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Fouling characteristics in pure oxygen MBR process according to MLSS concentrations and COD loadings

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ABSTRACT

A submerged MBR with a pure oxygen system was operated at high COD loading conditions to find out how high a level of COD loading can be treated consistently in an aerobic condition. Pure oxygen was supplied with circulated MLSS to the aerobic tank by a two-phase nozzle to increase oxygen transfer efficiency. Tested COD loadings ranged from 2 to 10 kgCOD/m^3 day. And the effect of MLSS concentration on the membrane fouling was investigated from 5000 to 25,000 mg/L. The membrane fouling rates and filtration resistance were tested to evaluate the effect of COD loadings and MLSS concentrations. Over the range of COD loading tested (2.0–10 kgCOD/m^3 day), the effluent qualities ranged from 35 to 69 mg/L and the COD removals ranged from 99.1 to 99.7 for synthetic wastewater. The membrane fouling rates increased seven-fold over a five-fold increase in COD loadings. And the fouling rates increased almost nine-fold over a three-fold increase in MLSS concentration. The membrane fouling in high COD loading conditions was more sensitive to MLSS concentration than COD loading. The specific EPS productions in this test ranged from 6.9 to 10.9 mgEPS/gVSS, and the specific polysaccharide and protein productions were 9.2 mgPolysaccharide/gVSS and 1.8 mgProtein/gVSS, respectively.

1. Introduction

Selection of wastewater treatment processes has become more and more difficult because of stringent discharge limits in Korea. Therefore, existing wastewater treatment plants should often be modified or replaced with a more advanced process. An activated sludge process has been most widely used among biological wastewater treatment processes, but it is hard to treat the activated process with high COD loading wastewater because it has limits of oxygen transfer efficiency and biomass concentration [1,2]. Thus, an anaerobic digestion process has been widely used for high COD loading wastewater treatment. However, the anaerobic digestion process needs extra facilities, such as biogas collectors and desulfurizers. In addition, it also needs to follow an aerobic treatment process for the final discharge to a nearby river.

As an alternative, membrane bioreactors (MBR) have been popularly used because they have many advantages over conventional activated sludge processes. The most profound advantage is that substituting membrane separation for gravity sedimentation allows a much higher level of mixed liquor suspended solid (MLSS) concentration. High MLSS concentration reduces bioreactor volume for the same COD loading and solid residence time (SRT) [3,4]. However, membrane fouling is still one of the major issues of MBR research, and most of the attention in membrane fouling is currently paid to extracellular polymer substance (EPS) in either bound or soluble microbial products [5].

Membrane fouling is the systematic accumulation of suspended solids, colloids, and macromolecules on the membrane surface or inside the pores, causing a reduction in membrane permeability. Adsorption of solutes and colloids narrows and blocks pores. This type of fouling is considered irreversible, causes a characteristic slow permeability decline, and generally must be removed by chemical cleaning. Major parameters for causing a fouling are viscosity of solution, total EPS, soluble EPS (SMP), F/M ratios, the size distribution of sludge floc, and colloids [5–9]. There has been a lot of previous research concerning MBR operation treating sewage or wastewater with low and medium COD loadings of less than 1 kg/m^3 day, but it is hard to find research treating high COD loading because it is hard to maintain an aerobic environment with conventional aeration when treating high COD loadings of more than 2 kg/m^3 day because of a limit of oxygen transfer efficiency [10–12].

Aeration has two functions: supplying oxygen to aerobic microorganism as an electron acceptor and preventing sludge cake accumulation on the membrane surface. Therefore, both high oxygen transfer efficiency and high MLSS concentration are needed to treat high COD loading wastewater [13,14].

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In this research, a two-phase liquid jet nozzle and pure oxygen are used in the MBR process. A two-phase liquid jet nozzle is designed to induce a significant turbulence between pure oxygen and MLSS. And the pure oxygen can provide higher oxygen transfer efficiency that maintains the MBR aerobic condition even if it is under a high COD loading. First, the limit of COD loadings was investigated in the aerobic treatment to a level of 10 kgCOD/m^3 day by the pure oxygen MBR process. And then the membrane fouling characteristic and rates were evaluated according to MLSS concentrations and COD loading rates – the previous MBR research concerning F/M ratios and MLSS concentrations were tested with low COD loading conditions. Finally, composition of fouling and the EPS and its compositions were analyzed as proteins and carbohydrates.

2. Material and methods

2.1. Description of MBR structure with a two-phase nozzle device

The image of a membrane module and the configuration of liquid jet flow in the reactor are shown in Fig. 1. The circulation flow in Fig. 1(a) is induced by a liquid jet, and it strongly mixes suspended liquor. The liquid jet was made by a two-phase nozzle fitted with an attached air tube therefore the pure oxygen is drawn into the liquid jet by a local pressure drop at the nozzle tip. The mixed liquor and oxygen pass down the rectangular draft tube and then up the outside of the draft tube before re-entering the draft tube. The two-phase nozzle used in this study was made of stainless steel and composed of two parts: a nozzle body and a tip.

