Chemical Engineering Journal 240 (2014) 362–368

Contents lists available at ScienceDirect

Chemical Engineering Journal

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

Integrated anaerobic fluidized-bed membrane bioreactor for domestic wastewater treatment

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HIGHLIGHTS

- An integrated anaerobic fluidized-bed membrane bioreactor was developed.
- Methane productivity decreased while more VFAs accumulated with a shorter HRT.
- The membrane fouling was more serious at a shorter HRT than longer HRT.
- GAC addition reduced protein content in cake layer and helped membrane filtration.

ARTICLE INFO

Article history:
Received 8 September 2013
Received in revised form 1 December 2013
Accepted 5 December 2013
Available online 11 December 2013

Keywords:
Domestic wastewater
Resource recovery
Anaerobic membrane bioreactor (AnMBR)
Granular activated carbon (GAC)
Membrane fouling

ABSTRACT

An integrated anaerobic fluidized-bed membrane bioreactor (IAFMBR) system with granular activated carbon (GAC) as carrier was developed to treat domestic wastewater with energy recovery. We investigated a laboratory-scale IAFMBR with chemical oxygen demand (COD) of about 300 mg/L at different hydraulic retention time (HRT). The removal of COD of 75.8%, 73.6% and 54.1% was achieved at respective HRT of 8, 6 and 4 h, resulting in respective methane yield was 140, 180 and 190 L CH_4(STP)/kgCOD$_{removed}$ and conversion of 45.2%, 53.1% and 43.8% of COD into methane in biogas. The transmembrane pressure of membrane increased more rapidly at a shorter HRT than a longer HRT, suggesting that membrane fouling rate was accelerated at short HRTs. The amount of GAC added into the inner tube of IAFMBR controlled essentially the membrane fouling process. Supplementation of GAC reduced protein content in layer cake and helped membrane filtration.

1. Introduction

Recently, municipal wastewater has been considered as a resource, rather than a waste, for water, energy and fertilizer [1–3]. The concept to use anaerobic approach for domestic sewage treatment, not implementing aerobic biological process as a core technology, has been proposed for years via recovery energy as methane in biogas and possible fertilizer from the wastewater [4–7]. In 1960–1970s, the research groups of Dr. P. McCarty and Dr. G. Lettinga developed anaerobic filter (AF) and upflow anaerobic sludge blanket (UASB) reactor, respectively, for organic wastewater treatment with biogas recovery [8]. Traditionally, anaerobic process has been considered suitable for high strength organic wastewater treatment [8], although some anaerobic reactors have been applied to treat domestic wastewater at full scale wastewater treatment plants in tropical countries [9]. With high biomass retention, the high-rate anaerobic reactors are able to achieve high levels of biomass in anaerobic reactors and long SRTs while maintaining short HRTs.

Stoichiometrically, the aerobic removal of one gram of chemical oxygen demand (COD) equivalent organic matter from wastewater requires one gram of O_2 while anaerobic degradation of one gram COD equivalent organics produces 0.35 L of methane when biomass synthesis is ignored. Attempt to use anaerobic reactor for domestic wastewater has been tested for decades but the effluent quality did not meet the requirement for wastewater effluent to surface receivers. The anaerobic reactors tested for the treatment of low strength wastewater included UASB, anaerobic filter (AF), anaerobic SBR (AnSBR), anaerobic fluidized bed reactor (AFBR) and other modifications [10]. Among the anaerobic processes, fluidized bed reactor has good mass transfer efficiency due to growth of thin biofilm on media particles and well contact between biofilm biomass and bulk liquid [8,11,12]. It was reported that the ability of AFBR in removing suspended solid particles of domestic wastewater was better than UASB although energy consumption was higher [13].

Membrane bioreactor (MBR), which combines the conventional activated sludge process with effective membrane filtration, has

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http://dx.doi.org/10.1016/j.cej.2013.12.012

been successfully used for the aerobic treatment of domestic wastewater for years [14,15]. The effluent quality could reach well below current discharge standard and even meet the requirement for water reuse. However, in general, membrane fouling seems to be the most serious problem hindering the large-scale application of MBR [16,17]. The energy consumption of aerobic MBR is much higher than conventional activated sludge process due to use air bubbling to prevent the membrane from biofouling. Attempt to develop anaerobic MBR (AnMBR) for treatment of domestic wastewater has been tested for decades but less progress had been made mainly due to membrane fouling which causes high operational cost and unsustainable operation for long-term [18].

Previous research on membrane fouling control focused on the adsorption of fouling agents by adding powdered activated carbon (PAC) [19]. Recently, Professor McCarty and his colleagues developed a novel anaerobic system which consisted of an AFBR followed by another anaerobic fluidized bed membrane reactor (AFBMR) for a synthetic wastewater treatment, and the membrane fouling was controlled by granular activated carbon (GAC) addition in South Korea [20]. This invention first demonstrated the feasibility of controlling membrane fouling by fraction of solid media such as GAC for a long term. Based on the above concept [20]. Based on this concept, we proposed an integrated reactor configuration i.e. integrated anaerobic fluidized bed membrane bioreactor (IAFMBR) with GAC as carrier for domestic wastewater treatment. This system simplifies the reactor operation and occupies smaller footprint compared with above two stage system. The conceptual design of the reactor is illustrated in Fig. 1. The outer loop of the reactor performs as anaerobic fluidized bed reactor (AFBR) with GAC as carrier and the inner loop serves as anaerobic membrane bioreactor (AnMBR).

