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Research Paper

Flexible biogas production by pulse feeding maize silage or briquetted meadow grass into continuous stirred tank reactors

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The flexible production of biogas by the pulse feeding of maize silage and briquetted meadow grass was investigated using laboratory and pilot scale continuous stirred tank reactors. Results show that pulse feeding can elevate biogas production in the short term, with the maize silage presenting greater flexibility compared to briquetted meadow grass at both laboratory and pilot scales. The cumulative biogas yield when feeding with maize silage significantly enhanced the yield by 130% within 24 h, with the yield gradually decreasing over 2 days but kept producing at least 20% more gas than the control during the following 4 days. By contrast, pulse feeding of briquetted meadow grass enhanced the biogas production by 30–32% at days 1 and 2 then decreased to a value similar to that measured before the pulse feeding.

1. Introduction

As the result of greenhouse gas emission reduction policies, renewable energy sources, such as wind, geothermal, solar, biomass and incinerated waste, are likely to become major contributors to the energy transition occurring in Europe (EEA, 2017). Scenarios developed by the EU predict the renewable energy share of gross energy production to be between 55 and 97% by the year 2050 (Union, 2014). In Denmark, for example, electricity generated from renewables already accounted for 56.0% of Danish domestic electricity supply in 2015, of which the largest contribution (41.8%) came from wind power (Energy Statistics 2015, Danish Energy Agency). As outlined by Steinke, Wolfrum, and Hoffmann (2013), energy supplements, mainly coming from unpredictable sources such as solar or wind energy, will pose challenges for grid stability and there is a need to counterbalance the intermittent power supply produced by these sources.

Biogas plants enable power to be generated in a flexible way so that variable, renewable energy sources can be

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Nomenclature

Symbols

B	Cumulative methane yield (ml [CH_4] g^{-1} [VS])
B_0	Maximum or ultimate methane yield (ml [CH_4] g^{-1} [VS])
k	Degradation constant/Hydrolysis rate (d^{-1})

Abbreviations

AD	Anaerobic digestion
ADF	Acid detergent fibre
ADL	Acid detergent lignin
BMP	Ultimate CH_4 potential
BMG	Briquetted meadow grass
CM	Cattle manure
CSTR	Continuously stirred tank reactor
HRT	Hydraulic retention time
MG	Meadow grass
MS	Maize silage
NDF	Neutral detergent fibre
OLR	Organic loading rate
SMY	Specific methane yield
TAN	Total ammonia nitrogen
TCD	Thermal conductivity detector
TS	Total solids
VFA	Volatile fatty acids
VS	Volatile solids

integrated into the energy supply system (Hahn, Krautkremer, Hartmann, & Wachendorf, 2014; Lemmer & Krümpel, 2017; Mulat et al., 2016). It is possible to regulate biogas production through varying substrate mass addition, feeding intervals or types of substrates at times used when balancing of electrical power is required. It follows that reduced biogas production during periods when energy demand is low is necessary to avoid large extension of gas storage capacity at the power generation site (Hahn et al., 2014). However, as a biological conversion process, for optimum production is important to maintain a constant feeding pattern to ensure stable performance. Alteration of substrates or organic loading rate (OLR) may cause process disturbance or even digester failure (Ward, Hobbs, Holliman, & Jones, 2008). Currently, several studies focussing on flexible or demand-regulating biogas production have been published. Mauky, Jacobi, Liebetrau, and Nelles (2015) demonstrated highly flexible biogas production by regulating the feeding strategies with various substrates which did not have negative effects on stability. Mulat et al. (2016) reported flexible biogas production by changing feeding regimes, where both higher methane yield and stability were obtained. They also reported on a full-scale study and studied the variable production rates of up to 50% gas production achieved through feeding management (Mauky et al., 2017). Although many published works focus on flexible biogas production, it is clear that questions still exist over the process. The flexibility of biogas production is influenced by many factors such as the temperature, feeding substrates, initial loading rate and applied feeding strategies (Golkowska, Sibisi-Beierlein, & Greger, 2012; Laperrière et al., 2017; Terboven, Ramm, & Herrmann, 2017). Compared to the mesophilic temperature, the thermophilic processes normally has advantages such as higher methane yield, lower retention time, but it has a higher risk of system failure in response to a change of environmental conditions or the accumulation of inhibitory substances (Labatut, Angenent, & Scott, 2014; Qian et al., 2017; Shi, Wang, Stiverson, Yu, & Li, 2013). The substrates for biogas production can be characterised by the content of major chemical components (lipids, proteins and carbohydrates, the latter including fibres such as cellulose, hemicellulose and lignin) which determine both gas yields and rate of production. For instance, a rapid feeding response can be achieved when feeding easily degradable substrates, such as maize silage (MS) (Lv et al., 2014). The use of slowly degradable substrates in combination with pre-treatments to enhance the accessibility to microbes may be also feasible and they could lead to rapid degradation (Gupta, Shekhar Singh, Sachan, Vidyarthi, & Gupta, 2012).

In this study, the effect of pulse feeding on flexible biogas production was investigated using both laboratory-scale and pilot-scale continuous stirred tank reactors (CSTRs). MS and briquetted meadow grass (BMG) were chosen as two representative substrates characterised, respectively, by their easy or slow degradation during the AD process. The main objectives of the work presented here were to investigate flexible biogas production at different scales for the two substrates and evaluate their short and long-term stability after pulse feeding via the variant parameters (pH, CH_4 content and volatile fatty acids (VFAs)).

2. Materials and methods

2.1. Substrates

Cattle manure (CM) was obtained from Aarhus University Foulum, Tjele, Denmark and meadow grass was harvested from a meadow near Ribe, West Jutland, Denmark. The harvested meadow grass was left in the field and dried naturally for three days before collection. The dominant species in the meadow grass were: *Phalaris arundinacea* (80%), *Holcus lanatus* (10%) and *Glyceria fluitans* (5%). The meadow grass was firstly hammer-milled through a 20-mm sieve (Cormall HDH770, Denmark) and then briquetted with a BP 6500 briquetting unit (CF Nielsen, 9574 Bælum, Denmark) before being used for the experiment. MS was obtained from the biogas plant at Aarhus University Foulum, Tjele, Denmark, which is stored for regular feeding to a full-scale anaerobic digester. The maize was chopped to 9–15 mm prior to ensiling.

2.2. Batch test experiment

The batch tests were carried out following procedures suggested by Feng, Wahid, Ward, and Møller (2017) to determine the ultimate CH_4 potential (BMP) of CM, MS and BMG. Each bottle was filled with 200 ml of inoculum and substrate corresponding to an inoculum-substrate ratio of approximately 1:1, based on volatile solid (VS) content. A control with only inoculum was included as a blind reference. All bottles were