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Post digestion of biogas production residues at mid-range mesophilic temperature

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Abstract
A common way to store digestate from anaerobic digesters is in open air lagoons. The aim of this study was to investigate whether cooling of digestate before transfer to the storage prevents methane production. Furthermore, if methanogenesis is not prevented, to determine the potential maximum methane slip from an open air lagoon, supplied with heat exchanged digestate from a mesophilic co-digestion plant such as Linköping biogas plant. Results indicate that methane production is not terminated by cooling and that a high methane production can occur in open air lagoons if the conditions are advantageous. Furthermore, the results suggest that it can be worthwhile, from both an economical and an environmental point, to replace open air lagoons with closed post-digesting units. At 25 ^{o}C, the methane slip from an open air lagoon could reach as high as 2.6% of the total methane production of a biogas plant, even when the volume of the open air lagoon is only one third of the digesters volume. The combination of low additional cost of production, with significant decrease in release of green house gases to the atmosphere, makes the implementation of post-digestion units at larger biogas plants attractive.

Keywords
Post digestion; low temperature digestion; biofertilizer; methane slip; ammonium

INTRODUCTION

The increasing demand for biogas as a vehicle fuel has led to the expansion of the digester capacity at several biogas plants in Sweden. A common way to store the increasing amount of digestate is in open air lagoons. However, unless aerated, the environment in the lagoons can be expected to be anoxic from very shallow depths. Thus, if methane production proceeds, these type of storages may potentially release large amount of methane which can have adverse effect on climate by adding to the greenhouse effect. A typical process to cease methane production of the digestate at biogas plants is to cool the digestate before it is released to the lagoon. The main purpose of this is to reduce the microbial activity in the digestate and to recover heat. However, mesophlic temperatures ranges from 10-45 ^{o}C and although methane formation decreases with decreasing temperatures, there is an obvious risk of large methane production in open air lagoons even after the digestate has been cooled (Madigan M. *et al*,. 2009; Kettunen R.H. *et al* 1997). Decreasing the temperature of the digestate also serves to reduce ammonia slip from the lagoon, since the equilibrium between ammonia and ammonium is rapidly shifted towards ammonium with decreasing temperatures (Sung Sung *et al.*, 2003; Nordell *et al.*, 2010).

The aim of this study was to investigate whether cooling prevents methane production and to determine the potential maximum methane slip from an open air lagoon, supplied with heat exchanged digestate from a mesophilic co-digestion plant. Since it can have both an economical as well as an environmental value to collect any residual methane potential in the digestate, optimal conditions for methanogensis from the cooled digestate was tested in a laboratory scale post-digester unit. Applied conditions were; completely anaerobic conditions, a constant temperature in the mid part of the mesophilic temperature range (25^{o}C), agitation and a relatively constant hydraulic retention time. Other objectives were to determine what effects a post-digestion process will have on the properties and value of the resulting digestate as a biofertilizer after the post-digestion unit.

MATERIAL AND METHODS

Model plant

The Linköping biogas (LB) plant in the city of Linköping, Sweden, treats a mixture of slaughterhouse and food waste at the mesophilic temperature of 38 ^{o}C (Ek *et al.*, 2011). Through the nature of the substrate and the many process improving techniques implemented at the plant the anaerobic process has proved to be very efficent and normally reach a degree of digestion of approximately 80% (Ek *et al.*, 2011). Furthermore, storage of the digestate (cooled to 20-25 ^{o}C) take place in a open air lagoon. The digestate has very good fertilizer properties and is sold to local farmers as a biofertilizer.

CSTR experiment setup

Two in-house designed laboratory scale completely stirred tank reactors (CSTR) was inoculated and started from the full-scale LB plant. The first treating mixed slaughterhouse waste (digester 1) and the second (digester 2) treating the digestate from digester 1. The size ratio 3:1 between digester 1 (10 L) and digester 2 (3.3 L) was in accordance with the actual ratios between digester and digestate lagoon at the full-scale LB plant. Digester 1 was to the greatest extent treated in accordance to the full-scale LB plant; the same average organic loading rate (3.5 g VS $L^{-1}d^{-1}$) and same hydraulic retention time (40-55 days) was applied at mesophilic conditions (38 ^{o}C). The OLR was fixed and the HRT was allowed to vary with the organic content of the substrate. The mixed slaughterhouse waste (substrate) was a pasteurized (70 °C) mixture of slaughterhouse waste and food waste in 7:3 a ratio. Fresh substrate was collected weekly from the full-scale plant and stored in refrigerator before use. The average properties of the substrate were as follows: total dry solids 17.6 % and volatile solids 93 %. Digester 2 (post-digestion unit) was set to the optimal conditions for methanogensis that could possibly occur in the open air lagoon at the LB site; temperature at the mid mesophilic range (25 ^{o}C) and a semi-continuous supply of digestate at total anaerobic environment in an agitated tank. Both digesters were fed on a daily basis. In order to avoid that fresh substrate entered digester 2, digestate from digester 1 was withdrawn and transferred to digester 2 before digester 1 was supplied with new substrate. A start-up period of 12 days was applied to gradually increase the OLR from 2.0 to 3.5 g VS $L^{-1}d^{-1}$. The experiment was ended after 117 days. Both reactors were connected to an on-line system (BacVis, blueSense GmbH, Germany) for monitoring of total gas production (MGC-10, Ritter, Germany) and methane concentration with BlueSens gas sensor system (blueSens GmbH, Germany).

