BIOGAS PRODUCTION FROM PAPER DUST BRIQUETTES

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Abstract. As global warming is now undergoing major climate change, the need to reduce greenhouse gases has become more acute. Many processing industries have energy that we do not even think about on a daily basis. Residues of materials that are produced in many factories from technological processes are difficult for utilization. This is the case, for example, in the manufacture of corrugated cardboard, paper dust that accumulates in air filters. This type of waste, which is mechanically separated in technological processes in Latvia, accumulates about 250 tons per year. The company presses it into briquettes and burns. Incineration generates additional emissions. It would be more environmentally friendly to recycle such waste through anaerobic fermentation. The aim of the study was to determine the potential of biogas from paper dust briquettes in anaerobic fermentation. The study was conducted in four four-section bioreactors with a capacity of 40 litres. Anaerobic fermentation took place in mesophilic mode at 38 OC. The study lasted for 100 days, during which the following results were obtained. The biogas yield was on average 25.24 $L \cdot d^{-1}$ and the methane yield 12.3 $L \cdot d^{-1}$. The yield of biogas per gram of dry organic matter was on average 0.335 $L \cdot g_{DOM}^{-1}$, and the yield of methane was 0.163 $L \cdot g_{DOM}^{-1}$ at 48.7 % methane content. The novelty of the research was the use of paper dust briquettes and four-section bioreactors in anaerobic fermentation. The results are original. The results by sections are as follows: section 1 averaged 5.59 $L \cdot d^{-1}$, section 2 – 4.83 $L \cdot d^{-1}$, section 3 – 5.54 $L \cdot d^{-1}$, section 4 – 9.29 $L \cdot d^{-1}$. The study shows that paper dust briquettes are also well used for biogas production.

Keywords: biogas, four sections bioreactor, paper dust briquettes.

Introduction

As global warming is now undergoing major climate change, the need to reduce greenhouse gases has become more acute. Many processing industries have energy that we do not even think about on a daily basis. Residues of materials that are produced in many factories from technological processes are difficult for utilization. This is the case, for example, in manufacturing of corrugated cardboard, paper dust that accumulates in air filters. This type of waste, which is mechanically separated in technological processes in Latvia, accumulates about 250 tons per year (2013 data). The company presses it into briquettes and burns. There is a lot of this type of waste in Latvia.

The potential of biogas production from waste paper has been investigated worldwide. The biggest problems with the paper fermentation process are the colours and varnishes applied to the paper during the press release process.

Unlike animal manure and vegetable raw materials, paper must first be treated. Different methods are used – milling [1], beating [2], soaking, biological pretreatment – using four white-rot fungi [3] and rumen fluid [4].

Many countries (Scotland, Nigeria) are investigating the use of waste paper for biogas production.

Researchers at the University of West Scotland have investigating the yield of biogas from waste paper before it was beaten in a Hollander beater. The yield of biogas has been investigated varied with the beating time (0, 30 and 60 min) and the feedstock-inoculum ratio (0.3, 0.5 and 0.7). The best results, 253 mL CH_4 per 1 g_{DOM}^{-1}, were achieved at feedstock-inoculum ratio 0.3 and the beating time of 60 min. "Pretreated waste paper with a Hollander beater for 60 min improved the methane yield by 21 %" [2].

Researchers have investigated the potential of biogas and methane from unused paper waste in the LULST Bioenergy Laboratory. Shredded paper waste was mixed with inoculum and filled into 14 refillable bioreactors. Fermentation took place in mesophilic mode at 38 ºC. The results were as follows: the yield of methane 0.506 $L \cdot g_{DOM}^{-1}$ after 41 days of anaerobic digestion of office paper, 0.386 $L \cdot g_{DOM}^{-1}$, of toilet paper, 0.375 $L \cdot g_{DOM}^{-1}$, of packaging paper and 0.388 $L \cdot g_{DOM}^{-1}$ of cardboard were obtained. The study demonstrates that paper waste is a good raw material for production of methane [4].

"Cellulose hydrolysis is the rate-limiting step in anaerobic digestion. In the present investigation, waste paper was used as a model of cellulosic biomass and was pretreated with rumen fluid prior to methane production. To achieve a high methane yield, the reaction time of pretreatment was examined. Waste paper was soaked with rumen fluid for 6 and 24 h at 37 ^{O}C. Various volatile fatty acids, especially acetate, were produced by the pretreatment. Methane production was carried out over a 20-day period. The best daily methane yield was obtained by the 6-h pretreatment. The amount was 2.6 times higher than that of untreated paper, which resulted in 73.4 % of the theoretical methane yield. During methane production, the cellulose, hemicellulose and lignin degradability were improved by pretreatment. Pretreatment by rumen fluid is therefore a powerful method to accelerate the methane yield from cellulosic biomass." [5].

