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A Vertical Membrane Bioreactor for Water Recycling from Laboratory to Market

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ABSTRACT

Over the past century, human activity has dramatically changed global nutrient cycles, resulting in detrimental effects on human health and the Earth's system dynamics. In particular, eutrophication has resulted from the high nitrogen flux to coastal marine systems from both natural and anthropogenic sources. In N-sensitive estuaries, wastewater treatment plants are required to implement more advanced treatment methods in order to meet increasingly stringent effluent guidelines for total N. As a means of complying with current and anticipated water quality regulations, membrane technologies have been widely adopted around the world. In particular, membrane bioreactors (MBRs) have been increasingly and widely used for wastewater treatments in the last two decades due to their unique advantages such as good effluent quality and compact structure. Here, we introduce a novel vertical MBR (VMBR), which has been operated to reduce the problems on nutrient removal from wastewater and the volume of produced sludge. Firstly, operating parameters for the VMBR were selected and evaluated in a bench-scale reactor. Secondly, a pilot-scale VMBR treating municipal wastewater has been fabricated and operated under the optimum condition with various feed water temperatures. Finally, the VMBR has been fully commercialized and the quality of effluent was evaluated for recycling purposes.

1. INTRODUCTION

The continued depletion of fresh drinking water supplies throughout the world has increased the need for a variety of water treatment and recycling. The recycling of wastewater is often cited as a viable alternative to sea water desalination (Meng et al., 2009). However, it is known as that the wastewater-derived (N) is an important point source for N loading in many aquatic environments (Mesfioui et al., 2012).

Eutrophication is a key driver causing a number of pressing environmental problems including reductions in light penetration and increases in harmful algal blooms. In N-sensitive estuaries, wastewater treatment plants (WWTPs) are required to implement more advanced treatment methods in order to meet increasingly stringent effluent guidelines for total N (TN). According to the literature, biological nutrient removal (BNR) processes that incorporate coupled nitrification/denitrification have the potential to remove TN down to about 5 - 12 mg/L, in selected cases, down to 3 mg/L (Grady et al., 2011). The TN concentration in effluent is known as less than 10 mg/L at most inland municipal WWTPs.

In these regards, we developed a vertical MBR (VMBR) composed of anoxic and oxic zones in one reactor and optimized to reduce the problems on pollutant removal from wastewater and the volume of produced sludge from a bench-scale to field-scale systems.

2. MATERIAL AND METHODS

2.1. A bench-scale VSMBR fed with synthetic wastewater

A VMBR is composed of anoxic zone (lower layer) and oxic zone (upper layer). Influent and mixed liquor of suspended solid (MLSS) that was recycled from the oxic zone were introduced to the anoxic zone through the flow distributors. The aerobic zone is separated from the anoxic zone by a horizontal plate with a hole in the center. In the aerobic zone, disk-type diffusers were used to provide air bubbles for oxidation of organic and ammonia and to reduce membrane fouling. Final effluent was withdrawn through hollow fiber membranes (0.45 μm, poly-tetrafluoroethylene, Sumitomo Electric Fine Polymer, Inc.). The effects of various operating factors such as anoxic zone/oxic zone ratio, internal recycle rate, hydraulic retention time (HRT) on nutrient removal were studied using a laboratory-scale VMBR (working volume = 32 L) fed with synthetic wastewater containing glucose as a sole carbon source.

2.2. A pilot-scale VSMBR treating municipal wastewater

The effect of water temperature on nutrient removal was evaluated using a pilot-scale VMBR (working volume = 1,333 L) treating municipal wastewater. Final effluent was withdrawn through the hollow fiber membranes (0.45 μm, poly-tetrafluoroethylene, Sumitomo Electric Fine Polymer, Inc.). In biological nutrient removal (BNR) processes, nutrient removal efficiencies are very sensitive to both quantity and characteristics (especially biodegradability) of organic source. To improve the nutrient removal efficiency in the pilot-scale VMBR, food waste was considered as a sustainable organic source. The food waste was converted to volatile fatty acid (VFA)-rich condensate in an anaerobic fermentor. The resultant was introduced to the anoxic zone with municipal wastewater in the reactor.

2.3. A field-scale VSMBR systems for water recycling

Since 2009, five field-scale VMBRs were installed by Daewoo Engineering & Construction (Table 1). Characteristics of membrane fouling and the effluent from the field-scale VMBR (Fig. 1) were studied for about one year at 8-hr HRT.

