Waste Management xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

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

Mesophilic anaerobic digestion of several types of spent livestock bedding in a batch leach-bed reactor: substrate characterization and process performance

S. Riggio [a,c,d], M. Torrijos [a], R. Debord [b], G. Esposito [c], E.D. van Hullebusch [d], 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

ARTICLE INFO

Article history:
Received 11 June 2016
Revised 27 September 2016
Accepted 20 October 2016
Available online xxxx

Keywords:
Spent livestock bedding
Dry anaerobic digestion
Leach-bed reactor
Percolation
Process scale-up

ABSTRACT

Spent animal bedding is a valuable resource for green energy production in rural areas. The properties of six types of spent bedding collected from deep-litter stables, housing either sheeps, goats, horses or cows, were compared and their anaerobic digestion in a batch Leach-Bed Reactor (LBR) was assessed. Spent horse bedding, when compared to all the other types, appeared to differ the most due to a greater amount of straw added to the litter and a more frequent litter change. Total solids content appeared to vary significantly from one bedding type to another, with consequent impact on the methane produced from the raw substrate. However, all the types of spent bedding had similar VS/TS (82.3–88.9)%, a C/N well-suited to anaerobic digestion (20–28, except that of the horse, 42) and their BMPs were in a narrow range (192–239 NmL CH_4/g VS). The anaerobic digestion in each LBR was stable and the pH always remained higher than 6.6 regardless of the type of bedding. In contrast to all the other substrates, spent goat bedding showed a stronger acidification resulting in a methane production lag phase. Finally, spent bedding of different origins reached, on average, (89 ± 11)% of their BMP after 60 days of operation. This means that this waste is well-suited for treatment in LBRs and that this is a promising process to recover energy from dry agricultural waste.

1. Introduction

Dry anaerobic digestion processes have spread widely in the past few years compared to the wet ones due to their advantages in accepting substrates with total solids (TS) higher than 20% (Karthikeyan and Visvanathan, 2012). In countries like France, agriculture and livestock rearing are well developed and the use of primary products (e.g. cereals) as feed for anaerobic digestion (AD) plants is forbidden by national legislation (Assemblée Nationale, 2014). In such a context, manure occupies a dominant position among rural waste. Indeed, the French national audit FranceAgrimer (2012) reported an annual production of about 90 million tonnes of solid manure and 180 million tonnes of slurry.

Thanks to its particular characteristics mainly related to a high nitrogen content and alkalinity, manure have been used in AD for a long time, especially in co-digestion with other substrates. This is also linked to the very tight legislation on manure management because of problems like greenhouse gas emission, nitrogen contamination of water (Smith and Frost, 2000) and nuisance odours (Wilkie, 2000). Manure can vary greatly in relation to its TS, which mainly depends on the farm housing practices. In deep-litter housing systems, bedding is used to absorb excrements and urine, thus creating a solid waste rather than a liquid one (i.e. slurry). Such solid waste is a soiled bedding that accumulates in the stables and which is referred to as spent bedding (Tait et al., 2009) or spent straw if the latter is used for bedding material. In France, where deep-litter housing practices are widely used, 53.8% of the produced spent cow bedding has a TS higher than 18% (Degueurce et al., 2016a) which can in turn support the development of AD processes adapted to their treatment.

One of the AD processes gaining a foothold in the rural context is the Leach-Bed Reactor (LBR) operated in batch mode. In this dry process, the solid substrate is loaded into the reactor, while a liquid

* Corresponding author.
E-mail addresses: silvio.riggio@supagro.inra.fr (S. Riggio), michel.torrijos@supagro.inra.fr (M. Torrijos), romain.debord@naskeo.com (R. Debord), giovanni.esposito@unicas.it (G. Esposito), Eric.vanHullebusch@univ-paris-est.fr (E.D. van Hullebusch), jean-philippe.steyer@supagro.inra.fr (J.P. Steyer), renaud.escudie@supagro.inra.fr (R. Escudié).

http://dx.doi.org/10.1016/j.wasman.2016.10.027
0956-053X/

Nomenclature

AD	anaerobic digestion
BMP	biomethane potential
CHP	combined heat and power
COD	chemical oxygen demand
LBR	Leach-Bed Reactor
RM	raw mass
S/X	substrate VS/inoculum VS
SB_cow	spent cow bedding (SB_cow_g, SB_cow_h and SB_cow_m)
SB_cow_g	spent bedding from cows fed with round bale grass silage (as roughage)
SB_cow_h	spent bedding from cows fed with hay (as roughage)
SB_cow_m	spent bedding from cows fed with maize silage (as roughage)
SB_goat	spent goat bedding
SB_horse	spent horse bedding
SB_sheep	spent sheep bedding
TAN	total ammonia nitrogen
TKN	Total Kjeldahl Nitrogen
TS	total solids
TVFA	total volatile fatty acids
VFA	volatile fatty acid
VS	volatile solids

phase, usually stored in a separate container, is sprinkled over the solid bulk, percolates through it and finally returns to its storage tank. So far, only few authors investigated the digestion of spent animal bedding alone in a LBR (Table 1), with the first example reported 30 years ago by Hall and Hawkes (1985). In literature, the most common spent bedding treated in LBRs mainly originated from cow stables and only a few from horse ones. It is worth noting that very little evidence on the use of spent sheep bedding was reported (Blanco et al., 2010), while nothing regarding spent goat bedding.

