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Short Communication

Improvement of dairy manufacture effluent anaerobic digestion with biological waste addition using a Chinese dome digester

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ABSTRACT

Anaerobic co-digestion of dairy manufacture effluent (DME) and biological waste (BW) was investigated at various DME/BW ratios using laboratory batch digesters. The biogas yield ranged 0.34–0.88 l biogas g^{-1} volatile solids (VS) removed. The highest VS reductions of 58% and 62% were obtained for DME/BW ratios of 60:40% and 80:20%, respectively. Results were used to operate a pilot-scale digester of 5 m^3. The highest biogas yield of 0.48 l g^{-1} VS removed was obtained at an organic loading rate (OLR) of 1.64 g VS l^{-1} d^{-1} corresponding to a DME/BW ratio of 80:20%. This could be mainly attributed to the higher biodegradability of DME and the correction of the C:N ratio by the addition of the BW. The N, P and K contents were increased significantly in the TS of the digestate to be around 6.8%, 0.64% and 1.26%, respectively.

1. Introduction

The dairy manufacture effluent (DME) production has increased over the years in the world. It presents a serious problem because it is highly pollutant with a chemical oxygen demand (COD) of 60–80 g l^{-1} (Mockaitis et al., 2006). Several possibilities have been assayed for DME recycling and treatment. However, the anaerobic digestion offers an excellent alternative in terms of both energy recovery and pollution removal. Various types of anaerobic digesters have been used in laboratories to treat DME (Saddoud et al., 2007; Gannoun et al., 2008). However, the anaerobic digestion of DME is not wide spread in the dairy industry. This is largely due to the poor process stability.

The mixture of DME with other waste is a solution for reducing its anaerobic digestion instability. Therefore, the combination of DME and BW treatment could be a practical alternative in the Vocational Training Centre in Sidi Thabet (Tunis) for the simultaneous recycling of different types of organic wastes generated in the same centre. A particularly strong reason for co-digestion is the adjustment of the carbon-to-nitrogen (C:N) ratio (Bouallagui et al., 2009).

The aim of this work was the optimisation of the co-digestion of DME and BW in batch digesters. The outcome of the co-digestion was then further tested in a Chinese pilot-scale digester to confirm the laboratory results.

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2. Methods

2.1. DME and BW sources

The DME used in this study was obtained from cheese factory located in Vocational Training Centre in Sidi Thabet (Tunis, Tunisia). The BW was collected from the cowshed of the same centre, in which the evacuations of cattle are mixed with the water of washing.

2.2. Digesters design and operational conditions

A series of seven lab-scale batch stirred digesters (D1–D7) with a working volume of 500 ml were operated at 35 °C for a period of 60 days. At the beginning, reactors were fed with 125 ml of diluted BW until the steady-state conditions were achieved; shown by a very low biogas production rates. The obtained digested sludge was used as inoculums for reactors. The other digesters (D) working volumes of 375 ml were filled with different mixed DME/BW ratios (R1–R7). The characterization of the different DME/BW mixtures (R1–R7) were summarised in Table 1.

The pilot-scale experiment was carried out in a semi-continuous Chinese dome digester. The unit has a 3.5 m^3 working volume. The reactor was placed in the earth and it was feed successively by BW (run1) and a mixtures of DME/BW (run2 and run3). The fed flow rate of the digester depended to the production rates of DME in the cheese factory of the farm; in the average there was 150 l of the mixture daily.

Table 1
Characteristics of the different DME/BW mixtures wastes.

	R1: 100% BW–0% DME	R2: 80% BW–20% DME	R3: 40% BW–60% DME	R4: 50% BW–50% DME	R5: 40% BW–60% DME	R6: 20% BW–80% DME	R7: 0% BW–100% DME
TS (%)	5.63 ± 0.3	5.7 ± 0.36	4.68 ± 0.26	4.56 ± 0.36	4.4 ± 0.32	4.3 ± 0.3	4.6 ± 0.38
VS (%)	4.7 ± 0.23	4.68 ± 0.28	4.3 ± 0.31	4.1 ± 0.26	3.99 ± 0.32	3.92 ± 0.32	3.8 ± 0.3
TSS (g/l)	38.6 ± 0.6	32.4 ± 0.4	29.4 ± 0.4	27 ± 0.35	18.2 ± 0.3	12.6 ± 0.3	8.6 ± 0.4
pH	7.1 ± 0.1	6.85 ± 0.05	6.8 ± 0.1	6.5 ± 0.2	6.42 ± 0.1	5.9 ± 0.2	4.5 ± 0.2
TN (% of TS)	5.1 ± 0.2	4.3 ± 0.15	3.7 ± 0.2	3.2 ± 0.1	2.81 ± 0.1	2.1 ± 0.2	1.4 ± 0.1
TC (% of TS)	56.5 ± 0.8	61.1 ± 1.7	62.5 ± 0.7	63.3 ± 1.1	61.3 ± 0.8	51.9 ± 1.2	50.7 ± 1.1
P (% of TS)	0.34 ± 0.02	0.29 ± 0.01	0.26 ± 0.02	0.24 ± 0.01	0.21 ± 0.01	0.19 ± 0.01	0.14 ± 0.01
K (% of TS)	0.18 ± 0.01	0.23 ± 0.01	0.24 ± 0.01	0.28 ± 0.01	0.26 ± 0.02	0.31 ± 0.01	0.38 ± 0.02
C/N	11.1 ± 0.04	14.2 ± 0.02	16.9 ± 0.01	19.8 ± 0.02	21.9 ± 0.02	24.7 ± 0.02	36.2 ± 0.1

2.3. Technical analysis

Analysis of total solid (TS), total suspended solid (TSS), VS, COD, total volatile fatty acids (VFAs), alkalinity and pH were determined according to the standard methods (APHA, 1995). Total nitrogen was determined by the Kjeldahl method. Total carbon (TC) was measured by catalytic oxidation on a TC 1200 Euro glace analyser. Phosphorus and potassium were measured by spectrophotometric methods. The biogas production was determined by the displacement of water in a graduated column for batch reactors and by a gas meter for the pilot-scale digester. The methane content was measured using a HP Hewlette 5890 parckard Series II gas chromatograph. The most probable number (MPN) standard method was used to determine total coliforms, *Escherichia coli* and *Enterococcus* spp. concentrations (APHA, 1995).

