CO-DIGESTION OF CATTLE MANURE WITH PAPER DUST BRIQUETTES

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Abstract. In the world, around 26% of waste in landfills is paper waste. One way to recycle this kind of waste would be anaerobic digestion (AD) fermentation to produce biogas and methane. The aim of this research is to find specific volume of biogas and methane in anaerobic co-digestion of cattle manure with paper dust that was collected from a corrugated board production plant. Before anaerobic co-digestion (AD), the dry matter content and organic matter content of paper dust, cow manure and a mixture of both components were determined. The anaerobic digestion process for the cow manure - paper dust mixture was provided in three 4-section bioreactors with a working volume of 40 l per 4-section bioreactor. A mixture of cow manure and paper dust was added to the first section of the series-connected bioreactor sections, and digestate was removed from the fourth section during a 70-day anaerobic digestion process. Anaerobic digestion was provided at the mesophilic temperature of 38 °C, and the amount of paper dust in the input substrate was gradually increased from 50 grams to 180 grams. Organic load increased from 0.25 $g\cdot(dL)^{-1}$ to 2.9 $g\cdot(dL)^{-1}$. Biogas yield varied from 19.1 $L\cdot d^{-1}$ to 35 $L\cdot d^{-1}$ depending on the organic load. The maximum value of the specific yield of biogas is 0.428 $L\cdot g_{DOM}^{-1}$. The concentration of methane in biogas started from 55%, and the maximum value – 60%, and the maximum specific methane yield was 0.254 $L\cdot g_{DOM}^{-1}$. The obtained maximum specific methane yield from co-digestion of cattle manure and paper dust was higher compared to previous studies where only paper dust was digested.

Keywords: anaerobic digestion, cattle manure, paper dust, biogas.

Introduction

Paper was discovered centuries ago in ancient China and has since been widely used in the production of writing paper, newspapers, banknotes and packaging, most of which ends up in the waste stream.

MSW generally consists of food waste, paper, glass, metals, plastics, textiles, yard waste, etc., but the characteristics of MSW vary around the world. It has been found that developing countries have a high proportion of organic municipal waste [1], while developed countries have a relatively higher proportion of plastics and paper.

In many countries, waste paper is used as an energy source, for example, in Germany it is burned in special waste plants – refuse derived fuel (RDF) power plants [2].

Anaerobic digestion has become the preferred way to treat the organic fraction of municipal solid waste, as the digestate produced can be used as an organic fertiliser or soil conditioner in addition to the biogas energy produced, which makes anaerobic digestion commercially attractive [3].

An important factor is microbial community used for pretreatment or/and anaerobic fermentation of lignocellulosic materials. Rumen fluid with waste paper pieces (0.1% w/v) was incubated for 120 h at 37 °C, resulting in the decomposition of approximately half of the cellulose and hemicellulose content of the waste paper and the accumulation of some volatile fatty acids. Clostridia (e.g. Ruminococcus and Clostridium) were the predominant bacteria before and after 60-h pretreatment, and their relative abundance was increased during pretreatment. The best daily methane yield obtained by a 6-h pretreatment was 2.6 times higher compared to untreated paper and resulted in 73.4% of the theoretical methane yield [4].

Paper or cardboard (CB) waste have a high C:N ratio usually, therefore co-digestion with nitrogen rich material, e.g. chicken manure (CM), co-digestion of CM with CB increased the bio-availability of the system, at 65:35 ratio of CB mixed with CM reached the highest improvement (14.2%) and produced 319.62 $mL_{CH4}\cdot g_{VS}^{-1}$ [5].

Anaerobic digestion can be accelerated by mechanical pre-treatment of paper biomass to obtain small particles. A mechanical pretreatment of waste paper using the Hollander beater [6] for 60 minutes improves the yield of methane 254 $mL\cdot g_{VS}^{-1}$ or by 21% increase compared to unprocessed waste paper.

In agricultural farms with cattle, biogas can be produced using paper waste and cow dung. In one study, two digesters were used, one charged with paper waste alone as control and the other charged with cow dung and paper waste. The retention period of the AD process was 44 days, the cumulative biogas yield for paper alone was 210.5 $mL_{CH4}\cdot g_{VS}^{-1}$, while that of paper blended with cow dung was 322.5 $mL_{CH4}\cdot g_{VS}^{-1}$ [7].

Priadi C. studied the co-digestion of cattle manure with paper waste and found that AD using paper waste with cattle manure produces methane of 269 $mL\cdot g_{VS}^{-1}$ compared with anaerobic digestion using only paper waste which produced 14.7 $mL\cdot g_{VS}^{-1}$ [8].