All of the above paper fermentation studies were related to paper pretreatment, but not direct paper fermentation.

The aim of this work is to investigate paper dust briquette fermentation in a four-section bioreactor and the potential of biogas production without using special pretreatment methods.

Materials and methods

The paper dust briquette investigation was performed in the LULST Bioenergy Laboratory. They were obtained in the corrugated cardboard manufacturing plant SIA Stora Enco, in the technological processes from air filters. Initially, the four four-section bioreactors (work volume 40 liters) were filled with cow manure, and when the anaerobic fermentation process was stable (a favourable bacterial association was cultivated to ensure a good bioconversion process), paper dust briquettes were added in the bioreactors, which were dissolved in water for 24 hours. The first step of the investigation was cultivation of the beneficial bacterial association in each bioreactor section for forty days and investigation of the addition of paper dust with various organic loads for one hundred days.

Fig. 1. **Paper dust briquettes**

At the beginning they were filled with 100 grams of diluted paper dust daily, and at the end of the investigation with 150 grams of diluted paper dust.

Dry organic matter (DOM) content was determined by weighting the initial biomass samples, drying in dry matter weights Shimazu at 120 ºC and then placed for ashing in the oven ("Nabertherm" type) at 550 ºC. Gas volumes were measured using water batch. The composition of gases, including oxygen, carbon dioxide, methane, and hydrogen sulphide was measured by help of the gas analyser (GA2000). The substrate pH value was measured before and after finishing the AD process, using a pH meter (model PP-50) with accessories. Scales (Kern, model KFB 16KO2) was used for weighting of the total weight of substrates before and after the AD process [6; 7].

The anaerobic fermentation process takes place in four stages – hydrolysis, acidogenesis, acetogenesis, and methanogenesis. Therefore, the bioreactor is divided into four sections for better anaerobic fermentation. The first three sections are the same in volume, but the fourth section is larger, because the biogas is released more in the methane-forming phase. Each section has three outlet pipes, one for the biogas output, and two for measuring instruments – pH and temperature sensors. The sensors are connected to a control panel, where the measurement results are displayed. A mixer is installed in order to improve the release of biogas from the substrate, where the operating cycle of which is adjusted from the control panel. The substrate is introduced into the first bioreactor section and the digestate output from the bottom of the fourth section. The picture of the four-section bioreactor is shown in Figure 2.

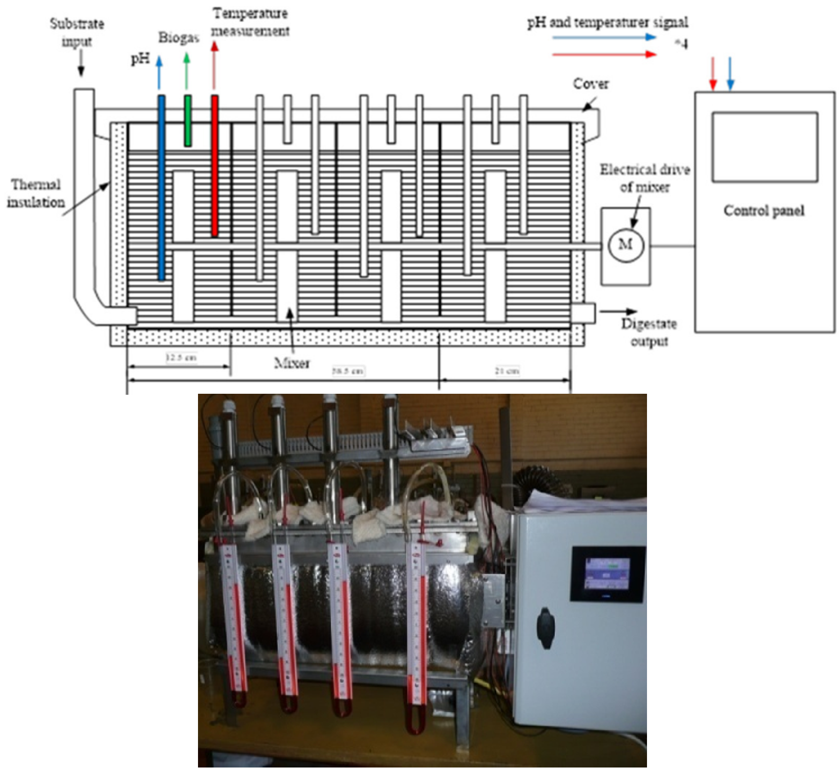

Fig. 2. **Four sections bioreactor**

The data of the substrate pH value, gas volume and composition were registered every day.

