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Development of an energy-saving anaerobic hybrid membrane bioreactors for 2-chlorophenol-contained wastewater treatment

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ABSTRACT

A novel energy-saving anaerobic hybrid membrane bioreactor (AnHMBR) with mesh filter, which takes advantage of anaerobic membrane bioreactor and fixed-bed biofilm reactor, is developed for low-strength 2-chlorophenol (2-CP)-contained wastewater treatment. In this system, the anaerobic membrane bioreactor is stuffed with granular activated carbon to construct an anaerobic hybrid fixed-bed biofilm membrane bioreactor. The effluent turbidity from the AnHMBR system was low during most of the operation period, and the chemical oxygen demand and 2-CP removal efficiencies averaged 82.3% and 92.6%, respectively. Furthermore, a low membrane fouling rate was achieved during the operation. During the AnHMBR operation, the only energy consumption was for feed pump. And a low energy demand of 0.0045–0.0063 kWh m^{-3} was estimated under the current operation conditions. All these results demonstrated that this novel AnHMBR is a sustainable technology for treating 2-CP-contained wastewater.

1. Introduction

Chlorophenols (CPs), which are widely used chemicals in industry, are regarded as an important class of environmental pollutants, due to their high toxicity, bioaccumulation and persistence in the environment (Hu et al., 2005). Many CPs have been listed as priority pollutants (Keith and Telliard, 1979). Commonly, these pollutants can be biodegraded via either aerobic or anaerobic pathway. However, in aerobic pathway, the biodegradation of chlorinated aromatic compounds is not only incomplete but also the by-products may be more toxic than the contaminants. In contrast, reductive dechlorination in anaerobic process produces less toxic and easily biodegradable metabolite (Chang et al., 2003; Majumder and Gupta, 2008). Moreover, since high energy demand for aeration in aerobic processes, anaerobic processes have been popularly used to removal CPs through reductive dechlorination with low energy consumption (Basu et al., 1996; Khodadoust et al., 1997; Bajaj et al., 2008).

In recent years, anaerobic membrane bioreactor (AnMBR) technology is being emerged as a very appealing alternative for wastewater treatment due to its significant advantages over conventional anaerobic treatment, such as high quality effluent (Lin et al., 2013). AnMBRs have been used for refractory industrial wastewater treatment, e.g. textile wastewater (Spagni et al., 2012), bamboo industry wastewater (Wang et al., 2013) and petrochemical wastewater (Van Zyl et al., 2008). Membrane processes have been used in anaerobic dechlorination system for tetrachloroethene separation from wastewater (Pampel and Livingston, 1998) and for biofilm cultivation (Chang et al., 2003). However, little literatures have been reported for 2-CP-contained wastewater treatment using AnMBR.

Before using the AnMBR for 2-CP-contained wastewater treatment, its inherent drawback of serious membrane fouling problem should be given more consideration. Tremendous efforts have been made to control membrane fouling in the AnMBR in previous studies. To counteract the effects of membrane fouling, maintenance by periodic or online physical or chemical cleaning needed to be carried out, which inevitably increased the operation costs (Skouteris et al., 2012; Lin et al., 2013). Some effective strategies were induced to increase membrane surface shear force to control cake development, such as gas sparging (Cerón-Vivas et al., 2012; Prieto et al., 2013), intensive hydraulic circulation (Yoo et al., 2012) and online ultrasound (Yu et al., 2012). Although the membrane fouling could be partly reduced through these fouling control strategies or cleaning measures, the energy input into this energy-sustainable system would be significantly increased. Fluidized-bed technology, by using active particles, such as granular activated carbon (GAC) or particle activated carbon (PAC) has been integrated into anaerobic membrane bioreactor to suppress membrane fouling (Kim et al., 2011; Yoo et al., 2012; Zhao et al., 2012). The adsorption of

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contaminants and microbes in the fluidized-bed GAC bioreactor can increase the retention time of the compounds being biologically removed, which will enhance their removal efficiency and reduce the membrane fouling (Khodadoust et al., 1997). However, the separation of these particles and the fluidization for reactors would further increase the complicated operation and the energy demand of the fluidized-bed bioreactor, which would block its widely application.

The use of fixed-bed biofilm reactor instead of fluidized-bed would avoid the energy demand for particles separation and fluidization. The adsorption of contaminants and microbes in the fixed-bed biofilm will also increase pollution removal and decrease membrane fouling reduction (Bajaj et al., 2008). To further reduce membrane fouling and decrease the energy demand for filtration, some mesh filter could be used to construct dynamic membrane for filtration in AnMBR (Ma et al., 2013). Thus, in this study a hybrid system of fixed-bed biofilm reactor and AnMBR with mesh filter was developed for enhancing chlorophenol-contained pollution removal, reducing membrane fouling and energy cost. In the anaerobic hybrid membrane bioreactor (AnHMBR) system, stainless steel mesh was used as filter and GAC was added into AnMBR to construct an anaerobic fixed-bed biofilm membrane bioreactor for low-strength 2-CP-contained wastewater treatment. The system performance in term of COD and 2-CP removal under different HRT and loading were evaluated. The feasibility of membrane fouling mitigation without additional energy input in the AnHMBR system was investigated. Moreover, the mechanism of fouling reduction as well as energy demand of the system were discussed.