Anette T. Jansson conducted studies with the digestion of food and paper waste at different concentrations of their doses in the substrate. The highest production of methane – 402 $mL_{CH4}\cdot g_{VS}^{-1}$ and 229 $mL_{CH4}\cdot g_{VS}^{-1}$ has been obtained by digestion of FW and PW, respectively, at 14% TS, corresponding to a S/I ratio of 0.5 [9].

Momoh O.L.Y. studied the co-digestion of cattle manure, waste paper and water hyacinth. In the pre-treatment operations, approximately 500 g of freshly harvested water hyacinths were weighed and dried in the sun for 30 days, followed by drying in an oven at 60 ºC for 5 hours. The effect of waste paper on the production of biogas from digestion of a fixed amount of cattle dung and water hyacinth was studied at room temperature in five bioreactors for more than 60 days. Maximum production of biogas of 1.11 litres was observed at optimal amount of waste paper of 17.5 g combined with 5 g of cattle dung and 5 g of water hyacinth in 250 mL of water [10].

The purpose of this study is to investigate the obtained results of co-digestion of cattle manure and paper dust briquettes in four-section bioreactors and the production of biogas without the use of specific pre-treatment methods.

Materials and methods

One of the factories where cardboard waste from recycling accumulates is the corrugated board production plant of Stora Enso Ltd. A lot of paper dust is generated when cutting cardboard. This can cause many health problems, such as breathing problems. When the paper dust mixes with the air flow it is sucked into the ventilation system, transported to a dispenser/separator and collected in a dust container. At the bottom of the container are positioned conveyors transporting the dust to the press (Fig. 1) which is forming paper dust briquettes (Fig. 2).

Fig. 1. **Dust press**

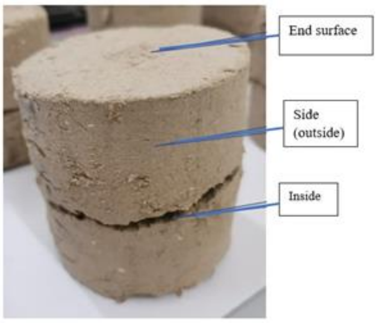

Fig. 2. **Paper dust briquets**

Paper dust briquettes contain a lot of dry organic matter, so the biogas potential may be high. Before digestion, paper dust briquettes were soaked in water. Soaked paper dust briquettes were weighted, mixed with cattle manure and filled in every bioreactor according to the experimental plan.

Before digestion of paper dust, physicochemical analyses were performed with them at the Latvia University of Life Sciences and Technologies (LBTU) Biotechnology Scientific Laboratory, the Department of Agronomic Analysis and the Department of Smart Technologies.

Studies on dust briquettes were performed, by using a SEM microscope Tescan MIRA3 XMU, in three places: (1) outside of briquette; (2) briquette end surfaces, (3) inside of briquette (Fig. 2).

Ten points (Spectrum) were selected in each sample, where X-ray spectroscopy (EDS) with Oxford Instruments X-Act 10 mm2 detector was performed (Fig. 3).

The planning and execution of the experiments were based on a standard experimental methodology developed by German specialists [11] and Latvian scientists. The determination of the physical parameters – total solids, ash and dry organic matter was similar to that described in the previous study [12].

