Process Biochemistry 47 (2012) 792–798

Contents lists available at SciVerse ScienceDirect

Process Biochemistry

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

Anaerobic submerged membrane bioreactor (AnSMBR) treating low-strength wastewater under psychrophilic temperature conditions

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A R T I C L E I N F O

Article history:
Received 2 December 2011
Received in revised form 31 January 2012
Accepted 13 February 2012
Available online 3 March 2012

Keywords:
Anaerobic submerged membrane bioreactor
Membrane fouling
Critical flux
Low-strength wastewater treatment
Psychrophilic treatment

A B S T R A C T

An anaerobic submerged membrane bioreactor (AnSMBR) treating low-strength wastewater was operated for 90 days under psychrophilic temperature conditions (20 °C). Besides biogas sparging, additional shear was created by circulating sludge to control membrane fouling. The critical flux concept was used to evaluate the effectiveness of this configuration. Biogas sparging with a gas velocity (U_G) of 62 m/h together with sludge circulation (94 m/h) led to a critical flux of 7 L/(m^2 h). Nevertheless, a further increase in the U_G only minimally enhanced the critical flux. A low fouling rate was observed under critical flux conditions. The cake layer represented the main fouling resistance after 85 days of operation. Distinctly different volatile fatty acid (VFA) concentrations in the reactor and in the permeate were always observed. This fact suggests that a biologically active part of the cake layer contributes to degrade a part of the daily organic load. Hence, chemical oxygen demand (COD) removal efficiencies of up to 94% were observed. Nevertheless, the biogas balance indicates that even considering the dissolved methane, the methane yield were always lower than the theoretical value, which indicates that the organic compounds were not completely degraded but physically retained by the membrane in the reactor.

1. Introduction

Because of the many advantages of anaerobic digestion over conventional aerobic biological processes such as the biogas production, the lower sludge production as well as the fact that no energy for aeration is required, anaerobic digestion can be regarded as one of the most promising wastewater treatment systems for meeting the desired criteria for future technology in environmentally sustainable development [1].

Typically, anaerobic reactors are operated in the mesophilic (25–37 °C) or thermophilic (45–60 °C) temperature range to ensure optimal microbial activity [2]. Nevertheless, excluding tropical countries, a significant amount of energy is required to heat wastewater streams up to the optimal temperature range [3]. Therefore, the anaerobic treatment for cold (<20 °C), low-strength, high volume wastewater (e.g. many industrial and municipal wastewaters in temperate regions) has, to date, been limited by economic factors [2].

Low operational temperature and wastewater strength involve slow biochemical reaction rates such as growth rate of methanogens [4]. Therefore, the feasibility of anaerobic treatment for low-strength wastewater at low temperatures depends on the reactor capacity to retain viable biomass, among others [3]. Under such conditions, membrane bioreactors (MBRs) appear to be an appropriate option since they offer independent control of the solid (SRT) and hydraulic retention time (HRT). Main advantages of MBR over conventional process include the production of a high quality, clarified and largely disinfected permeate product in a single stage, among others [5]. However, membrane fouling represents the biggest hurdle for wider application of MBRs. In fact, two of the most significant components of MBR operation costs are membrane replacement and energy consumption and both related to fouling [5]. Therefore, membrane fouling has been widely studied from various perspectives including the causes, characteristics, fouling mechanisms and methods to prevent or reduce membrane fouling [6]. However, despite about a decade of worldwide research on the complex topic of fouling in MBRs, so far many questions still remain unanswered [7].

Membrane fouling can be defined as the restriction, occlusion or blocking of membrane pores at the membrane surface that results in an increasing filtration resistance, and hence in a reduction of flux [5]. The movement of a particle near a porous membrane is the result of the forces acting on such particle toward and away the membrane. In general, permeation flux results in a drag force toward the membrane, while shear-induced diffusion is the major strategy to increase back-transport mechanisms [8].

Two principle approaches to membrane design and operation can be identified [9]. The membrane can be operated under vacuum

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doi:10.1016/j.procbio.2012.02.011

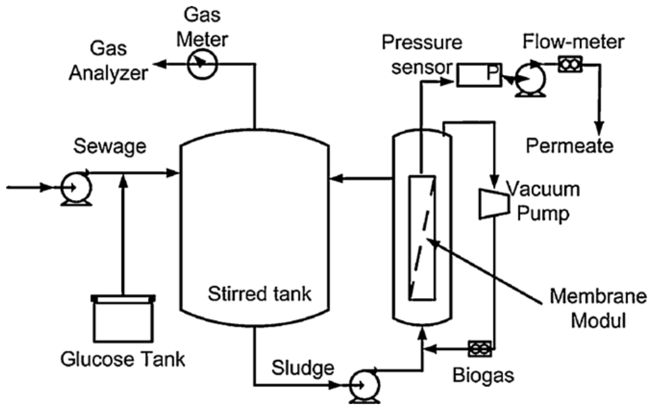

Fig. 1. Schematic of the pilot AnSMBR.