Results and discussion

The weight of raw material in Table1 is provided with the error value depending on accuracy of the respective weight measuring instrument used. The weight of total solids (TS) and dry organic matter (DOM) in Table1 is provided with accuracy ± 0.001 g. As it can be seen from the raw material (Table 1), paper dust briquette biomass has a relatively high dry matter and organic dry matter content. This is explained due to the fact that the paper dust briquettes are dry.

Table 1

Results of analysis of paper dust briquettes

Materials	Weight, g	TS, %	TS, g	ASH, %	DOM, %	DOM, g
Paper dust briquets	100	11.40	11.40	10.31	78.29	78.29

The biogas yield from each bioreactor section is shown in Table 2 and Figure 3. As it can be seen from the figure, the most biogas (average 9.29 $L \cdot d^{-1}$) was obtained in the fourth bioreactor section, where the growth of the methanogenesis bacteria occurred predominantly. Each bioreactor produced an average of 25.24 liters of biogas per day.

Table 2

Yield of biogas from each section

Name	Section 1, $L \cdot d^{-1}$	Section 2, $L \cdot d^{-1}$	Section 3, $L \cdot d^{-1}$	Section 4, $L \cdot d^{-1}$	Average per bioreactors, $L \cdot d^{-1}$
Bioreactor 1	6.40	6.54	6.70	8.78	28.43
Bioreactor 2	5.18	5.05	5.51	11.38	27.13
Bioreactor 3	5.15	4.06	5.41	8.27	22.90
Bioreactor 4	5.60	3.65	4.52	8.74	22.51
Max	6.40	6.54	6.70	11.38	31.03
Min	5.15	3.65	4.52	8.27	21.59
Average per sections, $L \cdot d^{-1}$	5.59	4.83	5.54	9.29	25.24

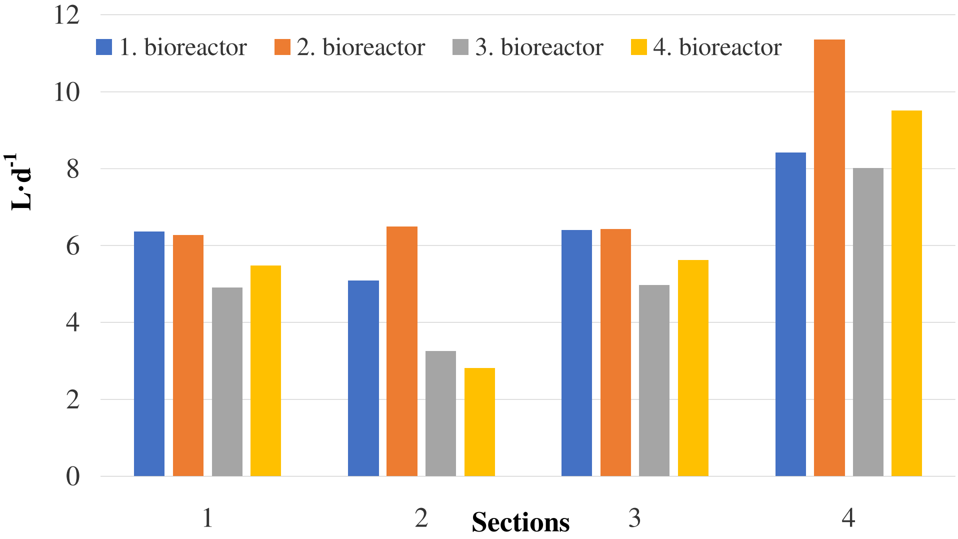

Fig. 3. **Biogas yield by sections**

The biogas quality indicators were as follows – the methane content of biogas, considering the indicators of each section, was on average 48.71 %. The lowest methane content in the first section was 46.64 %, which is due to the fact that in the first section the hydrolysis process is going on, which produces much less methanogenesis bacteria.

Table 3

Amount (%) of methane and carbon dioxide contained in biogas

Section	Bioreactor 1		Bioreactor 2		Bioreactor 3		Bioreactor 4		Average	
	CH_4	CO_2	CH_4	CO_2	CH_4	CO_2	CH_4	CO_2	CH_4	CO_2
Section 1	48.84	43.78	40.71	36.24	49.26	42.62	47.76	42.30	46.64	41.24
Section 2	50.25	44.42	49.17	44.59	49.18	43.19	48.46	42.52	49.26	43.68
Section 3	49.53	43.97	47.96	44.14	49.84	44.62	50.48	42.55	49.45	43.82
Section 4	49.46	43.22	47.58	43.10	50.12	44.08	50.81	44.03	49.49	43.61
Average	49.52	43.85	46.35	42.02	49.60	43.63	49.38	42.85	48.71	43.03

This raw material, containing a lot of dry organic matter (78 % from total weight), is well suited for biogas production. Biogas and methane yields from paper dust briquettes are shown in Figure 4.

