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Reduction of membrane fouling by simultaneous upward and downward air sparging in a pilot-scale submerged membrane bioreactor treating municipal wastewater

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ABSTRACT

A vertically oriented hollow fiber membrane module equipped with a downward aerator as well as an upward aerator for the simultaneous upward and downward air sparging was evaluated in a pilot-scale bioreactor. The operation was divided into three consecutive phases based on different membrane air sparging configurations: the simultaneous upward and downward air sparging (Phase 1), the single upward air sparging (Phase 2), and the simultaneous upward and downward air sparging (Phase 3). Although the SMBR operation, process performances including particulate matters, organic matters, and nutrients removals were stable, the membrane fouling characteristics were significantly different for the different air sparging configurations. The parameters such as the trans-membrane pressure increasing rate, the permeability decreasing rate, the irreversible membrane fouling rate, and the fouling resistance increased when the air sparging configuration was changed from the simultaneous upward and downward mode to the single upward mode (i.e., Phase 1 → Phase 2), while the parameters decreased when the air sparging configuration was switched from the single upward mode to the simultaneous upward and downward mode (i.e., Phase 2 → Phase 3). Taken together the results strongly support the effectiveness of the simultaneous upward and downward membrane air sparging in reducing membrane fouling.

1. Introduction

Wastewater treatment processes using membrane bioreactor (MBR) have a variety of advantages over conventional biological processes including smaller footprint, superior treated water quality, improved process-control through uncoupling of solids and hydraulic retention times, and more stable operation for changing loading conditions. Moreover, stringent effluent regulations as well as the decrease in both membrane and process operating costs have led to globally widespread installation of MBRs for more than a decade [1]. The introduction of submerged membrane bioreactors (SMBRs) has significantly reduced the energy consumption associated with reactor operations compared to side-stream MBRs [2], which has accelerated the application of MBR in wastewater treatment.

As for all membrane processes, fouling remains the most crucial problem in the successful application and cost-efficient operation of SMBRs at present, and thus the control of fouling is the key to the stable maintenance of SMBRs [3–5]. During the operation of SMBRs, colloidal particles and macromolecules tend to deposit in the pore of the membrane and on the membrane surface, which reduces the membrane permeability over operation time. Rapid decline of the membrane permeability increases the cleaning frequency, operational and maintenance costs, and decreases the lifetime of the membrane [3,6].

In order to reduce membrane fouling, several strategies such as the pre-treatment of feedwater, chemical or physical cleaning of membrane, flux reduction, and application of turbulent air sparging are employed [1]. Membrane air sparging, in particular, is postulated to be a critical factor in controlling membrane fouling in an SMBR [2]. Air sparging produces effective turbulence and membrane movement, which results in scouring the particles and other deposited materials away from the membrane surface. This produces an increase in the air flow rate at the membrane surface which increases the flux due to an increased back-transport of deposited materials on the membrane surface by turbulent shear [2,3]. The detailed theoretical description of the air sparging was well reviewed by Cui et al. [7].

Vertically oriented hollow fiber membrane modules, in which the dual header design has both top and bottom headers where membrane fibers are potted (e.g., Zenon's ZeeWeed modules), have been widely introduced [1,7]. In this module, an upward aerator is typically located under or near the bottom header in order to sparge air bubbles for the purpose of scouring cake deposition off the membrane surface. However, scraped

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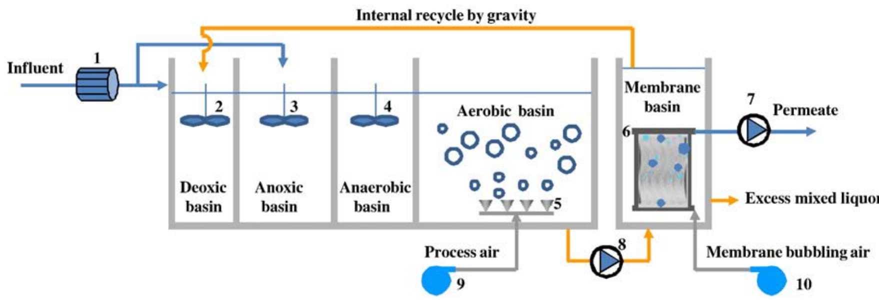

Fig. 1. A schematic of the pilot-scale submerged membrane bioreactor. Legends: 1. drum screen; 2. mixer for the deoxic basin; 3. mixer for the anoxic basin; 4. mixer for the aerobic basin; 5. fine-bubble diffusers; 6. membrane module; 7. permeate pump; 8. pump for recycling mixed liquor from the aerobic basin to membrane basin; 9. blower for the aerobic basin; 10. blower for the membrane basin.

solids (e.g., mixed liquor suspended solids, debris, hairs, etc.) tend to be accumulated near the top header area during air sparging [8]. Accumulated solids near the top header area reduce membrane permeability possibly through the conversion of reversible fouling into irreversible fouling [5,9], thereby increasing the suction pressure as well as the membrane cleaning frequency, and consequently shortening the lifetime of the membrane module. It is thus crucial to minimize the deposition of solids at the top header area in the vertically oriented dual header hollow fiber membrane module equipped with single upward aerator, in order to stably maintain suction pressure and membrane flux.

