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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

Table 1
Experimental design and substrate properties.

Experiment A (Screw press, Fibre Master, Germany)												
Sample no.	Slurry	Fraction	Treatment	Screen size (mm)	Plate tension (mm)	TN ($g\ kg^{-1}$)	TAN ($g\ kg^{-1}$)	Sulphur ($kg\ ton^{-1}$)	TS (%)	VS (%)	VFA ($mg\ L^{-1}$)	I:S ratio
1	Sow	Slurry	Acidified	–	–	3.32	2.36	3.14	4.20	2.97	2840	0.64
2	Sow	Liquid	Acidified	0.35	48^{*}	3.38	2.40	3.19	3.28	2.11	2967	0.46
3	Sow	Liquid	Acidified	0.75	48	3.39	2.40	3.09	3.26	2.09	2903	0.46
4	Sow	Solid	Acidified	0.25	48	6.91	1.31	3.85	38.45	35.03	u.d	0.33
5	Sow	Solid	Acidified	0.35	48	7.44	1.78	3.71	27.30	24.63	262	0.44
6	Sow	Solid	Acidified	0.50	48	6.11	1.40	3.61	35.27	32.04	u.d	0.35
7	Sow	Solid	Acidified	0.75	48	6.91	1.51	3.67	33.85	30.47	578	0.36
8	Sow	Solid	Acidified	0.35	25^{**}	6.71	1.48	3.39	34.64	31.40	u.d	0.34
9	Sow	Solid	Acidified	0.50	25	5.95	1.33	3.55	40.74	36.86	u.d	0.33
Experiment B (Drum screen, Reko-Netherland, drum diameter 80 cm)												
Sample no.	Slurry	Fraction	Treatment	Screen size (mm)	Drum speed (rpm)	TN ($g\ kg^{-1}$)	TAN ($g\ kg^{-1}$)	Sulphur ($kg\ ton^{-1}$)	TS (%)	VS (%)	VFA ($mg\ L^{-1}$)	I:S ratio
10	Pig	Raw	Acidified	1	7	5.02	3.31	2.99	4.36	3.08	8138	0.59
11	Pig	Liquid	Acidified	1	7	4.68	3.22	2.96	3.31	2.10	8089	0.45
12	Pig	Solid	Acidified	1	7	4.07	2.61	2.29	10.60	9.55	7289	0.84
Experiment C (belt press, UTS, Gmbh, Germany)												
Sample no.	Slurry	Fraction	Treatment		Screen size (mm)	TN ($g\ kg^{-1}$)	TAN ($g\ kg^{-1}$)	Sulphur ($kg\ ton^{-1}$)	TS (%)	VS (%)	VFA ($mg\ L^{-1}$)	I:S ratio
13	DCS	Raw	Acidified		-	3.47	1.95	2.64	6.51	4.61	5878	0.69
14	DCS	Liquid	Acidified		0.30	3.37	2.15	2.36	4.16	2.75	5863	0.52
15	DCS	Solid	Acidified		0.30	6.47	1.60	2.86	22.92	21.04	4961	0.53
16	DCS	Raw	Non-acidified		-	3.65	2.01	0.47	5.86	4.67	7012	0.70
17	DCS	Liquid	Non-acidified		0.30	3.53	2.15	0.33	3.93	2.71	6584	0.53
18	DCS	Solid	Non-acidified		0.30	6.56	1.30	1.11	22.51	20.35	3091	0.56

u.d: Undetected.
* Low pressure.
** High pressure.

gas production had practically completed. Only the liquid fraction was subsequently used to inoculate the batch tests. TS, VS, total ammonia nitrogen (TAN) and total VFA of inoculum following incubation at 35 °C were 1.97%, 0.97%, 1.35 g L^{-1} and 65.29 mg L^{-1}, respectively. The amount of inoculum in each batch digester was 150 ± 1 g and the inoculum to substrate ratio in terms of VS can be seen in Table 1.

2.3. Analytical procedures

Biogas production was measured using an acidified water displacement method at 20 °C (in a temperature controlled room) and at a pressure of one atmosphere. Gas samples were analysed for CO_2 and CH_4 using a Perkin Elmer Clarus 500 gas chromatograph. Total VFA (C_2-C_5) concentration was determined by a gas chromatography (Hewlett Packard 6850A) with a flame ionization detector. TS and VS were determined according to APHA (1998). TAN was measured colorimetrically at 690 nm with a Merck® spectrophotometer (NOVA 60, NH_4^+ test 1.00683.0001). Total sulphur (S) was measured by ICP technology (Optima 2000DV, Perkin Elmer) following drying and destruction using HNO_3 in an autoclave.

