Waste Management 77 (2018) 140–146

Contents lists available at ScienceDirect

Waste Management

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

Biological stability of multi-component agri-food digestates and post-digestates

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ARTICLE INFO

Article history:
Received 22 November 2017
Revised 9 May 2018
Accepted 10 May 2018

Keywords:
Biological stability
Post-digestates
Biogas productivity
Aerobic respiration activity
Anaerobic post-treatment

ABSTRACT

The use of digestate in agriculture has been an efficient way to mitigate greenhouse gas emissions through the recycling of organic materials. However, harmful effects can arise if the organic matter is unstable. The goal of this study was to determine the biological stability (4-day oxygen demand for degradation of readily biodegradable organic matter (AT4), 21-day anaerobic biogas potential (GP21), and organic matter (VS) content) of six digestates after mesophilic digestion, and that of the corresponding post-digestates after psychrophilic post-digestion. Moreover, the kinetics of the changes in biological stability during post-digestion were determined. Mesophilic digestion of six multi-component agri-food feedstocks consisting of maize silage, bovine manure, mallow silage, pig slurry, glycerin, and spent wash from distillation was carried out at an organic loading rate of 2–3 kg VS/(m^3·d), and at a hydraulic retention time of 45–60 days. Digestates were left in stirred reactors, imitating storage digesters, and kept for the next 120 d under anaerobic psychrophilic conditions (20 ± 1 °C) for further stabilization.

The additional biogas yields during post-digestion (50.9–114.9 dm^3/kg TS) accounted for 8.5–27.4% of the biogas productivity of the feedstocks and 40–80% of that of the digestates. The efficiency of the loss of organic matter content was 22.5–40.2%. The decrease in the values of AT4, GP21 and VS content made the post-digestates more biologically stable than the digestates (digestates: AT4 = 13.7–67.0 mg O_2/g TS, GP21 = 71.5–130.1 dm^3/kg TS; post-digestates: AT4 = 6.6–37.4 mg O_2/g TS, GP21 = 15.7–79.2 dm^3/kg TS). For digestates and post-digestates, AT4 values strongly correlated with GP21 values.

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1. Introduction

The large quantities of biodegradable sources produced by the intensive livestock production systems, agro-food industry and from dedicated crops can be anaerobically digested for biogas production as an energy recovery process and for digestate production to recover nutrients and carbon for fertilization. The variability in the biochemical properties of anaerobic digestates is considerable, reflecting the diversity of biomass input (Teglia et al., 2011). Anaerobic digestion (AD) can be used to transform organic wastes, such as cattle manure (Gomez et al., 2007), livestock manure and agricultural residues (Amon et al., 2007; Tambone et al., 2010), and organic solid wastes and sewage sludge (Gomez et al., 2007), into digestate, which contains organic matter and nutrients in forms available to plants (Tambone et al., 2010). The properties of the resulting digestate are affected by the feedstock composition and the technological parameters of the process (Alburquerque et al., 2012a; Holm-Nielsen et al., 2009). Unfortunately, optimizing AD for methane production mostly entails the use of a shorter hydraulic retention times or higher organic loadings than those necessary for stabilization of the organic matter. Thus, the unstabilized digestate that is produced often needs to be stored in aboveground, uncovered tanks. This method of digestate storage can create a number of problems, including odor emission, as well as production of toxic compounds and pathogen re-growth, which can cause the digestate to have unfavorable effects on the soil, thus limiting its potential fertilizing value (Abdullahi et al., 2008). Using unstable digestates can immobilize nitrogen or exhaust oxygen due to an excessive increase in soil microbial activity (Alburquerque et al. 2012a, Holm-Nielsen et al. 2009). Rather than just a simple disposal method, the agricultural use of digestates is also a recovery process. Thus, technological processes should not only produce the maximum possible yield of biogas, but also safe, biologically stable digestate that is suitable for application to agricultural soil. There is no formal definition of biological stability. It can be defined as the extent to which biodegradable organic matter has decomposed or the resistance of the organic matter to further biodegradation. Brewer and Sullivan (2003) determined the stability and maturity indices for yard trimmings compost. Those

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https://doi.org/10.1016/j.wasman.2018.05.016
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authors stated that maturity is a general term describing the suitability of the compost for a particular end use, while stability refers exclusively to the resistance of the organic matter content in compost to further degradation. With the use of respirometric tests, they identified a period of high respiration rates during active composting and a period of relatively low respiration rates during the latter part of the process. This could relate to the low stability and high biodegradability of the substrate before and during active composting, and the high stability of final product, compost. Generally, during biological processes (composting/aerobic stabilization, anaerobic digestion) the biodegradability of organic substrates should be reduced, and thus their stability should be increased.

The stability of organic substrates can be evaluated using non-biological methods, including determination of TS (total solids), organic matter (as VS) and total organic carbon (TOC) content, and by biological methods, including aerobic and anaerobic tests (Astals et al., 2012; Barrena et al., 2014). Nonetheless, there is little agreement about which indicators and threshold limits should be used to assess the biological stability of digestate. For example, to evaluate the biological stability of lignocellulosic substrates (agriculture and forest by-products), Liu et al. (2015) suggested using the aerobic biodegradability (BD_{aero}, % of COD_{tot}), expressed as the BOD/COD_{tot} ratio, and the anaerobic biodegradability (BD_{ana}, % of COD_{tot}), expressed as the ratio of methane yield to COD_{tot}. For the same purpose, Schievano et al. (2008) determined, among others, the following stability indicators of the feedstocks and digestates from full scale biogas plants: the anaerobic biogasification potential (ABP), the VS content (% of TS), the TOC/TKN ratio, and the oxygen demand in a 20-h respirometric test (OD20).

