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Anaerobic digestion of acidified slurry fractions derived from different solid–liquid separation methods

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HIGHLIGHTS

- ▶ B_0 acidified slurry fractions from different separation methods were evaluated.
- ▶ Batch assay processing raw and liquid fractions of acidified manure showed inhibition.
- ▶ A larger screen size gave higher B_0 of solid fractions acidified sow manure.
- ▶ A lower plate tension gave a lower B_0 of solid fractions acidified sow manure.
- ▶ No effect of acidification on B_0 of solid fractions acidified dairy cow manure.

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ABSTRACT

Batch assays investigating the ultimate methane yields (B_0) of acidified slurry fractions produced with different solid–liquid slurry separation techniques were done. The result showed that the anaerobic digestion (AD) process was inhibited when raw and liquid fractions of sow, pig and dairy cow acidified slurry are digested, but AD treating solid fractions (SF) acidified slurry showed no sulphide inhibition. The B_0 of SF acidified sow slurry increased significantly with increasing screen size in the screw press. No significant effect of acidification processes on B_0 of SF dairy cow slurry (DCS) was observed. The ultimate methane yields of SF acidified DCS and SF non acidified DCS were 278 ± 13 and 289 ± 1 L kg VS^{-1}, while in term of fresh weigh substrate were 59 ± 2.8 and 59 ± 0.3 L kg $substrate^{-1}$, respectively.

1. Introduction

Animal slurry is the most important source of ammonia (NH_3) emission to the atmosphere in Denmark (Kai et al., 2008). The emission sources are animal housing, manure storage and field application. Slurry acidification with sulphuric acid is a commonly used technology to reduce ammonia emissions from animal slurry in Denmark and can reduce the NH_3 emission by 70% in pig houses (Kai et al., 2008). Furthermore, as acidification of animal manure can significantly reduce volatilisation of NH_3 (Sørensen and Eriksen, 2009), it can increase the nitrogen and sulphur fertilizer value of acidified slurry, since acidified slurry is widely used as fertilizer (Eriksen et al., 2008).

High sulphur content in the acidified slurry might inhibit anaerobic digestion (AD). Parkin et al. (1990) reported a sulphide inhibition threshold of 100–800 mg L^{-1} for dissolved sulphide or 50–430 mg L^{-1} for undissociated H_2S. However, since solid fractions (SF) of animal slurry have a high energy content in terms of fresh weight substrate (Hjorth et al., 2010), the utilization of acidified manure in AD is still possible by utilizing the SF of acidified slurry that contains most of the methane potential but only a small fraction of the sulphur. The number of farms that use the slurry acidification technology to reduce ammonia emission is expected to increase in the future, so better knowledge about the potential methane production from the anaerobic digestion of acidified slurry will be required. This is because of the abundance of animal slurry as a source of organic material for AD in Europe (Holm-Nielsen et al., 2009) and the advantages of using slurry as a substrate in AD including a high buffering capacity and a wide range of nutrients for microorganisms (Angelidaki and Ellegard, 2003).

Co-digestion of raw animal slurry with the SF of animal slurry is a method of increasing methane production per digester volume unit. This strategy can improve the economy of biogas plants treating manure since methane production from manure is relatively

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low in terms of volume (Møller et al., 2007a). Sutaryo et al. (2012) found that a digester treating a mixed substrate (30% SF acidified dairy cow slurry (DCS) and 70% raw non-acidified DCS (w/w),) can produce approximately 50% more methane in terms of digester volume compared to a control digester treating DCS alone. This digester furthermore operated in a stable state, indicated by a stable biogas production and low volatile fatty acid (VFA) concentrations. In addition, even though the digester was treating a substrate with high total solid (TS) concentration of 14.1%, problems related to the mechanical digester mixing system were not observed (Sutaryo et al., 2012). Similarly, Møller et al. (2007b) found that a pilot scale continuous stirred tank reactor processing a mixed substrate (60% solid fractions pig manure and 40% raw pig manure with a combined TS of 15.5%) ran satisfactorily using a mechanical mixing system and progressive cavity feeding pumps, of a type similar to those used at full scale biogas plants in Denmark. Therefore, up to 15.5% substrate TS concentration, a biogas plant does not necessarily need modifications to the mixing or feeding systems, although it is expected that extra energy input may be required for both.