2.4. Calculations

The mass balance calculation in this paper was based on the TS content in the raw slurry, the SF and the liquid slurry fraction according to Bauer et al. (2009). This method was chosen because the result was more reliable than if based on the sulphur content. The relevant equation is:

$$TS_{RW} = xTS_{LF} + yTS_{SF} \quad (1)$$

where TS_{RW} is the TS of raw slurry; TS_{LF} is the TS of the liquid fraction, TS_{SF} is the TS of the solid fraction and x and y are the proportions of TS_{LF} and TS_{SF}, respectively, the sum of which is equal to one. The methane balance and $VS_{balance}$ were calculated using Eqs. (2) and (3):

$$CH_{4balance}SF = \frac{CH_4SF}{CH_4SF + CH_4LF} \text{x } 100\% \quad (2)$$

$$VS_{\ balance}SF = \frac{VS\ SF}{VS\ SF + VSLF} \text{x } 100\% \quad (3)$$

where $CH_{4balance}$ SF is the CH_4 proportion of the solid fraction, CH_4 SF is the methane production of the solid fraction, CH_4 LF is the methane production of the liquid fraction, $VS_{balance}$ SF is the VS proportion of the solid fraction, VS SF is the VS concentration of the solid fraction and VS LF is the VS concentration of the liquid fraction. The sulphur input (mg) from substrate to the digester was calculated using Eq. (4):

$$S_{input} = \left[\frac{\text{Sulphur concentration}}{1000}\right] \times \text{Amount of sample} \times 1000 \quad (4)$$

Data were statistically analysed using the GLM and t-test procedure in SAS® software (Cary, NC). Duncan multiple range tests were used in post ANOVA analysis when differences were found to be significant at the $P = 0.05$ level.

3. Results and discussion

3.1. Effects of screw press screen size and plate scale tension on the methane yield of solid fractions acidified sow slurry

The effects of different screen sizes in the screw press (with unchanging plate scale tension to the opening cylindrical screen (48 mm)) on the cumulative methane yield of the SF of acidified sow slurry are presented in Fig. 1A and Table 2. On average, a larger screen size gave a higher B_0 in term of VS ($p < 0.05$) (Table 2). When a smaller screen size was applied, the VS concentration of the SF was higher than that with the bigger screen size (Table 1) except for sample number five which might because of sampling error. This may be due to the smaller screen size resulting in a higher pressure, forcing raw acidified sow slurry through the cylindrical screen, resulting in a high VS concentration in the SF. With the small screen size there will therefore be more dissolved organic matter (that is easily converted to methane) in the liquid fractions instead of the SF. This gave a lower methane yield in term of VS in the substrate with a high VS concentration than in the substrate with a low VS concentration. Another explanation for this phenomenon could be the inhomogeneity of the substrate VS, where the VS in the VS-rich substrate was dominated by lignocellulosic material that has a low biodegradability in the AD process. This agrees well with the findings of Møller et al. (2007a) who found a 40–50% lower methane yield in term of VS from the SF with the centrifuge manure separation method, because it has a higher VS concentration than raw manure.

Results using the same screen size but different plate scale tensions to the cylinder mesh opening are presented in Fig. 1 B and Table 2. In order to get precise data, the effect of different plate scale tensions on the methane production from the SF of the acidified sow slurry, the experiment was repeated using two (0.35 and 0.50 mm) screen sizes (Table 2). In principle, lowering plate scale tension to the cylindrical screen opening increases the pressure to the SF in the screw press chamber. Table 2 shows the methane yield from the SF acidified sow slurry. In fact, a lower scale plate tension gave a lower methane yield ($p < 0.05$) of SF acidified sow slurry, particularly in 0.5 mm screen size treatment (Table 2). The effect of low plate scale tension and small screen size was similar, both resulting in high pressure in the pressure chamber and producing a SF with a high VS concentration but lower methane production in term of VS than from the SF with low VS content.

The ultimate methane yields of SF acidified sow slurry (L kg substrate^{-1}) are presented in Table 2. In general, the smaller screen size and the lower plate scale tension gave a higher B_0 in terms of substrate fresh weigh (Table 2). The explanation of this is simply that smaller screen size and lower plate scale gave a higher VS concentration.

