Bioresource Technology 159 (2014) 193–198

Contents lists available at ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

Treatment of domestic wastewater by an integrated anaerobic fluidized-bed membrane bioreactor under moderate to low temperature conditions

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HIGHLIGHTS

- The accumulation of VFAs was affected by temperature significantly.
- Low temperature accelerated membrane fouling process.
- Proteins were the dominant EPSs causing membrane fouling at low temperature.
- Granular active carbon can mitigate membrane fouling via protein absorption.

ARTICLE INFO

Article history:
Received 8 January 2014
Received in revised form 19 February 2014
Accepted 22 February 2014
Available online 3 March 2014

Keywords:
Domestic wastewater
Resource recovery
Anaerobic membrane bioreactor (AnMBR)
Temperature
Membrane fouling

ABSTRACT

The performance of a novel integrated anaerobic fluidized-bed membrane bioreactor (IAFMBR) for treating practical domestic wastewater was investigated at a step dropped temperature from 35, 25, to 15 °C. The COD removal was 74.0 ± 3.7%, 67.1 ± 2.9% and 51.1 ± 2.6% at 35, 25 and 15 °C, respectively. The COD removal depended both on influent strength and operational temperature. The accumulation of VFAs (Volatile Fatty Acids) was affected by temperature, and acetic acid was the most sensitive one to the decrease of temperature. The methanogenic activity of the sludge decreased eventually and the methane yield was dropped from 0.17 ± 0.03, 0.15 ± 0.02 to 0.10 ± 0.01 L/L d. And as compared with a mesophilic temperature, a low temperature can accelerate membrane biofouling. Proteins were the dominant matters causing membrane fouling at low temperature and membrane fouling can be mitigated by granular active carbon (GAC) through protein absorption.

1. Introduction

Domestic wastewater has been regarded more as a resource rather than a waste (McCarty et al., 2011; Wang et al., 2012), especially for current world that faces severe risks such as climate changes, energy crisis and water scarcity. Anaerobic process, which has been widely used to treat high-strength industrial wastewater for energy reclaiming, is currently recognized as a promising technology for domestic wastewater treatment (Foresti et al., 2006; Seghezzo et al., 1998). Many full-scale anaerobic treatment plants have been set up in tropical countries, such as India, Colombia, and Brazil (Seghezzo et al., 1998; Florencio et al., 2001). Given the common perception that anaerobic bioreactors can be operate efficiently under the mesophilic (30–40 °C) or thermophilic (50–60 °C) temperature. However, the temperatures of domestic wastewaters in regions without hot climates are relatively low (average of 16 °C in the U.S.) (Smith et al., 2013), thus it's quite practical to study anaerobic technologies in a lower temperature (<20 °C). Now the performance of anaerobic treatment for domestic wastewater at low temperatures is being closely focused (Bandara et al., 2012; Donoso-Bravo et al., 2013; Elmitwalli et al., 2002; Gao et al., 2011a).

A technology for domestic wastewater treatment now actively being pursued is anaerobic membrane bioreactor (AnMBR), which allows high mixed liquor suspended solids (MLSS), enables high removal of organic matter and low production of excess sludge. The membrane leads to nearly absolute biomass retention, with the potential to generate a high quality effluent. Studies have been focused on assessing AnMBR performance for domestic wastewater treatment, which evaluated AnMBR performance at psychrophilic temperatures (Ho and Sung, 2010; Smith et al., 2013). Another alternative for anaerobic treatment of domestic wastewater at low temperatures could be the two-stage system, which consists of two high-rate reactors for allowing an increase in the

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http://dx.doi.org/10.1016/j.biortech.2014.02.086
0960-8524/

methanogenic activity (Elmitwalli et al., 2002; Alvarez et al., 2008). These studies examined the performances of different anaerobic reactor combination for domestic wastewater treatment at low temperatures. In view of the advantages of AnMBR, it makes good sense to try using membrane bioreactor as one of the combination reactors. In fact, several studies have used compact systems containing AnMBR to meet the more stringent environment regulation and recover resources (An et al., 2009; Kim et al., 2011). However, membrane bioreactor technology is still facing another serious problem, membrane fouling, which hindered the large-scale application of MBR (Gao et al., 2010; Meng et al., 2009). Membrane fouling can mainly be attributed to an accumulation of cells, extracellular polymeric substances (EPS) and soluble microbial product (SMP) on the membrane surface (Meng et al., 2009). Previous studies reported that granular activated carbon (GAC) or powder activated carbon (PAC) was adopted to reduce or alleviate the membrane fouling as they can effectively adsorb microbial metabolic products (Choo et al., 2000; Akram and Stuckey, 2008; Hu and Stuckey, 2007). Recently, fluidized GAC was used to alleviate the membrane fouling by scouring action on the membrane surface (Kim et al., 2011; McCarty et al., 2011).