There is a large, significant correlation between the results of the aerobic tests and those of the anaerobic tests (Ponsá et al., 2008), and these results can be used to determine the best methods for treatment and post-treatment of organic waste composting (Barrena et al., 2009; Liu et al., 2015). However, little research (Maynaud et al., 2017) is available on the relationships between the digestate that serves as the input for post-digestion and the biological stability of the output, i.e. the post-digestate. Not many studies have focused on the stability of digestates after anaerobic digestion and the possibility of further stabilization of these digestates via psychrophilic post-digestion. The additional biogas yield during post-digestion is especially interesting, not necessarily from an economic point of view, but rather because of the possibility of reducing uncontrolled methane emissions.

Thus, the purpose of the present study was to provide information on the change in the biological stability of six multi-component agri-food digestates during 120 days of psychrophilic anaerobic post-digestion, with a particular focus on additional biogas production. Furthermore, during post-digestion, the kinetics of the changes in indicators of the biological stability of the digestates were determined.

2. Materials and methods

2.1. Technological conditions of anaerobic psychrophilic post-digestion

After mesophilic anaerobic digestion, six multi-component agri-food digestates (the composition of these digestates is explained below) were left in stirred reactors, simulating storage digesters, and kept for the next 120 d under anaerobic psychrophilic conditions (20 ± 1 °C) for further stabilization.

The characteristics of the process of mesophilic anaerobic digestion (35 ± 2 °C) of the six multi-component agri-food feedstocks were as follows: hydraulic retention times (HRT) of 45 or 60 d and organic loading rates of (ORL) of 2 or 3 kg VS/(m^3·d). The volume of the reactors was 10 L, and their working volume was 6 L. The reactors were equipped with water-jacket heaters to maintain the required temperature. Mesophilic anaerobic digestion proceeded for 75–200 days to allow the microorganisms to acclimatize to the feedstocks and to achieve stable conditions. During this period, stable biogas production and organic matter degradation took place (data not shown). For mesophilic anaerobic digestion, the following feedstocks were used:

- a two-component feedstock comprised of maize silage (M) and bovine manure (B) (MB) (50% of VS derived from M, and 50% of VS derived from B),
- three-component feedstocks comprised of maize silage (M) or mallow silage (P), with pig slurry (S) and glycerine (G) (MSG and PSG) (87.5% of VS derived from M or P, 6.25% of VS derived from S, and 6.25% of VS derived from G),
- a four-component feedstock comprised of maize silage (M), pig slurry (S), glycerine (G), and spent wash after distillation (D) (MSGD) (87.5% of VS derived from M, 4.2% of VS derived from S, 4.2% of VS derived from G and 4.1% of VS derived from D).

All of these substrates came from working farms and plants located in north–east Poland.

The digestates that were produced by mesophilic anaerobic digestion and used in anaerobic psychrophilic post-digestion are referred to with abbreviations that indicate the composition of the feedstock and the OLR and HRT of mesophilic anaerobic digestion: MB/2/45, MB/3/60, MSG/2/45, MSG /3/45, PSG/2/45, MSGD/3/45. For example, MB/2/45 indicates the two-component feedstock with maize silage (M) and bovine manure (B) at an ORL of 2 kg VS/(m^3·d) and an HRT of 45 d, and MSG/3/45 indicates the three-component feedstock with maize silage (M), pig slurry (S), and glycerine (G) at an ORL of 3 kg VS/(m^3·d) and an HRT of 45 d, etc.

2.2. Chemical analyses

Total solids (TS) and volatile solids (VS) in digestates, in samples that were taken every 3–7 days during post-digestion, and in post-digestates were determined with standard procedures according to APHA (Greenberg et al., 1992). Then, the same samples were centrifuged for 25 min at 9000 rpm. In the liquid phase, the content of organic compounds as COD, and as dissolved organic carbon (DOC) (after filtration with a 0.45 μm filter), were determined.

2.3. Biological stability measurements

Two respirometric tests were used to determine the biological stability of the digestates, of the samples taken during 120 days of post-digestion, and of the post-digestates. Firstly, the aerobic respiration test (AT4) was carried out during 4 days under aerobic conditions by measuring the oxygen consumed for degradation of readily biodegradable organic matter using a manometric Oxi-Top Control set (German Standard AbfAblV, Anhang 4 (Anon, 2001)). Secondly, the GP21 anaerobic test (gas potential) was carried out during 21 days under anaerobic conditions by measuring biogas production per kg of total solids in the tested sample, with the use of an inoculum consisting of fermented sludge from the anaerobic digester of a wastewater treatment plant (WWTP) (German Standard AbfAblV, Anhang 4 (Anon, 2001)). AT4 and GP21 values were determined in triplicate for each sample.

2.4. Calculations

The efficiency of the loss of organic matter content (E_{VS}) during 120 day post-digestion was calculated according to Paredes et al. (2000):

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