PVDF (Kolon, Korea) hollow fibers membrane with a pore size of 0.1 μm were used to prepare submerged membrane modules with a flux of 20 LMH. The membrane module had fixed ends with a plastic frame, and the PVDF hollow fibers were potted in both ends by epoxy resin. One end of the hollow fibers was sealed with a plastic frame without a hole, and the other end was sealed with a plastic frame with a hole that can be used to withdraw the line as shown in Fig. 1(a). General operation conditions used in the MBR were shown in Table 1.

2.2. Operation of the MBR with high COD loading

The MBR process included two reactors: an anoxic reactor of 9 L volume for denitrification and an aerobic reactor with a two-phase nozzle that had a working volume of 21 L and a degassing tank for immersing membrane modules and removing foam. Activated sludge used for seeding was taken from *SH* Sewage Treatment Works in Korea and applied to the synthetic wastewater and food leachate for 1 year, respectively.

The composition of the synthetic wastewater was shown in Table 2. The COD concentration of the synthetic wastewater had a range of 4000 mg/L–20,000 mg/L. The pH control in the reactor was adjusted to around pH 7 by adding sodium bicarbonate. Pure oxygen was supplied to the MBR, and a constant flow of the pure oxygen from 0.0125 to 0.1 L/min was mixed with MLSS in the two-phase nozzle to increase the oxygen transfer rate. The mixed MLSS was circulated to provide turbulence in the reactor with a flow rate of 8 L/min. In case of raw food leachate, TCOD was from 82,617 to 151,000 mg/L and the SS of the food leachate ranged from 41,400 to 85,200 mg/L and has an average value of 67,700 mg/L. In addition, food leachate showed average total nitrogen concentration of 1538 mg/L and total phosphorus of 223 mg/L.

The COD loadings of influent were controlled from 2 to 10 kg COD/m^3 day while maintaining 2 days of hydraulic retention time. To minimize the anaerobic environment in an anoxic tank, the recycle ratio, Q_R – defined as recycle flows between an aerobic tank and an anoxic tank – was between four and ten times greater than inflow. The Q_R was increased with the change of the COD loading. Though the recycle ratio was high, with a value of 10, the DO of the anoxic tank was maintained from 0.1 to 0.5 mg/L because the COD loading of influent was high enough.

The assembled membrane module as shown in Fig. 1(a) was immersed in the degasing tank, and coarse bubble aeration of 300–500 L/min was used to decrease membrane fouling. The

Table 1
Operation conditions used in the MBR process.

Items	Values
COD of feed water (mg/L)	4000–20,000
Hydraulic retention time (HRT, day)	2
Organic loading rate (kgCOD/m^3 day)	2–10
MLSS (mg/L)	5500–25,000
Sludge retention time(SRT, days)	4
Circulation flow rate (L/min)	7–8
Membrane flux (L/m^2 h)	20
Membrane Mean pore (μm)	0.1
Membrane material	PVDF

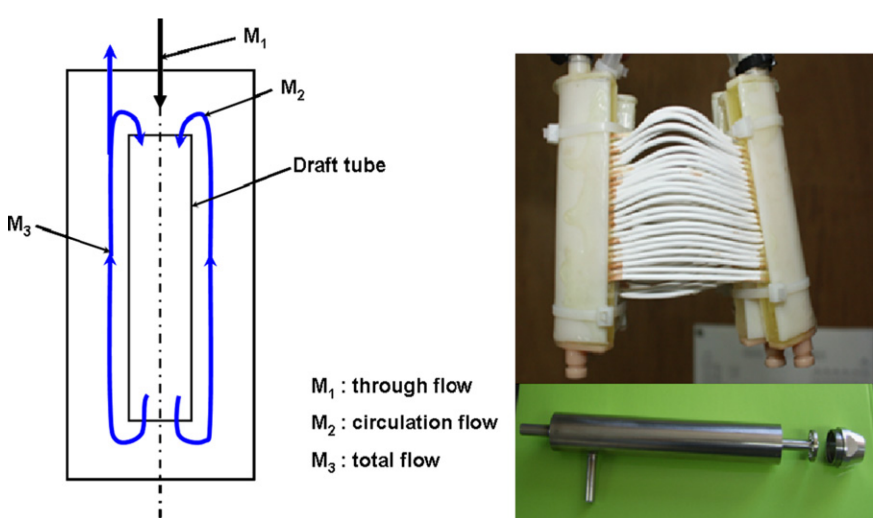

Fig. 1. PVDF membrane module and configuration of liquid jet flow in the reactor. (a) Configuration of the liquid jet reactor and (b) PVDF membrane module and two-phased nozzle.