This study introduces a unique dual header design for a vertically oriented hollow fiber membrane module named KIMAS-20. This module was equipped with a downward aerator as well as an upward aerator (i.e., dual aerators) to minimize the deposition of solids near the top header. In order to evaluate the characteristics of the membrane module, a pilot-scale SMBR treating municipal wastewater operated for a period of 160 days. The primary focus of this study was to evaluate the effects of the simultaneous upward and downward air sparging on the reduction of membrane fouling and the increase of membrane permeability by systematically comparing the results of this study with that obtained from an operation using the single upward air sparging configuration.

2. Materials and methods

2.1. SMBR set-up

A pilot-scale SMBR was set up at the Sungnam Wastewater Treatment Plant (WWTP) (Sungnam, Korea) which treated 245,000 m^3 of municipal sewage per day. The Sungnam WWTP operated with a conventional activated sludge process removing mostly particulate and organic pollutants. As shown in Fig. 1, the SMBR consisted of deoxic, anoxic, anaerobic, aerobic, and membrane basins with 2.1, 8.3, 2.9, 4.2, and 8.3 m^3 of working volumes, respectively. The liquor was completely mixed using mechanical mixers installed on the top of the deoxic, the anoxic, and the anaerobic basins, respectively. Air was provided to the bottom of the aerobic basin through fine-bubble diffusers for the growth of aerobic microorganisms at a rate of 430 m^3 air/day. Mixed liquor was recycled from the membrane basin to the deoxic basin by gravity flow of around 150 m^3/day. Solids retention time (SRT) was controlled by continuously wasting mixed liquor from the membrane basin. A membrane cassette submerged in the membrane basin consisted of 10 hollow fiber membrane modules (200 m^2 of an overall membrane surface area). For the membrane basin, air sparging was applied to the membrane modules for the main purpose of membrane cleaning at an overall rate of 1.18 m^3 air/min.

2.2. Membrane module

The membrane module by the name of KIMAS-20 (Kolon Engineering & Construction, Kwacheon, Korea) consisted of polyvinylidene difluroride (PVDF) hollow fiber membranes with a nominal pore size of 0.07 µm. The overall membrane surface area of the module was 20 m^2. The detailed specifications of the membrane module and the hollow fiber membrane are presented in Table 1.

As shown in Fig. 2, each membrane module was comprised of two rectangular headers holding vertically oriented hollow fiber membranes. The ends of the hollow fiber membranes were potted into the bottom and the top headers. Each header was equipped with a permeate collection pipe and an aerator (i.e., an upward aerator for the bottom header and a downward aerator for the top header), respectively. Through the hollow fiber membranes, treated wastewater was intermittently permeated due to a partial vacuum inside the hollow fibers created by a suction pump, which was operated for 9 min and paused for 1 min. Membrane permeate was collected through the permeate collection pipes located in the top and the bottom headers, respectively, while air sparging for membrane cleaning was supplied through the aerators. After 138 cycles of suction and pause (23 h), two sessions of back-flushing and relaxation operations were conducted (1 h in total). Back-flushing was performed by passing permeate containing 200 mg/L of NaOCl solution through the membrane for 20 s, and then relaxation was performed by stopping the back-flushing process for 29 min and 40 s.

2.3. Wastewater

The supernatant of a primary clarifier of the Sungnam WWTP was screened through a 2.0 mm mesh-sized drum screen, and was used as influent for the SMBR. The influent used in this study was the domestic sewage generated mostly from residential and commercial areas in the city of Sungnam. The flow rate of the influent was set at around 100 m^3/day. Characteristics of the influent wastewater are shown in Table 2. The soluble chemical oxygen demand (COD) was about 47% of the total COD, while 63% of the total COD was attributed to biochemical oxygen demand (BOD_5). The fraction of ammonia–nitrogen was approximately 75% of the total nitrogen (TN). The nitrate–nitrogen in the influent was

Table 1
Specifications of the membrane module and the hollow fiber membrane used in this study.

Description	Unit	Value
Membrane module		
Name		KIMAS-20
Module size	mm	850 (L) × 77 (W) × 1,770 (H)
Surface area	m^2	20
Manufacturer		Kolon Engineering & Construction Co.
Hollow fiber membrane		
Membrane material (skin)		Polyvinylidene difluoride (PVDF)
Membrane length	mm	1500
Nominal pore size	µm	0.07
Outer diameter	mm	2.0
Inner diameter	mm	0.8
Membrane resistance (R_m)	m^{-1}	5.9×10^{11}
Manufacturer		Kolon Industries Inc.