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Mesophilic and thermophilic anaerobic digestion of the liquid fraction of pressed biowaste for high energy yields recovery

Federico Micolucci [a,*], Marco Gottardo [b], Cristina Cavinato [b], Paolo Pavan [b], David Bolzonella [a]

[a] Department of Biotechnology, University of Verona, Verona 37134, Italy
[b] Department of Environmental Sciences, Informatics and Statistics, Venice 30121, Italy

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ABSTRACT

Deep separate collection of the organic fraction of municipal solid waste generates streams with relatively low content of inert material and high biodegradability. This material can be conveniently treated to recovery both energy and material by means of simplified technologies like screw-press and extruder: in this study, the liquid fraction generated from pressed biowaste from kerbside and door-to-door collection was anaerobically digested in both mesophilic and thermophilic conditions while for the solid fraction composting is suggested. Continuous operation results obtained both in mesophilic and thermophilic conditions indicated that the anaerobic digestion of pressed biowaste was viable at all operating conditions tested, with the greatest specific gas production of 0.92 $m^3/kgVS_{fed}$ at an organic loading rate of 4.7 $kgVS/m^3$ d in thermophilic conditions. Based on calculations the authors found that the expected energy recovery is highly positive.

The contents of heavy metals and pathogens of fed substrate and effluent digestates were analyzed, and results showed low levels (below End-of-Waste 2014 criteria limits) for both the parameters thus indicating the good quality of digestate and its possible use for agronomic purposes. Therefore, both energy and material were effectively recovered.

1. Introduction

Anaerobic digestion is a proven and widespread technology for the management of organic waste of different origin (De Baere and Mattheeuws, 2012). There are currently more than 14,000 plants running in Europe, 28% of which are dedicated to the treatment of wastewater sludge, municipal and industrial organic waste, while the remaining 72% use agro-waste as feedstock (EBA, 2014).

With specific reference to municipal waste management, the success of this technology in recent years has been determined by the implementation of deep separate collection schemes: this determined the possibility of handling streams with a reduced amount of inert material and high moister content and biodegradability like segregated food waste (Valorgas, 2010; Bernstad et al., 2013).

Beside anaerobic digestion, the other biological process widely diffused within EU for the management of organic wastes is the aerobic stabilization, or composting: at present a compost production of around 10.5 million tonnes of organic waste is reported (European Union law http://eur-lex.europa.eu).

Noticeably, the two processes, i.e., anaerobic digestion and composting, can be integrated together since the solid fraction of digestate can be treated aerobically (Nayono et al., 2009) so to recovery both renewable energy and nutrients from organic waste. At present some 8 million tons of biowaste are anaerobically digested within EU Countries and normally the biowaste is pretreated and prepared for the AD process by means of several mechanical steps. A large number of plants treating organic waste started their operations in the 1980s, when both the amount and the composition of biowaste were quite different from the present situation. This has resulted in the need for some modifications both in plant management and operating conditions (Di Maria et al., 2012). In fact literature showed that during conventional pretreatment methods around 30% of the initial wet material could

Abbreviations: AD, anaerobic digestion; ALK tot, total alkalinity; COD, chemical oxygen demand; CSTR, continuous stirred tank reactor; DM, dry matter; DW, dry weight; GP, gas production; GPR, gas production rate; HRT, hydraulic retention time; MSW, municipal solid waste; OFMSW, organic fraction of municipal solid waste; OLR, organic loading rate; Ptot, total phosphorus; SGP, specific gas production; SMP, specific methane production; SSC, steady state condition; TKN, total kjeldahl nitrogen; TS, total solids; TVS, total volatile solids; CFU, colony forming unit; VFAs, volatile fatty acids; VS, volatile solids; WW, wet weight.

* Corresponding author at: Via Cesare Pavese 18, 31100 Treviso, Italy.
E-mail address: federico.micolucci@univr.it (F. Micolucci).

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be rejected without any treatment (Pognani et al., 2012). The pre-treatment of the organic fraction of municipal solid waste is in fact one of the main challenges in mechanical–biological treatment plants equipped with anaerobic digesters (Romero-Güiza et al., 2014).

Recent literature highlights the observations related to the loss of biodegradable organic matter during the pre-treatment steps (Müller et al., 1998; Bolzonella et al., 2006a,b; Ponsá et al., 2010). Moreover, these steps are time and energy consuming (Tonini et al., 2014) and generally are not able to achieve high removal yields for inert materials like small pieces of plastics and fine heavy materials like crashed glass, sea shells and sand. These materials could then accumulate inside the reactor determining a reduction of the reaction volume and a possible risk of process failure (Angelidaki and Boe, 2010).

Another important aspect to be considered is then the reduction of the energy demand for pre-treatment processes and if possible enhance the biogas production of the anaerobic digestion plants that treat the municipal biowaste (de Araújo Morais et al., 2008).

In order to address all these issues an interesting option is the use of very simple pre-treatment steps like presses and extruders: in these machines the size of the organic material is reduced while inert material (mainly plastic) is eliminated.

