Waste Management xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

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

Assessment of micro-scale anaerobic digestion for management of urban organic waste: A case study in London, UK

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ARTICLE INFO

Article history:
Received 7 September 2016
Revised 19 January 2017
Accepted 24 January 2017
Available online xxxx

Keywords:
Anaerobic digestion
Biogas
Food waste
Urban organic waste
Ammonia inhibition
Micro-scale

ABSTRACT

This paper describes the analysis of an AD plant that is novel in that it is located in an urban environment, built on a micro-scale, fed on food and catering waste, and operates as a purposeful system. The plant was built in 2013 and continues to operate to date, processing urban food waste and generating biogas for use in a community café. The plant was monitored for a period of 319 days during 2014, during which the operational parameters, biological stability and energy requirements of the plant were assessed. The plant processed 4574 kg of food waste during this time, producing 1008 m^3 of biogas at average 60.6% methane. The results showed that the plant was capable of stable operation despite large fluctuations in the rate and type of feed. Another innovative aspect of the plant was that it was equipped with a pre-digester tank and automated feeding, which reduced the effect of feedstock variations on the digestion process. Towards the end of the testing period, a rise in the concentration of volatile fatty acids and ammonia was detected in the digestate, indicating biological instability, and this was successfully remedied by adding trace elements. The energy balance and coefficient of performance (COP) of the system were calculated, which concluded that the system used 49% less heat energy by being housed in a greenhouse, achieved a net positive energy balance and potential COP of 3.16 and 5.55 based on electrical and heat energy, respectively. Greenhouse gas emissions analysis concluded that the most important contribution of the plant to the mitigation of greenhouse gases was the avoidance of on-site fossil fuel use, followed by the diversion of food waste from landfill and that the plant could result in carbon reduction of 2.95 kg CO_{2eq} kW h^{-1} electricity production or 0.741 kg CO_{2eq} kg^{-1} waste treated.

1. Introduction

Anaerobic Digestion (AD) in the UK and Europe has enjoyed a wide uptake in the past 20 years, due to governments' introduction of feed-in tariffs and renewable heat incentives improving its economic viability (Edwards et al., 2015). However, although there has been much development at scales over 125 kWe electrical output, there has been very limited uptake of the technology at the micro scale (5–15 kWe or equivalent) (NNFCC, 2016).

The use of AD on a micro-scale is used mainly in developing countries, with an estimated 5 million household scale digesters across India and China alone, as it provides a convenient way of processing and sanitising local waste such as animal slurries (Lansing et al., 2008), as well as producing biogas. However, in the developed world, AD is generally restricted to larger scale plants. There are currently 316 non-sewage-based AD plants operating in the UK, with a total installed capacity of 290 MW (average of 918 kW per plant) (NNFCC, 2016). These AD plants are fed on a variety of feedstocks, including energy crops, dairy effluent, food waste and animal slurries and manures.

Abbreviations: AD, Anaerobic Digestion; COD, Chemical Oxygen Demand; COP, Coefficient of performance; GHG, Greenhouse gas; HRT, Hydraulic retention time; kWe, Kilowatts of electrical output; LCV, Lower calorific value; OLR, Organic loading rate; TPA, Tonnes per annum; TS, Total solids; VFA, Volatile fatty acids; VS, Volatile solids.

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http://dx.doi.org/10.1016/j.wasman.2017.01.036
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However, across the UK there is now a growing introduction of source segregated food waste collections and a need to reduce waste and emissions wherever possible to achieve climate change targets. Micro-AD plants in an urban environment could offer support for these issues in the form of non-centralised (i.e. distributed) organic waste management. There are a number of challenges specific to the urban environment that AD can address (Stoknes et al., 2016).

Micro-scale AD applications have the potential to deliver a variety of advantages relative to conventional AD plants including; reduced transport requirements, potential for community involvement, and the fostering of a circular economy by means of creating a 'biorefinery' that will dispose of local waste, utilise its energy potential, and also produce a natural fertiliser that can be used in urban agriculture, horticulture and hydroponics. The demonstration of small-scale AD will also make the technology more familiar and accessible, which could potentially increase its uptake by adding understanding of the field and capturing feedstocks from sources that are out of the catchment area of larger plants.

This paper describes a monitoring study of a novel micro-AD system, with an innovative process design and unusual setting, implemented in a community wildlife park in London in the UK. The paper includes a system description, and performance, energy and carbon evaluations with the purpose of presenting and assessing the concept of micro-AD in the urban environment.

2. Materials and methods

2.1. Site description

The pilot system was designed and installed by a consortium of companies and researchers in 2013, and the monitoring took place from October 2013 to November 2014. The plant was built within the grounds of the Camley Street Natural Park in London, UK and the site was used to convert locally produced, commercial organic waste, collected by cargo bicycle, into biogas for cooking, heating and electricity.

