Start-up optimization of a batch anaerobic digestor for the treatment of solid cow manure

Silvio Riggio, Michel Torrijos, Romain Debord, Eric D. van Hullebusch, Joaquim Comas, Jean-Philippe Steyer, Renaud R. Escudie

Start-up optimization of a batch anaerobic digestor for the treatment of solid cow manure

S. Riggio*, M. Torrijos*, R. Debord**, G. Esposito***, E.D. van Hullebusch****, J. Comas*****, J.P. Steyer*, R. Escudié*

*INRA, UR0050, Laboratoire de Biotechnologie de l'Environnement, Avenue des Etangs, F-11100 Narbonne, France
(E-mail: *silvio.riggio@supagro.inra.fr; michel.torrijos@supagro.inra.fr; jean-philippe.steyer@supagro.inra.fr; renaud.escudie@supagro.inra.fr*)
** Naskeo Environnement, 52 rue Paul Vaillant Couturier – 92240 Malakoff, France
(E-mail: *romain.debord@naskeo.com*)
***Department of Civil and Mechanical Engineering, University of Cassino and Southern Lazio, Via Di Biasio, 43, 03043 Cassino (FR), Italy
(E-mail*: giovanni.esposito@unicas.it)*
****Université Paris-Est, Laboratoire Géomatériaux et Environnement (LGE), EA 4508, UPEMLV, 77454 Marne-la-Vallée, France
(E-mail: *Eric.vanHullebusch@univ-paris-est.fr*)
*****LEQUIA, Institute of the Environment, University of Girona, Campus Montilivi, E-17071 Girona, Spain
(E-mail: *joaquim.comas@udg.edu*)

Abstract
In dry anaerobic digestors operated in batch mode where a liquid phase is sprinkled on a static solid phase, the choice of a liquid or a solid recycle form a previous batch into a new one is a key factor for a better industrial management when looking for a balance between energy production, substrate biodegradability and the initial investment.
This work aims at studying the influence of this recycling on the kinetics and the performances of three systems filled-up with only solid cow manure. In the first batch the solid fraction (SF) of a previous reactor is recycled in the new system, in the second only the liquid fraction (LF) is recycled while in the third none was used and the system was started only with water (W).
Results show that the use of the LF is a better choice in terms of volumetric methane production, whereas using SF is more useful to improve the kinetics of the process and the VS degradation. In contrast, the third batch shows that an additional inoculation is not absolutely necessary for manure. Indeed, the simple use of water does not conduct to a start-up failure but induces lower global performances.

Keywords
Anaerobic Percolation Biocel Reactors, inoculation, cow manure, dry anaerobic digestion, batch

INTRODUCTION

Anaerobic Percolation Biocel Reactors (APBR) are dry anaerobic digestors functioning in batch mode and filled-up with a solid substrate with a high total solids content (TS). In this kind of reactors, two separated phases co-exist: the solid phase which remains static and the liquid phase which is sprinkled over the top of the solid phase and percolates through the bulk (Brummeler & Horbach, 1991). The start-up phase is a crucial step for the right management of discontinuous anaerobic digestors since the strategy used can influence the overall process. Normally, the start-up of a new batch in APBR is achieved by inoculation with both liquid and solid fractions since the liquid fraction is kept in the system and used for humidification of the raw substrate and a part of the solid fraction is recycled from the previous batch for inoculation. However, the need of both fractions could be questionable in some cases and with particular substrates. Indeed, some previous works demonstrated the possibility to start, without failure, a batch with the organic fraction of municipal solid waste (OFMWS) only recycling a liquid phase (Michele et al., 2015).
Contrary to most of the other substrates, cow manure contain already a methanogenic inoculum population (Solli et al., 2014) since AD process takes place in the digestive system of all ruminants.

As a consequence, in a system using cow manure, the inoculation can be realized by the substrate itself. Kusch et al. (2008) reported the possibility to start-up a digester packed with horse manure through the simple addition of drinking water.

The aim of this study was to elucidate the influence of different start-up strategies on the efficiency of APBR packed with only cow manure in a further goal to improve industrial site management.

MATERIALS AND METHODS

Experimental device

The reactors used were 6 L jacketed glass containers of 14 cm in diameter. The solid and the liquid fractions were separated by a mesh located at the bottom of the reactor and the liquid fraction or leachate was stored in the volume below the mesh. The leachate was recirculated by sprinkling it on the top of the solid bulk thanks to a peristaltic pump connected to a timer. Finally, an exit placed on the top allowed the biogas to pass through a volumetric flow meter before being rejected out of the system. Two ports, one on the liquid and the other on the gas circuits, allowed taking samples.