Based on the concept of AFBR and AnMBR, an integrated anaerobic fluidized bed membrane bioreactor (IAFMBR) was proposed for domestic wastewater treatment. In the previous study, the treatment efficiency of IAFMBR for practical domestic wastewater under different hydraulic retention times (HRTs) was discussed (Gao et al., 2014). As temperature was a vital factor in an anaerobic process, the IAFMBR application under moderate to low temperature was worth substantial attention.

On this basis, a study was continued conducted to assess the feasibility of actual domestic wastewater treatment by an IAFMBR. The primary objectives of this study were to investigate the effect of temperature on the performance under relatively moderate to lower temperature. A mass balance on COD at different temperatures was conducted to assess the pathway of the organic. In addition, the membrane fouling at different temperatures was also studied in order to provide references for the practical project.

2. Methods

2.1. Reactor design

A laboratory-scale integrated anaerobic fluidized bed membrane bioreactor (IAFMBR) which was made of 8 mm thick plexiglas plate and the total volume was 7.6 L with effective volume 5.8 L, consisted of three parts, i.e. outer tube, middle tube and inner tube (Gao et al., 2014). The outer tube was served as AFBR with granular activated carbon (200–300 g) as a carrier, and the inner tube performed as anaerobic membrane bioreactor (AnMBR) which installed hollow fiber membrane (Mitsubishi Rayon Co., Ltd. Tokyo, Japan). The designed membrane flux was 11.3 L/(m^2 h) with a total area of 0.19 m^2 and an average pore diameter of 0.4 μm. The operating flux was 7.1 L/(m^2 h) at the a hydraulic retention time (HRT) of 6 h.

2.2. Feed stock

The reactor was fed with synthetic wastewater containing acetate as a substrate at start-up period and then gradually fed with domestic wastewater (Gao et al., 2014). The actual domestic wastewater was daily collected from a septic tank located within a community near university campus (Harbin, China), with a pH of 7.18–7.99.

2.3. Seed sludge

The reactor was inoculated with 5 L of waste sludge from a municipal wastewater treatment plant in Harbin, China, with an initial MLSS and MLVSS concentration of approximately 20,500 mg/L and 13,300 mg/L, respectively (MLVSS/MLSS = 0.65).

2.4. Operation of IAFMBR

The reactor was equipped with a temperature sensor and a water-heating system for temperature control. The experiment was conducted at different temperatures, reducing from 35 °C, 25 °C to 15 °C. The reactor was operated at 35 °C for 31 days, for the following 33 days at 25 °C, and for 37 days at 15 °C. The water permeation was kept at about 23.2 L/d in IAFMBR, which corresponded to a hydraulic retention time (HRT) of 6 h. And 40 g GAC (10 × 30 mesh) was added into the inner tube (AnMBR) of IAFMBR to prevent membrane surface from the formation of biomass cake and clogging. The membrane module was cleaned before a new cycle each time (Gao et al., 2011b).

2.5. Analytical methods

COD and MLSS were tested according to the standard methods (APHA, 2001). DO and pH were monitored by Handheld Multi-Parameter Instruments (pH/Oxi 340i, WTW, Germany). The volume of biogas production was measured daily at room temperature using a wet gas meter. The concentration of acetic acid, propionic acid, butyric acid and valeric acid in effluent samples was determined by gas chromatography (HP7890 Agilent Technologies, Palo Alto, CA) equipped with a flame ionization detector (GC-FID) (Gao et al., 2011a). Biogas content (methane, carbon dioxide and hydrogen) was determined by gas chromatography according to the literature (Gao et al., 2011a). For the methane dissolved in effluent, a calculation based on the Henry's Law was considered to compensate under estimation total methane production, assuming that methane in effluent was saturated (Gao et al., 2011a). The solubility constant in each temperature period was dependent on methane content in biogas and experience data obtained from the literature (Perry and Chilton, 1973).

The extracellular polymeric substance (EPS) and soluble microbial product (SMP) samples were collected according to the previous study (Gao et al., 2011b), and then extracted based on the reference (Malamis and Andreadakis, 2009). The content of polysaccharides was tested by the phenol–sulphuric acid method (Dubois et al., 1956). Proteins' concentration was measured by the Modified BCA kit (Sangon, China).

3. Results and discussion

3.1. The performance of IAFMBR

3.1.1. COD removal

The influent concentration fluctuated greatly, in the range of 247–449 mg/L for COD (Fig. 1). In general, there was no significant decrease in the COD removal for IAFMBR when temperature dropped from 35 °C to 25 °C. When temperature dropped further to 15 °C, the COD removal decreased obviously (Fig. 1). The performance of IAFMBR at different temperatures was summarized in Table 1. The respective COD removal was 74.0 ± 3.7%, 67.1 ± 2.9% and 51.1 ± 2.6% when temperature decreasing from 35, 25 to 15 °C. The volumetric COD removal rate was 0.95, 0.81 and 0.73 gCOD/L d at 35, 25 and 15 °C, respectively. The COD removal efficiency was the highest at 35 °C, and then dropped with the decreasing temperature. In contrast, one point should be noted,