Bioresource Technology 234 (2017) 466–471

Contents lists available at ScienceDirect

Bioresource Technology

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

Short Communication

Comparison of the mesophilic and thermophilic anaerobic digestion of spent cow bedding in leach-bed reactors

S. Riggio [a,c,d], M.A. Hernandéz-Shek [b], M. Torrijos [a], G. Vives [b], G. Esposito [c], E.D. van Hullebusch [d,1], J.P. Steyer [a], R. Escudié [a,*]

[a] LBE, INRA, 102 avenue des Etangs, 11100 Narbonne, France
[b] Naskeo Environnement, 52 rue Paul Vaillant Couturier, 92240 Malakoff, France
[c] Department of Civil and Mechanical Engineering, University of Cassino and Southern Lazio, Via Di Biasio, 43, 03043 Cassino (FR), Italy
[d] Université Paris-Est, Laboratoire Géomatériaux et Environnement (LGE), EA 4508, UPEM, 77454 Marne-la-Vallée, France

HIGHLIGHTS

- Spent cow bedding digestion was compared in mesophilic and thermophilic conditions.
- Thermophilic temperature (TT) enhanced mainly easily-degradable matter digestion.
- Mesophilic and thermophilic reactors reached the same methane yield after 42 days.
- Higher biogas fluctuation at TT induced a decrease in the electricity production.
- The digestion of spent cow bedding at TT started easily without digestate addition.

ARTICLE INFO

Article history:
Received 13 December 2016
Received in revised form 12 February 2017
Accepted 15 February 2017
Available online 20 February 2017

Keywords:
Dry anaerobic digestion
Leach-bed reactor (LBR)
Thermophilic temperature
Discontinuous biogas production
Electric energy production

ABSTRACT

Anaerobic digestion of spent cow bedding in batch leach-bed reactors (LBRs) was compared in mesophilic and thermophilic conditions for the first time. Results show that the use of thermophilic conditions enhanced only the degradation kinetics of easily-degradable matter during the first days of the digestion, whereas similar methane yields (80% of the Biomethane Potential) were reached after 42 days at both temperatures. Therefore, the anaerobic digestion in LBRs of spent cow bedding, a substrate rich in slowly-degradable compounds, was not improved in term of methane production considering the overall digestion time. Moreover, the high initial biogas production rate in thermophilic reactors was found to significantly reduce the energetic performance of the cogeneration unit at industrial scale, leading to a 5.9% decrease in the annual electricity production when compared to a mesophilic one.

1. Introduction

Anaerobic digestion (AD) is a very widespread biological process aiming at the treatment of organic waste and the production of green energy. Spent animal bedding, the accumulating mixture of animal faeces with a bedding material (e.g. straw, wood chips) onto the soil of a stable, has been proved to be efficiently treated in discontinuous dry anaerobic digesters such as leach-bed reactors (LBRs) (Riggio et al., 2017). Spent animal bedding constitutes a slowly-degradable substrate mainly because of its high content in lignocellulosic material (Buffiere et al., 2006). For this reason digestion times ranging from 40 to 60 days are generally used in discontinuous LBRs at industrial scale. In order to improve the economic performance of the entire process, there is a real interest in increasing the substrate degradation kinetics, thus reducing the overall digestion time. In this regard, the use of thermophilic conditions in LBRs treating spent cow bedding could represent an effective solution to enhance the process performance. Indeed, when comparing the influence of mesophilic and thermophilic temperatures, several authors agreed on the faster degradation kinetics when using thermophilic conditions to treat different substrates such as: spent horse bedding (Böske et al., 2015), the organic fraction of municipal solid waste (Fernández-Rodríguez et al., 2013), spent cow bedding (Gómez et al., 2011), vegetable waste mixed to wood chips (Hegde and Pullammanappallil, 2007) and cow dung (Jha et al., 2013).

* Corresponding author.
E-mail address: renaud.escudie@inra.fr (R. Escudié).
[1] Current address: Department of Environmental Engineering and Water Technology, UNESCO-IHE Institute for Water Education, PO 3015, 2601 DA Delft, The Netherlands.

http://dx.doi.org/10.1016/j.biortech.2017.02.056
0960-8524/

In the literature, few data comparing mesophilic and thermophilic treatment are available on spent animal bedding consisting of faeces and straw. Böske et al. (2015) used a continuous upflow anaerobic solid-state (UASS) reactor to treat spent horse bedding, whereas Gómez et al. (2011) used a dry unmixed batch system to digest spent cow bedding. In thermophilic conditions, the first authors observed higher kinetics and methane yield than at mesophilic temperature, while the second reported higher kinetics and a lower methane yield. In addition to the discrepancy between their results, these latter hardly seem applicable to a different system such as a LBR because of the technical differeces among these processes.

The use of a LBR in thermophilic condition has not been frequently reported in the scientific literature except for very few cases: Koppar and Pullammanappallil (2013) used it to treat citrus peel waste, Liang et al. (2014) to treat smooth cordgrass and Rico et al. (2015) to treat raw dairy manure. Moreover, no direct comparison has been made between LBRs run in mesophilic and thermophilic temperatures and nor has research ever involved two specific challenges connected with this discontinuous process: the start-up conditions (i.e. the inoculation) and the discontinuous biogas production. Inoculation, repeated at every digester loading, affects the methane production rates if it is not well managed, while the discontinuous gas production causes problems during combustion in a Combined Heat and Power (CHP) unit. This latter issue is particularly important when dealing with LBR plants in rural areas because a reduced number of reactors (the main cause of a fluctuation in the biogas production) is often chosen to decrease investment costs and make the project economically viable.