Table 1. Installation of field-scale VMBRs treating municipal wastewater

Location	Capacity (m^3/day)	Note
Dangjin-si, South Korea	3,500	In operation since 2009
Gumi-si, South Korea	8,000	In operation since 2010
Jecheon-si, South Korea	1,100	In operation since 2011
Anseong-si, South Korea	3,000	In operation since 2012
Anseong-si, South Korea	2,200	In operation since 2012
Kwangju-si, South Korea	16,000	Under construction

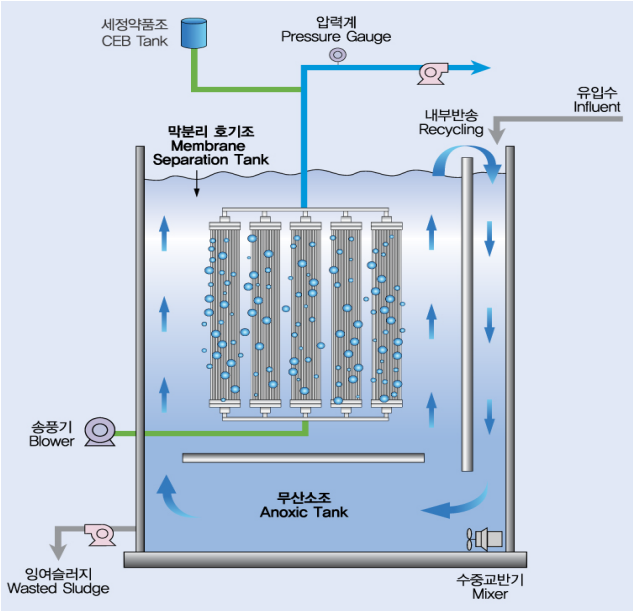

Fig. 1. Schematic diagram of a field-scale VMBR.

3. RESULTS AND DISCUSSION

As shown in Fig. 2, it was found that the optimum volume ratio between anoxic and oxic zones was 0.6 in the laboratory-scale VMBR. The desirable internal recycle rate and HRT for effective nutrient removal were 400% and 8 hr, respectively. Under these conditions, the average removal efficiencies of TN and total phosphorus (TP) were 75% and 71%, respectively.

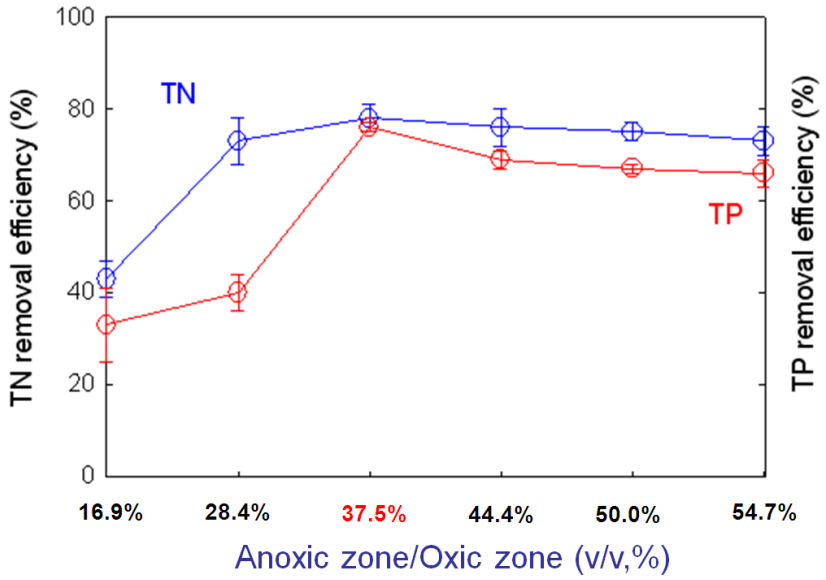

Fig. 2. Effects of anoxic zone/oxic zone ratios on nutrient removal.

A pilot-scale VMBR treating municipal wastewater was operated for about one year under the optimum conditions. As a result, it was found that total suspended solid (TSS) and total organic carbon (TOC) were removed by 100% and higher than 98%, respectively regardless of fluctuation of temperature (13 - 25°C) (data not shown). Average removal efficiencies of TN and TP were found to be 74% and 78%, respectively. As shown in Table 2, as the condensate of food waste (CFW) was supplied as an additional carbon source (0.86% of the influent flow rate, v/v), the TN and TP removal efficiencies increased to 81% and 91%, respectively.

Table 2. Effects of the condensate of food waste on removal efficiencies of nutrients in the pilot-scale VMBR

HRT=8hr at 18-20°C	Total Nitrogen			Total Phosphorus (mg/l)		
	In (mg/l)	Out (mg/l)	Re. (%)	In (mg/l)	Out (mg/l)	Re. (%)
Without CFW	44.6	10.3	76	3.2	0.7	78
+ CFW 0.43%(v/v)	40.5	9.8	76	3.2	0.5	88
+ CFW 0.86%(v/v)	43.5	8.1	81	3.3	0.3	91

Since 2009, a field-scale VMBR was operated over two years. From the long-term operation of the field-scale VMBR treating municipal wastewater, it was found that organic matter and nutrients (i.e., nitrogen and phosphorus) are effectively removed at 8-hour HRT. Moreover, the effluent quality of the VMBR could be possible for various recycling purposes such as toilet flushing, sprinkling, and car washing (Table 3). During the operating period, the transmembrane pressure (TMP) was maintained at between

0.1 and 0.4 kgf/cm^2 with membrane permeate flux at 18 L/m^2/h (LMH) more than 300 days (Fig. 3).

