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Demonstration of a full-scale plant using an UASB followed by a ceramic MBR for the reclamation of industrial wastewater

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HIGHLIGHTS

- A full-scale UASB reactor followed by a ceramic MBR was demonstrated for 395 days.
- The system achieved a power consumption of 0.76 kWh m^{-3} during 25 LMH operation.
- Bacteria in the UASB reactor adopted to treat this mixed industrial wastewater.
- Ceramic membrane completely recovered TMP by cleaning after 395 days operation.

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ABSTRACT

This study comprehensively evaluated the performance of a full-scale plant (4550 m^3 d^{-1}) using a UASB reactor followed by a ceramic MBR for the reclamation and reuse of mixed industrial wastewater containing many inorganics, chemical, oil and greases. This plant was demonstrated as the first full-scale system to reclaim the mixed industrial wastewater in the world. During 395 days of operation, influent chemical oxygen demand (COD) fluctuated widely, but this system achieved COD removal rate of 91% and the ceramic MBR have operated flux of 21–25 LMH stably. This means that this system adsorbed the feed water fluctuation and properly treated the water. Energy consumption of this plant was achieved 0.76 kWh mm^{-3} and this value is same range of domestic sewage MBR system. The combination of an UASB reactor and ceramic MBR is the most economical and feasible solution for water reclamation of mixed industrial wastewater.

1. Introduction

During increased industrialization, some countries have been faced with a scarcity of water to use for industrial processes because of the increase in demand and a limited water supply, therefore the reclamation and reuse of industrial wastewater is essential. Mixed industrial wastewater displays typical characteristics, such as high strength and fluctuation in water quality, which is why the reclamation process requires a wide-range operation band in terms of fluctuated influent wastewater and stability. Researchers have investigated treatment of industrial wastewater using an membrane bioreactor (MBR) (Mutamim et al., 2013), up-flow anaerobic sludge blanket (UASB) (Tawfik et al., 2008), anaerobic MBR (Lin et al., 2013), and combined system with anaerobic and aerobic biological processes (Chan et al., 2009). Preferably, highly polluted industrial wastewaters are treated in an anaerobic reactor due to the high level of COD, potential for energy generation, and low surplus sludge production. An UASB is the most widely used high-rate anaerobic system for anaerobic sewage treatment, and a number of full-scale UASB systems have been installed worldwide (Mirsepasi et al., 2006). However, posttreatment after such systems were used was needed for reclamation. In addition, membrane filtration is common in the domestic wastewater reuse arena, and MBR is an effective process when combined with an activated sludge system for water reuse purposes (Galil and Levinsky, 2007). Typically, a MBR is applied to treat industrial wastewater due to its robustness, flexibility, compactness, complete solid separation performance, and capability of producing high quality reusable water (Di Bella et al., 2013).

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However, energy consumption is higher than it is for a conventional activated sludge system because an air scouring system is needed to prevent membrane fouling. The air scouring system is one of the key drivers to achieve stable filtration, but it is measure consumer of energy (Fenu et al., 2010).

There are two types of configurations for a membrane array: the membranes can be placed either outside or inside the bioreactor. In the external system with an inside-out type membrane, permeate flux generally varies between 50 and 120 L m^{-2} h^{-1} (LMH), and the transmembrane pressure (TMP) is in the range of 1–4 bar. In the submerged configuration with an outside-in type membrane, the permeate flux varies from 15 to 50 LMH, and the TMP is approximately 0.5 bar. The submerged configuration is more economical, based on energy consumption (Cicek et al., 1999).

Most of the MBR applications were initiated with organic membranes, which are much cheaper compared to their ceramic counterparts. However, in recent years, some studies have focused on ceramic membranes because of their supposed robust resistance to fouling and chemical attack, longer service life, and higher permeate flux (Noguchi et al., 2010; Jin et al., 2010). Moreover, ceramic membranes are resistant to extremes in pH, temperature, and pressure and can withstand rigorous cleaning with acids, bases, and hot water. Table 1 shows the advantages of ceramic membranes.

It is important to evaluate not only the performance and stability of the treatment process, but also the energy consumption. The authors reported energy consumption values of an MBR were in the range of 0.7–0.8 kWh m^{-3} (Krzeminski et al., 2012) and 0.4–0.7 kWh m^{-3} (Tao et al., 2010) when operating the MBR at optimal condition in municipal facilities. Gabarron et al. (2014) reported that energy consumption of a MBR using a flat-sheet membrane was lower than it was when using a hollow-fiber stand-alone MBR. In addition, specific organic load in industrial wastewater is higher than it is in wastewater from municipal facilities; thus, a combined process is key to reducing energy consumption.

