Journal of Membrane Science 497 (2016) 90–98

Contents lists available at ScienceDirect

Journal of Membrane Science

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

Development of a novel process to mitigate membrane fouling in a continuous sludge system by seeding aerobic granules at pilot plant

Muhammad Sajjad [a,b], In S. Kim [c], Kwang Soo Kim [a,b,*]

[a] Korea University of Science and Technology, 217 Gajeong-ro, Yuseong-gu, Daejeon 305-350, Republic of Korea

[b] Environmental Engineering Research Division, Korea Institute of Civil Engineering and Building Technology, 283 Goyangdae-ro, Ilsanseo-gu, Goyang-Si, Gyeonggi-Do 411-712, Republic of Korea

[c] School of Environmental Science and Engineering, Gwangju Institute of Science and Technology (GIST), 123 Cheomdan-gwagiro, Buk-gu, Gwangju 500-712, Republic of Korea

ARTICLE INFO

Article history:
Received 18 August 2015
Received in revised form
10 September 2015
Accepted 11 September 2015
Available online 13 September 2015

Keywords:
Continuous flow membrane bioreactor (CFMBR)
Pilot-scale
Seed granules
Membrane fouling
Soluble microbial products (SMP)

ABSTRACT

The main goal of the current studies was to cultivate granular sludge in a continuous flow membrane bioreactor (CFMBR) to enhance the membrane performance in a pilot-scale reactor. In this regard, CFMBR was operated in two stages for 220 days; stage 1 was run without the addition of aerobic granules, while in stage 2, the aerobic granules synthesized (after a period of regulations) in a granular sludge sequencing batch reactor were seeded in the reactor. The results showed that the particle size in stage 2 was increased to nearly 625 μm and SVI_5 decreased to 45 mL/g from that of 200 μm and 145 mL/g, respectively, during stage 1. The membrane fouling noted in terms of increase in transmembrane pressure values in CFMBR stage 2 was approximately 8 times lower than that of stage 1 of operation. Membrane cleaning was a regular phenomenon in stage 1, whereas no cleaning was needed during stage 2. The physicochemical analysis showed that a high PN/PS ratio (3.30) of the EPS, approximately 4-fold low soluble microbial products, a high particle size and sludge settleability were the main factors in mitigating this membrane fouling. The characterization of membrane foulants was done using FTIR spectroscopic technique.

1. Introduction

The membrane bioreactor (MBR) system is rapidly becoming a very popular technique for the treatment and reuse of industrial and municipal wastewater due to its generation of high quality effluent and reduction in sludge production. The other advantage associated with using an MBR is treatment capacity enhancement due to the increase in biomass concentration because of the retention of all microorganisms in the reactor [1–3]. However, membrane fouling (due to the deposition of fine and soluble particles) is a major obstacle for the widespread application of MBR systems as the fouling increases the operational cost. Because of the small particle size of the activated sludge, it penetrates inside the membrane and is adsorbed into the membrane pores along with other organic and inorganic matter, which decreases the permeate flux and induces membrane fouling [4,5]. The organic polymers secreted by the microorganisms are also considered as one of the foulants present in activated sludge systems [6,7]. They are mainly classified as extracellular polymeric substances (EPS) which are part of sludge particles and soluble microbial products (SMP) which are freely present in the wastewater. The effect of these bacterial products in membrane fouling is very complicated and contradictory results have been reported in the literature. In some studies EPS and in the others SMP have been linked with membrane fouling in MBRs [8–10].

These foulants can be eliminated by chemically cleaning the membranes, which is a very expensive and environment unfriendly process that also causes membrane aging [2,3]. To overcome these problems, laboratory-scale studies have been conducted by combining the membranes with sequencing batch reactors (SBR) [11,12]. These studies displayed the tremendous membrane flux due to the synthesis of large size aerobic granules in the SBR system [13,14]. Aerobic granules are formed by the interactions of microorganisms with EPS and other ionic species

Abbreviations: CFMBR, continuous flow membrane bioreactor; EPS, extracellular polymeric substances; PN/PS, protein/polysaccharide; FTIR, Fourier transform infrared; MBR, membrane bioreactor; SMP, soluble microbial products; SBR, sequencing batch reactor; GSBR, granular sludge sequencing batch reactor; COD, chemical oxygen demand; SVI, sludge volume index; MLSS, mixed liquor suspended solids; HRT, hydraulic retention time; TMP, transmembrane pressure; TN, total nitrogen; TP, total phosphorous; PVDF, polyvinylidene difluoride; VSS, volatile suspended solids; TOC, total organic carbon

* Corresponding author at: Environmental Engineering Research Division, Korea Institute of Civil Engineering and Building Technology, 283 Goyangdae-ro, Ilsanseo-gu, Goyang-Si, Gyeonggi-Do 411-712, Republic of Korea. Fax: +82 31 9100 291.
E-mail address: kskim@kict.re.kr (K.S. Kim).

http://dx.doi.org/10.1016/j.memsci.2015.09.021
0376-7388/

present in the sludge matrix [13,15]. The main characteristics associated with granular sludge are their much higher settleability, dewaterability, density and particle size than the activated sludge [16–18]. Unlike the activated sludge particles and due to the high particle size of aerobic granules, granular sludge cannot penetrate inside the membrane pores [12,14].

