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Research Paper

The efficiency of shredded and briquetted wheat straw in anaerobic co-digestion with dairy cattle manure

Cristiane A.N. Xavier [a,*], *Verónica Moset* [a], *Radziah Wahid* [a,b], *Henrik B. Møller* [a]

[a] *Aarhus University, Department of Engineering, Blichers Allé 20, DK 8830 Foulum Tjele, Denmark*
[b] *Universiti Teknologi Mara, Faculty of Chemical Engineering, 40450 Shah Alam, Malaysia*

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Anaerobic co-digestion of cattle manure (CM) with shredded or briquetted wheat straw (SS and BS, respectively) was evaluated in thermophilic continuously stirred tank reactors (CSTR) in two experiments (lab and full-scale). Three lab-scale CSTR (15 l) were used with 20 days hydraulic retention time (HRT); one was fed with CM and the other two with mixtures of CM (95% of fresh matter, FM) and SS or BS (5% FM). In the second experiment, two full-scale CSTR (30 m^3) were operated with 25 days HRT; one reactor was fed with CM and the other with CM + BS (9% FM). Ultimate CH_4 yield was analysed from each substrate. Biochemical CH_4 potential at 21 days for CM, SS and BS were 128; 187 and 200 l_{STP} $[CH_4]$ kg^{-1} [VS]. Anaerobic digestion of CM, CM + SS and CM + BS in lab-scale reactors yielded 165; 214 and 217 l_{STP} $[CH_4]$ kg^{-1} [VS]. In full scale-reactors, CM and CM + BS yielded 264 and 351 l_{STP} $[CH_4]$ kg^{-1} [VS]. Increments of 31 and 33% on CH_4 yield were achieved in CM + BS compared to CM in lab and full-scale reactors, respectively. Regarding the energy balance, the energy yields were the same for both reactors using straw as co-substrate (CM + SS and CM + BS) after subtracting the energy consumption of the pretreatment, corresponding to 1100 kWh of net energy output. However, briquetting technology could be advantageous for biogas plants where the straw might be transported over longer distances, due to reduction of the transportation costs.

1. Introduction

Anaerobic digestion is an interesting treatment for animal manure, not only because it can decrease the associated methane (CH_4) emission to the atmosphere, but also because the biogas produced can be used as renewable energy source (Sommer, Petersen, & Møller, 2004). However, anaerobic digestion using only animal manure produces a low CH_4 yield (Asam et al., 2011; Biswas, Ahring, & Uellendahl, 2012; Hamelin, Wesnæs, Wenzel, & Petersen, 2011). In order to

* *Corresponding author*. Present address: Animal Science, Federal University of Mato Grosso do Sul, Avenue Senador Filinto Müller, 2443, 79070-900 Campo Grande, Brazil. Tel.: +55 67 3345 3645.
E-mail addresses: crisanx@yahoo.com.br, crisanx@hotmail.com (C.A.N. Xavier).
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Nomenclature

ADF	acid detergent fibre
ADL	acid detergent lignin
BMP	biochemical methane potential
BS	briquetted wheat straw
C:N ratio	carbon:nitrogen ratio
CM	cattle manure
CM + BS	reactor fed with cattle manure and briquetted wheat straw
CM + SS	reactor fed with cattle manure and shredded wheat straw
CO_2	carbon dioxide
CSTR	continuously stirred tank reactor
°C	temperature unit (Celsius)
DM	dry matter
HRT	hydraulic retention time
H_2S	hydrogen sulfide
kWh N m^{-3}	kilowatt-hour of energy per volume (m^3) of methane
l_{STP} CH_4	volume of methane (l) corrected for standard condition of temperature and pressure
SS	shredded wheat straw
NDF	neutral detergent fibre
ppm	parts per million by volume
$P < 0.01$	significance level
R_{straw}	percentage of straw (weight, weight)
TAN	total ammonia nitrogen
TKN	total Kjeldahl nitrogen
V_{CH4_CM}	volumetric methane yield of cattle manure
V_{CH4_mix}	volumetric methane yield of cattle manure and straw
V_{CH4_straw}	volumetric methane yield of straw
VFA	volatile fatty acid
VS	volatile solids

