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Effect of psychrophilic temperature shocks on a gas-lift anaerobic membrane bioreactor (Gl-AnMBR) treating synthetic domestic wastewater

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ABSTRACT

Municipal wastewater is a renewable resource containing energy, nutrients and water. These valuables can be recovered via new, innovative technologies such as the gas-lift anaerobic membrane bioreactor (Gl-AnMBR), which is especially suitable for decentralized wastewater treatment. To better understand the effects of fluctuating environmental conditions on the treatment performance, the impact of short-term temperature shocks was studied. We present a laboratory study of a 10 L Gl-AnMBR equipped with an external tubular ultrafiltration membrane treating synthetic domestic wastewater at mesophilic (35 °C) conditions with a series of short-term (12–48 h) cold (15 °C) shocks applied prior to switching to psychrophilic (15 °C) conditions. The average COD removal under mesophilic conditions was as high as 94 ± 2%, even during the temperature shocks. Under psychrophilic conditions, more than 80% of the influent COD accumulated in the reactor (compared to 39% under mesophilic conditions). The results suggest that an abrupt and short-term temperature decrease from 35 to 15 °C can largely be absorbed by our system with no negative effect on effluent quality.

1. Introduction

Municipal wastewater is a by-product of sanitation in urban areas. While traditional wastewater treatment has focused on the removal of undesirable constituents (e.g., organic matter, nutrients, and pathogens), wastewater is increasingly viewed as a valuable source of energy, nutrients and water [11]. In addition to fresh water that can be reclaimed and nitrogen and phosphorus that can be captured as fertilizer, domestic wastewater contains considerable amounts of energy stored in the chemical bonds within the organic wastes. This stored chemical energy within wastewater is increasingly recognized as a valuable commodity that should be harvested at wastewater treatment plants (WWTPs), rather than removed. As the general paradigm shifts towards viewing wastewater as a resource, the need for developing more efficient and capable ways of recovering these resources becomes more apparent [35,38].

A large portion of the stored chemical energy in wastewater can potentially be recovered through anaerobic digestion (AD) of the organic material into methane gas. The typical approach is to utilize off-line anaerobic digesters to convert settled wastewater solids and waste activated sludge (WAS) biomass to biogas. There are two problems with this approach: (1) considerable energy is expended in conventional activated sludge (CAS) to convert the dissolved organic matter to cell mass [23], negating subsequent energy recovery from AD and; (2) the anaerobic conversion of WAS to methane comes after the step where at most 50% of the organic matter is aerobically assimilated to biomass, hence the energy transfer from dissolved organic to WAS to the methane, is rather inefficient. In recent years, the anaerobic membrane bioreactor (AnMBR) technology has gained popularity as an appealing alternative for direct wastewater treatment due to certain advantages over conventional aerobic and anaerobic treatment processes, as well as over the aerobic membrane bioreactor (MBR) technology [19,26].

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However, since the temperature of municipal wastewater in temperate climates is generally low (below 20 °C), anaerobic reactors experience diminished solids and organic removal efficiencies due to decreased kinetics. While there are many full scale anaerobic (mainly UASB reactors) applications for domestic wastewater treatment in tropical areas [1], psychrophilic temperatures remain challenging for treating low strength wastewaters [34].

A considerable number of studies on AnMBRs have focused on biofouling [7,20,22], which results in decreased permeate flux [37] and an increase of energy consumption [23,30,33,39]. Studies have also shown the feasibility of mesophilic (and thermophilic) AnMBRs for treatment of both synthetic and real municipal wastewaters [19,27]. In the past ten years, the phenomenon of increased methane solubility under psychrophilic temperatures, leading to its loss in the effluents of anaerobic digesters, has become an increasingly important concern. There are some studies of methane emissions during CAS [4,5], but thus far little is known about the energy lost via dissolved methane in the effluent during psychrophilic AD [10].

Another area of knowledge gap is reactor response to temperature changes and especially to abrupt drops in temperature, which may occur due to fluctuations in weather conditions or abrupt loss of reactor heating. Gao et al. reported a submerged AnMBR treating industrial wastewater can be highly resilient to temperature variations (from 37 to 55 °C) in terms of chemical oxygen demand removal and biogas production [8], although the temperature change affected the richness and diversity of microbial populations [9]. Furthermore, namely the issue of temperature decrease becomes even more important when considering small-scale installations with limited operation oversight and higher vulnerability to reactor heating failures. As decentralized wastewater treatment technologies gain prominence, short-term temperature fluctuations (i.e., shocks) and their effect on AnMBR performance need to be understood and characterized. This study aims at testing the robustness of a gas-lift anaerobic membrane bioreactor (Gl-AnMBR) meant for decentralized sewage treatment, such as communities of the future with sustainable sanitation. Knowing the minimal guaranteed pollutant removal efficiency will be a key factor which determines whether such technology is feasible and reliable for on-site sewage treatment or even resource recovery.

