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Waste cleaning waste: Ammonia abatement in bio-waste anaerobic digestion by soluble substances isolated from bio-waste compost

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ABSTRACT

Soluble bio-based substances are isolated from the alkaline hydrolysate of composted urban gardening wastes. These substances are capable to reduce the ammonia content in municipal biowaste anaerobic digestates. The present work reports the anaerobic fermentation of the organic humid fraction of solid municipal biowaste carried out in the presence the above soluble substances, added at 0.05–0.2% concentration in fermentation slurry. The results show that the ammonia in the digestate obtained under these conditions is 70–100% lower than the ammonia present in the digestate of control fermentation without addition of soluble biobased substances. Operational cost savings (up to 1.1 € per abated ammonia N kg) may result for the anaerobic digestion performed in the presence of the above soluble susbtances, compared to conventional technology for the digestate secondary treatment.

1. Introduction

Bio-waste processing is gaining much attention worldwide [1–3]. The short term objective is reducing the environmental impact caused by the accumulation of bio-waste, which has dramatically increased because of increasing population, urbanization, and consumption habits. The long term objective is valorizing bio-waste as renewable feedstock to obtain bio-based products, alternative to synthetic chemical derived from fossil sources. These objectives imply coping with two main criticalities. Compared to fossils, bio-waste contain relatively too much water and are spread over large areas. In addition, processes developed for bio-waste are not necessarily clean and economically sustainable. This paper reports a new virtuous municipal bio-waste cycle, which addresses the above criticalities through integration of biochemical and chemical technologies.

Among all bio-waste types from urban, agriculture and agro-industrial source, fermented municipal bio-waste are the most exploitable ones. The concentration of wastes in urban areas has allowed collecting natural bio-organic matter in well-confined spaces, with transportation costs covered by the tax payer. In addition, anaerobic and/or aerobic fermentation of this bio-waste allows reducing the content of water and obtaining materials with higher concentration of organic matter. By these features, urban wastes may be defined potential negative cost feedstock [4]. Nevertheless, not all processes for attaining these features are clean. A typical example is the anaerobic fermentation of bio-waste for the production of biogas. The aim is to recover the heat value of the bio-waste organic matter as bio-methane. The process converts the polysaccharide, fat and protein fraction of the bio-waste organic matter to biogas, whereas the lignin fraction remains in the digestate [5–7]. Unfortunately, the process requires a secondary treatment of the digestate. This is necessary because the process produces also ammonia by the action of proteolytic bacteria. The ammonia production in bio-waste anaerobic fermentation has important drawbacks [8,9]. Ammonia inhibits methanogenic bacteria that are especially sensitive to this compound. Ammonia is collected with the digestate that is normally recycled to farmland. Ammonia emission and/or nitrate leaching can occur due to inappropriate handling, storage and application of digestate as fertilizer [10]. In Europe, the Nitrate Directive (91/676/EEC) restricts the

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Abbreviations: SBO, soluble biobased substances obtained from municipal biowastes; CV, soluble substances obtained from public and private gardening all vegetable wastes.

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input of mineral nitrogen on farmland, aiming to protect the ground and surface water from pollution. Excess ammonia may be removed from the digestate [11,12] through chemical, physico-chemical, and biochemical processes. The former ones imply membrane separation, air stripping, ion exchange and chemical precipitation [12]. The latter ones are carried out through nitrifying and denitrifying bacteria that convert ammonia to nitrates, and then reduce the nitrates to N_2 [13]. These technologies are quite expensive. The ammonia abatement cost of 1.6 $ kg^{-1} N [13] through the biochemical Anammox process is among the lowest published. Other authors [12] report cost estimates running from 1 to 13 $ kg^{-1} N for ammonia recovery by the available physico-chemical technologies. The anaerobic fermentation example points out that, although in principle it is possible to valorize bio-waste, processes should be further developed in order not to generate secondary wastes needing further treatment.

Recently, papers have been published pointing out that bio-waste can be used to clean wastes produced by human activities. Two papers [14,15] report that soluble bio-based substances (SBO) isolated from municipal bio-waste, thanks to their photosensitizing properties, can be used for the photo remediation of industrial effluents containing organic pollutants. Another paper [16] reports that the same SBO, thanks to their surfactant properties, can perform in surfactant assisted soil washing for the remediation of soil polluted by industrial activities. For the production of SBO, a completely green process [17] has been developed at pilot scale. In the process the hydrolysis of the bio-waste feed is performed in water at relatively mild temperature. The liquid hydrolysate is separated from the insoluble solid (IS). The former is fed to a 5 kDa ultrafiltration membrane. The membrane retentate is dried to yield the SBO. The permeate is recycled to the hydrolysis reactor for further use. For the SBO, multiple uses in the chemical industry, agriculture and animal husbandry have been proven [18–29]. The insoluble solid (IS) has been proven a valid fertilizers for the cultivation of several food [27,30] and hornamental [31] plants. Thus, in the above process, solvent and reagent are completely recycled, and no waste is produced, which requires a secondary treatment. The present work reports a virtuous example of using municipal bio-waste and their fermentation products for the production of SBO. This is the abatement of ammonia in the anaerobic fermentation of municipal bio-waste by adding the above SBO to the fermentation slurry. Results were obtained by anaerobic fermentation batch experiments performed with feed slurry and inoculum sampled from the Acea Pinerolese municipal bio-waste treatment plant located in Pinerolo (TO), Italy. The plant performs integrated anaerobic and aerobic fermentation of municipal bio-waste. It represents a typical end-user of the above results.

