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BIOGAS YIELD FROM ANAEROBIC BATCH CO-DIGESTION OF SISAL PULP AND ZEBU DUNG

Ondřej Cundr[1*], Dagmar Haladová[2]

[1]*Czech University of Life Sciences Prague, Faculty of Engineering, Department of Power Engineering, Prague, Czech Republic*
[2]*Czech University of Life Sciences Prague, Institute of Tropic and Subtropic, Prague, Czech Republic*

Abstract: Co-digestion of various materials has been shown to improve the digestability of the materials and biogas yield. The degradation and biogas production potential of sisal pulp could be significantly increased by co-fermenation with zebu dung. Batchwise anaerobic digestion of sisal pulp and zebu dung was studied both with the wastes separately and with mixture in various proportions. While the highest methane yields from sisal pulp and zebu dung alone were 1.8 and 88 l $CH_4 \cdot kg^{-1}$ volatile solids (VS), co-digestion with 80% of sisal pulp and 20% zebu dung gave 173 l $CH_4 \cdot kg^{-1}$ VS. All experiments were carried out at total solids (TS) of 5%.

Key words*: sisal pulp, zebu dung, anaerobic co-digestion,*

INTRODUCTION

With today's energy-demanding lifestyles, the need to explore and exploit new energy sources that are renewable and ecologically sound is mandatory. In most developing countries, agro-industrial residues are available in abundance. Through anaerobic digestion and biogas production, these have very great potential in catering for the energy demand, especially in the small-scale or local energy sector. The biogas from sisal pulp, a waste product of the sisal industry, is of great interest as a renewable energy carrier that could be used for cooking and/or power generation [1]. Currently, the material has no specific technical application and creates huge disposal and ecological problems. Sisal is mainly grown on large estates (several thousands of hectares), with a central factory in the middle of the estate. Between the age of 2 and 4 years, the plant is

* Corresponding author. E-mail: cundr@tf.czu.cz

ready for its first cutting and further cuttings occur at 12-monthly intervals. After cutting, the leaves are transported to the central factory (decorticator) where the fibre is extracted from the leaf and the sisal waste is ''produced''. After decortication, the fibre is dried, brushed and packed for export or as basic material for sisal-based products. According to some decortication tests [2], 19 tones of sisal waste are produced for every tone of dry sisal fibre.

Table 1. Global sisal fibre production in kilo tons (2001 – 2007) [1]

	2001	2002	2003	2004	2005	2006	2007
Africa	**64**	**59**	**60**	**68**	**68**	**71**	**78**
Tanzania	24	24	24	27	28	31	37
Kenya	23	22	25	27	26	26	28
Madagascar	12	8,4	8,6	10	10	10	10
South Africa	2	2	2	2	2	2	2
Mozambique	1	1	1	1	1	1	1
Angola	1	1	1	1	1	1	1
Ethiopia	1	1	1	1	1	1	1
L. America	**141**	**151**	**155**	**153**	**133**	**139**	**127**
Brazil	127	138	142	140	119	126	113
Mexico	35	35	35	35	27	27	27
Venezuela	11	11	11	11	11	11	11
El Salvador	7	7	7	7	7	7	7
Haiti	2	2	2	2	2	2	2
Jamaica	0.3	0.3	0.3	0.3	0.3	0.3	0.3
China	**37**	**38**	**35**	**35**	**35**	**35**	**35**
Total	**241**	**248**	**250**	**255**	**236**	**246**	**241**

Estimated global sisal fibre production exedeed 241 kilo tons in year 2007 (see Table 1). It is estimated that global sisal waste procuction is aproximately 4500 – 5000 kilo tons of sisal pulp annualy (see Table 2) which is alignocellulosic short fibre residue, composed of 62% cellulose, 16% pentosans, 12% hemicellulose and 8% lignin on a dry weight basis [3]. A large part (40–50%) of the total solids in sisal fibres consists of biofibres. Biofibres can only be partially degraded during the biogas process [4]. Owing to a lack of feasible conversion technologies, the use of sisal fibre waste for renewable energy production has not become a practical technical option yet.

Currently, this waste is mainly landfilled and dumped in nearby rivers or in fields, where microorganisms degrade it. As a result, the untreated waste cause a consumption of oxygen in the recipient watercourses which leads to oxygen-deficient water zones with a negative effect on fish and other living organisms. In the anaerobic part of the degradation process, methane is produced and emitted into the atmosphere. Methane has a global warming potential that is 21–56 times higher than that of carbon dioxide, and is estimated to contribute to 18–21% of the overall global warming [1,5,6].