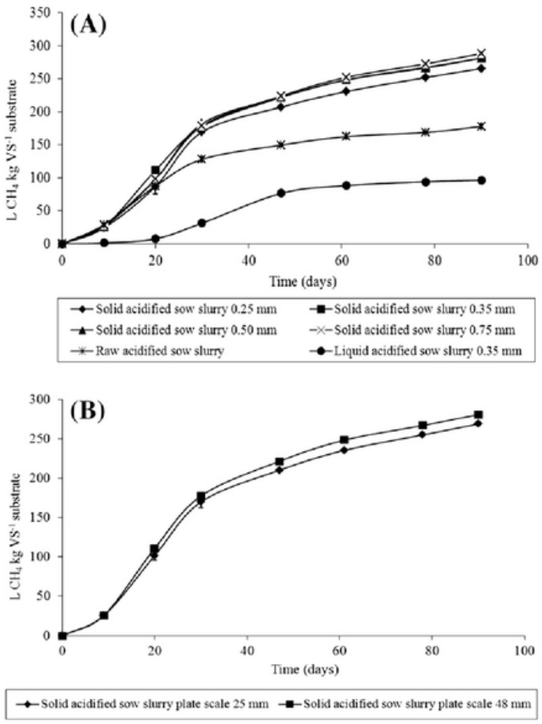

Fig. 1. Cumulative methane production (A: same plate tension (48 mm) but different screen sizes (0.25 mm,0.35 mm, 0.50 mm and 0.75 mm); B: same screen size (0.35 mm) but different plate tension (25 mm and 48 mm).

3.2. Effects of acidification on methane production of separated fractions acidified sow slurry

The methane yields of the SF from acidified sow slurry were for all screen sizes significantly higher ($p < 0.05$) than from raw and liquid-fraction acidified sow slurry (Table 2). The lower B_0 of raw and liquid fractions acidified sow slurry than in the SF indicates sulphide inhibition in the AD process in these substrates. This result supports the hypothesis that acidified slurry can inhibit methane production in the AD process. Sulphide inhibition in the liquid fractions seemed much higher than in the raw acidified sow slurry. Based on the data for sulphur concentration in Table 1 and the amounts of substrate for samples no. 1, 2 and 5 (raw, solid and SF of acidified sow slurry) this paper found that the amount of sulphur inputs from the substrate to the digester were 240 mg, 480 mg and 50 mg sulphur for the raw, liquid fractions and SF of acidified sow slurry, respectively. A larger input of sulphur from raw and liquid-fraction acidified sow slurry support the previous hypothesis that there was sulphide inhibition of AD processing of raw and liquid-fraction acidified sow slurry. Sutaryo et al. (2012) found sulphide inhibition during digestion of raw and liquid-fraction acidified DCS but not for the SF acidified DCS with inoculum to substrate ratio fixed at 1.2 ± 0.2 in terms of VS. In the present work, the amount of substrate VS of the SF of acidified sow slurry used in the batch tests was almost twice that of raw acidified sow slurry (lower I:S ratio) (Table 1: substrate no. 4, 6 and 7 versus no. 1). Although the I:S ratio in terms of VS was low for SF of acidified sow slurry, in terms of fresh weight the amount of raw and liquid fractions of acidified sow slurry were much higher than that of SF acidified sow slurry. Therefore the sulphur input from these substrates was much higher than the sulphur input from SF acidified sow slurry. This fact, therefore, can explain the sulphide inhibition of AD processing raw and liquid fractions sow slurry but no sulphide inhibition of AD treating SF acidified sow slurry. Fig. 1A shows that despite the lower I:S ratio for the SF of acidified sow slurry compared to raw acidified sow slurry, in terms of VS seems there was no sulphide inhibition, but there was sulphide inhibition in the AD treatment of raw acidified sow slurry with a lower VS content in the substrate. This study therefore confirms the result of the previous paper that there is sulphide inhibition in the AD treatment of raw and liquid-fraction acidified slurry. Chen et al. (2008) reported that there are two mechanisms for sulphate inhibition in AD: firstly, the competition of sulphate-reducing bacteria with other microorganisms such as methanogens, acetogens or fermentative microorganisms for acetate, H_2, propionate and butyrate (Colleran et al., 1995), and, secondly, by the toxicity of sulphide to some microorganisms (Colleran et al., 1998).

