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Research Paper

The effects of storage time and temperature on biogas production from dairy cow slurry

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ARTICLE INFO

Article history:
Received 15 April 2014
Received in revised form
14 September 2014
Accepted 17 September 2014
Published online 10 October 2014

Keywords:
Biogas
Methane
Anaerobic digestion
Cattle slurry
Storage conditions

The effects of length of storage time and storage temperature on subsequent biogas production from dairy cow slurry by anaerobic digestion were investigated. Slurry was stored under anaerobic conditions at 9 °C and 20 °C for between 1 and 26 weeks prior to digestion. Digestion was carried out in 7 l continuously stirred tank reactors, with an average hydraulic retention time of 25 d. Storage of slurry at 9 °C had no significant effect on subsequent biogas production. However, after 8 weeks of storage at 20 °C there was an increasing negative impact on subsequent biogas production so that after 26 weeks of storage at 20 °C biogas production had decreased from 16.4 $m^3\ t^{-1}$ to 5 $m^3\ t^{-1}$ of fresh slurry. This reduction was strongly related to the decrease in the concentration of volatile solids in the stored slurry which was approximately 0.4 g kg^{-1} $week^{-1}$. Storage time and temperature had no affect on the total nitrogen concentrations in the slurries, though both factors resulted in small increases in ammonia nitrogen concentrations.

1. Introduction

Anaerobic digestion (AD) of organic material produces biogas which when used as a fuel offers more than 80% savings in greenhouse gas emissions in comparison to diesel (EU, 2009). In particular, the AD of animal slurries can reduce the emission of greenhouse gases, especially methane, which may otherwise be released to the atmosphere (Amon, Kryvoruchko, Amon, & Zechmeister-Boltenstern, 2006). In Northern Ireland there is increasing interest in developing AD plants, with agricultural based materials (manures and grass silage) as the main feedstock. This interest is largely due to government incentives designed to encourage electricity production from renewable sources. Farmland in Northern Ireland is predominantly grass based, with grazed grass and grass silage being used as feedstock for ruminant livestock. The grazing period for these animals is normally from April to October. During the remainder of the year ruminant animals are normally housed and the excreta produced are usually stored as liquid slurries. These slurries are normally recycled during the growing season back to grassland as organic fertilisers. In Northern Ireland ruminant slurries account for approximately 88% of the 9.8 million tonnes of manures produced by housed livestock annually (Frost, 2005). Therefore, ruminant slurry is a major potential feedstock for on-farm anaerobic digesters in Northern Ireland. When ruminant animals are grazing there is no collection of excreta and as a result there is no fresh slurry feedstock available for AD. In these circumstances digester performance can be sustained

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http://dx.doi.org/10.1016/j.biosystemseng.2014.09.008
1537-5110/

Nomenclature

AD	anaerobic digestion
B_0	maximum methane potential per kg of volatile solids
BMP	biochemical methane potential
CSTR	continuously stirred tank reactor
FID	flame ionisation detector
GLC	gas–liquid chromatography
HRT	hydraulic retention time
IPCC	Intergovernmental Panel on Climate Change
MCF	methane conversion factor
NH_3-N	ammonia nitrogen
NH_4-N	ammonium nitrogen
PSS	programmed-temperature split/splitless
R^2	coefficient of determination
SD	standard deviation
SMY	specific methane yield
TKN	Total Kjeldahl nitrogen
TS	total solids
VFA	volatile fatty acid
VS	volatile solids

during the summer either by using alternative feedstock or/and by retaining some of the slurry produced during winter for use as feedstock during the summer.