Table 2. Estimated global sisal waste generation in kilo tons (2001 – 2007) [1]

	2001	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Africa	**1210**	**1121**	**1142**	**1286**	**1288**	**3308**	**1490**
Tanzania	447	448	454	509	528	587	701
Kenya	209	420	475	505	486	502	524
Madagascar	228	160	122	181	181	175	173
South Africa	32	30	30	30	30	30	30
Mozambique	19	19	19	19	19	19	19
Ethiopia	13	13	13	13	13	13	13
Angola	10	10	10	10	10	10	10
L. America	**2673**	**2871**	**2945**	**2901**	**2529**	**2643**	**2419**
Brazil	2419	2624	2698	2654	2263	2385	2153
Mexico	665	665	665	665	494	494	494
Venezuela	209	200	200	200	200	200	200
El Salvador	124	124	124	124	124	124	124
Haiti	40	40	40	40	40	40	40
Jamaica	6	6	6	6	6	6	6
China	**703**	**722**	**665**	**665**	**665**	**665**	**665**
Total	**4587**	**4714**	**4752**	**4853**	**4482**	**6616**	**4573**

MATERIAL AND METHODS

The sisal pulp used in the experiment was collected from a sisal-processing factory at Fort Dauphin, Madagascar. Sisal pulp was reduced to 1-5mm particle size by hand mixer. Zebu dung was collected at farm in Vyškov, Czech Republic. Inoculum used in experiment was collected at biogas plant Zemědělská stanice Krásna Hůrka, Czech Republic. Composition of sisal pulp and zebu dung is shown in Table 3. All materieals were stored at 4°C until used.

Table 3. Composition of sisal pulp and zebu dung

	Sisal	Zebu dung	inoculum
TS	16.60%	18.14%	7,50%
pH	4.39	9.1	7.8
C/N	45	14.6	
VS [% of TS]	87.5	86	
COD [$g \cdot kg^{-1}$]	60	160	

The experimental set-up consist of 7 anaerobic digesters, using wide-mouth 1.25 l Erlenmeyer flasks whitch had a working volume 0.9l. Each bioreactor was connected by silicon tubes with 15l plastic flasks for collecting biogas. Biogas was measured by amout of water displaced from 15l plastic flasks filled with solution of destiled water, H_2SO_4 (0.06 ml per l) and NaCl (10.2 $g \cdot l^{-1}$) in order to prevent disolving CO_2 into water. Bioreactors were mixed by hand shaking 2 times per day for 1 minute. The amout of biogas was measured minimum once per day. In order to keep the constant temperature at 30°C, the bioreactors were placed in waterbath. Measured pH at the beginning of the experiment ranged from 4.66 up to 9.1 (listed in Table 4) and there was not used any method to change pH to optimal range for anaerobic digestion (6.5 - 7.5). Methane content was measured by gas monitor EX2000C.

RESULTS AND DISCUSSION

The yield of methane from digestion of sisal pulp, zebu dung and co-digestion of sisal pulp and zebu dung in various concentratios is depicted in Table 4. The average CH_4 content of biogas produced from zebu dung alone was 59% and from digestion of sisal pulp the biogas content was 29%. The average CH_4 content of biogas produced from co-digestion of sisal and zebu dung ranged from 48% (60:80; sisal pulp : zebu dung) up to 61% (80 : 20). Interestingly, the best results were obtained from the mixture with ratio 40:60 and 80 : 20.

Table 4. Parameters of anaerobic co-fermetation of sisal and zebu dung

Fermentor	*Sisal:Zebu [%]*	*Sisal TS [g]*	*Zebu TS [g]*	*Inoculum TS [g]*	*pH start [-]*	*pH end [-]*	*Metan [%]*	*CH_4 [l $CH_4 \cdot kg^{-1}$ VS]*
1	20:80	5	20	22.5	7.51	7.3	53	144.4
2	40:60	10	15	22.5	6.2	7.54	52	170.8
3	60:40	15	10	22.5	5.48	5.91	48	48.7
4	80:20	20	5	22.5	4.66	4.9	61	173.3
5	0:100	0	25	22.5	9.1	7.44	59	88.4
6	100:0	20	0	22.5	4.39	7.3	29	1.8
7	inoculum	0	0	22.5	7.8	7.83	38	

According to the results of the study higher content of sisal in fermented mixture increases the production of biogas and slightly increases the content of CH_4 in biogas. There can be found trend in the intial values of pH with regards to the sisal pulp content. Sisal pulp itself had at the beginning of the experiment pH 4.39. When increasing the content of zebu dung, the initial pH also increased accordingly.

Generally, the trend is as follows. With the increasing content of sisal pulp in the mixture, the amount of produced biogas increases up to the ratio of sisal 80:20, which lead to the production of 173.3 litres of CH_4 per kg of VS added. With the increasing amount of biogas produced in the higher percentage mixtures of sisal pulp also increases the % of CH_4 in biogas; the best result was 61% of CH_4 produced in the mixture of 80:20.

Interrestingly, the fermentor 3 with ratio of sisal:zebu dung (60:40) had shown different results than the established trend of other fermentations. The initial very fast and high biogas production stopped after 69 hours of fermentation. Fermentor 4 with ratio of sisal : zebu dung (80:20) had shown fast and high biogas production as well.

When looking at the pH values at the end of the experiment, one can observe that the values for fermentor 3 and fermentor 4 are slightly lower than the rest of the end pH values. The reason for this might be unwanted acidification of the fermentation mixture that lead to the premature stop of the process of fermentation compared with the other fermentors.