make this technology more attractive to farmers, an increase in CH_4 yield can be achieved by co-digesting animal manure with inexpensive and easy accessible agricultural by-products. Co-digestion, a process where two or more substrates are used together in a single anaerobic reactor, provides numerous advantages. Indeed, this process not only improves methane production, alkalinity and carbon to nitrogen ratio, but also promotes dilution of inhibitory compounds, and increases microbial diversity (García-Gen, Lema, & Rodríguez, 2013; Giuliano, Bolzonella, Pavan, Cavinato, & Cecchi, 2013; Wang, Yang, Feng, Ren, & Han, 2012).

Wheat straw is the most abundant crop by-product in Europe and the second in the world (Ferreira, Donoso-Bravo, Nilsen, Fernandez-Polanco, & Pérez-Elvira, 2013; Kim & Dale, 2004). However, due to its high lignocellulosic content, this by-product presents a low biodegradation degree (Pohl, Heeg, & Mumme, 2013). In addition, the low bulk density of the wheat straw greatly increases the cost of handling, transportation (Theerarattananoon et al., 2012), and storage (Rijal, Igathinathane, Karki, Yu, & Pryor, 2012). Briquetting and pelletising are the two potential processes that can increase biomass densification and help in solving logistic issues (Kaliyan & Morey, 2010; Larsson, Thyrel, Geladi, & Lestander, 2008).

Briquetting is a mechanical process in which biomass with a low initial density (0.1–0.2 kg l^{-1}) is first shredded and then submitted to high pressure, promoting its agglomeration and densification. The resulting product (briquettes) can achieve a density of around 1.2 kg l^{-1} (Grover & Mishra, 1996). Theoretically, this process can also alter the chemical structure of the biomass. Firstly, the reduction of the particle size of biomass by shredding process increases its surface area and it can reduce both the degree of polymerisation and cellulose crystallinity (Krishania, Vijay, & Chandra, 2013; Zheng, Zhao, Xu, & Li, 2014). In addition, vaporisation of liquid content in the lignocellulosic material can be expected during the briquetting process due to the high pressure. According to Tumuluru, Wright, Hess, and Kenney (2011), this can promote hydrolysis of the hemicelluloses and lignin into lower molecular weight carbohydrates.

Therefore, particle size reduction through shredding and the application of high pressure and temperature during briquetting process could both accelerate the hydrolysis and acidogenesis of the biomass, achieving a faster and higher CH_4 yield. However, to our knowledge, the effect of briquetting as pretreatment for lignocellulosic material in anaerobic digestion has been scarcely evaluated until now.

In general, prior to feeding anaerobic reactors, particle size reduction of straw is required in order to enhance biomass biodegradability, avoid problems of clogging and provide a homogeneous mixture during digestion. Reduction in particle size of straw can be accomplished by milling or grinding machines, extruders and shredders (Carlsson, Lagerkvist, & Morgan-Sagastume, 2012; Zheng et al., 2014). This process seems less expensive than briquetting as lower energy input is required. However, for more accurate recommendation, technical and economic aspects from both pretreatments should be studied.

Thus, the aim of this study was to evaluate the use of shredded and briquetted wheat straw in the anaerobic co-digestion with dairy cattle manure and the feasibility of biogas plant operation with the best pre-treated straw added to cattle manure.

2. Material and methods

2.1. Substrates

The cattle manure (CM) used in this experiment were collected from the animal facilities of the Research Centre Foulum (Aarhus University, Denmark).

The CM used to feed lab-scale continuously stirred tank reactors (CSTR) and also for the batch assay were the same. It was stored in a 1.5 m^3 tank for three months at ambient temperature. In order to feed full-scale reactors, CM was collected weekly from the animal facilities.

The wheat straw was collected near Viborg (Denmark). Before the experiment, the wheat straw was kept on the courtyard, piled in round or square bales and brought to the shredding and briquetting machines using a tractor. A portion of straw was fed manually into a quad shaft shredder