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A specific pilot-scale membrane hybrid treatment system for municipal wastewater treatment

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HIGHLIGHTS

- A hybrid treatment system with new configuration was designed for better efficiency.
- High removal efficiency of pollutants was achieved in all run-modes.
- Internal recycling ratio significantly effects on the efficiency of T-N removal.
- A new hybrid treatment system was successful in reducing membrane fouling.
- The energy consumption for the completion of treatment was reasonably low.

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ABSTRACT

A specifically designed pilot-scale hybrid wastewater treatment system integrating an innovative equalizing reactor (EQ), rotating hanging media bioreactor (RHMBR) and submerged flat sheet membrane bioreactor (SMBR) was evaluated for its effectiveness in practical, long-term, real-world applications. The pilot system was operated at a constant flux, but with different internal recycle flow rates (Q) over a long-term operating of 475 days. At 4Q internal recycle flow rate, BOD_5, COD_{Cr}, NH_4^+-N, T-N, T-P and TSS was highly removed with efficiencies up to 99.88 ± 0.05%, 95.01 ± 1.62%, 100%, 90.42 ± 2.43%, 73.44 ± 6.03%, and 99.93 ± 0.28%, respectively. Furthermore, the effluent quality was also superior in terms of turbidity (<1 NTU), color (<15 TCU) and taste (inoffensive). The results indicated that with providing only chemically cleaned-in-place (CIP) during the entire period of operation, the membrane could continuously maintain a constant permeate flux of 22.77 ± 2.19 L/m^2 h. In addition, the power consumption was also found to be reasonably low (0.92–1.62 kWh/m^3).

1. Introduction

Due to growing awareness of problems associated with wastewater treatment plant effluent worldwide, major initiatives for controlling inadvertent organic, nitrogen and phosphorus enrichment of the pollutants in surface and ground water are being undertaken. A number of wastewater treatment plants have adopted various treatment systems that can simultaneously remove multiple pollutants from wastewater (Fan et al., 2009).

Among the biological wastewater treatment technologies, the advanced biofilm processes have been increasingly employed in wastewater treatment, in preference to using activated sludge, because of their many advantages. Those advantages include their capacity for strong resistance to high organic loading shock, capacity for higher biomass concentration, and larger surface areas for more effective mass transfer (Cresson et al., 2006; Jou and Huang, 2003; Jurecska et al., 2013; Li et al., 2013; Martin and Nerenberg, 2012; Nguyen et al., 2014; Tarjányi-Szikora et al., 2013). In recent years, biofilm technologies that somewhat alter the existing process have been attracting a great deal of attention as an enhanced wastewater treatment method (Chundong et al., 2012; Di Trapani et al., 2011; Ding et al., 2011; Kim et al., 2010; Nguyen et al., 2014; Tandukar et al., 2007).

One type of biofilm support media commonly studied is plastic media constructed from polyethylene (PE) and/or polypropylene (PP) thin flexible sheeting. These plastic media have some inherent advantages, such as high specific surface area, low apparent specific weight, and high resistance to environmental conditions (Levstek and Plazl, 2009; Nacheva and Chavez, 2010; Nguyen

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et al., 2011), as well as a relatively low cost. For these aforementioned merits and the high density presence of active microorganisms on the surfaces of these bio-films, the PE & PP media were selected as the carrier media in the hybrid system.

Nowadays, membrane bioreactors (MBRs) have emerged as an attractive technology for wastewater treatment due to their ability to actively support wastewater treatment that results in high quality effluent for various water reuse purposes (Patsios and Karabelas, 2011; Tadkaew et al., 2011). Membrane bioreactor processes have been widely used to reduce or eliminate not only nutrients and organic pollutants, but also to provide a superior rating for most bulk water quality indicators (Defrance et al., 2000; Hu et al., 2013; Judd and Judd, 2010; Le-Clech et al., 2006; Nguyen et al., 2014; Tadkaew et al., 2011). However, the membrane fouling control, excess sludge reduction and nutrient removal capacity of the conventional submerged MBR is limited due to its configuration. For instance, it lacks anaerobic or anoxic controls, which hinders the biological denitrification process, sludge disintegration, and biodegradation of treated sludge (Hu et al., 2013; Rajesh Banu et al., 2009; Yang et al., 2009). To date, there have been many individual studies of bio-film applications, and the MBR as a system component in wastewater treatment using laboratory-scale and bench-scale systems. However, there are very few published articles on the combined use of biofilm and MBR in a pilot-scale and/or a full-scale system. As a result, there is little data upon which a designer or engineer can base prospective planning for such systems in a retrofit design or new project. In addition, without such quantitative data, no reasonable cost/benefit analysis can be done to justify the limited additional costs of installation and maintenance of such a system.

