Applied Energy 150 (2015) 9–14

Contents lists available at ScienceDirect

Applied Energy

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

# Amount of energy recoverable from an existing sludge digester with the co-digestion with fruit and vegetable waste at reduced retention time

Francesco Di Maria *, Alessio Sordi, Giuseppe Cirulli, Caterina Micale

*LAR, Dipartimento di Ingegneria, University of Perugia, Via G. Duranti 67, 06125 Perugia, Italy*

## HIGHLIGHTS

- Pilot scale waste mixed sludge and FVW co-digestion was investigated.
- OLR increase increases bio methane production and reduces HRT.
- Maximum bio methane production is achieved for HRT of 11 days and OLR of 2.1 kg VS/$m^3$ day.
- Net electrical energy recoverable from a full-scale 3000 $m^3$ digester was of 3,500,000 kW h/year.

## ARTICLE INFO

*Article history:*
Received 14 January 2014
Received in revised form 20 November 2014
Accepted 16 January 2015
Available online 17 April 2015

*Keywords:*
Anaerobic co-digestion
Biomethane
Energy recovery
Fruit and vegetable waste
Organic loading rate
Waste-mixed sludge

## ABSTRACT

The working operations of a full-scale digester of a wastewater treatment plant for waste-mixed sludge (WMS) stabilization was reproduced using a pilot-scale apparatus. The effect of WMS co-digested with fruit and vegetable waste (FVW) was investigated at different organic loading rates (OLR), from 1.46 kg VS/$m^3$ day to 2.8 kg VS/$m^3$ day, and reduced hydraulic retention time, from 14 days to about 10 days. Methane production per unit of digester volume increased from about 140 NL/$m^3$ day to a maximum value of about 900 NL/$m^3$ day when OLR was increased from 1.46 kg VS/$m^3$ day to 2.1 kg VS/$m^3$ day. Higher OLR caused an excessive HRT reduction, decreasing the percentage of volatile solids degradation without significantly affecting process stability. The maximum electrical energy producible from the full-scale anaerobic facility was about 3,500,000 kW h/year. In these conditions the electrical power output and the net efficiency of the co-generator were 470 kW and 37%, respectively.


## 1. Introduction

There is a general consensus that global warming is mainly a consequence of greenhouse gas (GHG) emissions generated by anthropogenic activity. Since a large fraction of anthropogenic GHG arises from heat and power generation [1], its negative impact could be significantly reduced by enhancing the exploitation of renewable energy sources.

Among the different technologies and processes, anaerobic digestion (AD) could be a suitable way for producing renewable energy and contributing to reaching the 2020 EU objective [2,3]:

(1) GHG emission reduction compared to 1990 ⩾20%.
(2) Energetic needs generated by renewable sources ⩾20%.
(3) Increase of energetic efficiency ⩾20%.

In particular waste materials like manure, crop waste, sewage sludge, the organic fraction of municipal solid waste (OFMSW) and fruit and vegetable waste (FVW) are particularly important since they do not compete with food crops as substrate for AD [4]. AD is also widely used in wastewater treatment plants (WWTP) for the stabilization of waste-activated sludge (WAS) and waste-mixed sludge (WMS), a mixture of primary sludge and WAS. Primary sludge is generated during physical treatment in primary settlers, whereas WAS is generated in the biological treatment section of WWTP. About 36,000 WWTP operating in the EU use AD for sludge reactivity reduction [5]. About 10 million tonnes of sludge (on dry basis) are produced in the EU per year and its disposal accounts for about 50% of the global WWTP operating costs [6]. Generally the AD section of WWTP operates at a low organic loading rate (OLR) kg VS/$m^3$ day, suggesting that the OLR could be increased by co-digesting the sludge with other biodegradable substrates [5]. Among these substrates the OFMSW arising from source-segregated collection has been the one most investigated. Bolzonella et al. [7] reported that the co-digestion of the WAS

* Corresponding author. Tel.: +39 0755853738; fax: +39 0755853703.
*E-mail address:* francesco.dimaria@unipg.it (F. Di Maria).

