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BMP tests of source selected OFMSW to evaluate anaerobic codigestion with sewage sludge

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ABSTRACT

The aim of this study is to characterize different types of source selected organic fraction of municipal solid waste (SS-OFMSW) in order to optimize the upgrade of a sewage sludge anaerobic digestion unit by codigestion. Various SS-OFMSW samples were collected from canteens, supermarkets, restaurants, households, fruit–vegetable markets and bakery shops. The substrates characterization was carried out getting traditional chemical–physical parameters, performing elemental analysis and measuring fundamental anaerobic digestion macromolecular compounds such as carbohydrates, proteins, lipids and volatile fatty acids. Biochemical methane potential (BMP) tests were conducted at mesophilic temperature both on single substrates and in codigestion regime with different substrates mixing ratios. The maximum methane yield was observed for restaurant (675 NmlCH_4/gVS) and canteens organic wastes (571 and 645 NmlCH_4/gVS). The best codigestion BMP test has highlighted an increase of 47% in methane production respect sewage sludge digestion.

1. Introduction

To decrease the environmental pressure caused by landfill disposal, sustainable OFMSW management practices consist nowadays in composting or wet and dry anaerobic digestion. Anaerobic digestion (AD) is a biological process that involves the degradation of organic matter and the production of biogas, a mix of methane and carbon dioxide in variable percentage. Biogas is a renewable energy source and a key factor for a future fossil fuels independent society. AD technology, combined with digestate composting, allows energy recovery and nutrient soil replacement.

Anaerobic codigestion (AcoD) is a challenging technology applied for both treatment of solid and liquid organic wastes (Alatriste-Mondragón et al., 2006) when the AD process of these mixtures is sustainable. Sometimes AcoD of sewage sludge (SwS) with OFMSW may be one of the most viable solutions to optimize the oversized digesters efficiency in wastewater treatment plants (WWTPs): the typical free capacity of existing traditionally designed municipal SwS digesters can be well used adding the appropriate amount of OFMSW in AD process supply (Sosnowski et al., 2008). The substrate mixtures treated in AcoD process must be well balanced in all chemical–physical properties to allow positive interactions, to avoid inhibitions and to optimize methane production (Mata-Alvarez et al., 2011). The quality of organic wastes used in this process affects both the reactor operations and the subsequent use of the digestate as fertilizer on agricultural soils (Capela et al., 2008), likewise AD system management is strictly bound to the inlet waste mixture. An interesting study (Yoshida et al., 2012) reports greenhouse gas (GHG) emission analysis evaluation performed by different organic waste management practices in the City of Madison, Wisconsin (USA). Using Life Cycle Assessment (LCA) they found SwS and OFMSW AcoD process is a good practice not only for a general GHG emission reduction but also for the potential to save capital cost respect composting and mono-substrate digestion. The payback period on the investment of a SwS-OFMSW AcoD process is usually short (Mata-Alvarez et al., 2011): existing AD reactors and WWTP operational facilities can be utilize, saving most part of initial and operational costs (Yoshida et al., 2012).

Various studies are reported on AcoD process operating with SwS and OFMSW or fruit and vegetables solid wastes (FVWs) on lab scale (Stroot et al., 2001; Kim et al., 2003; Murto et al., 2004; Gómez et al., 2006; Gomez-Lahoz et al., 2007; Scaglione et al., 2008), pilot scale (Sosnowski et al., 2003; Caffaz et al., 2008; Liu et al., 2012) and full-scale plants (Rintala and Järvinen, 1996; Edelmann et al., 2000; Bolzonella et al., 2006; Zupančic et al., 2008; Zitomer et al., 2008). The main results show SwS characteristics play an important role in AcoD with OFMSW: the nitrogen content of secondary sludge can remedy a possible lack of nutrients in OFMSW cosubstrate as well as primary sludge (rich in lipids) can increase methane production yield of the AcoD process (Mata-Alvarez et al., 2011). Similarly, the rate and the extent of anaerobic degradation and solid stabilization are functions of the intrinsic properties of the wastes and the microorganism involved (Gunaseelan, 2007),

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where the composition of organic matter depends greatly on the source of the organic fraction (Chen et al., 2008). A way to understand accurately the properties of the substrate to be treated is to perform BMP assays (Raposo et al., 2011b), likewise macromolecular composition analysis in terms of carbohydrates, proteins, lipids and volatile fatty acids (VFAs) allows a good characterization of the organic features of substrates involved in the AD process.

All these studies lead to the statement that the nexus between wastewater treatment and organic waste management is strictly related to the need of reaching an environmental sustainable economic system able to provide treated water, bioenergy and biofertilizer: integrated solid waste and wastewater treatment management could play a fundamental role in this challenge. The aim of this work was to characterize the different OFMSW streams coming from an appropriate waste collection basin, as a perspective of the AD unit upgrade to AcoD, within WWTP of the city of Udine (Italy). The waste collection basin was set considering an essential OFMSW management, built on the most productive and clean material streams reaching anaerobic digester. SS-OFMSW selection criterion was fixed to conciliate minor distance to WWTP and higher quality waste, to avoid AD unit maintenance problems and to obtain the maximum biogas production. In BMP tests SwS together with the more representative substrates for AD unit process, within the waste collection basin, were analyzed. The organic substrates characterization was accomplished basing on traditional physicochemical parameters (commonly used in past to design anaerobic digesters), elemental analysis and macromolecular compounds. Further BMP tests on different SwS and SS-OFMSW mixing ratio were carried out to compare codigestion methane yields.