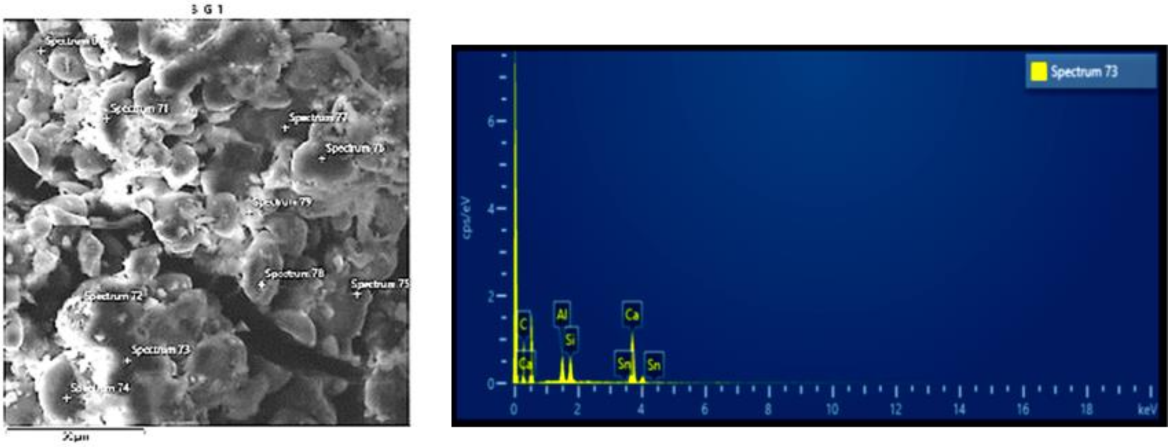

Fig. 3. **Illustration from microscope SEM Tescan MIRA3 XMU, X-ray spectroscopy (EDS) with Oxford Instruments X-Act 10 mm2 detector**

Also, the experimental setup for continuous operation of the 4-chamber anaerobic digesters and the methodology for daily filling of substrate and removing of digestate were similar to that described in the previous study [12]. In the four-chamber bioreactors, anaerobic fermentation of the biomass was carried out in a sequential four-step process - hydrolysis, acidogenesis, acetogenesis and methanogenesis [13]. The biomass substrate is loaded into the first chamber and the car moves in this order to all the reactors in series and the digestate is removed from the fourth chamber. A four-section bioreactor was developed and patented in the Bioenergy Laboratory of LBTU. Its development is based on information on the optimal conditions for the microorganisms involved in the anaerobic digestion process. To improve the production and quality of biogas, various microorganisms of anaerobic digestion are separated and a better living environment is created for them. Therefore, the bioreactor is divided into four sections.

Optimal conditions are created for each group of microorganisms. For methane formation in the sections, an additional device for immobilization of microorganisms is installed so that as much of it as possible remains in the bioreactor and is not removed together with the digestate.

The working volume of the four-section bioreactor is 40 litres. The four-section bioreactor consists of a tank divided into four sections. The tank is hermetically sealed with a cover equipped with pipes for measuring instruments and biogas discharge. The bioreactor tank is equipped with a temperature assurance system – thermal insulation. The injected biomass is fed through a pipe in the first section and mixed with the biomass in the second section. In these two sections hydrolysis and acid formation take place, H_2 is produced. The main gases emitted in these sections are CO_2, O_2, N_2 and H_2. The second section is connected to the third section and there is the formation of acids, especially acetic acid. When filling a fresh batch of biomass, the same amount enters the fourth section, where acetic acid is used by methane-producing bacteria. As their operation is slower, the space of the fourth section is larger. Each section has the output of a pH and temperature meter and a location where digestate samples can be taken for analysis. A stirrer is installed throughout the bioreactor room. The mixer ensures mixing of fresh and existing substrate, as well as prevents the formation of a crust on the surface of the substrate. It cyclically mixes the substrate according to a regular program. The produced biogas enters the biogas storage vessels via pipelines - from the first three sections to 15 litre and from the fourth section to 25 litre plastic tanks, which are filled with water and hermetically sealed. Three-way valves are installed in the biogas pipelines to connect the gas analyser. The amount of biogas produced is determined by the amount of water expelled from the plastic tanks. The squeezed water is collected continuously in containers. The amount of water displaced, and therefore the amount of biogas produced, is measured with measuring cups. The structure and dimensions of the bioreactor are given in the previous report, which is descriptive on this topic [12].

This investigation was in three four-section bioreactors andLasted for 70 days. The anaerobic digestion occurred in a mesophilic mode at 38 °C and the amount of paper dust in the injected substrate was gradually increased from 50 grams to 180 grams.

Results and discussion

Before the mixed substrate was introduced into the bioreactor, each component of the substrate – cattle manure and paper dust – as well as the mixed substrate itself, was weighed and the following characteristics were obtained: total solids (TS), ash and dry organic matter (DOM). The obtained characteristics are shown in the following table. The amount of water added was such that the dry matter content of the feedstock was not high (maximum 10%) and it could move freely inside the bioreactor. The amount of water added to each raw material mixture was different (not shown in Table 1).

Table 1

Results of analysis of raw materials

Raw material	Weight, g	TS, %	TS, g	Ash, %	DOM from TS, %	DOM, g
Paper dust	50	77.04	38.52	21.85	78.15	30.10
	80	77.04	61.63	21.85	78.15	48.17
	150	77.04	115.56	21.85	78.15	90.31
	180	77.04	138.67	21.85	78.15	108.37
Cattle manure	400	5.22	20.88	17.00	83.00	17.33
Paper dust + cattle manure + water	450	9.03	59.40	21.96	78.04	47.43
	480	9.03	82.51	21.96	78.04	65.50
	550	9.03	136.44	21.96	78.04	107.64
	580	9.03	159.55	21.96	78.04	125.70

The results of the paper dust composition and physicochemical analyzes from LULST laboratories were as follows (Fig.4 and Tab.2).