3.3. Methane production from separate fractions of acidified fattening-pig slurry using the drum screen slurry separation method

The ultimate methane yield of raw, liquid and solid fractions of acidified pig slurry from the fattening growth stage in term of VS using the drum screen solid liquid slurry separation method are given in Fig. 2A and Table 2. The methane production from the SF of

Table 2
Cumulative methane yields and statistical analysis of SF acidified animal slurry.

Sample no.	Screen size (mm)	Plate scale (mm)	At 20 d (L kg VS^{-1})	At 30 d (L kg VS^{-1})	At 90 d (L kg VS^{-1})	At 90 d (L kg substrate^{-1})
1	–	–	87.3 ± 11.4	127.9 ± 2.9	177.8 ± 3.7	5.3 ± 0.5
2	0.35	48	7.6 ± 1.8	31.4 ± 2.3	96.3 ± 0.7	2.0 ± 0.1
3	0.75	48	28.9 ± 1.1	58.9 ± 1.7	105.6 ± 2.2	2.2 ± 0.4
Effect of different screen size						
4	0.25	48	86.6 ± 1.1^{a}	169.3 ± 1.8^{a}	265.5 ± 0.9^{a}	92.9 ± 0.3^{a}
5	0.35	48	111.0 ± 4.1^{b}	177.5 ± 4.1^{ab}	280.9 ± 4.4^{b}	69.2 ± 1.1^{b}
6	0.50	48	97.4 ± 8.6^{a}	181.7 ± 6.7^{b}	281.3 ± 0.6^{b}	90.1 ± 0.2^{c}
7	0.75	48	97.6 ± 7.1^{a}	178.4 ± 3.5^{b}	288.2 ± 2.7^{c}	87.8 ± 0.8^{d}
Effect of different plate scale tension A						
5	0.35	48	111.0 ± 4.1^{a}	177.5 ± 4.1^{a}	280.9 ± 4.4^{a}	69.2 ± 1.1^{a}
8	0.35	25	101.8 ± 3.3^{b}	169.9 ± 5.9^{a}	269.1 ± 8.6^{a}	84.5 ± 2.7^{b}
Effect of different plate scale tension B						
6	0.50	48	97.4 ± 8.6^{a}	181.7 ± 6.7^{a}	281.3 ± 0.6^{a}	90.1 ± 0.2^{a}
9	0.50	25	102.5 ± 5.7^{a}	172.0 ± 6.3^{a}	273.1 ± 3.5^{b}	100.6 ± 1.3^{b}
Effect of acidification process						
15	0.30		144.3 ± 7.8^{a}	197.1 ± 7.7^{a}	278.4 ± 13.1^{a}	58.6 + 2.8^{a}
18	0.30		165.9 ± 8.5^{b}	212.6 ± 8.7^{a}	289.2 ± 1.2^{a}	58.8 ± 0.3^{a}
10	–		86.7 ± 2.8	193.9 ± 4.1	397.8 ± 0.2	12.3 ± 0.3
11	1		40.8 ± 1.1	47.5 ± 0.8	392.2 ± 15.12	8.2 ± 0.1
12	1		179.1 ± 2.7	241.1 ± 1.2	319.3 ± 1.9	30.5 ± 1.2
13	–		111.9 ± 7.9	170.7 ± 5.0	256.6 ± 2.3	11.8 ± 0.9
14	0.30		40.4 ± 2.3	99.9 ± 1.8	223.3 ± 2.9	6.1 ± 0.4
16	–		231.7 ± 5.2	289.4 ± 1.4	372.6 ± 2.2	17.6 ± 0.5
17	0.3		232.4 ± 11.5	310.9 ± 6.9	384.5 ± 1.4	10.5 ± 0.7

[abc] Values in each column and in the same treatment followed by the same letter are not significantly different ($p > 0.05$).