Batch LBRs offer several complementarities to animal husbandry and in particular when deep-litter housing practices are implemented. Firstly, being a discontinuous process, it is perfectly suited to the cyclic cleaning of stables, thus allowing the reduction of storage time as well as problems arising from it, such as odour nuisances, soil contamination and the loss of volatile solids (VS) by oxidation (Cui et al., 2011). Secondly, the process accepts undesirables like pebbles or ropes, which are commonly found in farm waste (Møller et al., 2004) and could create operating problems in conventional continuous stirred-tank reactors (CSTRs). Thirdly, thanks to the presence of bedding material, the substrate is characterized by good porosity, which is essential for adequate percolation (Myint and Nirmalakhandan, 2009). Furthermore, the robust and simple LBR design, free of any moving parts, reduces costs related to electro-mechanical spare parts investment and maintenance, making it highly suitable for rural context (Karthikeyan and Visvanathan, 2012). On the other hand, certain problems may originate with this process: an incomplete degradation of the substrate due to bad percolation and compaction (André et al., 2015), an unstable biogas production due to its discontinuous loadings, as well as a difficulty to exploit all the biogas produced due to the low methane content during the first days.

Considering that, in France, spent bedding from animal stables represents the highest fraction of the feed mixture in LBRs at industrial scale, it is important to better understand its characteristics, diversity and putative differences during its digestion for industrial-scale applications. In contrast to manure and straw separately, the properties of spent bedding are scarcely described in the literature. Moreover, spent bedding has to be considered as a substrate on its own since animal mechanical action on the litter and biological degradation during litter accumulation can modify the original properties of straw and animal excrements (Tait et al., 2009). Characterization of spent bedding and variability among different types is crucial to understand the properties of these substrates before loading them into an anaerobic digester. Additionally, it is worth mentioning that the few studies investigating the digestion of spent bedding in LBR operated in different conditions (e.g. inoculation, leachate recycle, etc.), thus hampering a clear and direct comparison of the substrates and their performances in LBRs.

Table 1
Comparative performance of Leach-Bed Reactor (LBR) treating spent livestock bedding or a synthetic mixture of livestock faeces and an external bulking agent.

Substrate	Reactor	Temperature	Batch duration	Methane yield	References
Spent cow straw bedding[a]	LBR	Mesophilic (30 °C)	40 days 70 days	166 L/kg V 215 L/kg V	Hall and Hawkes (1985)
Spent cow straw bedding[a]	LBR	Mesophilic (35 °C)	30 days	114.5 NL/kg VS	Degueurce et al. (2016b)
Spent cow straw bedding[a]	LBR	Mesophilic (37 °C)	32 days	–	André et al. (2015)
Spent cow straw bedding[a]	LBR	–	–	–	Shewani et al. (2015)[d]
Spent cow straw bedding[a]	LBR	Mesophilic (35 °C)	30 days	114.5 NL/kg VS	Degueurce et al. (2016b)
Spent pig/swine straw bedding[a]	LBR	Mesophilic (37 °C)	50 days	Not provided clearly	Yap et al. (2016)
Spent horse straw bedding[a]	LBR	Mesophilic (35 °C)	45 days	170 NL/kg VS	Kusch et al. (2008)
Cow manure (faeces only) + straw[b]	LBR (sequence)	Psychrophilic (20 °C)	84 days (21 days per batch)	147 NL/kg VS	Massé and Saady (2015)
Sheep manure + straw[b]	LBR	Mesophilic (35 °C)	94 days	184 NL/kg VS	Blanco et al. (2010)
Raw manure slurry + pistachios half-shell[b]	LBR	Psychrophilic (22 °C)	–	–	Myint and Nirmalakhandan (2009)
Spent horse softwood-pellet bedding[a]	LBR	Mesophilic (34–36 °C)	57 days	44.8 L/kg VS [c]	Wartell et al. (2012)
Solid phase of raw dairy manure slurry	LBR	Thermophilic (50 °C)	60 days	214–227 L/kg VS	Rico et al. (2015)
Cow manure + wood powder/chips[b]	LBR	Psychrophilic (20–24 °C)	–	Not provided clearly	Demirer and Chen (2008)

[a] Spent bedding: a mixture of excrements and bedding material (straw) directly sampled from the stables.
[b] Synthetic mixture of excrements and bedding/bulking agent.
[c] No adequate conditions for the process.
[d] They studied the percolation through the bed and no biological experiment was carried out on the substrate.

Please cite this article in press as: Riggio, S., et al. Mesophilic anaerobic digestion of several types of spent livestock bedding in a batch leach-bed reactor: substrate characterization and process performance. Waste Management (2016), http://dx.doi.org/10.1016/j.wasman.2016.10.027