2. Materials and methods

2.1. Reactor setup

A bench-scale AnHMBR with stainless steel mesh (Huayang Ironware Co., China) filter was constructed, whose structure was illustrated in Fig. 1. The column-type reactor was filled with 1.2 kg GAC (Sanye Carbon Co., China; 3–5 mm diameter). The total volume of the reactor was 1.6 L, while the net effective volume was 0.78 L. The flat stainless steel mesh filter, with an average pore size of 0.7 μm and an effective filtration area of 0.022 m^2, was fixed on the top of the reactor to enable an up-flow. Silicone tubes were installed on both ends of the plexiglass tube to connect inlet pipe, pressure transmitter and sampling pipe.

2.2. Inoculation and operation conditions

The AnHMBR was inoculated with 100 mL of concentrated anaerobic sludge with a concentration of 15 g L^{-1} from a laboratory-scale upflow anaerobic sludge blanket reactor. Before inoculation, the seeding sludge was acclimated with 2-CP-contained wastewater for more than two months. Synthetic wastewater was used in this work. The composition of the synthetic wastewater was: $CH_3COONa·3H_2O$, 150 mg L^{-1} or 300 mg L^{-1}; NH_4Cl, 57 mg L^{-1}; $K_2HPO_4·3H_2O$, 22 mg L^{-1}; $CaCl_2$, 11.5 mg L^{-1}; $MgSO_4$ 12 mg L^{-1} and 10 mL of trace element solution. The composition of the trace element solution (in μg L^{-1}) was: EDTA, 50, $ZnSO_4·7H_2O$, 22, $CaCl_2·2H_2O$, 8.2, $MnCl_2·4H_2O$, 5.1, $FeSO_4·7H_2O$, 5.0, $(NH_4)6Mo_7O_{24}·4H_2O$, 1.1, $CuSO_4·5H_2O$, 1.8, $CoCl_2·6H_2O$, 1.6. During the experiment, 2-CP (O-Chlorophenol) was used as model pollution. The COD and 2-CP concentrations in the influent at different operation days are listed in Table 1. The synthetic wastewater was continuously fed into the reactor at the bottom through a peristaltic pump (Lange Co., China), and then flew through the fixed-bed biofilm. After filtration through the stainless steel mesh, the effluent was finally discharged from the system. The system performances under various operating conditions (Table 1) were evaluated. During the operation, the temperature of the bioreactor was kept constant at about 25 °C using water bath.

In the system operation, the permeation flux was kept constant, and the trans-membrane pressure (TMP) across the steel mesh was monitored every 2 min by a pressure transmitter (LD187, Leide Electronic Ltd., China). After a long-term operation, the biofilm attached on steel mesh would become thick, and the TMP would increase sharply. Thus, off-line backwashing was periodically carried out to remove the overgrown biofilm. Finally, the fouled filter was flushed with tap water to remove the sludge layer and then used again.

2.3. Analysis and calculations

COD concentration and turbidity were measured following the Standard Methods (APHA, 1998). The concentrations of 2-CP and its dechlorined product, phenol, were determined using an HPLC (Model 1100, Agilent Inc., US) with a Hypersil-ODS reversed-phase column and detected at 280 nm using a variable wavelength detector. The temperature for the column in the HPLC was 30 °C. The mobile phase was a mixture of water with 0.2% acetic acid and methanol (35:65) delivered at a flow rate of 1 mL min^{-1}.

To visualize the architecture of the sludge layer on stainless steel mesh, the mesh samples were taken from the reactor after the 92 d operation and flushed with tap water. Then, the surface of new mesh filters and the fouled ones, after flushed with tip water were observed using a microscope (BX41, Olympus Co., Japan).

The total filtration resistance was estimated by Darcy's equation as follows (Lee et al., 2001):

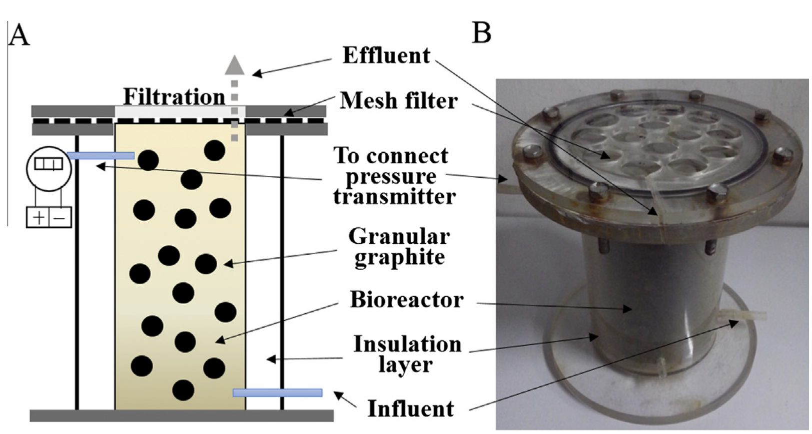

Fig. 1. (A) Schematic diagram and (B) photograph of the AnHMBR system.