A review of the previous work highlighted that the occurrence of granular sludge in MBR system enhanced the membrane permeability up to 50% by eliminating the concentration of floc particles. Moreover, the pollutant removal rates were significantly increased in these type of sludge systems [15,19]. Similarly, it has been suggested that the MBR with aerobic granules can be operated at high flux rates without the deterioration of granules; and it presents a low specific resistance to filtration compared with floc particles [20,21]. However, in these studies, the MBRs were run either by inoculating the already synthesized aerobic granules or by operating them as SBRs (batch style) [15,19–21]. Moreover, the majority of the reported literature is based upon laboratory-scale experiments using synthetic wastewater at high organic loading rates. Very few pilot-scale studies have only highlighted the formation of aerobic granules in the SBRs, but did not provide any information about the membrane filtration characteristics of the developed granules [22,23]. Furthermore, the problem is that an SBR system operates in batch sequence, and much time is needed to complete each cycle; therefore, it cannot be used for large communities. Presently, no data are available describing the granulation and membrane filtration of aerobic granules developed in a continuous flow-type reactor at a pilot-scale using low-strength real wastewater as the influent.

Therefore, the present studies were designed to develop a novel process for the synthesis of aerobic granules in a continuous flow stirred tank reactor coupled with a membrane (CFMBR) to reduce the membrane fouling during its long-term operation at the pilot plant. In this regard, one reactor was operated as SBR and the other as CFMBR during stage 1 and the physicochemical characteristics of sludge in the two reactors were compared. In stage 2, the granular sludge from SBR was added into the CFMBR which already contained activated sludge particles of stage 1. It was expected that the augmentation of granular sludge as seed granules will help to cultivate the aerobic granules by uniting the fine particles of CFMBR due to intermolecular interactions, which eventually will lead toward the mitigation of membrane fouling.

2. Materials and methods

2.1. Set up and operation of the pilot plant

The pilot plant was installed at the Ilsan Wastewater Treatment Plant in South Korea and run for 220 days (a schematic diagram of the pilot plant is shown in Fig. 1). The plant consisted of an influent storage tank, a granular sludge sequencing batch reactor (GSBR) and a continuous flow stirred tank reactor coupled with a hollow fiber membrane (CFMBR). Wastewater (COD approximately 300 mg/L) from the primary clarifier of the main treatment plant was pumped into the influent storage tank before being fed into the reactors, where the debris and other floating particles were settled down and discharged from the storage vessel. The GSBR had a total volume of 1.73 m^3 (workable volume 1.60 m^3) with a 100-cm inner diameter and a 220-cm height. The total volume capacity of CFMBR was 17 m^3, while the workable volume was 14 m^3 (the dimensions of CFMBR were $325L \times 210W \times 250H$ cm^3). The aerobic granules were initially cultivated in GSBR and then seeded into the CFMBR to synthesize the granular sludge in it. The entire operation was divided into two stages as mentioned below.

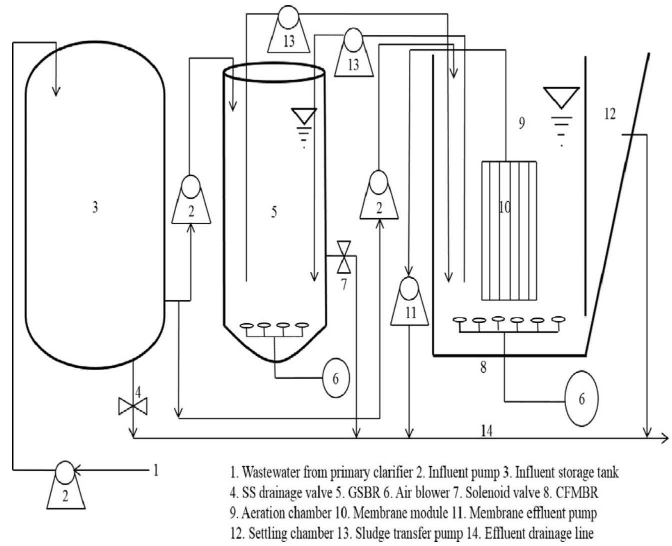

Fig. 1. Schematic diagram of the pilot plant.

2.1.1. Operating strategy during stage 1 (days 1–100)

The activated sludge with a sludge volume index (SVI_{30}) of 210 mL/g and a mixed liquor suspended solids (MLSS) concentration of 3500 mg/L was inoculated as the seed sludge in both reactors. In GSBR, the influent was added from the top and the effluent discharged from the center of the reactor by using the solenoid valve. The characteristics of the wastewater and seed sludge are summarized in Table 1. Air was supplied from the bottom of the reactor through the fixed blower, and all unit operations were automatically controlled through the control panel. During this stage, GSBR was run in three phases to optimize the cultivation parameters of the aerobic granules for enhanced filterability and settleability by changing the operating conditions. In phase-I (days 1–40), the duration for each SBR cycle was 6 h, with 4 min of influent feeding, 321 min of aeration, 30 min of settling and 5 min of effluent withdrawal. The organic loading rate was then increased by decreasing the cycle length to 4 h (days 41–80) and then to 3 h (days 81–100) during phase-II and phase-III, respectively. The aeration time in phase-II and phase-III was adjusted to 201 and 141 min, respectively, while the feeding, settling and effluent withdrawal periods were similar to phase-I.

The CFMBR was fed with the same influent wastewater, and the organic loading rate was maintained at similar levels to GSBR. The organic loading was controlled by adjusting the HRT (hydraulic retention time) at 12, 8 and 6 h during phases-I, II and III, respectively. The aeration and influent feeding were continuously provided, and the effluent was removed through the membrane. The membrane module was inserted into the aeration chamber and mounted vertically in the reactor above the air diffusers, between the baffle plates. The pump connected to the module took out the effluent from the membrane.

Table 1
Characteristics of the real wastewater and seed sludge used in the experiment

Components	Concentration
MLSS (mg/L)	3500
SVI_{30} (mL/g)	210
COD (mg/L)	300 ± 25
TN (mg/L)	30 ± 5
TP (mg/L)	7 ± 1
pH	7.2 ± 0.3