Biowaste pressing produces two streams: one semi-liquid to be digested and a second one solid to be composted (Hansen et al., 2007). Nowadays another advanced energy saving pre-treatment approach has been developed: biowaste squeezing. This is a mechanical pre-treatment process. The advantages of mechanical pretreatment include an easy implementation, better dewaterability of the final anaerobic residue and a moderate energy consumption (Ariunbaatar et al., 2014). Pretreatment and digester design are the key techniques for enhanced biogas optimization (Shah et al., 2015).

Only few examples of such approach can be found in literature at the best of our knowledge.

Nayono et al. (2009) studied AD of pressed off leachate from OFMSW and the co-digestion of press water and food waste (Nayono et al., 2010) for improvement of biogas production. The co-digestion of press water and food residues with defibred kitchen wastes (food waste), operated at an OLR in the range 14–21 kgCOD/m^3 d, reported greater biogas production rates then sole biowaste. An increment of the OLR of biowaste by 10.6% with press liquid fraction increased the biogas production as much as 18%, with a biogas production rate of 4.2 m^3/m^3 d at an OLR of 13.6 kgCOD/m^3 d. These experimentations were conducted through laboratory scale reactors, from 1 to 8 liters working volume.

According to the scenario reported above and the evidences of recent studies, this study was dedicated to the anaerobic digestion of the liquid fraction of pressed biowaste at pilot scale so to identify bottlenecks, consumes and yields of interest for a possible process scale-up. The use of a screw press allows for the production of two streams, one liquid, clean and very biodegradable, easy to convert into biogas (thus energy), and another one semi-solid with a level of biodegradability and water content and C/N ratio suitable for composting.

Clearly, the liquid stream, because of its characteristics, is particularly suitable also for co-digestion with sludge in wastewater treatment plants.

In this study particular attention was paid to the definition of the optimal operating conditions and yields for the anaerobic reactor.

Beside this the digestate characteristics were considered in detail also in order to respond to the requirements defined in the "End of Waste Criteria" technical proposal by the Joint Research Center of Sevilla (2014). Based on suggested criteria, pathogens and metals in the digestates were analyzed in order to evaluate the necessity of further anaerobic digestate treatment, for example in a co-composting process.

2. Materials and methods

2.1. Pretreatment strategy and experimental set up description

A pilot-scale press, specifically designed for this experimentation, was used in order to pre-treat separately collected biowaste and split it into two streams, one liquid to be anaerobically digested and a second one solid to be composted.

Door-to-door collected biowaste from Treviso area (Italy) was first shredded into a knife mill and treated in a press for solid–liquid separation. Only the liquid fraction was then sent to the anaerobic process while the semi-solid part, characterized by a higher content of dry matter, was suitable for aerobic stabilization process.

The semi-liquid stream was then sent to two pilot scale CSTR anaerobic digesters, one mesophilic (37 °C ± 0.1) and the other thermophilic (55 °C ± 0.1), working with an organic loading rate in the range 3–6 kgVS/m^3 per day and a hydraulic retention time of 20 days to simulate the best operating conditions expected for a full-scale treatment plant. Organic matter degradation at increasing OLR (and decreasing HRT) was investigated. The research was carried out using two pilot scale reactors completely equal in terms of electro-mechanics, working volume (0.23 m^3) and heating system. The reactors were made of stainless steel AISI-304 and the mixing was ensured by mechanical anchor-bars agitators in order to maximize the mixing degree inside the reactor, thus avoiding the typical stratification of floating materials on the top and of sinking heaviest materials on the bottom of the reactor. The temperature of 37 °C (mesophilic thermal range) and 55 °C (thermophilic thermal range) of the reactors was maintained constant by an external jacket; in which heated water was recirculated. The biogas produced was sent to a hydraulic guard with the purpose of maintaining an operating pressure of 0.1 m water column inside the reactor. Reactors were fed once a day.

2.2. Analytical methods

Biowaste commodity class was analyzed in accordance with the procedure reported by MODECOM™ (1998). The reactor effluents were monitored 3 times per week in terms of TS, TVS, COD, TKN and P total. For TS determination, 105 °C drying temperature was adopted and no losses were caused (Peces et al., 2014). The process stability parameters, namely pH, volatile fatty acids (VFAs) content and distribution, conductivity, total and partial alkalinity and ammonium (NH_4^+–N), were checked daily. All the analyses performed according to the APHA (2005). The analysis of the volatile fatty acids was carried out with a Carlo Erba™ gas chromatograph equipped with a flame ionization detector (T = 200 °C), a fused silica capillary column Supelco NUKOL™ (15 m × 0.53 mm × 0.5 μm thickness of the film), while hydrogen was used as carrier gas. The analysis was conducted using a temperature ramp from 80 °C to 200 °C (10 °C/min). The samples were analyzed before being centrifuged and filtered with a 0.45 μm filter. Biogas production was monitored by a flow meter (Ritter Company™), while methane, carbon dioxide and oxygen in biogas were determined through a portable infrared gas analyzer GA2000™ (Geotechnical Instruments™) continuously and a Gas Chromatograph 6890N, Agilent Technology™, once a day.

The content of heavy metals and pathogens of fed substrate and digestates, in the two experimentations (mesophilic and thermophilic), were analyzed (EPA 3051A 2007 + EPA 6020A 2007).