduction of granules or sponge materials into MBRs effectively removes the cake/gel layer from the membrane surface [3–6]. Additionally, a previous study indicated that the introduction of granules could reduce 50% of the aeration rate in a pilot-scale MBR [7]. Thus, the introduction of granules or sponges into submerged MBRs has the potential to significantly reduce the operation cost.

Some of the materials examined in previous studies were originally developed as biofilm carriers in wastewater treatment. Therefore, when introducing those biomass carriers into MBRs, a certain amount of biomass should be present as biofilm, which may affect the process performances of MBRs. The possession of biofilms in MBRs improved the removal efficiency of nutrients compared to conventional MBRs [1,8,9]. Various types of biofilm carrier configurations are commercially available, including fixed rope or mesh material hung in the reactor [10,11], a gear or cylindrical ring shape of the plastic material suspended in the reactor [4,9,12,13], and granules/sponge suspended in the reactor. In some studies, the fluidizing space for the carriers was separated from the membrane tank to prevent damage to the membrane surface [9,12–15]. It has been reported that the combination of biofilm and the MBR process mitigates membrane fouling by improving the filterability of mixed liquor suspensions [1,4,14–16]. In contrast, some researchers have noted that this combination process induced membrane fouling because of the promotion of the accumulation of cake on the membrane surface [17,18]. These contradicting results suggest that the configuration and/or type of biofilm carriers (moving or fixed in the reactor) used in the combination process influence the characteristics of membrane fouling. To choose an optimum biofilm carrier for the mitigation of membrane fouling in the combination process, the influence of the properties of the biofilm carrier on the characteristics of membrane fouling need to be investigated. However, a comparison among different types of biofilm carriers in terms of the control of the fouling in MBRs has rarely been conducted.

The objective of this study was to investigate the influence of different biofilm carriers on the operation and membrane fouling in MBRs. In this study, a fixed rope carrier, a granular carrier and a sponge carrier were examined. In the cases of granular or sponge

* Corresponding author.
E-mail address: kkatsu@eng.hokudai.ac.jp (K. Kimura).

http://dx.doi.org/10.1016/j.seppur.2016.05.026

carriers, the carriers freely moved in the reactor and made contact with the membrane surface. In contrast, rope carriers were immobilized in the reactor; there was no contact between the carriers and the membrane surface. Bench-scale MBRs with the above-mentioned biofilm carriers were operated continuously side by side with synthetic wastewater. The filtration resistance and components of mixed liquor suspensions in each MBR were investigated. In addition, the characteristics of membrane fouling were analysed and compared from various aspects.

2. Materials and methods

2.1. Operation of bench-scale MBRs

In this study, four identical bench-scale MBRs were operated in parallel. The effective volume of the bench-scale MBRs was 7.5 L. Three MBRs were operated with different biofilm carriers: a rope carrier (denoted as MBR-A hereafter), a granular carrier (MBR-B), and a sponge carrier (MBR-C). The remainder was operated without a carrier (Control-MBR). The rope carrier (RingLace, Kajima Corp., Japan) consisted of polyvinylidene fluoride (PVDF) fibre strings that were loosely woven into the form of a rope. The outer diameter of this carrier was 25 mm. The rope carrier was cut into a length of 10–15 cm and hung in the MBR vertically. The total length of rope carriers in MBR-A was 2.5 m, in accordance with the recommendation of the manufacturer, 0.33 m/L of tank volume. Degradation and dissipation of the rope carrier were not observed during the operation. The granular carrier (BCN, Nisshinbo Chemical Inc., Japan) had a cylindrical shape and was used by the authors in previous research [5]. The size (both diameter and height) and specific gravity were approximately 4 mm and 1.01, respectively. The main component of the granular carrier was polyethylene glycol. The sponge carrier (Achilles Corp., Japan) used in this study was made from polyether-urethane foam and had a cubic shape. The density of the sponge carrier was 35 kg/m^3 with 46 cells per 25 mm. The dimensions of the cubes were $4 \times 4 \times 4$ mm. The apparent volume of the granular and sponge carriers introduced into the MBRs was 5% of the reactor volume, which was determined based on the authors' previous research [7]. The rope carrier and sponge carrier used in this study are used in integrated biofilm activated sludge (IFAS) and moving bed biofilm reactor (MBBR) applications [19]. The rope carriers were fixed in the reactor to prevent contact with the membrane surface. In the cases where granular or sponge carriers were used, the carriers moved freely in the reactor and made contact with the membrane surface.