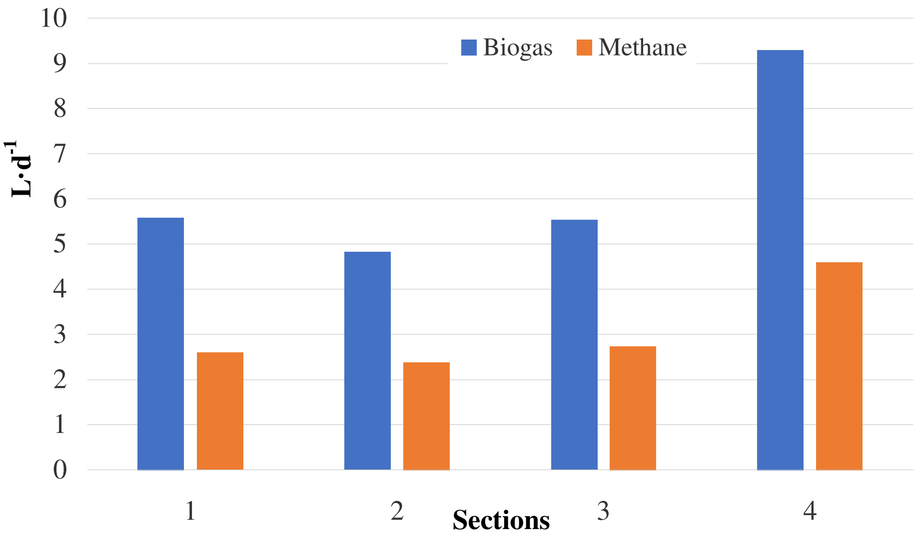

Fig. 4. **Biogas and methane yield average from each section**

The specific biogas and methane yield from bioreactors filled with paper briquettes and considering that the dry matter of the feedstock (100 g) was 78 %, shown in Figure 5.

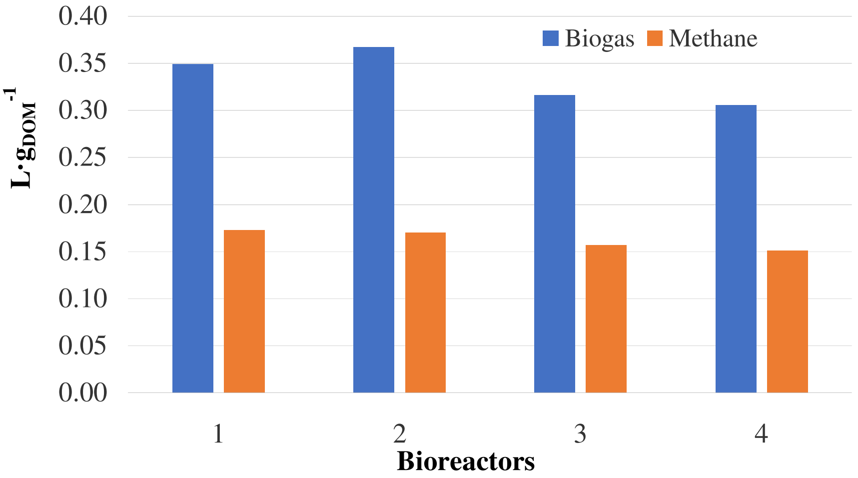

Fig. 5. **Specific biogas and methane yield**

Conclusions

1. The paper proved that paper dust briquettes can also produce good results in biogas production.
2. The average yield of biogas from the bioreactor was 25.24 litres per day.
3. Most of the biogas was extracted from the fourth section of the bioreactor (average 9.29 litres per day), which could also be predicted because of the growth of methanogenesis bacteria in that section.
4. Compared to other similar investigations, the methane content in biogas from paper dust briquettes was on average 48.71 %.
5. The specific biogas and methane yields per gram of dry organic matter were good – 0.335 $L \cdot g_{DOM}^{-1}$ for biogas, 0.163 $L \cdot g_{DOM}^{-1}$ for methane.
6. Better biogas yield was obtained by filling the bioreactors with 100 gr dissolved paper dust briquettes. The specific yield of biogas and methane decreases, when filling bioreactors with 150 gr of dissolved paper dust briquettes. The specific biogas yield – from 0.335 $L \cdot g_{DOM}^{-1}$ to 0.212 $L \cdot g_{DOM}^{-1}$ and the specific methane yield – from 0.163 $L \cdot g_{DOM}^{-1}$ to 0.103 $L \cdot g_{DOM}^{-1}$.

Acknowledgements

This work has been supported b y the project G4 "Feasibility Study of Biomass Anaerobic Fermentation Process Efficiency"

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