The efficiency of thermophilic treatment of spent cow bedding in LBRs remains an open question. Therefore, the aim of this work was to investigate whether the operation of thermophilic mode when treating spent cow bedding in LBRs could be an effective measure for reducing the digestion time and increasing methane yield. In order to reach this objective, specific problems related to inoculation and the challenge connected to the combustion of biogas in a CHP unit were analyzed in detail.

2. Materials and methods

2.1. Experimental set-up

The three leach-bed reactors used in the present study were made of stainless steel; the internal diameter and total height were 40 cm and 80 cm, respectively, for a total volume of about 100 L. A mesh (3 mm holes) placed at 20 cm from the bottom separated the solid and the leachate volumes: 75 L and 25 L, respectively. To maintain the temperature, each reactor was connected to a dedicated thermo-regulated water bath. A centrifugal pump (Rover Pompe BE-M 20) was used to sprinkle the leachate, stored at the bottom of the reactor, over the top of the bulk. A valve in the leachate circuit enabled samples to be taken for analysis while a port on the biogas circuit permitted the same for gas. The operating principle of the LBRs involved has been further detailed by Riggio et al. (2017).

2.2. Substrate collection and experimental conditions

Three conditions were tested: two reactors were inoculated with a mixture of digestate and leachate and were operated under mesophilic (37 °C) or thermophilic (55 °C) conditions: M_inoc and T_inoc, respectively; a third reactor was started up in thermophilic conditions but without specific inoculation: T_no inoc. Two successive runs were carried out in order to establish the process stability and repeatability. The spent cow bedding used in each run was collected at the same farm during two different stable cleanings. The substrates sampled were stored for 2–3 days in plastic bags at ambient temperature before being used. The solid digestates and leachates used in run 1 were sampled from two previous batches adapted to thermophilic and mesophilic conditions for over three months (with two consecutive loadings). For run 2, the digestates and leachates collected at the end of run 1 were used instead. Total solids (TS), volatile solids (VS) and Biomethane Potential (BMP) tests of the digestates and spent cow bedding used in both run are reported in Table 1a. The protocols used have been described by Riggio et al. (2017).

The operating conditions for each run are described in Table 1b. In each reactor, about 1.5 kg of total solids (TS) of spent bedding was added. For the reactors inoculated, solid digestate was manually mixed to the spent bedding to reach a digestate TS/(substrate TS + digestate TS) of 13%. The leachate was diluted before being added to the reactor in order to keep a N-NH_4^+ concentration in the leachate below 0.9 g L^{-1} at the start-up and to avoid any risk of nitrogen inhibition (Angelidaki and Ahring, 1993). The total amount of leachate to be added was chosen to keep the initial TS of the mix (manure + digestate + leachate) at 11.5%, close to the one reported by Riggio et al. (2017) in similar systems. Before starting the digestion process, leachate was recirculated continuously for 10 min in order to achieve water saturation of the waste bed. Finally, the reactors were closed and the internal recirculation of the leachate was scheduled twice a day for a total volume of 1 L kg^{-1}TS d^{-1}. During digestion, volatile fatty acids (VFAs), pH, alkalinity and biogas volume, as well as its composition, were monitored. The frequency of analysis and the protocols used have been described by Riggio et al. (2017).

2.3. Hypothesis for electrical production

Based on the experimental results obtained in run 1, the electrical production of an industrial site running in thermophilic and mesophilic temperatures was simulated, and the overall amount of electrical energy produced was compared. The simulation considered the following hypothesis: treatment of 9,400 tons $year^{-1}$ of spent cow bedding and 4 LBRs working in parallel, staggered over time with a batch duration of 44 days: every 11 days a LBR was emptied and reloaded. 4 LBRs were chosen as a representative number of digesters in this kind of farm plant. In fact, more digesters would affect the economic viability of the project. A batch length of 44 days was chosen, not only because it is a representative digestion time for this kind of substrate, but also because the methane yields of the two conditions tested were the same after this time slot, cancelling the influence due to this factor on the comparison made. Finally, a staggering time of 11 days between the start-up of the digesters was indirectly set after the previous choices (4 digesters and 44 days of batch duration).

Biogas storage was not considered. A CHP unit with an electrical nominal power (P_{nom}) of 250 kW_{elec} (Schnell, 2016) was chosen, based on the average annual energy production of the site (considering the annual amount of substrate and the duration time evoked above). A minimum methane content of 45% was set for injection into the CHP unit and the electrical efficiency (η_{elec}) was set at 45.5% at P_{nom} based on manufacturer recommendation. The electrical efficiency was considered to vary linearly (Bianchi et al., 2014) between electrical nominal power (max_η_{elec} 45.5%) and the electrical minimal power P_{min} (min_η_{elec} 41.0%) with the equation min_η_{elec} = max_η_{elec} × 0.9. It is important to note that the electrical minimal power P_{min} (50% of P_{nom}) corresponds to the power under which the CHP shuts down.