Each MBR was equipped with 0.06 m^2 flat-sheet microfiltration membranes (Toray, Japan). The membrane was made from PVDF and had a nominal pore size of 0.1 μm. Aeration was performed continuously (aeration rate: 17 L/min) beneath the membrane modules. Intermittent operation (12 min operation was coupled with a 1-min pause) was carried out in this study. The membrane flux was set at 18.8 LMH. The resulting hydric retention time (HRT) was 7.2 h. A fixed amount of mixed liquor suspension (380 ml) was wasted daily from each MBR. As a result, the solid retention time (SRT) in Control-MBR was 20 days. Properties of the membrane used in this study and operational parameters of the MBRs are summarized in Table 1. The temperature in the MBRs was maintained at 20 °C using a water bath. When membrane fouling became significant (trans-membrane pressure (TMP) >40 kPa), the membrane modules were removed from the reactor and the membrane surface was manually wiped with a sponge. The bench-scale MBRs operated in this study were inoculated with sludge collected from a pilot-scale MBR installed at a full-scale municipal wastewater treatment facility (Soseigawa Wastewater Treatment Center, Sapporo, Japan). The synthetic wastewater used in this study was prepared by following the Organization for Economic Cooperation and Development (OECD) guidelines 302A and 303A [20]. The major carbon sources of this synthetic wastewater were peptone and a meat extract. Biomass was acclimatized to the synthetic wastewater for 40 days. One month after the acclimatization started, the mobility of the sponge carriers was significantly lowered because of the excess growth of biofilm. Therefore, an extra aerator was placed in the bottom of MBR-C and was intermittently used (20 s aeration with a 5-min pause) to facilitate the movement of sponge carriers.

Table 1
Properties of the membrane used in this study and operational conditions of the MBRs.

Membrane configuration	Flat sheet
Membrane pore size	0.1 μm
Membrane material	PVDF
Membrane surface area	0.06 m^2
Flux	18.8 LMH
Aeration rate	17 L/min
HRT	7.2 h
SRT	20 days

2.2. Assessment of the filterability of the mixed liquor suspensions

At the termination of the operation, the filterability of the mixed liquor suspensions was assessed by a series of batch filtration experiments using a dead-end stirred cell system (Advantec Tokyo, Japan). The membrane used in these experiments was identical to that used in the bench-scale MBRs. The effective membrane area in the stirred cell was 37.4 cm^2. In each filtration, virgin membranes were used. The stirred cell was filled with 300 ml of mixed liquor suspensions, and compressed N_2 gas was used to filtrate the suspensions. The filtration pressure was fixed at 10 kPa, and the stirring speed in the cell was set at 300 rpm. The membrane flux was measured using an electronic balance. The membrane filtration resistance was determined according to Darcy's law:

$$R = \Delta P/(J \cdot \mu)$$

where R is the membrane filtration resistance (m^{-1}), ΔP is the TMP (Pa), J is the membrane permeate flux (m^3/m^2/s), and μ is the viscosity of the permeate (Pa s). In a series of batch filtration experiments, the membrane permeate flux reached a plateau when the filtration time exceeded approximately 20 min. Subsequently, 5 min of additional filtration was conducted, and the membrane filtration resistance (i.e., the filtration resistance of the mixed liquor suspensions) was calculated based on the average membrane flux during the additional filtration time.

2.3. Analytical methods

The concentrations of the total organic carbon (TOC) and dissolved organic carbon (DOC) were determined using a TOC analyser (TOC-VCSH, Shimadzu, Japan), which could also be used to determine the concentration of total nitrogen (T-N). Analysis of the DOC, dissolved polysaccharides and dissolved proteins in mixed liquor suspension samples was performed after the suspensions had been centrifuged (2100g, 5 min) and filtered with a 0.45-μm mix cellulose ester (MCE) filter (Advantec Tokyo, Japan). The phenol-sulfuric acid method [21] and the Lowry method [22] were used to determine the concentration of polysaccharides and proteins, respectively. Glucose and bovine serum albumin (BSA) were used as standards for the measurements of polysaccharides and proteins, respectively. Analysis of the monosaccharide composition of dissolved polysaccharides was conducted using a Dionex DX 500 HPLC equipped with a pulsed amperometric detector