Process and digestate analyses

Parameters that was monitored in both CSTRs to assess the general process stability was; volatile fatty acids (VFA), pH, alkalinity, total dry solids (TS), volatile solids (VS) and ammonium. FA was measured with GC-FID (Clarus 500, Perkin-Elmer), column: Perking Elmer Elite-FFAP (Perkin-Elmer, USA). Ammonium-nitrogen was analyzed according to FOSS Tecators application sub note 3502 with a Kjeltec 8200 (FOSS in Scandinavia, Sweden). The total organic nitrogen, Kjeldhal-nitrogen was analyzed according to Tecators AN 300 Sv 1999-04-09 v. 2 with a Kjeltec 8200 (FOSS in Scandinavia, Sweden). pH was measured according to SS-EN 12176 with the pH electrode WTW Inolab pH Level 2 (Weilheim, Germany). Alkalinity was measured with a hydrochloride acid titration method according to guidelines in SS-EN ISO9963. Total solids and volatile solids were analyzed according to Swedish Standard SS 028113 - issue 1 of 1981-05-20.
Degree of degradation (DD) was calculated according to equation 1.

Equation (1)
$$DD = 1 - \frac{V_{outlet} \times TS_{Digester} \times VS_{Digester}}{V_{inlet} \times TS_{substrate} \times VS_{substrate}}$$

RESULTS AND DISCUSSION

Within the start-up period, digester 2 was greatly disturbed by the temperature change from 38 ^{o}C to 25 ^{o}C and volatile fatty acid concentrations of up to 3 g/L was determined. However, from day 15 and onwards, the volatile fatty acids concentration was at not significant toxic levels (<0.5 g/L). In digester 1, volatile fatty acid concentrations was pending during the experiment but was at average 0.7 g/L. The average total biogas production in the digesters is illustrated in figure 1. The start-up period of 12 days has been excluded from the calculations and the graph. The average biogas production was 24 L/day in digester 1 and 0.57 L/day in digester 2 (table 1). At the same time, the methane concentration in digester 2 was stabilized at 74 %, which is significantly higher than the average methane content in digester 1 (68 %). Thus, the methane production in digester 2 corresponds to 2.6 % of the methane production in digester 1.

The significantly higher methane concentration in the biogas produced from digester 2 indicates a high methanogenic activity in the digester. High methane concentration is often acquired from the degradation of primary fermentation products such as volatile fatty acids. As figure 1 show, the concentration of VFA in the digestate of digester 1, which is transferred to digester 2, correlates well with the gas production in digester 2. Notably, when high amounts of VFA occur in digester 1, the gas production was increased the following days in the post-digestion unit digester 2 (fig. 1). Thus, the excess VFA from digester 1 are consumed in digester 2 and the VFA in the post-digester is thus consistently low. Furthermore, the free ammonium concentration in digester 2 was 16 % higher than in digester 1 (table 1). This suggests that there is also a continuous degradation of nitrogen rich organic compounds. A feasible explanation to this is that slaughter house waste contains degradation recalcitrant proteinasceous substances that has not been degraded in digester 1 and that this degradation proceeds in digester 2. It is well known that degradation of proteins theoretically provides high methane content, which can also explain the increased methane concentration in the biogas produced in digester 2.