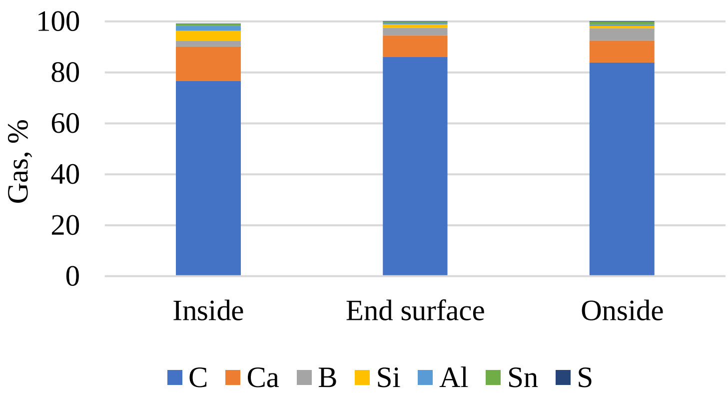

Fig. 4. **Percentage distribution of metals in paper dust briquettes**

Table 2

Results of briquette investigation

Metals and parameters	Results
C, weight, %	82.16*
Ca, weight, %	10.24*
B, weight, %	3.32*
Si, weight, %	2.08*
Al, weight, %	1.08*
Sn, weight, %	0.79*
S, weight, %	0.11*
Cu, in dry matter, %	61.25**

Table 2 (continued)

Metals and parameters	Results
Mn, in dry matter%	70.57**
Fe, in dry matter%	2624.26**
Zn, in dry matter%	179.74**
Total nitrogen, %	0.19**
pH	8.42**
Ammonium nitrogen (N/NH4), $g \cdot kg^{-1}$	0.17**
Wood fiber, in dry matter%	50.93**
Fat, in dry matter%	1.07**
Lignin, %	13.76**

* – The Department of Smart Technologies
** – The Department of Agronomic Analysis

Paper dust briquettes (PDB) quickly absorb moisture from the bioreactor, dissolving and settling in the bioreactor. Inoculated bacteria have easy access to organic matter. As it can be seen from the raw materials (Tab.2), the biomass of paper dust briquettes has a relatively high dry matter and organic dry matter content.

The results of the LULST laboratory showed that there was more metal directly inside the briquette than on the end surface and outside (Fig. 6). The concentration of different metals from both laboratories can be explained by the fact that only a few points (spectrum) were studied in the Smart Technology Laboratory, but the Laboratory of Agronomic Analysis worked with the whole briquette weighing 150 grams (Table 2).

The presence of calcium indicates a sulphite process in the production of paper when lignin, which contains cellulose fibres, is broken down. Boron is an adhesive used in the production of corrugated boards. Chlorine is used to bleach paper (Tab.2).

When diluting paper dust briquettes with cattle manure and water, the total dry matter decreases from 77.04% to 9.03%, but the dry organic matter from total solid does not decrease so significantly – from 78.15% to 78.04%. This can be explained by the fact that cattle manure contains more dry organic matter% compared to paper dust briquettes – 83% and 78%, respectively. The organic load thus varied from 1.25 $g \cdot (dL)^{-1}$ to 2.9 $g \cdot (dL)^{-1}$.

The yield of biogas, relative to the weight of paper dust briquettes in the injected substrate, increased from 19.04 litres per day for 50 grams of PDB to 35.83 litres per day for 180 grams of PDB. Considering the yield of biogas by bioreactor sections, the highest yield of biogas was from section 4 – from 8.88 litres per day to 18.63 litres per day.

Table 3

Average yields of biogas from each section

Raw materials, g	Biogas from sections, L				Sum, L
	1.	2.	3.	4.	
50 PDB + 400 CM	3.54	3.15	3.82	8.88	19.08
80 PDB + 400 CM	5.37	4.66	5.35	12.65	28.04
150 PDB + 400 CM	6.43	5.51	6.15	17.49	35.31
180 PDB + 400 CM	6.39	5.10	5.72	18.62	35.83
100 PDB	5.61	4.87	5.57	9.31	25.36

The methane concentration in the biogas ranged from 55% to a maximum value when injected 150 grams of PDB – 60%.