Hence, in this study, the application of a pilot-scale hybrid system consisting of innovative equalizing tank (EQ), RHMBR and submerged MBR, was developed and evaluated the applicability of its real-world use in treating wastewater. This study not only focused on a particular configuration and its performance in terms of removals of nutrients, organic, total coliform, suspended solids, turbidity and color, but also investigated membrane fouling and specific energy costs.

2. Methods

2.1. Wastewater characteristics

The long-term study was conducted using municipal wastewater from a fully-operating municipal wastewater treatment plant (WWTP). Table 1 shows some basic characteristics of the raw municipal wastewater obtained at different internal recycling ratios assayed throughout while operating the hybrid system.

Table 1
Characteristics of raw municipal wastewater.

Parameters	Units	Raw water	
		Range	Average
pH	Unitless	7.0–8.0	7.70
SS	mg/L	175–460	281.90
BOD_5	mg/L	166.73–222.32	205.76
COD_{Cr}	mg/L	187.7–334.9	238.83
T-N	mg/L	30.83–63.08	41.16
NO_3^--N	mg/L	0.00–1.06	0.20
NH_4^+-N	mg/L	18.89–43.54	29.85
PO_4^{3-}-P	mg/L	2.51–6.95	4.46
T-P	mg/L	3.00–8.39	5.45
Alkalinity	mg $CaCO_3$/L	90–220	163.43
Coliform bacterial	MPN/(100 mL)	1.5E + 6–2.0E + 7	7.56E + 06

2.2. Pilot-scale design, setup and description

The pilot-scale hybrid treatment system was designed to treat 53 m^3/day of municipal wastewater at a WWTP of Y City, Korea, for 475 days of continuous operation (Fig. 1).

This treatment system combined an innovative equalizing reactor (EQ), a rotating hanging media bioreactor (RHMBR) and a submerged flat sheet membrane bioreactor (SMBR). The pilot system was constructed with a bracing framework covered by a flexible, easy-to-use wall plate paneling (Gentrol Co., Ltd, Korea). The equalizing reactor (EQ) was divided into three sequential compartments: EQ1, EQ2, and EQ3 with a working volume of 1.226 m^3, 1.197 m^3, and 1.9885 m^3, respectively. An agitator and impeller was installed in each work unit and set at a speed of 120 rpm to ensure complete mixing of the solution. The RHMBR and MBR have a total working volume of 1.226 m^3, 1.197 m^3, 1.9885 m^3, 9.922 m^3, 9.438 m^3, respectively. From the collection basin of WWTP of Y City, the wastewater was continuously to the pilot system by two pumps (Wilo Pump, Korea).

Two flat-sheet modules of commercial submerged membrane used in the MBR were microfiltration membranes with an average pore size of 0.25 μm and total active surface area of 120 m^2. The trans-membrane pressure was determined using a vacuum gauge (VG) (Nguyen et al., 2014).

Coarse bubble aeration was supplied through an air diffuser system from beneath each membrane module by two air blowers (B1& B2) to maintain adequate dissolved oxygen (DO) ratios to the biomass, to aid the passage of permeate flow (to scour the membrane), and to induce turbulence and thus, adequate contact between biomass and substrate in the MBR. All the electrical equipment used in the hybrid system was controlled automatically using a programmable logic controller (PLC) and occasional manual operational adjustments. The operating procedures and the characteristics of the hybrid system were described in detail in a previously authored report (Nguyen et al., 2014).

2.3. Operating conditions

The operating conditions of the new hybrid treatment system, and each reactor, including specific parameters, such as MLVSS, MLSS, DO, TMP, permeate flux, organic loading rate, and discharged excess sludge are shown in Tables 2 and 3.

2.4. Analytical methods

The influent and effluent samples, as well as samples from each tank, were collected two to three times per week to investigate the system performance.

The water quality parameters including biological oxygen demand (BOD_5), chemical oxygen demand (COD_{Cr}), total coliform bacteria, mixed liquor suspended solids (MLSS), total suspended solids (TSS), mixed liquor volatile suspended solids (MLVSS), alkalinity, total nitrogen (T-N), ammonia nitrogen (NH_4^+-N), nitrate nitrogen (NO_3^--N), total phosphorus (T-P), phosphate (PO_4^{3-}-P), oxidation reduction potentials (ORPs), pH values, DO concentration and temperature (Temp.) were determined according to standard methods (Nguyen et al., 2014).

3. Results and discussion

3.1. System operation

EQ, RHMBR and MBR were operated under uniform conditions, maintaining consistent composition and a stable flow rate. Using different condition to each compartment (reactor), in which a