http://dx.doi.org/10.1016/j.apenergy.2015.01.146
0306-2619/

and bio-waste in the AD section of a full-scale WWTP facility led to an increase in biogas production from 4000 to 18,000 $m^3$ per month together with methane. Cavinato et al. [8] reported the benefits achievable with the co-digestion of WAS and OFMSW when the operating temperature was increased from mesophilic to thermophilic conditions. Increasing the OLR of a sludge digester by co-digestion with food waste and FVW led to a daily biogas production increase up to 100%, along with significant GHG emission reduction as a consequence of energy recovery [9]. Gomez et al. [10] analyzed the effect of co-digestion of a mixture of primary sludge and FVW at mesophilic conditions. Results showed that for an OLR ranging from 0.8 kg VS/$m^3$ day to 3 kg VS/$m^3$ day, the specific biogas production (SBP) ranged from 0.3 $m^3$/kg VS to 0.8 $m^3$/kg VS. In all these studies the hydraulic retention time (HRT) (day) was $\geqslant$19 days (Table 1). Generally co-digestion of sludge in existing full-scale digesters can be performed by maintaining the operational conditions of existing equipment and in particular the stirring system. The most commonly used stirring systems can continue operating correctly if the total solids (TS) concentration is maintained close to that of the design. For this reason co-digestion can lead to an increase in the daily volumetric feed rate consequently affecting the HRT. The effect of reduced HRT was previously investigated at the lab-scale for sludge [11] and dewatered sludge [12] digestion. Results show that the noticeable increase in biogas generable per unit of volume of the digester ($m^3/m^3$ day) was a consequence of the increased OLR. Depending on temperature, these studies show that the anaerobic process is stabile for HRT reduced up to 9 days with a maximum in biogas generation achieved for HRT of about 10 days. Possible influences due to co-digestion with other substrates was not investigated. These results show that the effects of co-digesting WMS with bio-waste at a reduced HRT (*e.g.* <15 days) in existing digesters is an interesting concept for renewable energy generation, but needs further investigation. In the present study the possibility of co-digesting WMS and FVW in the digester of an existing 90,000 PE WWTP was investigated using a pilot-scale apparatus. Specific methane production (SMP) (NL$CH_4$/kg VS), volatile solids (VS) removal and total volatile fatty acids (TVFA) concentration were investigated for assessing the process stability at increased OLR and reduced HRT. Furthermore, an energetic analysis of the full-scale digester was also performed.

**Table 1**
Food components (% by weight) used for fruit and vegetable waste (FVW) generation.

| Component | % |
|---|---|
| Potato | 55 |
| Fruit and vegetables | 28 |
| Bread | 5 |
| Paper | 2 |
| Rice and pasta | 10 |

## 2. Material and methods

### 2.1. Sampling and characterization

The WMS was withdrawn from an existing WWTP of 90,000 PE at the thickener outlet. The amount of sludge necessary for running the pilot-scale apparatus for 1 week was stored at +4 °C. The remaining amount was frozen at −20 °C. FVW is usually produced in wholesale markets and generally contains impurities such as plastics, metals and other inert materials. These impurities can damage not only some components of the pilot-scale apparatus (Fig. 1) but also the equipment used for sample conditioning such as grinders and mixers. Since it is very difficult to completely remove these materials, the FVW was made in the laboratory according to Sosnowski et al. [13,14] by blending the materials indicated in Table 1.

TS (% w/w) and consequently moisture content (MC) (% w/w) were determined by measuring weight loss after heating at 105 °C for 24 h. VS (% TS) was determined by measuring the change in weight of TS after burning at 550 °C for 24 h. The main chemical parameters were determined using the HACH Lange DR 3900 spectrophotometer. Chemical oxygen demand (COD) (mg$O_2$/L), biological oxygen demand after 5 days ($BOD_5$) (mg$O_2$/L) and total volatile fatty acids (TVFA), expressed as acetate equivalent (mg/L), were determined using HACH Lange cuvettes, respectively, LCK 014, LCK 555 and LCK 365. The same methodology was also used for total nitrogen ($N_{tot}$) and total phosphorous ($P_{tot}$) (mg/L) determination using, respectively, cuvettes LCK 238 and LCK 350. pH was determined with a kp 50 Delta Hom probe, whereas total dissolved solids (TDS) (mg/L) and electrical conductivity (EC) (mS/cm) were determined with a hd 2305.0 Delta Hom probe.

Analyses were performed at least in triplicate both on the fresh substrates and on the digestate withdrawn from the pilot-scale apparatus.

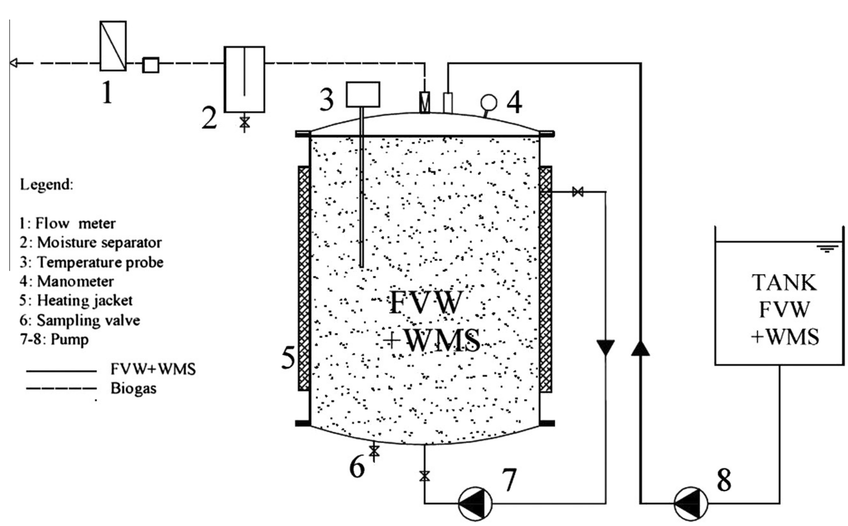


**Fig. 1.** Pilot apparatus scheme.