2. Materials & methods

2.1. Fermentation liquor and SBO preparation

The fermentation liquor was collected from the Acea Pinerolese waste treatment plant. It consisted in the urban organic humid fraction feed to the plant anaerobic digester and the recirculated digestate recovered from the plant biogas reactors. In the routine plant operation, these materials are prepared as follows. The municipal solid bio-waste recovered from town bins is normally contained in plastic bags. These are first shredded by means of a bag opener and then separated in a disc screen with 50 mm openings. The finer matter is mechanically treated to separate inert material as bones, stones, heavy objects and residual plastic material to obtain the solid bio-organic fraction. This is taken up with hot process water in a mixer to yield a 12% solid wet suspension that constitutes the organic humid fraction feed for the anaerobic digester. The recirculation digestate is obtained as follows. The organic humid fraction feed is heated to 65 °C that is then conveyed to the digester bioreactor. The reactor is operated with 14 days hydraulic retention time of the fermentation medium at 50 ± 5 °C. The digestate from the anaerobic digester is 12 mm sieved to remove residual non-biodegradable scraps such as wood and nutshells. This material constitutes the recirculated digestate used as inoculum in the present work. The SBO were available from previous work [17]. They were isolated from the alkaline hydrolysate of compost obtained from a vegetable mix of private and public gardening urban wastes. Hereinafter, this type of SBO is referred to with the CV acronym.

2.2. Set up of anaerobic digestion trials in this work

Batch fermentation trials were performed with a set of nine reactors. Each reactor, having 6.5 liters capacity, was filled up with 4 liters of basic fermentation slurry. This was made from the materials sampled from the Acea plant, i.e. the organic humid fraction and the digestate inoculum mixed in 1/2 w/w ratio, respectively. Triplicate runs were performed for the control slurry mix containing no added CV, and for the same mix added with CV at 0.05% and 0.20% level. In each run, the nine reactors were started at the same time by heating up to 55 °C and then operated at this temperature for 15 days, when the biogas production was substantially negligible. The reactors were equipped with mechanical stirrer, gas sampling septum, and for automatic measuring and recording of the biogas cumulative volume, temperature, pH and redox potential. All parameters were monitored on line in real time and acquired through SCADA software. Under the above experimental conditions, two fermentation runs were performed. In run 1, the fermentation slurry mix containing 4.1% dry total solids (TS) was first diluted with water to 1.6% TS content, and then transferred to the reactor. In run 2, each reactor was charged with the undiluted 4.1% TS mix. Except for the TS content, the two runs were operated in the same way. As run 1 and 2 were performed in two separate dates, run 2 one month after the completion of run 1, the organic humid fraction and digestate inoculum materials required for carrying out each run were also delivered in two separate dates. Each delivery was received two days before the start of the intended run. The as received materials were first homogenized by means of a mechanical stirrer placed within each drum. The proper amounts were then sampled from each drum and added in each reactor.

2.3. Reactors mass balance and analytical procedure

The reactors were charged with a previously weighed amount of the basic fermentation slurry. At fermentation end, the total content of the reactor was weighed. Triplicate analyses were performed on samples withdrawn from the starting and the final liquor of each reactor as follows. The sample was centrifuged. The separated liquid and solid phase were weighed to determine their relative content in the reactor liquor. The samples were analyzed as follows. The content of moisture and volatile solids was obtained by thermal gravimetric analysis measuring the weight loss at 105 and 650 °C by means of a TGA-700 LECO instrument, operated in air at each temperature to constant sample weight. The total carbon and nitrogen content in the liquid and solid fractions were analyzed with an elemental analyzer CHN 628 (LECO) following the method LECO-ASDM-D 5291. The inorganic nitrogen (N_{NO3}, N_{NO2} and N_{NH3}) was analyzed by ion-chromatography (DIONEX), as previously reported [32,33]. This procedure allowed calculating the total amount of the above analytes in each reactor at the beginning and at the end of the anaerobic digestion process. However, as the elemental microanalysis was performed on samples dried at 105 °C, at which temperature loss of ammonia occurs [34], it was assumed