Of the solid–liquid slurry separation technologies used, mechanical separators or screens are a better option because of their efficiency in producing a SF with a high TS content (Hjorth et al., 2010). Menardo et al. (2011) found that the screw press recovered 73% TS when separating digested slurry into solid and liquid fractions, where the compression roller only succeeded in recovering 43% TS. Utilization of SF slurry with a high TS content as a co-digestion substrate in centralized biogas plants has advantages such as a reduction of transport costs (Asam et al., 2011), an increase in the quality of the digested slurry as fertilizer (Kaparaju and Rintala, 2008) and an increase in the methane yield per digester unit volume (Sutaryo et al., 2012). Previous studies have measured the methane yield of the liquid and SF of animal slurry from the solid–liquid separation of either pig slurry using a single screen size in a screw press (González-Fernández et al., 2008) or the SF in digested slurry (Menardo et al., 2011), but none, to our knowledge, has measured the methane yield of the SF acidified animal slurry produced from different solid–liquid separation processes.

The size of the screen in the slurry separation process may influence the transfer of the VS in the animal slurry to the SF, causing yields of methane from the SF slurry to vary. A method of determining methane productivity of biomass in terms of VS loaded as residence time approaches infinity is the ultimate methane yield (B_0) (Møller et al., 2004). Ultimate methane yield in terms of VS substrate and volumetric methane yield of the substrate are furthermore important parameters for the economy of AD plants (Møller et al., 2004). The objectives of this study were to: (1) determine methane production of slurry fractions derived from acidified sow slurry separated by a screw press with different settings in terms of screen size and pressure in the press chamber, (2) determine methane production of acidified fattening pig slurry fractions separated by a drum/rotating screen, and (3) determine methane production of slurry fractions from acidified and non-acidified DCS separated by a belt press separator.

2. Methods

2.1. Experimental setup

The experiments were performed in batch assays using 0.5 L infusion bottles following the method described by Møller et al. (2004). Each digester contained inoculum and substrate except for the control that contained inoculum only. The net gas production from the substrate is calculated as the total gas production after the gas production from the inoculum control has been subtracted. Prior to incubation at 35 °C for 90 d, each digester was sealed using butyl rubber stoppers and aluminium caps and the headspace was flushed with 99.9% nitrogen for two minutes. The batch assays were done in triplicate. The substrates used for batch digestion and experimental design are presented in Table 1.

2.2. Substrate and inoculum

Substrates were obtained from several Danish farms using acidification technology developed by Infarm A/S (Aalborg, Denmark). The dairy cow farm location is in Nibe with 300 head populations, while for sow and pig farm location are in Skals and Karup with 1000–1100 and 5000–6000 head populations, respectively. In practical, the farmer only use screw press solid–liquid slurry separation method with 0.5 mm screen size. In the batch assay SF substrate was used directly without any water addition.

Slurry acidification processes are described by Kai et al. (2008). Sulphuric acid (96% H_2SO_4) was used for the slurry acidification at a ratio of approximately 5 kg H_2SO_4 t^{-1} slurry to achieve a final pH of 5.5 (Eriksen et al., 2008). The solid fractions were produced using either a screw press (Fibre Master, Germany), belt screw press (UTS, Gmbh, Germany), or drum screen separation (Reko, The Netherlands).

2.2.1. Screw press separation of acidified sow slurry

With the screw press technology, animal slurry is fed into the machine and forced by a screw auger along a wire screen. The liquid fraction will pass through the screen and be collected separately in an enclosing container, while the auger will transport the SF retained on the screen to the end where it is removed. At the end of the axle, there is a pressure plate to extract more liquid from the SF and the SF will drop between the plate and opening of the cylindrical screen (Ford and Fleming, 2002; Hjorth et al., 2010). Therefore, a lower scale plate tension applied to the opening cylindrical screen results in a higher pressure applied to the SF in the cylindrical mesh chamber. This experiment evaluates the effect of four different screen sizes and two different plate scale tensions (Table 1) on the methane production of SF from acidified sow slurry.

2.2.2. Drum screen separation of acidified fattening pig slurry

With drum/rotating screen separation, animal slurry is fed at a controlled rate into a continuously rotating drum screen. The liquid fraction passes through the drum screen and is collected in a container under the drum screen, while the SF is scraped from the surface of the screen and collected in a container (Ford and Fleming, 2002). Therefore with this method the raw slurry is not forced through the drum screen.

2.2.3. Belt press separation of acidified and non-acidified dairy cow slurry

The last slurry separation method used in this experiment was the belt press. With this method the liquid fraction drains by gravity from the SF in the separator. The SF cake is continuously transported on a belt, therefore the animal slurry loading space and SF unloading change over continuously. The filter separators are screens that consist of a rotating perforated cylinder with a loading area at the top and a scraper to remove the SF, while the liquid fraction passes through the screen and drains off (Hjorth et al., 2010). Substrate properties can be seen in Table 1.

2.2.4. Inoculum

The inoculum was sourced from the post-digestion tank at Research Centre Foulum, Denmark, after separation (GEA Westfalia separator type: UCD 305–00-02, D-59302 Oelde, Germany) to produce a more homogenous inoculum from the liquid fraction. It was kept at mesophilic temperature (35 °C) for 21 d to ensure that the