acidified pig slurry was significantly lower than from the raw and liquid fractions at 90 d incubation, but higher at the beginning of incubation period (⩽30 d). The low methane production from the raw and liquid fractions in the early period of incubation indicates that there was either sulphide inhibition or an organic overload. The VS content in the raw and liquid fractions was higher (lower I:S ratio) than in the SF (Table 1). However, sulphide inhibition might have more roles to this phenomenon. The previous result showed that there was no inhibition in the AD treatment of the SF of acidified sow slurry with a higher VS content than in the raw and liquid fractions of acidified sow slurry where there was inhibition (see Section 3.1, Fig. 1A). The present work evaluates the different amount of SF, higher (Section 3.1) and lower amounts (Section 3.2) of SF than raw and liquid acidified slurry in term of VS, and in both case found there was sulphide inhibition during AD of raw and liquid fractions acidified slurry but no sulphide inhibition of AD treating SF acidified slurry was observed. The amounts of sulphur added to the batch digesters were calculated to be 240 mg, 460 mg and 40 mg for respectively the raw, liquid and SF of acidified fattening pig slurry. Moreover, in this experiment no ammonia inhibition was expected, since TAN values of substrate after inoculation with inoculum were considerably below the TAN inhibition threshold as reported by Hashimoto (1986).

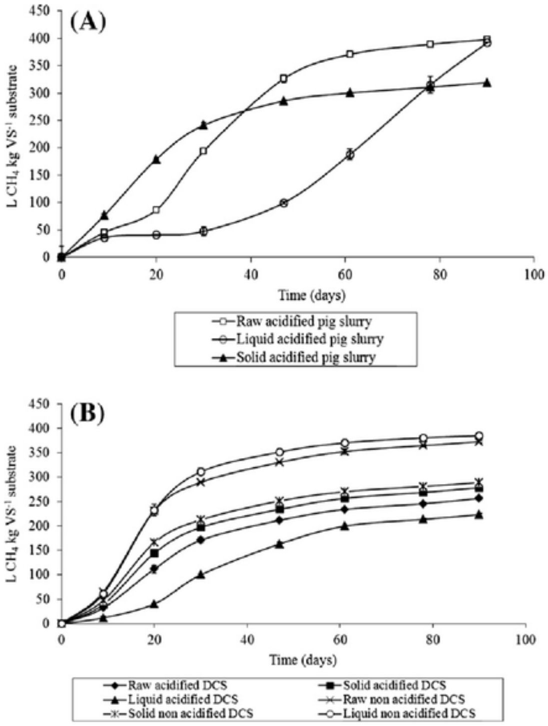

Fig. 2. Cumulative methane yields (A: drum separation method, B: belt press).

The increase in methane production later in the batch assay experiment suggests that the microorganism has been adapted with high sulphide concentration and/or there was a lowering the sulphide concentration in the liquid phase because of transfer of H_2S from the liquid phase to the gas phase followed by removal of biogas during biogas measurement (Sutaryo et al., 2012). Elferink et al. (1994) reported that the concentration of free H_2S in the gas phase of a digester is affected by the rate of biogas production. A high rate of biogas production will lead to an increased transfer of H_2S from the liquid phase to the gas phase. It is also possible that the batch assays had been overloaded, i.e. the I:S ratio that was too low, leading to a build-up of VFA that may reach a level that is inhibitory to biogas production, although VFA was not measured during the batch assays. Over time, the VFA would be consumed and biogas production would no longer be inhibited.

The B_0 in term of VS of the SF of acidified fattening pig slurry with the drum screen method is slightly higher than that of sow slurry using the screw press method, irrespective of screen size.

Table 3
Mass balance of acidified slurry fractions based on the TS of the slurry fractions derived from different slurry separation methods.

Set 1. Screw press[a]	Sample no.	VS (%)	Mass balance				B_0	CH_4 balance
			Fraction (eq. 1) (kg)	VS (kg)	VS (eq. 2) (%)	CH_4 (eq. 3) (%)	(L kg VS^{-1})	(L 100 kg raw $slurry^{-1}$)
Raw slurry	1	2.97	100	2.97	100	100	177.81	528.07
Solid fractions	5	24.63	3.81	0.94	31.6	57.4	280.95	263.87
Liquid fractions	2	2.11	96.19	2.03	68.4	42.6	96.31	195.44
Solid + liquid fractions		–	–	2.97	100	100	–	458.32
Set 2. Screw press[b]								
Raw slurry	1	2.97	100	2.97	100	100	177.81	528.07
Solid fractions	7	30.47	3.08	0.94	31.6	55.8	288.18	270.11
Liquid fractions	3	2.09	96.92	2.03	68.4	44.2	105.61	213.92
Solid + liquid fractions		–	–	2.97	100	100	–	484.02
Set 3. Drum screen[c]								
Raw slurry	10	3.08	100	3.08	100	100	397.83	1225.32
Solid fractions	11	9.55	14.40	1.37	43.2	38.4	319.25	438.90
Liquid fractions	12	2.10	85.60	1.79	56.7	61.6	392.25	705.15
Solid + liquid fractions		–	–	3.16	100	100	–	1144.05
Set 4. Belt press[d]								
Raw slurry	13	4.61	100	4.61	100	100	256.61	1182.96
Solid fractions	14	21.04	12.53	2.64	52.3	57.7	278.44	733.98
Liquid fractions	15	2.75	87.47	2.40	47.7	42.3	223.27	537.06
Solid + liquid fractions		–	–	5.04	100	100	-	1271.04