Substrates and inoculum

The manure used was collected directly from a dairy farm in the South-West of France during the clean-up of a part of the barn. This cleaning operation made it possible to take a representative sample of the entire site. Digestate (Solid Fraction, SF) and leachate (Liquid Fraction, LF) used were collected from a previous experiment treating cow manure in the same experimental system.

Experimental setting

The amount of SF was set based on the results of Kusch et al. (2008). These authors demonstrated an optimal inoculation ratio (digestate / (manure + digestate)) expressed in total solids between 10% and 20%. This ratio is also representative of on-site industrial practices for the management of APBR systems. For the LF, all the leachate from a previous reactor was used. This fraction was completed with drinking water to reach the desired volume of liquid. Three conditions were tested in duplicate for a total of 6 reactors (Table 1) running for 60 days. The total mass added in the reactors was in the range of 3.4-3.6 kg, while the global TS within the reactors was between 9,8% and 11,3%.

Table 1. Experimental set-up - reactors loading

Addition of	Name	Manure	Digestate	Leachate	Drinking water
		kg	kg	L	L
Water (W)	W_1	1.30	-	-	2.28
	W_2	1.32	-	-	2.28
Solid Fraction (SF)	SF_1	0.97	0.33	-	2.10
	SF_2	0.97	0.33	-	2.10
Liquid Fraction (LF)	LF_1	1.30	–	1.69	0.59
	LF_2	1.30	-	1.70	0.58

Analysis

Biogas production was measured with volumetric gas counters (MilliGascounter, Ritter®) while its composition was measured with a micro-GCPRO CP-4900 using helium as gas vector.

Spectroquant kit 0-1,500 mg/L was used to analyse total and soluble COD. VFA were measured with VARIAN I-MET-0084, pH with Mettler Toledo InPro 4260i probes and alkalinity as advised

by Hill and Jenkins (1989). These measurements were performed during the entire experiments.

Characterization of the initial substrate and of the final digestate (were also performed. The TS content was measured after drying at 105 °C for 24 h, followed by 3 h of calcination (550 °C) for VS determination. NTK, Pt, COT and fibers analysis were effectuated but not included in this paper.

RESULTS

Process stability

For the three tested conditions (W, SF or LF), the reactors were stable and no sign of inhibition was detected: pH remained above 6.6 and alkalinity was sufficient to prevent the system from falling into acidification at any time. The lowest pH values corresponded to the respective VFA peaks which stayed within acceptable range (below about 6 g/L). Indeed, APBR is known to reach high concentration in VFA without being inhibited (Brummeler et al., 1992; Massaccesi et al., 2013).

The use of manure as substrate can explain the good stability of the system even when only drinking water was added. In fact, manure is a slowly degradable substrate with an high concentration of nitrogen which provides a good buffering capacity (Zhang et al., 2013). The use of more easily degradable substrates (food wastes, OFMSW) would make the risk of inhibition by acidification a greater issue in this kind of system (Liao et al., 2014; Michele et al., 2015).

Methane production

Since methane is the final and most important AD end-product, total methane production and specific cumulated methane yield (Fig.1a-b) give important information on the system efficiency.

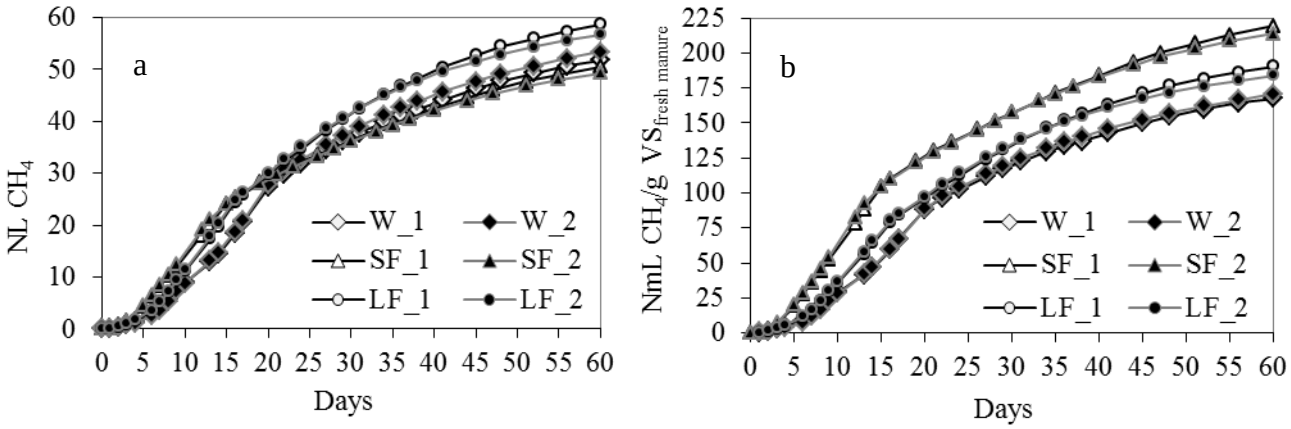

Figure 1. Evolution with time of (a) total CH_4 production - (b) specific CH_4 production expressed on VS basis of fresh sustrate

