BIOGAS PRODUCTION POTENTIAL FROM AGRICULTURAL BIOMASS AND ORGANIC RESIDUES IN LATVIA

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Abstract. Biogas production from straw, leaves and algae was investigated using the number of small reactors. Biomass mixed within oculums (fermented cow manure) was investigated for biogas production in eleven digesters, operated in batch mode at temperature38 ± 1.0 °C. The investigated average specific biogas yield was 377 ± 22 l·kgVSA-1, 438 ± 67 l·kgVSA-1 and 307 ± 221 l·kgVSA-1per unit of volatile solids added (VSA). The average specific methane yield from fallen leaves of trees was 204 ± 19 l·kgVSA-1and average methane (CH4) content was 54 %. The average methane yield from chopped barley straw was 280 ± 39 l·kgVSA-1and average methane content was 64 %. The average methane yield from algal biomass from the Baltic Sea was 119 ± 62 l·kgVSA-1and average methane content was 42 %. Addition of carbon rich biomass is recommended for anaerobic fermentation of algal biomass to increase the substrates C:N ratio. All investigated biomass can be utilized for local bioenergy production in Latvia.

Keywords: agricultural waste, anaerobic digestion, biogas, energy crops, methane.

Introduction

There is a need for investigation of the energy potential obtainable from organic waste or residues not competing with food or fodder production, to fulfil the obligations for Latvia to increase the share of renewable energy up to 40 % of gross energy consumption in 2020. Biogas production can be regarded as the most environmental method for energy extraction from biomass, as the post fermentation digestate can be utilized for soil enrichment with plant nutrients and organic matter. According to the Regulation of The Cabinet of Ministers of the Republic of Latvia the share of electric energy produced in biogas plants should provide 7.93 % of the total electricity consumption in the 2010 – 2020 periods in Latvia [1].

It is important to clarify the potential of readily available and cheap biomass resources for biogas production from local biomass. Straw is a by-product obtainablefromcerealsraisedonarea0.513 million ha and providing1.4milliontonsofcerealgraininLatviain2011.Barley was grown on area 94.7 thousands ha and provides the grain yield 227 thousand tons with average yield 0.24 t ha^{-1} in Latvia in 2011. The amount of straw utilizable for energy can be calculated as difference between the amount of the harvested straw and the amount of straw utilized for fodder, litter, technical needs and for compensation of losses of soil organic matter [2]. The total potential of barley straw was 160 thousand tons and the share of barley straw available for bioenergy purposes can be estimated as 50 % or 80 thousand tons in Latvia in 2011.

Fallen leaves, collected in parks or populated areas, are land filled usually. Utilization of organic material in biogas plants complies with the existing EC and Latvian legislation on substantial reduction of the share of biodegradable organic wastes in landfills. According to the national waste management plan [2] biodegradable municipal waste going to landfills must be reduced by50 % and 65 % in 2013 and 2020 respectively, compared to biodegradable waste landfilled in 1995 [3]. Utilization of fallen leaves for biogas production will provide energy production as well as returning of the plant nutrients into the plant growing cycle.

Algae biomass growing rate increases in recent years due to accelerating eutrophication and global warming processes. Algae biomass was blown by dominant Western winds and was settled at the Baltic Sea seaside stretching over 497 km within the territory of Latvia. Algae biomass can be obtained during cleaning of seaside, lakes or from wastewater treatment ponds covered with algal biomass.

The aim of the investigation is evaluation of biogas and methane potential obtainable from barley straw, fallen leaves and algal biomass in the anaerobic fermentation process.

Materials and methods

Investigation of anaerobic fermentation of fallen leaves, barley straw and algal biomass was provided in 11 small batch reactors in the volume of 0.8 litters. The leaves, barley straw and algae were chopped in small pieces and analysed for the moisture, dry matter and organic matter content.

The fallen leaves were collected in the Jelgava city park in the autumn 2011. The leave sample was composed of oak, maple and birch leaves. Three replicates of the leave sample were filled in the reactors R1 – R3 together with inoculums for the anaerobic fermentation process. Inoculum was obtained from fermented cow manure.

The barley straw sample was obtained from barley harvested in Jelgava municipality. Barley straw was chopped and soaked thoroughly in water before the experiment. Three replicates of barley straw with inoculum were filled in the reactors R5 – R7 for anaerobic digestion.

Algal biomass was collected in Jūrmala, at the seaside of the Baltic Sea, where algae accumulate on a regular basis. Four replicates of the algal sample were mixed with inoculums, and filled in the reactors R8 – R11 for the anaerobic digestion process. The fermented cow manure was used as inoculum in all 11 reactors. Only inoculum was filled in the reactor R4 (control). The biogas or methane volumes obtainable from inoculum in the reactor R4 were used for evaluation of net biogas or methane obtainable from the added biomass. The biogas volume produced from the added biomass calculates as following:

$$V_{BA} = \frac{V_{BS} - V_{BIN}}{M_{VSA}}, \tag{1}$$

where V_{BA} – biogas produced from volatile solids of added biomass, $l \cdot kg_{VSA}^{-1}$;
V_{BS} – biogas produced from substrate in anaerobic fermentation process, l;
V_{BIN} – biogas volume produced from inoculum in anaerobic fermentation process, l;
M_{VSA} – mass of volatile solids in added biomass, kg_{VSA}.

