Journal of Environmental Management xxx (2016) 1–9

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

Decentralised schemes for integrated management of wastewater and domestic organic waste: the case of a small community

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A R T I C L E I N F O

Article history:
Received 30 December 2015
Received in revised form
20 November 2016
Accepted 24 November 2016
Available online xxx

Keywords:
Anaerobic treatment
Decentralised systems
Domestic wastewater
Short-cut nitrification denitrification
LCA

A B S T R A C T

This study assesses from an environmental perspective two different configurations for the combined treatment of wastewater and domestic organic waste (DOW) in a small and decentralised community having a population of 2000. The applied schemes consist of an upflow anaerobic blanket (UASB) as core treatment process. Scheme A integrates membranes with the anaerobic treatment; while in Scheme B biological removal of nutrients in a sequencing batch reactor (SBR) is applied as a post treatment to UASB effluent. In energy-related categories, the main contributor is electricity consumption (producing 18–50% of the impacts); whereas in terms of eutrophication-related categories, the discharge of the treated effluent arises as a major hotspot (with 57–99% of the impacts). Scheme B consumes 25% more electricity and produces 40% extra sludge than Scheme A, resulting in worse environmental results for those energy categories. However, the environmental impact due to the discharge of the treated effluent is 75% lower in eutrophication categories due to the removal of nutrients. In addition, the quality of the final effluent in Scheme B would allow its use for irrigation (9.6 mg N/L and 2 mg P/L) if proper tertiary treatment and disinfection are provided, expanding its potential adoption at a wider scale. Direct emissions due to the dissolved methane in the UASB effluent have a significant environmental impact in climate change (23–26%). Additionally, the study shows the environmental feasibility of the use of food waste disposers for DOW collection in different integration rates.

1. Introduction

Historically, centralised wastewater treatment facilities have played an important role in water management (Gikas and Tchobanoglous, 2009). However, due to morphological conditions (Libralato et al., 2012), this solution is not feasible in many areas, or not the most cost-effective one. A different approach, focused on decentralised systems, can be necessary to develop sustainable water management for small communities, especially in areas affected by severe water shortages (Gikas and Tchobanoglous, 2009). There are many small communities where sustainable water and waste management solutions should be applied. For example, in Italy more than 9000 wastewater treatment plants (WWTPs) serve less than 2000 population equivalent (PE).

Among the different available technologies for decentralised wastewater treatment, the upflow anaerobic sludge blanket (UASB) process has several advantages compared to aerobic treatment, such as reduced capital investment, lower energy requirements, limited sludge generation and biogas production for bioenergy recovery (Chernicharo, 2006). Although this technology accomplishes significant removal of organic matter, the treated effluent still contains significant concentrations of suspended solids, while nutrients are practically not removed (Malamis et al., 2013). Part of the methane which is produced in the UASB reactor remains as dissolved methane in the treated UASB effluent causing direct methane emissions to the atmosphere and thus increasing the environmental impact of the process (Souza et al., 2012). In addition, to meet the requirements of the European Union Directive 91/271/EEC concerning the discharge of the treated urban wastewater to water recipients further treatment of the UASB effluent can be

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http://dx.doi.org/10.1016/j.jenvman.2016.11.053
0301-4797/

required for the further decrease of organic matter and suspended solids.

The biological process can be coupled with membranes in an anaerobic membrane bioreactor (AnMBR) for the solid/liquid separation. The application of the AnMBR technology can convert WWTPs into resource (i.e. energy, reclaimed water rich in nutrients) recovery facilities. This process has lower energy requirements than the aerobic membrane bioreactor (MBR) and produces less amount of sludge. The main barriers for the application of AnMBRs for domestic wastewater treated are related with the operating cost for membrane fouling control and mitigation (Li et al., 2013).

Decentralised wastewater management increases reuse opportunities, since the treated effluent is often available close to the potential points of use; avoiding the cost related with reclaimed water distribution systems (Hophmayer-Tokich, 2000). Despite its important content in nutrients, which can be beneficial for the cultivated products, the reclaimed water often needs to comply with strict national or regional regulations concerning its reuse (Norton-Brandão et al., 2013). For instance, the Italian Decree for water reuse (Decreto Ministeriale n. 185, 2003) sets up maximum concentrations of phosphorus and nitrogen in the reclaimed water (2 mgP/L and 15 mgP/L, respectively). In this case, biological and/or physicochemical post-treatment processes must be applied to remove or to recover nutrients from the anaerobically treated effluent such as ammonia stripping (Walker et al., 2011), struvite precipitation (Battistoni et al., 2006), biological nutrients removal (BNR) (Frison et al., 2013a). BNR via nitrite together with denitrifying phosphorus removal via nitrite (DPRN) has recently gained attention due to several advantages over the conventional via nitrate pathway (Gustavsson, 2010; Zhang et al., 2010).