or under pressure. In the vacuum-driven configuration, surface shear created by gas sparging is widely used to enhance permeate flux [8], while high cross-flow velocities (CFV) resulting in high shear rates on the membrane surface are widely used to control membrane fouling in the pressure-driven MBRs. In the vacuum-driven configuration, the membrane can be submerged either directly into the bioreactor or in a separate chamber. If the membrane is submerged in a separate chamber, the sludge should be circulated from the reactor to the membrane chamber and such a circulation can be used as CFV, which can enhance the surface shear created by gas sparging. Nevertheless, it should be considered that high shear rates can induce the decrease in particle size. Since smaller particles are directly associated with fouling tendency [10], an increase in shear rate can therefore indirectly lead to a higher fouling.

In the present research, an anaerobic submerged membrane bioreactor (AnSMBR) treating low-strength wastewater composed of municipal wastewater and glucose was operated for nearly 90 days under psychrophilic conditions (20 °C). Besides biogas sparging, sludge was circulated to create additional surface shear to control membrane fouling. The main objective was to evaluate the overall performance of the reactor under different flux conditions, assessing membrane fouling as well as the anaerobic treatment of the feed wastewater.

2. Materials and methods

2.1. Experimental set-up

A pilot scale AnSMBR was operated for nearly 90 days (Fig. 1). It consisted of two containers – one was used as anaerobic reactor, the other one as membrane container, where the membrane module was submerged in the mixed liquor. A flat sheet polyether sulfone ultra-filtration membrane with a mean pore size of 38 nm and a total membrane surface of 3.5 m^2 was used (Microdyn-Nadir, Germany). The operational temperature was controlled by two electric heaters linked to a temperature controller at 20 ± 1 °C. The active volume of the reactor was 350 L. Biogas sparging with a superficial biogas velocity (U_G) of 62 m/h and sludge circulation with a CFV of 94 m/h were used together to control membrane fouling.

2.2. Reactor operation

MBRs can be operated over extended periods at a fixed flux if this flux is substantially below the critical flux [11]. However, real operational conditions sometimes require an increase in the operational flux. Therefore, the reactor was also operated under supra-critical flux conditions to evaluate the stability of the process. Table 1 summarizes the main operational conditions.

The reactor was operated in cycles consisting of (1) feeding, (2) filtration, (3) pause/relaxation and (4) backwashing. The filtration phase was set to 10 min. A 30 s pause was included in the cycle to relax the membrane. Backwashing (1 min) was applied by reversing the direction of the permeate pump. The flux during backwashing phases was kept at the same value than during filtration. Feeding phases last from 1 to 2 min. The transmembrane pressure (TMP) was calculated as the difference between permeate pressure and the pressure inside the reactor considering the mean hydraulic head at the mid-point of the membrane module. A more detailed description of the reactor and reactor operation can be found in our previous research [12].

2.3. Inoculum and feed wastewater

After assessing a period of mesophilic conditions and the transition to psychrophilic conditions as reported in [12], the reactor was further operated under psychrophilic conditions.

The reactor was initially fed with municipal wastewater from WWTP Garching, Germany. However, the COD concentration of raw municipal wastewater was very low (250 ± 60 mgCOD/L). A concentrated solution of glucose (14.2 ± 0.5 gCOD/L) was used in order to achieve a COD concentration of the feed wastewater of around 600 mgCOD/L. The ratio glucose/municipal wastewater expressed in terms of COD was around 1.5.

2.4. Critical flux determination

In the present research, the critical flux was determined following the flux-step method [13] using fouling rates as response variable. The critical flux was assumed to be exceeded when dTMP/dt exceeded 2 mbar/min. In order to have similar membrane initial conditions, a cleaning protocol was followed every time the critical flux was determined or when new flux conditions were imposed. This consists of 30 min pause/relaxation and a 5 min backwashing keeping a flux of 7 L/(m^2 h).

Table 1
Fouling rate and operational conditions.

Period (days)	Flux (L/(m^2 h))	dR_{FR}/dt (1/(m d))	TSS (reactor) (g/L)	sCOD (reactor) (g/L)	OLR (gCOD/L d)
0–11	7	2.6×10^{11}	17.3 ± 1.4[a]	0.64 ± 0.06	0.61 ± 0.15
25–36	12	8.7×10^{11}	12.6 ± 1.5[a]	1.37 ± 0.22	0.81 ± 0.05
36–41	10	1.2×10^{12}	14.2 ± 1.4[a]	1.05 ± 0.12	0.69 ± 0.14
42–63	7	8.4×10^{10}	14.7 ± 0.7	1.33 ± 0.31	0.52 ± 0.09
68–76	7	1.5×10^{11}	9.5 ± 0.4	1.25 ± 0.07	0.67 ± 0.08
80–85	7	3.9×10^{11}	10.4 ± 1.1	2.35 ± 0.85	0.72 ± 0.09

[a] Accumulation of solids was observed during these experiments.