[a] acidified sow slurry using screw press with 0.35 mm screen size.
[b] acidified sow slurry using screw press with 0.75 mm screen size.
[c] acidified fattening pig slurry using drum screen.
[d] acidified DCS using belt press with 0.30 mm screen size.

This result is in accordance with Møller et al. (2004) who found methane production in fattening pig slurry to be higher than in sow slurry. This dissimilarity may be caused by: (1) different substrate compositions; Rico et al. (2011) reported that the composition of manure depends on the diet and growth stage of the animal; (2) smaller particles in the SF from drum screen separation than from screw press separation, and (3) a more readily digestible fraction in drum screen samples compared to samples from the screw press separator, since the raw slurry was not forced through the drum screen, but was forced through the screen in the screen chamber of the screw press.

3.4. Effects of acidification process on methane yield of the slurry fraction of dairy cow slurry

Fig. 2B shows the methane production in term of VS of raw, liquid and solid fractions of both acidified and non-acidified DCS using the belt press technique. Even though the average ultimate methane yield of the SF from non-acidified DCS was higher in term of substrate VS, statistically there was no significant effect ($p > 0.05$) of the acidification process on the B_0 (Table 2). The B_0 of raw acidified DCS was significantly lower ($p < 0.05$) than the B_0 of raw non-acidified DCS with respective mean values of 256.6 and 372.7 L kg VS^{-1}. This result confirms the previous result on sulphide inhibition of the anaerobic digestion of acidified raw DCS (Sutaryo et al., 2012).

3.5. Mass balance

Calculations of mass, VS and methane balances of each acidified slurry fractions from different slurry separation methods based on the TS of each slurry fraction are set out in Table 3. The VS content of the SF of acidified sow slurry from screw press separation was much higher than VS content of SF acidified pig slurry from drum screen separation and SF of acidified DCS using the belt press (Table 2). This means that the screw press is much more efficient than the drum screen and belt press methods at producing a SF with a high VS content. Møller et al. (2002) similarly found the screw press to be efficient at TS recovery to the SF but not at total phosphorus and total nitrogen recovery during solid–liquid slurry separation. Due to of much higher VS content of SF acidified sow slurry from the screw press than SF of acidified pig from the drum screen press and SF acidified DCS from the belt press, SF acidified sow slurry from screw press produced much higher methane yields in term of fresh weight substrate than SF acidified pig and SF acidified DCS (Table 2). The average B_0 of SF acidified sow slurry from all screen sizes was 87.5 ± 10.5 L kg $substrate^{-1}$, while B_0 of SF acidified pig slurry and SF acidified DCS were 30.5 ± 1.2 and 58.7 ± 0.1 L kg $substrate^{-1}$, respectively.

The methane potential that can be produced by the solids is indicated by the separation efficiency of the B_0 value. Using the screw press method, the SF will constitute 3.08–3.81% of the slurry on a weight basis, but in terms of methane balance the SF from this method produced 55.8–57.4% of the methane production in term of VS expected from the digestion of the raw acidified sow slurry (Table 3). The drum screen and belt press produced SF that made up, respectively, 14.4% and 12.5% of the total weight and produced, respectively, 38.4% and 57.7% of the overall methane production in term of VS. However, the ratio of the methane potential that can be produced by the solids compared to methane potential of the raw manure is an equally important parameter.

4. Conclusions

A bigger screen size and a higher plate scale tension in the screw press separator produced a SF from acidified sow slurry with a higher B_0 in term VS substrate compared to smaller screen sizes and a lower plate scale tension. Sulphide inhibition affected the AD of raw and liquid-fraction acidified slurry, but no effect with SF acidified slurry. Methane production in terms of fresh weight of SF acidified DCS was 3.3 times higher than that of raw non-acidified DCS. Thus an acidified SF is suitable as a co-digestion substrate to increase methane production in term of digester volume.

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