The integrated system with an UASB reactor followed by a MBR has the above-mentioned benefits when treating industrial wastewater (Buntner et al., 2013). The advantages of an UASB alone are that it not only treats mixed industrial wastewater with low energy consumption, low sludge production, and generation of biogas for in-house power generation, but also adsorbs fluctuated feed water quality and produces good quality effluent water constantly with high strength wastewater. The ceramic MBR process accepts a fluctuation in feed water also with less impact or shock of TMP fluctuation and achieved the stabilization of product water quality because the ceramic membranes remove suspended matters without any suffering damage including attack by chemicals and emulsion oils.

Much of the pioneering research of MBRs occurred in North America, France, the UK, South Korea, China, Germany, and Japan (Yang et al., 2006). On the other hand, some of the researchers have investigated about integrated systems using UASB reactor and MBR (Qiu et al., 2013).

However, few papers have evaluated the process performance with energy consumption for a full-scale industrial wastewater treatment system because of high variation in wastewater among industries and different feed water quality. Typically no research was founded about performance of a full-scale plant using UASB reactor and ceramic MBR to reclaim the mixed industrial wastewater including energy consumption and growth of microorganism. Thus, the aim of this study was to provide knowledge of full-scale plant operation using a system with an UASB reactor followed by a ceramic MBR to expand this technology at the Jurong Water Reclamation Plant (JWRP) in Singapore. A detailed analysis of the foulant on a ceramic membrane was conducted with scanning electron microscopy coupled with energy dispersive X-ray (SEM/EDX). The 16S rRNA genes in the UASB granular sludge and MBR activated sludge were studied to understand the microbial communities that treat industrial wastewater.

Table 1
Advantages of ceramic membranes versus polymeric membranes.

- Long-life span and recyclable
- High resistance to chemical erosion and emulsion oil
- Capability of treating wastewater including inorganic matter
- High recoverability through chemical cleaning
- Strength against extreme high/low pH impacts
- Applicable for high temperature wastewater

2. Materials and methods

2.1. System description

The experiments were carried out with a full-scale UASB reactor and ceramic MBR system at the JWRP in Singapore. Fig. 1 presents a schematic flow of this full-scale plant. The feed water to this demonstration plant at the JWRP was taken only from the industrial wastewater, which was the mixed discharge water of over 300 factories including from the food, beverage, and pharmaceutical industries from the Jurong industrial area, and contained solvent, oil, and chemicals. Raw feed water from the existing distribution chamber of the industrial wastewater was distributed to this demonstration plant by volute pumps and through a 2-mm screen. The equalization tank, which had an effective volume of 760 m^3, was installed upstream of the UASB reactor to stabilize certain fluctuations in the feed water. There are 2 reactors of UASB, and both reactors consisted of a rectangular concrete tank with an effective volume of 600 m^3 and a gas solid separator above the reactor to prevent biomass washout. Effluent from the UASB reactor was fed to the ceramic MBR. The ceramic MBR consisted of three process parts: an anoxic zone, an aerobic zone, and a membrane tank where ceramic flat-sheet membrane (CFSM) units with 9600 m^2 of total surface area were installed. The specifications for the CFSM unit used throughout this study are shown in Table 2. The effective work volume of the bioreactor was 1520 m^3. The permeate water from the ceramic MBR through to the pressure meter and flow meter by suction pump with Variable Sequential Drive (VSD) and fed to the permeate tank, and the backwash pump was installed on a backwash line. Two blowers were installed, one for aeration of the aerobic biological process, which was controlled automatically by dissolved oxygen (DO), and one for scouring air for the ceramic membrane unit. This system was automated fully by PLC and SCADA.

2.2. Operation condition

After a 2-month start-up period, the plant operated for a little over a year from March 1, 2014 to March 30, 2015. Each UASB reactor was run at a fixed flow rate of 113.4 m^3 h^{-1}. Based on the results of previous pilot-scale studies, the UASB reactor in the present study was operated at a continuous hydraulic retention time (HRT) of 6.3 h, and the up-flow velocity was set to 1.2 m h^{-1}. Granular sludge was used from an industrial beverage company, which had 47,760 mg L^{-1} of mixed liquor suspended solid (MLSS).

The ceramic MBR process was done in series and operated at a flux of 21–25 LMH, and permeate flow was controlled to 190 m^3 h^{-1} for 10 min of sequential batching. The HRT was 8 h. Prior to this full-scale plant, a preliminary evaluation had been carried out using pilot-scale test equipment, and the results were that