This research expands the Gl-AnMBR concept described by Prieto [30] and investigated the aforementioned gap in the literature by the long-term operation of an Gl-AnMBR treating low-strength synthetic municipal wastewater. The bioreactor was operated under mesophilic and psychrophilic conditions, with a transition period between mesophilic and psychrophilic phases containing several psychrophilic shocks (12–48 h) to gauge the stability of the system. The issue of dissolved methane is also discussed.

2. Material and methods

2.1. Experimental set-up

The laboratory-scale Gl-AnMBR was comprised of an upflow anaerobic bioreactor column (10L liquid volume plus 3L headspace) coupled to external tubular ultrafiltration membrane modules (Fig. 1). The external membrane system consisted of two modules, each with three 8 mm ID polyvinylidene fluoride (PVDF) tubular membranes (Pentair X-Flow, F5385) with a mean pore size of 0.03 μm and overall active filtration area of 0.066 m^2 per module. During the whole reactor operation, no biomass was wasted, except sampling, which resulted in a sludge retention time above 300 days. Temperature control at 35 and 15 °C was provided by a water jacket and water bath.

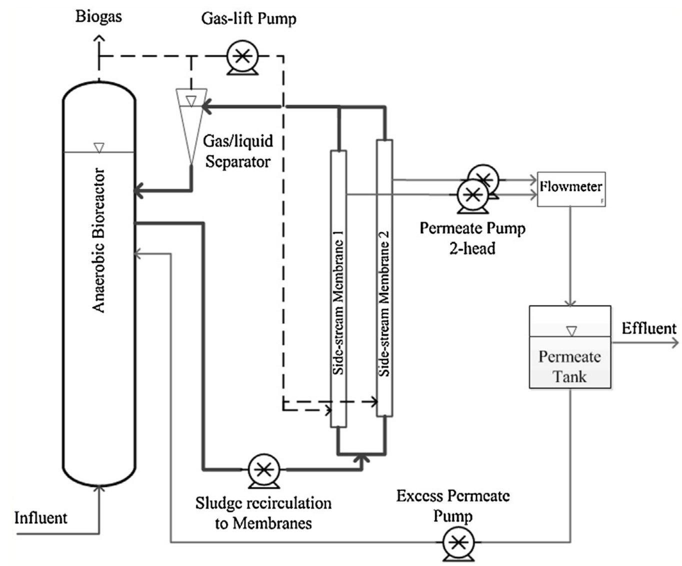

Fig. 1. Gl-AnMBR flow scheme (dashed line indicates gas stream, thick lines indicates sludge stream, thin lines indicate influent/permeate/effluent stream).

Membrane feed (reactor liquor) was taken from the upper part of the bioreactor column and delivered to the membrane by a peristaltic pump with a cross flow velocity (CFV_L) of 0.1 m s^{-1}. To minimize membrane fouling, recirculated biogas taken from the headspace was introduced to the bottom of the membrane tube at a CFV_G of 0.02 m s^{-1}. The rising gas bubbles were expected to improve the filterability of the reactor supernatant, which reduced pumping requirements for membrane feed flow and permeate production [6]. According to this, a gas/liquid flow ratio (ε) of 0.2 was applied, similarly as suggested previously [30]. Periodic backwashing with permeate, via permeate pump reversal (50 min forward, 3 min reverse), was also used to help reduce biofouling. The same flux for forward and reverse operation was used, according to Lew et al. [18]. Chemical cleaning of the membranes with bleach solution (at a NaClO concentration of 500 ppm for 30 min) was applied three times (on day 19, 42 and 89), after the transmembrane pressure (TMP) exceeded 20 kPa. A membrane permeate flux (J) of approximately 4.5 L m^{-2} h^{-1} (LMH) was maintained at both mesophilic and psychrophilic temperatures.

The system was operated as described by Torres et al. [37], i.e. excess permeate was recirculated back to the bioreactor, which allowed the system to achieve a constant HRT of 30–36 h. All of the following data were recorded using a HOBO data logger (ONSET Computer Corporation, MA, USA): permeate flux measured continuously using a self-fabricated flow measurement device consisting of a level sensor and a discharge pump (which generated discrete pulses corresponding to finite volumes of permeate discharged as it was being produced by the system), biogas production values using a modified wet-tip meter (WetTipGasMeter.com), reactor temperature via ONSET temperature probes, and TMP via pressure transducers (Cole Parmer, IL) installed in feed, retentate and permeate lines of the membrane modules.

2.2. Synthetic sewage

For mimicking real sewage with its typical properties, Complex Organic Particulate Artificial Sewage (COPAS) was used, as reported previously [30]. This feeding is based on granular cat food in which organic matter i.e. volatile solids (VS) 92% and 8% ash is composed of 40% proteins, 43% carbohydrates and 17% lipids, with overall elemental composition C:N:P ratio of 48.1:6.4:1.6 (w/w) and biodegradable fraction of approximately 65%. COPAS was used