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Research Paper

Anaerobic digestion of pig manure fibres from commercial pig slurry separation units

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The composition of manure fibres (MF) from 17 commercially separated pig slurries and seven raw pig slurries were characterised in terms of dry matter (DM), volatile solids (VS), protein, hemicellulose, cellulose and lignin. The average lignocellulose concentration in manure fibres and pig slurries was 790 and 370 g kg^{-1} [VS] respectively. Biochemical methane potential was ascertained after 60 days, revealing a trend in biochemical methane potential between the different separation technologies used: pig slurry > shaking filter and screw press combined ≈ decanter centrifuge > flocculation, belt and screw press combined ≈ screw press. The maximum methane yield of manure fibres from decanter centrifuges and the combined shaking filter and screw press was approximately 330 l [CH_4] kg^{-1} [VS] at standard temperature and pressure (STP), while manure fibres from a screw press and a combination of belt press and screw press on average produced approximately 220 l [CH_4] kg^{-1} [VS]. Initial methane production can be described using a first-order kinetic model. The average rate constant for manure fibres was 0.030 d^{-1} and for pig slurry 0.071 d^{-1}, showing that pig slurry is digested much faster than manure fibres.

1. Introduction

In the face of the growing requirements for renewable energy, and the issue of global warming, animal manure has become an area of interest in sustainable energy production as well as in the reduction of greenhouse gas (GHG) emissions through anaerobic digestion (AD). Hamelin, Wesnæs, Wenzel, and Petersen (2011) reported that biogas production from animal slurry is the most socio-economic and cost-efficient technology for reducing GHG emissions and for recycling plant nutrients. The European Commission has set mandatory national targets with the aim of obtaining 20% of its energy from renewable sources by 2020 (EREC, 2010). The Danish government has therefore set a target of 40% of animal slurry being used for anaerobic digestion by 2020 (Green growth, 2009). As dry matter (DM) typically makes up 1–10% of animal slurry content (Thygesen Triolo, & Sommer, 2012), biogas production from animal slurry alone is not economically viable (Møller, Jensen, Tobiasen, & Hansen, 2007; Triolo, Pedersen, Qu, & Sommer, 2012), hence the co-digestion of animal slurry with organic industrial waste has been a widespread practice in

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Nomenclature

A	Sulphuric acid addition
AD	Anaerobic digestion
ADF	Acid detergent fibre
ADL	Acid detergent lignin
B_0	Maximum value of BMP, l [CH_4] kg^{-1}[VS] at STP
B_t	Cumulative methane yield at time t, l [CH_4] kg^{-1}[VS] at STP
BMP	Biochemical methane potential, l [CH_4] kg^{-1}[VS] at STP
BMP_x	Biochemical methane potential after x days, l [CH_4] kg^{-1}[VS] at STP
BP	Belt press
DC	Decanter centrifuge
DM	Dry matter, g kg^{-1}
GHG	Greenhouse gas
k	First-order kinetic constant, d^{-1}
MF	Manure fibre
NDF	Neutral detergent fibre
NL	Normal litre
PAM	Polyacrylamide
SF	Shaking filter
SP	Screw press
STP	Standard temperature and pressure, 0 °C and 100 kPa
t	Time, d
TAN	Total ammoniacal nitrogen, g kg^{-1}
TKN	Total Kjeldahl nitrogen, g kg^{-1}
VS	Volatile solids, g kg^{-1} [DM]

Denmark. However, the limited availability of the co-substrates that are currently used has been a limiting factor in the increase of biogas production from animal slurry. As a result, there is on-going research into sustainable alternative co-substrates. First generation bio-fuel production from primary food sources is not considered sustainable since it may require additional land use impacting on habitats and ecosystems, and exacerbating food insecurity (Hensgen, Richter, & Wachendorf, 2011). However, second generation technologies using cheap and unutilised lignocellulosic materials are potentially more cost effective when commercialised (Naik, Goud, Rout, & Dalai, 2010). In Denmark, 90,000 t of manure fibres are produced annually from separation, corresponding to 3% of annual animal slurry production (Birkmose & Thygesen, 2010). Co-digestion of the main substrate with manure fibre produced by separation technology could be an alternative second generation feedstock, with the potential to increase methane yield through concentration of the main feedstock. However, knowledge regarding manure fibres used in biogas production is limited and very few studies have been published that focus on optimising the AD of manure fibres (Møller et al., 2007; Sommer et al., 2014; Sutaryo, Ward, & Møller, 2013). This study investigates biochemical methane potential (BMP) and refractory carbon pools of manure fibres from full-scale separation currently in operation on Danish farms. Methane production was measured for one year, considerably extending the time span of the current BMP protocol, VDI 4630 (VDI, 2006), owing to the slow bioconversion of refractory pools of manure fibres. Van Soest's characterisation (Goering & Van Soest, 1970; Van Soest, 1963) and a kinetic analysis of the methane production rate were performed to study the anaerobic digestibility of manure fibres.

2. Materials and methods

2.1. Collection of biomass samples

The dry matter-rich fractions of the separated pig slurry (manure fibres, MF) used in the study were collected between the months of April and June 2010 from 17 commercial separation plants located at Danish farms; these plants comprise 50% of the separation plants currently operating in Denmark (Birkmose & Thygesen, 2010). The manure fibres were collected 0–8 weeks after separation. At six of the separation plants, polyacrylamide (PAM) polymer was added as a flocculent during separation (Table 1). Pig slurries were obtained from seven Danish farms.

The separated dry matter-rich fractions were sampled at the outlet of the separator by collecting five subsamples with a total volume of 8–10 l. The samples were stored in airtight plastic containers during transportation to the laboratory. All samples were homogenised and frozen at −18 °C upon arrival at the laboratory.

2.2. BMP assay

The methane production of each manure fibre and pig slurry sample was determined using a batch laboratory scale digester with a working volume of 1 l. The fermentation was conducted in accordance with standard VDI 4630 (VDI, 2006), which corresponded to batch fermentation for approximately 60 d, except for the fermentation of MF which continued for one year. The methane production rate and final methane production were compared. To compare the production rates, first-order kinetics, widely-used kinetic model in AD, was used since the cumulative methane curves follow first-order kinetics where the hydrolysis process is the rate limiting process (Batstone et al., 2002; Myint, Nirmalakhandanb, & Speecec, 2007).

Mesophilic inoculum was obtained from the Fangel biogas plant in Denmark which operates at 37 °C and is fed a mixture of approximately 80% animal slurry and 20% organic industrial waste. The collected inoculum was degassed for 14 d at 37 °C. The pH of the inoculum and DM were 8.1 and 44.1 g kg^{-1} respectively. The volatile solids (VS) concentration in the DM was 57%. The average methane concentration in biogas released from the inoculum was 64%. Each reactor was flushed with nitrogen gas to ensure an anaerobic atmosphere. All assays were performed in triplicate. Digestion was carried out under mesophilic conditions at 37 °C. During a working day, each reactor was mixed by hand shaking. The volumes of gas were corrected to standard temperature and pressure