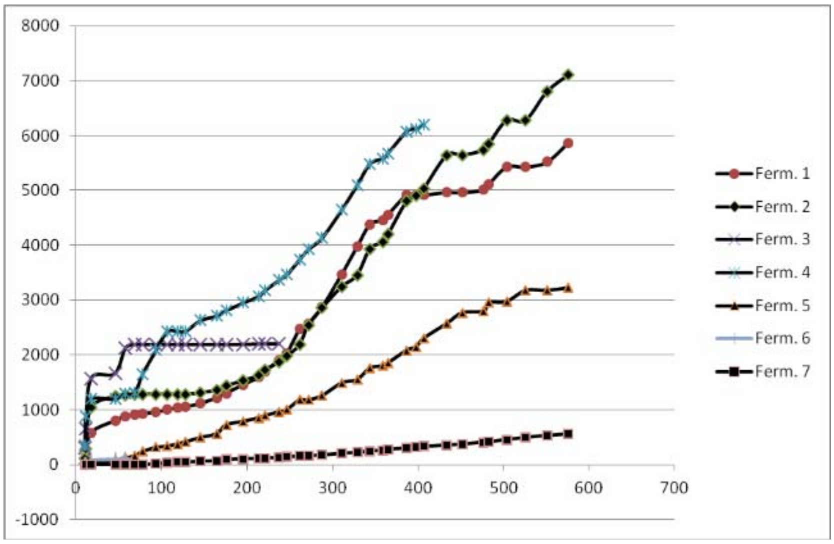

Figure 1. Amount of biogas in ml

First fermentor where the premature stop of the fermentation occurred was fermentor 3 which ended fermentation process after only 69hours of fermentation (see Figure 1 for details). The end pH of fermentor 3 was 5.91, whereas the fate of fermentor 4 was slightly more dramatic.

After 407 hours of fermention in fermentor 4, the inhibition of fermentation reaction occured and pH droped to 4.9. The fermetation process stoped. We would like to prevent this occurrence in the future experiments by stabilising pH at the beginning of the experiment to pH 7.0.

The experiement with anaerobic fermentation of pure sisal pulp shown very low biogas production 1.8 CH_4 per 1kg VS added with the methane content of 29% only. The probable cause of this is the high content of fibre and lignocellulose that requires hydrolysis in anaerobic conditions.

The results suggest that the optimal ratio of mixture of sisal pulp and zebu dung was between 60 : 40 to 80 : 20. Further exeperiments to verify this trend will be held. Although the amout of biogas produced by all bioreactors during the experiement was much lower than reported in literature[8], we believe that the future adjustments of this methodology can surely yield higher amounts of biogas produced.

CONCLUSIONS

This study has shown that anaerobic co-digestion of sisal and zebu dung is feasible process. Furthermore, the anaerobic co-digestion of sisal pulp and zebu dung is a viable alternative for recovering energy in the form of biogas with 48 - 61% methane content, while at the same time abating environmental pollution. The observations have shown that co-digestion of sisal pulp and zebu dung enhances anaerobic digestion and improve the biogas yield. The highest amout of biogas (173.3 l $CH_4 \cdot kg^{-1}$ of VS) was produced by bioreactor filled with 80% sisal pulp and 20% zebu dung at 5% of TS with highest content of methane as well (61% of CH_4). The sisal industry produce globaly over 4500 kilotons of sisal waste that can be use for biogas production. This can help to improve the economy of sisal producer and reduce ecologial and disposal problems of sisal industry. The batch anaerobic co-digestion can be applied in developing countries where low and cheap technology is needed in any cases.

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PRODUKCIJA BIOGASA PRI ANAEROBNOJ FERMENTACIJI MEŠAVINE USITNJENE MASE SISAL AGAVE I TEČNOG STAJNJAKA ZEBU GOVEDA

Ondřej Cundr[1], Dagmar Haladová[2]

[1]Češki Univerzitet prirodnih nauka Prag, Mašinski fakultet, Institut za pogonsko mašinstvo, Prag, Češka Republika
[2]Češki Univerzitet prirodnih nauka Prag, Institut za trope i subtrope, Prag, Češka Republika

Sažetak: Zajednička fermentacija različitih materijala je upotrebljena kako bi se poboljšala razgradivost materijala i povećala produkcija biogasa. Razgradivost i potencijal pulpe sisal agave za proizvodnju biogasa mogu se značajno povećati njenim mešanjem sa tečnim stajnjakom zebu goveda i fermentacijom dobijene smese. Anaerobna fermentacija pulpe sisala i zebu stajnjaka proučavana je posebno na ovim materijalima pojedinačno i na njihovim smesama u različitim odnosima. Najveće dobijene količine metana pojedinačno iz sisal pulpe, odnosno zebu stajnjaka, iznosile su 1.8 i 88 l $CH_4 \cdot kg^{-1}$ (redom) isparene suve materije (VS), dok je pri fermentaciji smese sa 80% sisal pulpe i 20% zebu stajnjaka dobijeno 173 l $CH_4 \cdot kg^{-1}$ VS. U svim ogledima je korištena masa sa 5% ukupne suve materije (TS).

Ključne reči: *pulpa sisal agave, tečni stajnjak zebu goveda, anaerobna ko-fermentacija*

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