The goal of this study was to investigate the feasibility of IAFMBR for domestic wastewater treatment with methane recovery. With a laboratory-scale reactor, we tested the reactor performance and membrane fouling at three different hydraulic retention times (HRTs) i.e. 4, 6 and 8 h and examined the dosage of GAC added in relation to the transmembrane pressure (TMP), i.e. membrane fouling.

2. Materials and methods

2.1. Reactor design

A laboratory-scale IAFMBR was made of 8 mm thick plexiglass plate and the total volume was 7.6 L with an effective volume of 5.8 L. The reactor consisted of an outer tube, a middle tube, an inner tube, and a three-phase separator. The lower end of outer tube was 685 mm high and had a diameter of 100 mm. The upper end of outer tube was 70 mm tall, with diameter up to 200 mm. The middle tube was 780 mm high, with a diameter of 65 mm. The reactor consisted of an 800 mm high by 40 mm diameter inner tube containing hollow fiber membrane (Mitsubishi Rayon Co., Ltd. Tokyo, Japan) with a total area of 0.19 m^2 and an average pore diameter of 0.4 μm. The designed membrane flux was $0.27 m^3/(m^2\ d)$. The outer tube performed as AFBR with GAC (200–300 g) as carrier and the inner tube served as anaerobic membrane bioreactor (AnMBR). The reactor configuration is shown in Fig. 1. The influent entered the reactor from the bottom of AFBR by a peristaltic pump, flowed upward to maintain GAC fluidization, then through the three-phase separator to separate gas and liquid from solid. Part of the effluent of AFBR flowed downward into the middle tube, and then flowed through the middle tube into inner tube (AnMBR). The operational temperature was maintained at 35 ± 2 °C.

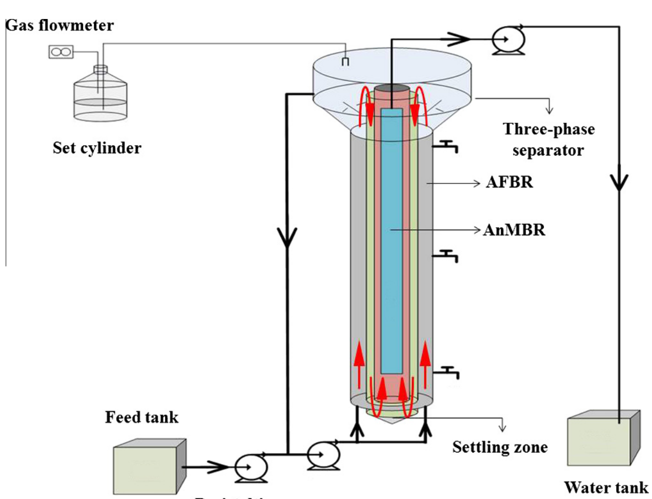

Fig. 1. Schematic diagram of integrated anaerobic fluidized bed membrane bioreactor (IAFMBR).

2.2. Inoculation

The reactor was inoculated with waste sludge from a domestic wastewater treatment plant in Harbin, China. The initial MLSS (mixed liquor suspended solid) and MLVSS (mixed liquor volatile suspended solid) concentration of sludge were approximately 20,500 mg/L and 31,500 mg/L, respectively.

2.3. Feed composition

After start-up, the system was fed with synthetic wastewater containing acetate as substrate and then fed with domestic wastewater. The composition of the synthetic wastewater was as follows (mg/L): sodium acetate, 133; urea, 30; NH_4Cl, 145; K_2HPO_4, 44; $MgSO_4$, 53 and $CaCl_2$, 13. The domestic wastewater was collected daily from a septic tank near our university campus in Harbin, China. Over our test period, it contained average COD concentration of 320 ± 44.15 mg/L with pH 7.5 ± 0.21.

2.4. Operation of IAFMBR

The IAFMBR was started with the synthetic wastewater at influent flow rate of 17.4 L/d, and recycle ratio at 10. Initially, the reactor was operated with a HRT of more than 8 h, and influent COD of about 300 mg/L. After 27 days of operation, soluble COD removal of more than 60% was achieved. From day 28, the domestic wastewater was gradually added into the reactor influent. The fraction of the synthetic wastewater in the influent was reduced daily by following a formula $1 - 0.05n$ (n stands for the day since domestic wastewater was fed to IAFMBR) till the influent was composed of only domestic wastewater. The influent COD concentration varied between 234.2 and 425 mg/L and the start-up stage ended on day 62 (Fig. 2). Data were collected for analysis at steady-state conditions as COD removal efficiency reached 75% and biogas production was 400 mL/d. The IAFMBR was then operated in sequence under three different HRTs i.e. 8 h (day 63–day 96), 6 h (day 97–day 127) and 4 h (day 128–day 160). The effluent discharged was maintained at about 17.4, 23.2 and 34.8 L/d in IAFMBR for respective HRT 8, 6 and 4 h. Moreover, the effect of addition of GAC (10 × 30 mesh) on membrane fouling was investigated separately by adding 0, 40 and 80 g of GAC into the AnMBR (inner tube of IAFMBR) which was operated with HRT of 6 h, respectively. The same reactor and hollow fiber membrane module was used in the membrane fouling control trail, and the membrane module was cleaned before the addition of GAC each time.