2. Material and methods

2.1. Organic wastes and inocula

OFMSW samples were obtained by source selected producers in a 30 L bins. The SS-OFMSW sampling has regarded the organic residues collected from two canteens (Canteen 1, Canteen 2), two supermarkets (Supermarket 1, Supermarket 2), one restaurant, one household, two fruit and vegetable markets (FVW 1, FVW 2) and one bakery. Household wastes were withdrawn before truck collection to avoid sample squeeze. The SwS was drawn from the sludge thickener of Udine WWTP, Italy. SwS was a mixture of primary sludge and waste activated sludge. The inocula was extracted by the primary mesophilic anaerobic digester by the same WWTP.

2.2. Experimental set-up and procedure

BMP tests were carried out following guidelines proposed by two recent studies (Raposo et al., 2011b; Angelidaki et al., 2009). BMP tests were performed in two experimental phases: in the first one, tests were carried out on SwS and SS-OFMSW monosubstrates and in the second phase on SwS and SS-OFMSW mixture (OFMSW-MIX) in AcoD regime (these tests were named CO-DIG1 and CO-DIG2).

In the first experimental session, glass bottles with a working volume of 400 ml and headspace volume of 100 ml were used. Bottles were maintained at mesophilic temperatures (37 °C) in a thermostatic bath for 30 days and stirred by mechanical mixing at 40 rpm for 10 s every 1 min. Before starting anaerobic digestion, each bottle headspace was flushed by N_2 gas. Methane measurements were performed by a volumetric device (AMPTS II, Bioprocess Control, Sweden) with alkaline solution for biogas washing. No pH and alkalinity adjustments were performed due to high buffer capacity of sewage sludge seed and also to check process behavior without any chemical interference (Sosnowski et al., 2008). No any mineral medium was added to the mixture with the hypothesis that the lack in micronutrient and trace elements is offset by the inoculum. Blank controls were conducted to obtain the residual biogas production by inoculum alone. Particle size can affect process kinetics, due to the amount of available specific surface area for microorganism action (Lesteur et al., 2010). Accordingly, OFMSW samples were ground by a mincer, diluted with tap water and shredded by a kitchen mixer obtaining a common optimal $\leqslant$10 mm particle size (Raposo et al., 2011b) in the mixture, in which Total Solids (TSs) were maintained below 3–4.5% TS. Inocula and substrates were stored for 3 days at 4 °C before tests. BMP tests were carried out in triplicate.

In the second experimental session, glass bottles working volume was increased to 1600 ml with an headspace volume of 400 ml, with the aim to supply significative amounts of substrates to AcoD. The same procedure previously described was followed.

The net methane production of organic substrates in BMP test, was obtained detracting the inoculum contribution of the blank control. Methane and biogas yields were referred, together to specific methane production rates, to Standard Temperature and Pressure (STP) conditions. The results reported are expressed as average of three samples.

2.3. Inoculum to substrate ratio (ISR)

In literature experimental data demonstrated that the ultimate methane yield as well as the methane production rates are dependent on the specific substrates and inoculum (Eskicioglu and Ghorbani, 2011). Large inoculations volumes ensure high microbial activity, low risk for overloading and low risk of inhibition (Angelidaki and Sanders, 2004). Some researchers (Raposo et al., 2011a) considering that an ISR $\geqslant$ 2 has never been reported as inhibitory, suggest this ratio as mandatory for standardized tests. In this work BMP tests were conducted at a safe ISR of 3, which was chosen to prevent any inhibitory effect, bound to OFMSW anaerobic digestion. Only for BMP tests on SwS, different ISR (1, 1.5, 2 and 3) were adopted to verify the influence of this parameter on the biomass degradation activity.

2.4. Analytical methods

Total Solids (TSs), Volatile Solids (VSs), Chemical Oxygen Demand (COD), Total Kjeldahl Nitrogen (TKN), ammonium nitrogen (N-NH_4^+), total phosphorus, sulfate SO_4^{2-}, pH and alkalinity were measured according to Standard Methods (APHA, 2005). Soluble fractions of samples were obtained passing slurries through 0.45 μm cellulose filter. Volatile Fatty Acids (VFAs) concentrations were determined by gas-chromatography with mass spectrometer (Agilent 6890 Plus/5973N) equipped with capillary column (Agilent HP-5MS). Carbohydrates were analyzed using Dubois method (Dubois et al., 1956) with glucose as standard. Total proteins were estimated multiplying organic nitrogen (TKN – N-NH_4^+) by 6.25. Lipids were measured by gravimetric analysis after acetone-hexane extraction. Elemental analysis (C, H, N) was carried out by Flash EA 1112 Elemental Analyzer (Thermo Finnigan, Italy).

3. Results and discussion

3.1. Wastes characteristics

SS-OFMSW samples showed different composition: canteens and restaurant residues were the most heterogeneous with vegetables peels, rice, pasta, bread, meet and other scraps types. Supermarkets wastes were exclusively constituted by fruit and