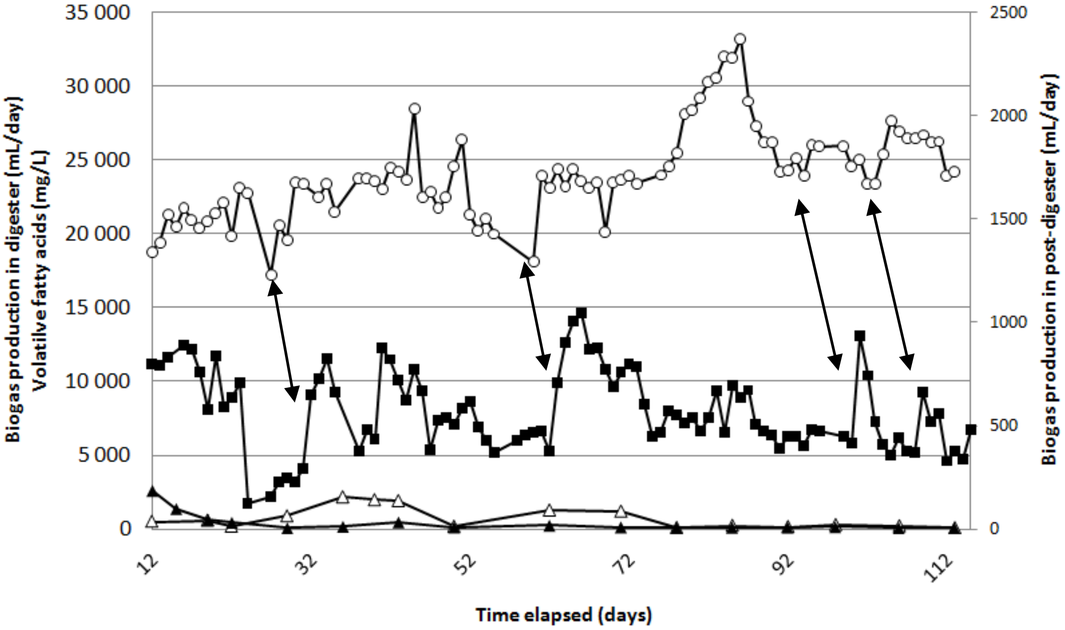

Figure 1. Biogas production in digester 1 (○); VFA in digester 1 (Δ); biogas production in digester 2 (■) and VFA in digester 2 (▲). Slanted arrows indicate correlations between high VFA and/or low gas production in digester 1 and the subsequent increased gas production in digester 2.

The degree of degradation was 77 % in digester 1 and 15 % in digester 2. Calculated over the entire unit, from substrate inlet of digester 1 to digestate outlet from digester 2, the degree of degradation increased from 77% to 81 %.

Table 1. Values of monitored process parameters.

		Digester 1		Digester 2 (post digester)	
	unit	Average	Std.	Average	Std.
TS	%	5.9	0.2	5.2 [A]	0.2 [A]
VS	% of TS	71	3	69	2
Gas production	$L\ d^{-1}$	24.1	3.1	0.57	0.19
Methane content	%	68	1	74[A]	2[A]
Ammonium	g/kg	5.1	0.2	5.9[B]	0.1[B]
Kjeldhal-nitrogen	g/kg	9.2	0.3	9.2[B]	0.3[B]
OLR	$g\ VS\ L^{-1}d^{-1}$	3.5	0	1.7	1.0
HRT	days	48	5	29	9
pH		8.2	0.1	8.1	0.2
Alkalinity	$g\ CO_3^-$ eq./L	23	0.5	26 [A]	1.8 [A]

A: Day 0-40 excluded due to dilution effects derived from the start-up inoculum. B: Average values between day 85 to 114. C: Automatic temperature regulation at 38 ^{o}C, temperature not measured separately.

The results indicate that a high methane production can occur in open air lagoons if the conditions are advantageous, even though the digestate has been cooled. At 25 ^{o}C, the methane slip from an open air lagoon could reach as high as 2.6% of the total methane production of a biogas plant. What is more is that this level was reached despite that the post-digesting unit was coupled to a biogas plant with a high degree of degradation, had only one third of the volume and thus only one third of the average retention time of the biogas plant. These may not be considered to be dramatic volumes, but for larger biogas plants this represents biogas of considerable economic value, which could be collected with no or very little energy input (no additional substrate and no heating). Furthermore, with a global warming potential over 20 years (GWP_{20}) of 72 for methane, collecting the methane in a controlled manner would reduce the environmental burden from green house gases. As a positive side effect the concentration of ammonium nitrogen in the digestate from the post-digester increased, which will in turn increase the digestate value as a bio-fertilizer.

CONCLUSION

The results suggest that it can be worthwhile, from both an economical and an environmental point, to replace open air lagoons with closed post-digesting units. The combination of low additional cost of production, with significant decrease in release of green house gases to the atmosphere, makes the implementation of post-digestion units at larger biogas plants attractive.

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REFERENCES

Ek A., Hallin S., Vallin L., Schnürer A., Karlsson M. (2011). Slaughterhouse waste co-digestion - Experiences from 15 years of full-scale operation. World Renewable Energy Congress 2011 – Sweden. Accepted conference paper.

Kettunen, R.H., Rintala, J.A. (1997). The effect of low temperature (5-29 °C) and adaptation on the methanogenic activity of biomass. Applied Microbiology and Biotechnology 48 (4), pp. 570-576.

Madigan M., Martinko J., Dunlap P., Clark D. (2009). Brock Biology of Microorganism 12. Chap. 6 Microbial Growth., 12, pp. 159.

Nordell E., Hallin S., Johansson M., Karlsson M. (2010). Venice, Italy : s.n., 2010. Third International Symposium on Energy from Biomass and Waste. ISBN 978-88-6265-008-3.01.

Sung S., Liu T. (2003). Ammonia inhibition on thermophilic anaerobic digestion. Chemosphere 51 (1), pp. 43-52.