2.4. Statistical analysis

In order to determine whether the observed differences between digesters performances were significantly different, data were subjected to the ANOVA tests (StatSoft Inc, 1997). Differences between co-substrates additions effects (*p*) were compared with 0.05.

3. Results and discussion

3.1. Performances of lab-scale digesters

3.1.1. Biogas production and VS removal efficiency

Results showed that the volume and the methane content of biogas produced in the digesters containing a mixture of DME/BW are higher than those of DME and BW that were treated separately (Table 2). The ANOVA analysis of the data indicated that digesters performances enhancement were statistically significant ($p < 0.05$). The higher cumulative biogas productions of 5.69 and 4.83 l were obtained with D4 and D6, respectively.

The best biogas yields of 0.88 and 0.76 l g^{-1} VS removed were obtained with D4 and D6, respectively. However, the highest methane contents of 54% and 51% were obtained with D3 and D6, respectively. It appeared that the addition of BW increased the methane production rate over that of the digestion of the DME alone. In fact, the BW served as a nitrogen supplement and a buffering reagent.

The co-digestion of BW with municipal wastes has been also reviewed and has also been shown to enhance methane production (Callaghan et al., 1999). The combination of DME and BW can be capable to maintain the proper C/N ratio (20:24) in digesters. When DME was treated alone, the C:N ratio was outside the required range (20–30) with regard to producing a maximum specific methane yield (Thomas et al., 2007).

The VS and TSS reductions decreased with the increase of BW to the DME. Most of the biodegradable carbon in the BW feed is already digested in the rumen. Thus, BW has a lower potential to produce biogas and the methane content in biogas is lower (Weiland, 2003). The best VS and TSS reductions were obtained with the D6 which was fed with a DME/BW ratio of 80:20%.

3.1.2. pH, alkalinity and VFAs variations

Initial pH of the raw DME and BW were 4.5 and 7.1, respectively. When the proportion of DME was important in digesters 4, 5, 6, and 7 a solution of 2 N sodium hydroxide was added to maintain the pH around 7–7.5 especially during the two first weeks of trials. During the anaerobic digestion of DME, pH dropped due to the rapid formation of VFAs by the acid-forming bacteria. When digesters were operated on BW and low proportions of DME, the pH was in the optimum range. This was due to the high

Table 2
Performances of batch digesters operated under mesophilic (35 °C) conditions.

	D1: 0% DME–100% BW	D2: 20% DME–80% BW	D3: 40% DME–60% BW	D4: 50% DME–50% BW	D5: 60% DME–40% BW	D6: 80% DME–20%BW	D7: 100% DME–0% BW	*p*
Cumulate biogas (ml)	2900 ± 90	4820 ± 120	4470 ± 142	5695 ± 95	4760 ± 124	4830 ± 88	3485 ± 92	0.000
Methane (%)	43.4 ± 1.5	48.23 ± 1.2	54.2 ± 1.4	48.1 ± 1.1	40.5 ± 1.2	51.5 ± 1.2	36,6 ± 0.9	0.003
TSS removal (%)	32.2 ± 1.1	34.8 ± 1.2	38.7 ± 1.1	44.8 ± 0.9	51.7 ± 2.1	56.6 ± 1.3	52.2 ± 1.4	0.021
VS removal (%)	50.7 ± 2.1	52.5 ± 1.8	53.6 ± 1.6	54 ± 0.9	58.1 ± 1.8	62.3 ± 1.9	60.3 ± 2	0.011
Biogas yield (l g^{-1} VS removed)	0.34 ± 0.02	0.49 ± 0.02	0.67 ± 0.03	0.88 ± 0.03	0.76 ± 0.03	0.76 ± 0.04	0.43 ± 0.02	0.000
pH	8.3 ± 0.2	8.4 ± 0.15	8.8 ± 0.1	8.9 ± 0.1	8.7 ± 0.09	8.8 ± 0.2	8.9 ± 0.1	0.062
Alkalinity (mg l^{-1})	5770 ± 120	4310 ± 145	3380 ± 60	3220 ± 58	3000 ± 110	2530 ± 60	2880 ± 50	0.000
VFA (mg l^{-1})	285 ± 15	319 ± 22	497 ± 24	547 ± 30	1871 ± 42	2560 ± 44	4160 ± 55	0.000
TN (% of TS)	14.9 ± 0.5	15.5 ± 0.3	10.8 ± 0.3	11.1 ± 0.2	8.2 ± 0.1	7.9 ± 0.2	5.6 ± 0.1	0.001
P (mg l^{-1})	1.64 ± 0.01	1.14 ±	1.13 ±	1.12 ±	1.01 ±	0.87 ±	0.78 ±	0.006
K (mg l^{-1})	1.81 ± 0.01	1.66 ± 0.01	1.76 ± 0.01	1.44 ± 0.01	0.99 ± 0.01	1.12 ± 0.01	0.92 ± 0.01	0.02