Journal of Environmental Management 179 (2016) 83–92

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

Economic and environmental sustainability of an AnMBR treating urban wastewater and organic fraction of municipal solid waste

R. Pretel [a], P. Moñino [a], A. Robles [a, *], M.V. Ruano [b], A. Seco [b], J. Ferrer [a]

[a] Institut Universitari d'Investigació d'Enginyeria de l'Aigua i Medi Ambient, IIAMA, Universitat Politècnica de València, Camí de Vera s/n, 46022 Valencia, Spain

[b] Departament d'Enginyeria Química, Escola Tècnica Superior d'Enginyeria, Universitat de València, Avinguda de la Universitat s/n, 46100, Burjassot, Valencia, Spain

A R T I C L E I N F O

Article history:
Received 7 March 2016
Received in revised form
26 April 2016
Accepted 29 April 2016
Available online 12 May 2016

Keywords:
Anaerobic membrane bioreactor (AnMBR)
Ambient temperature
Energy consumption
Life cycle analysis (LCA)
Organic fraction of municipal solid waste (OFMSW)
Urban wastewater (UWW)

A B S T R A C T

The objective of this study was to evaluate the economic and environmental sustainability of a submerged anaerobic membrane bioreactor (AnMBR) treating urban wastewater (UWW) and organic fraction of municipal solid waste (OFMSW) at ambient temperature in mild/hot climates. To this aim, power requirements, energy recovery from methane (biogas methane and methane dissolved in the effluent), consumption of reagents for membrane cleaning, and sludge handling (polyelectrolyte and energy consumption) and disposal (farmland, landfilling and incineration) were evaluated within different operating scenarios. Results showed that, for the operating conditions considered in this study, AnMBR technology is likely to be a net energy producer, resulting in considerable cost savings (up to €0.023 per m^3 of treated water) when treating low-sulphate influent. Life cycle analysis (LCA) results revealed that operating at high sludge retention times (70 days) and treating UWW jointly with OFMSW enhances the overall environmental performance of AnMBR technology.

1. Introduction

Nowadays, electricity consumption is a key element in the life cycle analysis (LCA) of a wastewater treatment plant (WWTP), mainly due to its environmental impact through global warming potential (GWP) (Garrido-Baserba et al., 2014; Corominas et al., 2013). In this respect, there has been increased interest during the last years in studying the feasibility of using submerged anaerobic MBRs (AnMBRs) to treat urban wastewater (UWW) (Fenu et al., 2010; Lin et al., 2013; Ozgun et al., 2013). This interest focuses on the greater sustainability of anaerobic rather than aerobic processes: lower sludge production; lower energy consumption since oxygen is not required for organic matter removal; and recovery of energy through methane production (Giménez et al., 2011; Robles et al., 2012; Raskin, 2012; Smith et al., 2013). On the other hand, the food industry produces considerable amounts of lipid-rich waste in slaughterhouses and in the processing of edible oils, dairy products and olive oil (Ramos et al., 2014). Therefore, treating the organic fraction of municipal solid waste (OFMSW) jointly with UWW in an AnMBR system may represent a great sustainable option due to the following: 1) increasing biogas production since more organic matter is entering the system; 2) reducing fossil fuel consumption related to OFMSW transportation, since it can be collected together with the grey water from kitchens; and 3) avoiding environmental issues (contamination of soil, water and air) that may occur when OFMSW is landfilled. Moreover, Cirne et al. (2007) stated that lipids are attractive substrates in anaerobic digestion and co-digestion processes due to their high theoretical methane yield when compared to proteins or carbohydrates.

Despite its advantages, several issues have been recognised elsewhere as potential drawbacks which may affect the sustainability of AnMBR technology. One key issue is the competition between Methanogenic Archaea (MA) and Sulphate Reducing Bacteria (SRB) for the available substrate (Hulshoff Pol, 1998) when there is significant sulphate content in the influent, reducing therefore the available COD for methanisation. For UWW, which can easily present low COD/SO_4-S ratios, this competition can critically affect the amount and quality of the biogas produced.

* Corresponding author.
E-mail addresses: rutprejo@upv.es (R. Pretel), patmoiam@upv.es (P. Moñino), ngerobma@upv.es (A. Robles), m.victoria.ruano@uv.es (M.V. Ruano), aurora.seco@uv.es (A. Seco), jferrer@hma.upv.es (J. Ferrer).

http://dx.doi.org/10.1016/j.jenvman.2016.04.057
0301-4797/

Specifically, 2 kg of COD are consumed by SRB in order to reduce 1 kg of influent SO_4-S (see, for instance, Giménez et al., 2011; Pretel et al., 2014). Therefore, higher biogas productions would be achieved when there is little sulphate content in the influent. Another key issue is membrane fouling and cleaning, which can be significantly important in anaerobic digesters treating lipid-rich wastes (He et al., 2005; Ramos et al., 2014; Dereli et al., 2014). Membrane fouling is the result of the interaction between membrane surface and sludge suspension (Lin et al., 2011), affecting system performance in terms of economic viability and effluent quality. In this respect, membrane fouling and cleaning issues remain a critical obstacle limiting the widespread application of membrane systems in wastewater treatment (Jeison, 2007; Judd, 2011; Stuckey, 2012; Lin et al., 2013). Hence, both physical and chemical cleaning technics should be considered for fouling mitigation, maintaining efficient membrane performance and therefore the well balanced behaviour of the whole system.