Table 3. Characteristics of influent and effluent in the field-scale VMBR (Dangjin, South Korea).

(Unit : mg/ℓ, CFU/㎖)

Item	Influent		Effluent		Removal(%)	
	Range	Avg.	Range	Avg.	Range	Avg.
BOD	50.1~134.4	80.0	0.2~2.8	1.0	96.8~99.7	98.7
COD_{Mn}	48.7~126.2	79.7	3.5~8.0	5.5	88.8~96.1	93.0
SS	40.0~168.0	73.6	0.5~1.5	0.6	97.8~99.7	99.1
T-N	21.2~52.8	34.0	3.1~13.4	7.9	56.7~89.9	77.3
T-P	2.02~7.10	4.05	0.19~1.65	0.89	40.0~94.4	81.3
E.Coli.	29,000~95,000	63,170	<30	<30	-	-

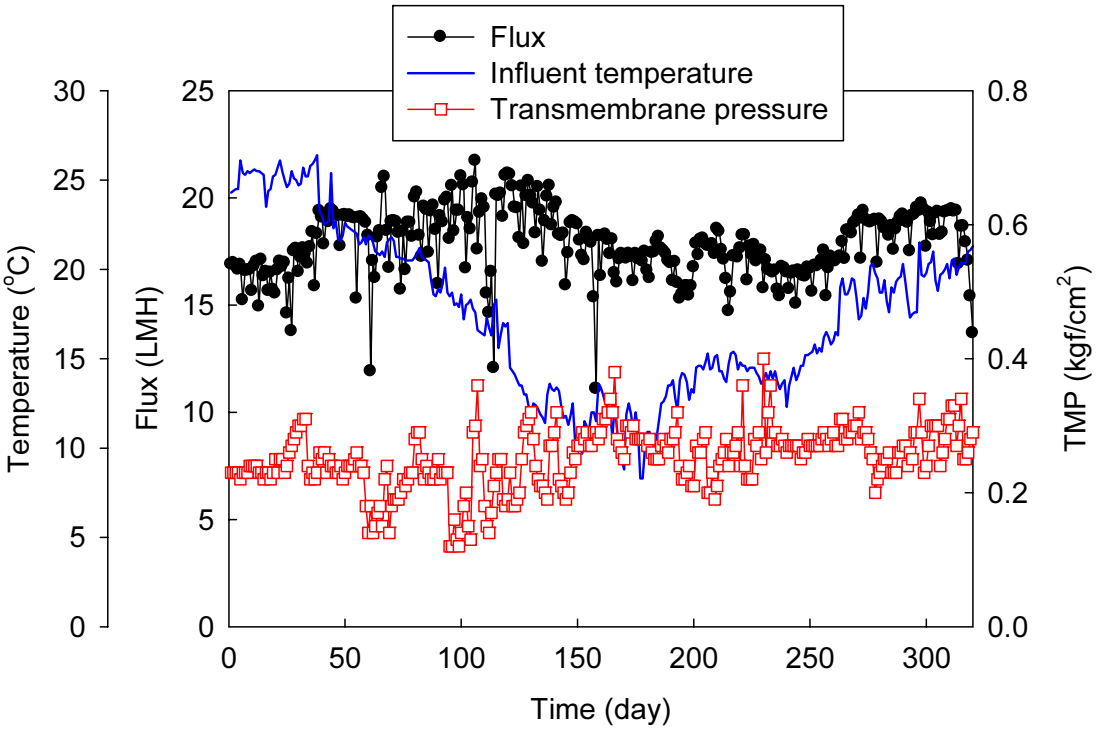

Fig. 3. Progress of membrane fouling in a field-scale VMBR (Dangjin, South Korea).

4. CONCLUSIONS

A novel VMBR composed of anoxic and oxic zones in one reactor was developed in an attempt to reduce the problems concerning effective removal of nitrogen and phosphorus from municipal wastewater for water recycling. Total suspended solids and total organic carbon were removed by 99% and higher than 98%, respectively. Moreover, the average removal efficiencies of total nitrogen and total phosphorus were found to be 81% and 88% at 8 h-hydraulic retention time.

Accordingly, it was concluded that the supply of condensate of food waste enriched with volatile fatty acids improved enhanced biological nutrient removal activity of microorganisms resulting in improvement of nutrient removal efficiency. As a result, it was concluded that the VMBR had great potential in removing organic matter, and its stability was maintained for the long-term operation. Especially, this process can be strongly recommended for the advanced wastewater treatment and water reuse purposes in urban and rural area.

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