It is well established that breakdown of organic matter in slurry stores increases with temperature and length of storage period. Steed and Hashimoto (1994) found that the biochemical methane potential (BMP) of cattle slurry stored for 5 months at 10 °C was virtually unchanged, whereas the BMP of the same slurry stored for a similar time at 20 °C had been reduced by up to 55%. Moller, Sommer, and Ahring (2004a, 2014b) found that the reduction in BMP of slurry stored for 90 days was strongly influenced by storage temperature (15–20 °C). Sommer, Petersen, Sørensen, Poulsen, and Møller (2007) concluded that carbon emissions from stored slurry were strongly influenced by time and storage temperatures between 10 and 20 °C. A number of studies have been carried out to measure gaseous emissions from slurry stores and formulate possible mitigation strategies (Amon et al., 2006; Clemens & Ahlgrimm, 2001; Sneath, Beline, Hilhorst, & Peu, 2006). However, little information is available on the effects of storage temperature and length of storage on subsequent biogas yields in a continuously stirred tank reactor (CSTR). CSTRs are commonly employed for digesting liquid manures, often in conjunction with energy crops to enhance biogas production. In Northern Ireland, temperatures of 9 °C for slurry stored in below ground tanks during winter are considered by the authors to be typical of the region (based on observed data). However, in above ground stores during summer, it is suggested by the authors that slurry temperatures of up to 20 °C could be possible, depending upon factors such as ambient temperature and surface area to volume ratio of the store. The current experiment was carried out to determine the effects of length of storage period and storage temperature on subsequent production of biogas by AD from dairy cow slurry.

2. Materials and methods

2.1. *Slurry sampling*

The experiment consisted of two replicates of dairy cow slurry, stored at two temperatures, 9 °C (treatment T9) and 20 °C (treatment T20), for different time periods of between 1 and 26 weeks. The slurries used in the experiment originated from underground tanks in slatted dairy cow housing at the Agri-Food and Biosciences Institute, Northern Ireland. A vacuum tanker was used to transfer these slurries to an above ground slurry tank (200 m^3 capacity). The tank contents were thoroughly mixed with a submerged propeller mixer, prior to pumping through a macerator (designed to reduce particle size to 12 mm) and collection in 25 l screw top containers. The containers were stored at 6 °C, before being randomly assigned to treatment T9 or treatment T20. This process was repeated 1 week later to obtain slurry for the second replicate. Slurries for each replicate were less than two weeks old at the time of collection. Slurries in the containers for treatment T9 were stored at 9 °C in a thermostatically controlled 500 l capacity refrigerator prior to digestion. Slurries in containers for treatment T20 were stored at 20 °C prior to digestion in a thermostatically controlled 300 l water bath. Each container for treatment T20 was fitted with an airlock on its screw lid. Containers for slurries stored on treatment T9 were sealed with the screw lid. Each 25 l container was initially filled close to maximum capacity to favour anaerobic storage conditions as slurry stored in the zone below the surface layer naturally becomes anaerobic (Cooper & Cornforth, 1978). The headspace conditions in the current experiments sought to imitate headspace conditions in farm-based covered slurry storage tanks. The temperature treatments were applied to the slurries for 1 week prior to the start of the anaerobic digestion experiment.

2.2. *Laboratory digesters*

The laboratory digesters (Greenfinch Ltd, Ludlow, Shropshire, UK) were stainless steel cylinders with a 2 mm wall thickness (200 mm diameter × 240 mm high), with a 5 mm thick clear acrylic plastic top and a working volume of 6.8 l. The digesters were maintained by thermostatic control at 37 °C, with a standard deviation (SD) of 1 °C, via 240 V electrical heating elements mounted around the outside of each digester. The sides of each digester cylinder were insulated with 10 mm rock wool with an aluminium foil outer membrane. Mixing of digester contents was via a central shaft rotating a vertically orientated paddle at 29 rpm for 20 s of mixing every 10 min. Digestate was removed from the digesters once per day through a 30 mm diameter valve fitted approximately 20 mm above the base of the digester. Feeding was carried out once per day after digestate removal via a 20 mm diameter port on the top of the digester that extended approximately 100 mm below the digestate level. The feeding port was sealed with a rubber bung when not in use. The digesters were fed 6 d out of 7, to maintain a nominal mean hydraulic retention time of 25 d. Biogas was collected from the top of each digester via an 8 mm outside diameter pipe fitted to an 8 mm internal