The investigation lasted for 70 days. Specific average yield of biogas and methane $L \cdot g_{DOM}^{-1}$ of every load group are shown in Fig. 5 and Table 4.

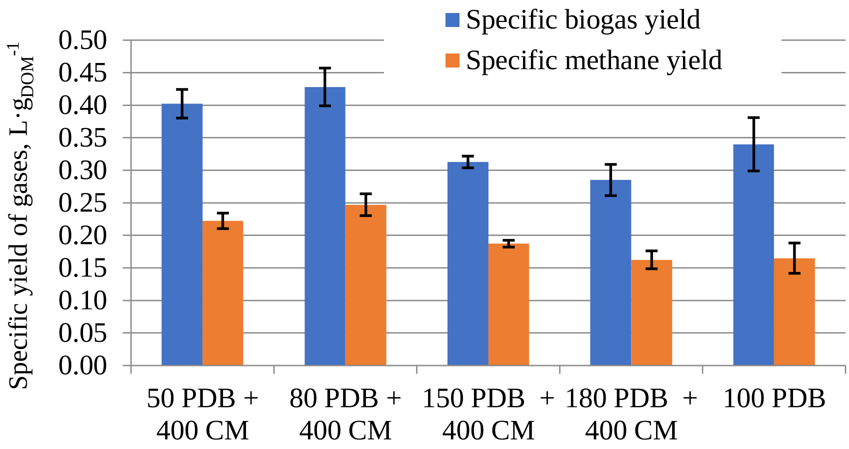

Fig. 5. **Specific yields of biogas and methane**

Table 4

Average specific yield of biogas (L g_{DOM}^{-1}) by bioreactors

Raw materials, g	Bioreactors, L·g_{DOM}^{-1}			Average, L·g_{DOM}^{-1}	± stdev	CH4		
	1.	2.	3.			%	average	± stdev
50 PDB + 400 CM	0.377	0.415	0.414	0.402	0.022	55.3	0.222	0.012
80 PDB + 400 CM	0.423	0.460	0.402	0.428	0.029	57.7	0.247	0.017
150 PDB + 400 CM	0.314	0.321	0.304	0.313	0.009	59.9	0.187	0.005
180 PDB + 400 CM	0.306	0.290	0.259	0.285	0.024	57.0	0.162	0.014
100 PDB	0.381	0.323	0.302	0.345	0.041	48.7	0.165	0.023

The specific yield of biogas and methane was higher compared to the previous investigation [12] when the bioreactors were filled with only 100 grams of paper dust briquettes. The maximum biogas and yield of methane values were - 0.345 L·g_{DOM}^{-1} and 0.247 L·g_{DOM}^{-1}, respectively.

Conclusions

Compared to previous studies, where only paper dust digestion was studied, co-digestion of paper dust with cattle manure showed better biogas parameters, perhaps, due to improved C:N ratio.

The maximum biogas yield obtained from co-fermentation of paper dust and cow manure was 35.85 L·d^{-1}, which is 43.1% more than found in the previous study in which only paper dust was digested.

Specific biogas and methane yields were by 26% and 49.5% higher respectively compared to the previous investigation in which only paper dust was digested.

Maximum methane concentration in biogas was 60% reached when bioreactors were filled with 150 grams of PDB.

By increasing the organic load between 1.25-2.9 g·$(dL)^{-1}$, the maximum specific yield of biogas (methane) 428 (247) L·g_{DOM}^{-1} was observed at the organic load of 1.66 g·$(dL)^{-1}$.

The co-digestion process with cattle manure speeds up the digestion process, as cattle manure contains bacteria community facilitating anaerobic digestion. The results were good also because the paper dust particles were small and the microorganisms had better access to the paper particles due to increased contact area.

The four-section bioreactor can be successfully used for anaerobic co-digestion of waste biomass residues like paper dust briquettes or/and cattle manure.

Research shows that paper dust can be used to generate energy, such as biogas. The use of this type of waste wouldLead to financial and energy savings for companies involved in the production of paper and packaging products.

Author contributions

Conceptualization, IS and VD; methodology, VD; software, VD; validation, Indulis Straume and Vilis Dubrovskis; formal analysis, VD and IP; investigation, IS; resources, IS; data curation, IS; writing – original draft preparation, IS; writing – review and editing, VD and IP; visualization, IS; supervision, VD; project administration, VD.

Conflicts of interest

The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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