The objective of this study was to evaluate the LCA of an AnMBR system treating UWW and OFMSW at ambient temperature in mild/hot climates. To this aim, power requirements, energy recovery from methane (biogas methane and methane dissolved in the effluent), consumption of reagents for membrane cleaning and sludge handling (polyelectrolyte and energy consumption) and disposal (farmland, landfilling and incineration) were evaluated within different operating scenarios.

2. Materials and methods

2.1. AnMBR plant description

An AnMBR pilot plant was continuously operated using the effluent of a full-scale WWTP pre-treatment jointly with food waste collected from university canteens. The food waste was grounded into small particles through an experimental set-up simulating a household food waste grinding system. The average AnMBR influent characteristics are shown in Table 1. This influent was characterised by a COD/SO_4-S ratio from approx. 5.5 to 9.5 kg COD kg^{-1} SO_4-S.

The AnMBR plant consists of an anaerobic reactor with a working volume of about 0.9 m^3 connected to two membrane tanks (MT1 and MT2) each one with a working volume of 0.6 m^3, giving a system total working volume of 2.1 m^3. Each membrane tank includes one ultrafiltration hollow-fibre membrane commercial system (PURON®, Koch Membrane Systems, 0.05 μm pore size, 31 m^2 total filtering area). The filtration process was studied from experimental data obtained from MT1 (operated recycling continuously the obtained permeate to the system), whilst the biological process was studied using experimental data obtained from MT2 (operated for controlling the hydraulic retention time (HRT) without recycling the obtained permeate). Hence, different 20 °C-standardised transmembrane fluxes (J_{20}) were tested in MT1, without affecting HRT. For the introduction of OFMSW to the AnMBR, a rotofilter of 0.5-mm screen-size was installed. A 0.2-m^3 tank for OFMSW equipped with a stirrer for homogenisation of the sample and membrane diffusers for aeration and removal of fats and oils was also included in the plant. Further details on this AnMBR can be found in Robles et al. (2015) and Moñino et al. (2016).

2.2. AnMBR operating conditions

The AnMBR plant was operated for 536 days within a wide range of operating conditions regarding both biological and filtration processes. Five operating scenarios were selected to conduct the LCA of the AnMBR system, extracted from Moñino et al. (2016). Specifically, this study comprised two different operating periods. Firstly, the AnMBR performance was evaluated when only UWW was fed to the plant (Scenarios 1 and 2). Then, the system performance was evaluated when feeding also the OFMSW (Scenarios 3, 4 and 5).

2.2.1. Biological process

Variations in sludge retention time (SRT) and penetration factor (PF, defined as the percentage of population having a kitchen disposer) were studied to account for the dynamics in methane and sludge productions over time. During the 536-day experimental period, the plant was operated at SRT of 40 and 70 days, whilst PF was set to 0, 40 and 80% (varying therefore the COD/SO_4-S ratio in the influent). The results obtained in this study correspond with results obtained in an AnMBR system operated at ambient temperature in mild/hot climates (25–30 °C). Methane and sludge productions were compared among the different scenarios. It must be said that a dissolved methane capture efficiency of 80% was considered in this study (the remaining 20% was considered to be discharged in the effluent (10%) and emitted to the atmosphere (10%)).

As commented before, five different experimental scenarios related to biological process were considered to evaluate the economic and environmental sustainability of the AnMBR plant when treating high-sulphate influent (around 98–115 mg SO_4-S L^{-1}). Table 2 shows the average of the main operating conditions and the resulting performance indexes regarding the biological process throughout the selected scenarios. Further details as regards the performance of the biological process in the AnMBR can be found in Moñino et al. (2016).

The effect of the influent sulphate on the economic and environmental sustainability of the AnMBR was also evaluated. As mentioned before, the UWW and OFMSW fed to the AnMBR plant was characterised by low COD/SO_4-S ratios (from approx. 5.5 to 9.5 kg COD kg^{-1} SO_4-S). Therefore, an important fraction of the influent COD was consumed by SRB (from about 36 to 20% of the influent COD). To be precise, the sulphate content in the influent ranged from 98 to 115 mg SO_4-S L^{-1}, from which approx. 98% was reduced to sulphide. Therefore, about 192–225 mg L^{-1} of influent COD were consumed by SRB, reducing the amount of methane produced in the pilot plant (*i.e.* methane was not fully efficiently produced). Specifically, methane production was reduced around

Table 1
Average characteristics of the AnMBR influent in the five scenarios evaluated in this study.

Parameter	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Treatment flow rate (m^3 day^{-1})	1.6	2.2	2.9	2.3	2.2
TSS (mg L^{-1})	260	226	318	414	627
VSS (mg L^{-1})	207	196	279	352	530
COD (mg L^{-1})	643	635.9	650	853	947
SO_4-S (mg L^{-1})	98	114	89	109	99
N_T (mg L^{-1})	49.6	44.5	40.8	69.1	53.5
P_T (mg L^{-1})	5.0	5.4	7.9	7.3	7.9