Methane production of W batches (Fig. 1a) confirmed the fact that AD of cow manure in an APBR system can be performed without any major problem without inoculum. However, despite the same amount of fresh matter was loaded in W and LF batches (Table 1), a slower kinetic and a 9% lower final CH_4 production were obtained, on average, with W batches compared to LF batches. The slightly better performance in kinetics and CH_4 production does not seem to be associated to a microbial effect (low SS concentration of LF) but rather to other properties of the LF like high initial alkalinity, CODt and an environment globally richer in P, N and other ions.

SF batches were loaded with 25% less fresh manure than LF batches (Table 1). This had an evident influence on the final CH_4 volume, which was 13.5% higher for LF compared to SF reactors. Degradation kinetics were slightly higher in SF reactors which could be explained by the consistently higher inoculation brought. However, despite of the different loading strategy, the CH_4 production of SF batches reached the same level than the LF ones at day 17 (Fig. 1a) and was lower

afterwards.

Figure 1b provides information on manure biodegradability in the three experimental conditions. SF reactors have a higher CH_4 specific yield compared to LR and W reactors. This suggests that in two months a higher inoculation allowed the production of more energy on a VS basis of substrate only (This last does not take into account the inoculum).

CONCLUSION

The present experimental study indicates that in an APBR treating manure is worth paying attention to the start-up. Cow manure has been shown not to really need an external inoculation to start an AD process. However, the use of the LF from a previous reactor instead of drinking water seems to have beneficial effect on the total CH_4 production through a combined action of additional inoculation and a richer liquid phase more adapted to bacterial growth. On the other hand, recycling a SF provides a consistent additional inoculation which improves the degradation kinetics and the specific CH_4 production, indicating a better degradation of the substrate. But its use would decrease the amount of fresh substrate treated per cycle and hence the total volume of biogas produced.
From these results it can be concluded that, with cow manure as sole or major substrate, recycling LF is advisable from a volumetric CH_4 production point of view compared to SF inoculation. However, attention should be paid to the accumulation of non-degradable compounds as N which could become inhibitory after a certain number of cycles. On the other hand the incorporation of SF allows accelerating the process and increasing degradation of the added VS as part of the solids are recycled from one batch to the other. This strategy becomes particularly important especially when the fresh substrate has not a proper inoculation already.
Consequently, when designing an APBR, an optimum needs to be found between the specific substrate and its need in external inoculation, the amount and kind of inoculum, the digestion time and the reactor volume.

REFERENCES

Brummeler, E. ten & Horbach, H.C.J.M., 1991. Dry Anaerobic Batch Digestion of the Organic Fraction of Municipal *Solid Waste. J. Chem. Tech. Biotechnol*, **50**, pp.191–209.

Brummeler, E.T., Aarnink, M.M.J., Koster, I.W., 1992. Dry anaerobic digestion of solid organic waste in a biocel reactor at pilot-plant scale. *Water science and technology*, **25**(7), pp.301–310.

Hill and Jenkins, 1989. Measuring alkalinity accurately in aqueous systems containing high organic acid concentrations. Transactions of the ASAE, **32**, pp.2175 – 2178.

Kusch, S., Oechsner, H. & Jungbluth, T., 2008. Biogas production with horse dung in solid-phase digestion systems. *Bioresource Technology*, **99**, pp.1280–1292.

Liao, X. et al., 2014. Anaerobic co-digestion of food waste and landfill leachate in single-phase batch reactors. *Waste management* (New York, N.Y.), **34**(11), pp.2278–84.

Massaccesi, L. et al., 2013. Chemical characterisation of percolate and digestate during the hybrid solid anaerobic digestion batch process. Process Biochemistry, **48**(9), pp.1361–1367.

Michele, P. et al., 2015. Optimization of solid state anaerobic digestion of the OFMSW by digestate recirculation: A new approach. *Waste management* (New York, N.Y.), **35**, pp.111–8.

Solli, L. et al., 2014. A metagenomic study of the microbial communities in four parallel biogas reactors. *Biotechnology for biofuels*, **7**(1), p.146.

Zhang, C. et al., 2013. The anaerobic co-digestion of food waste and cattle manure. *Bioresource technology*, **129**, pp.170–176.