The integration of domestic organic waste (DOW) within the decentralised wastewater management scheme is an option that can contribute to the diversion of DOW from landfilling, in accordance to the Landfill Directive (European Union, 1999). DOW can be a source of short-chain fatty acids (external carbon source) that are required for the biological nitrogen and phosphorus removal (Frison et al., 2013b). Alternatively, the fermented DOW can be applied in the anaerobic process in order to increase the organic loading rate (OLR) and thus, the biogas production. Alternative systems exist for DOW collection and delivery into the treatment facility. Food waste disposers (FWDs) are applied in several countries (e.g. USA, Canada, Brazil, Japan and Australia) for the integrated management of domestic wastewater and DOW (Battistoni et al., 2007). The use of FWDs reduces the frequency of waste transport and generates less odours compared with the conventional separate waste collection schemes (Marashlian and El-Fadel, 2005). However, a number of important drawbacks, such as additional energy requirements, use of extra tap water for dragging the waste mixed with the wastewater, increased organic loads in the sewerage system and the WWTP burdens their feasibility (Marashlian and El-Fadel, 2005).

The assessment of the treatment systems from an environmental life cycle perspective can improve the environmental profile of the decentralised treatment schemes. The current study evaluates the environmental performance of alternative decentralised schemes for wastewater and DOW co-treatment in a small and decentralised community of 2000 PE following a Life Cycle Assessment (LCA) approach.

2. Materials and methods

2.1. Goal and scope definition

The selection of the main configuration for combined wastewater and DOW treatment was based on the results of our previous study (Katsou et al., 2014), taking into consideration economic criteria (cost reduction), legislative aspects for the treated effluent quality and DOW management and topographical factors (i.e. characteristics of small community in terms of waste collection). The decentralised schemes include the anaerobic treatment of wastewater, a fermentation unit in order to produce short-chain fatty acids and a composting unit to stabilise the sludge produced from the process. Scheme A includes an AnMBR, while Scheme B applies SBR for the BNR via nitrite. Different waste collection systems are considered within each configuration. The functional unit (FU) is the service provided by the system, which includes the management of the wastewater and DOW produced by 2000 inhabitants per day.

2.2. Description of the treatment schemes

Each treatment scheme applies screening prior to the anaerobic process. The organic loading rate (OLR) of the UASB in Chemical Oxygen Demand (COD) terms ranges from 1.8 to 2.4 kg COD/$m^3 \cdot d$, with a hydraulic retention time (HRT) of 8 h and an upflow velocity of 1 m/s (Katsou et al., 2014). The concentration of the dissolved methane in the effluent of the UASB was assumed to be 20 mg CH_4/L. The composition of the produced biogas is 60% methane, 39.9% carbon dioxide and 0.1% hydrogen sulphide. The biogas is treated in a biotrickling filter in order to remove hydrogen sulphide with a removal efficiency of 75%. Finally, the biogas is burnt in a boiler and is used to cover the heat requirements of the fermentation tank. The received DOW is grinded and then acidogenic fermentation is performed to produce volatile fatty acids (VFA). The HRT is between 5 and 6 days and the OLR in terms of volatile solids (VS) is 10 kg VS/$m^3 \cdot d$. After a solid/liquid separation, the VFAs are fed to the UASB in order to increase the OLR and the biogas generation (Scheme A) and/or are used as carbon source to promote the BRN in the SBR (Scheme B). The separation of the fermented effluent and the excess sludge from the UASB is performed using a screw-press. The produced sludge is mixed with a bulking agent (straw) in order to provide suitable porosity and optimum carbon to nitrogen ratio (25:1–35:1) for the composting process to take place. Sludge is composted in an enclosed system equipped with a biofilter consisting of wood chips for odour treatment (Colón et al., 2009). The compost is applied in agricultural land as a soil conditioner.

2.2.1. Scheme A

The total liquid stream produced from the screw-press is fed to the UASB. Consequently, the OLR increases from 1.8 to 2.4 kg COD/$m^3 \cdot d$, resulting in increased biogas production (theoretically 0.35 m^3 CH_4/kg $COD_{removed}$). Coupling the treatment scheme with membranes results in the production of a final effluent free of total suspended solids (TSS).

2.2.2. Scheme B

The liquid stream produced after the separation step is fed to the SBR in order to provide the required carbon source for nutrient removal. The UASB effluent which is fed to the SBR is characterised by a very low COD/N ratio (2.3 kg COD/kg N) and even lower ratio of readily biodegradable COD to nitrogen (rbCOD/N), which is not enough to remove nutrients. The SBR has a solids retention time (SRT) of 18 days and a volumetric nitrogen loading rate (vNLR) of 0.19 kg N/m^3 d. The SBR operates with the following sequence: feeding (0.17 h), aerobic phase (1.8 h), anoxic phase (0.81 h), sedimentation (0.33 h) and discharge (0.17 h).

The flowcharts of the examined configurations are presented in Fig. 1. As mentioned, each of treatment schemes has also been evaluated considering different collection systems.

Please cite this article in press as: Lijó, L., et al., Decentralised schemes for integrated management of wastewater and domestic organic waste: the case of a small community, Journal of Environmental Management (2016), http://dx.doi.org/10.1016/j.jenvman.2016.11.053