The following is a list of the key components installed as part of the micro-AD system:

- 2 m^3 anaerobic digester (Methanogen UK Ltd., UK) containing an automated mechanical mixer and heated by an internal water heat exchanger.
- Pre-feed system consisting of a chopper mill, a 0.65 m^3 mixed 'pre-feed' tank on load cells and a feeding pump (Guy Blanch Bio Development Ltd, UK).
- Hydrogen sulphide scrubber filled with activated carbon pellets.
- 1 m^3 floating gasometer for biogas storage.
- 0.46 m^3 digestate sedimentation tank.
- 0.2 m^3 digestate liquor storage tank.
- Purpose built automated biogas boiler.
- Biogas hob.
- A data logging system and a suite of sensors for online monitoring.

A full schematic of the system is shown in Fig. 1.

2.2. System operation

The system was commissioned and began operating on the 16/10/2013 and continues to operate into 2017. The main feedstocks being added to the pre-digester tank during the monitoring period can be separated into four phases:

Phase 1: Day 1 to 15: apple pomace, catering waste, café waste, oats, tea leaves, water.
Phase 2: Day 16 to 107: catering waste, café waste, tea leaves, water.
Phase 3: Day 108 to 294: catering waste, soaked oats, soaked paper bin liners, water.
Phase 4: Day 295 to 399: predominantly catering waste with some soaked paper bin liners, water.

The phases are illustrated in Fig. 2, which shows that both the type of feedstock and the quantity were very variable, due to variances in the collections sources over time. The system was designed with a pre-digester to smooth out these variations.

The digester feed was expected to be in the range of 15–20 kg day^{-1}, although the average feed during the course of the experiment was lower than this, at 14.3 kg day^{-1}, due to commissioning and operational issues. The pre-digester tank was loaded manually, through a breaker mill, twice a week. From day 1 to 190, feeding was not automated, so the feedstock pump was operated by hand 4–5 times per week to pump the entire feed for the day from the pre-digester tank into the digester (i.e. 20 kg). After day 190, the feeding was automated and feed was automatically

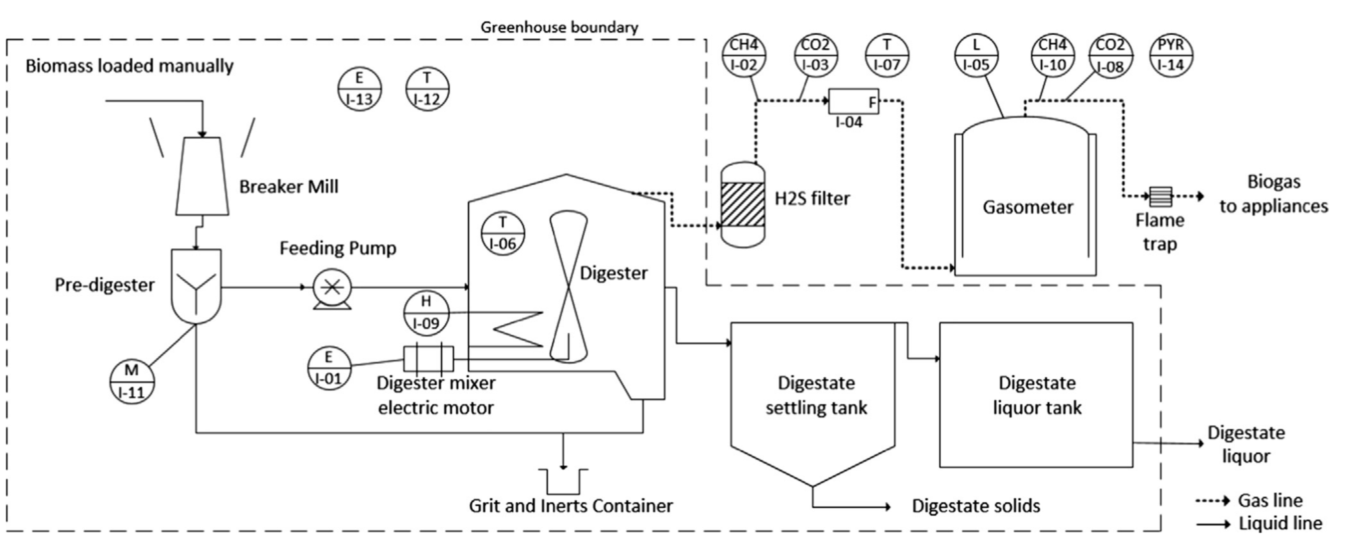

Fig. 1. Schematic of equipment at the micro-AD site (Sensor abbreviation M – Mass, E – Electricity, T – temperature, H – heat, CH_4 – methane%, CO_2 – carbon dioxide%, F – Gas flow, L – Level, PYR – Incident solar radiation).

Please cite this article in press as: Walker, M., et al. Assessment of micro-scale anaerobic digestion for management of urban organic waste: A case study in London, UK. Waste Management (2017), http://dx.doi.org/10.1016/j.wasman.2017.01.036