The methane volume produced from added biomass calculates as following:

$$V_{CH_4} = \frac{V_{CH_4S} - V_{CH_4IN}}{M_{VSA}}, \tag{2}$$

where V_{CH4A} – methane produced from added biomass, $l \cdot kg_{VSA}^{-1}$;
V_{CH_4S} – methane produced from substrate in anaerobic fermentation process, l;
V_{CH_4IN} – methane produced from inoculum in anaerobic fermentation process, l.

All 11 reactors were positioned in a heated camera having automatic temperature control at 38 ± 1 ºC. Fermentation was provided in the period up to 30 days or until no biogas was released from the reactors.

The dry matter, ashes content and pH level were measured before and after the anaerobic fermentation process. The biomass weight was measured on the scales Kern16KO2 FKB having accuracy ± 0.2 g. The measurement of pH level was provided by help of the equipment PP-50. By help of a specialized unit Shimazy the biomass samples were dried for moisture and the total solid content at temperature 105 ºC with mass weighting accuracy ± 0.001 g. Aches for volatile solid content evaluation was measured by help of the oven Nabertherm at temperature 550 ºC. Biogas from every reactor was guided into external storage bags for gas volume measurement and analysis of gas composition. The gas composition, e.g., methane, carbon dioxide, oxygen and hydrogen sulphide content, was measured with the gas analyser GA 2000. The standard error was estimated by help of standardized data processing tools for each group of digesters.

Results and discussion

The parameters of inoculum, biomass added, substrates and volumes of released biogas and methane from the reactors are shown in Table 1. Substrates in replications within each group of reactors have exactly the same composition and weight as at the start of anaerobic treatment (see Table 1). Variant results were obtained for the parameters during the experiment in each reactor;

therefore, average values (with standard error) were used for the parameter evaluation of every group of replicates having the same biomass type added (see Table1).

Table 1

Substrates and biogas parameters in anaerobic fermentation process

Reactors	R1-R3	R4 (inoculum)	R5-R7	R8-R11
Substrate composition, %	96.15 IN 3.85 FL	100 IN	96.15 IN 3.85 BS	96.15 IN 3.85 AL
Substrate pH (start)	7.28	7.44	7.34	7.34
Substrate (start), g	520	500	520	520
Biomass added (start), g	20	–	20	20
Substrate total solids (start), %	5.83	3.69	6.90	4.28
Substrate volatile solids (start), %	4.83	2.98	5.91	3.39
Total solids added (start), g	11.86	–	17.42	3.83
Volatile solids added (start), g	10.22	–	15.87	2.74
SubstratepH (final)	7.11 ± 0.54	7.09	7.16 ± 0.22	7.22 ± 0.10
Biogas(from substrate), l	4.45 ± 0.34	0.60	7.55 ± 3.23	1.44 ± 0.64
Aver. methane (from substrate) content, %	50.2 ± 9.7	24.7	61.0 ± 18.5	33.4 ± 7.1
Biogas (from added biomass), $l \cdot kg_{VSA}^{-1}$	377 ± 28	0	438 ± 185	307 ± 235
Methane (from added biomass), $l \cdot kg_{VSA}^{-1}$	204 ± 20	0	280 ± 108	119 ± 66

Notes: IN – inoculum, FL – fallen leaves, BS – barley straw, AL – algal biomass, VSA – volatile solids added.

All reactors with the same added biomass (or all replicates) have an identical substrate composition at the start of the anaerobic treatment process. The substrate pH level was in the range of 7.28 – 7.44 at the start of anaerobic digestion and decreases to 7.09 – 7.22 at the end of the anaerobic process (see Table 1). The highest biogas production was observed during the first week of anaerobic treatment and ceases in the following period. The biogas and methane production in reactors containing inoculum and chopped fallen leaves is shown in Figure 1.

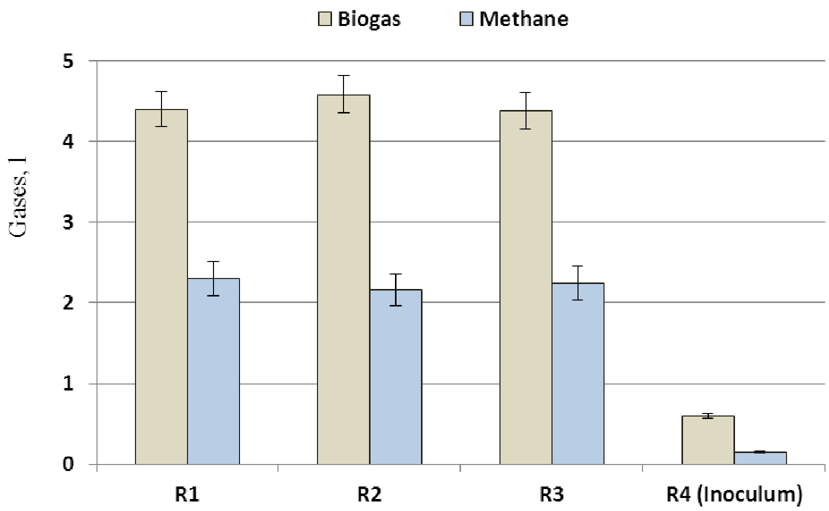

Fig. 1. **Biogas and methane release from reactors R1-R3 containing inoculum and fallen leaves and from reactor R4 containing inoculum**

There are very small differences in biogas or methane production between the reactors R1-R3, possible due to mixing carefully of different types of leaves and providing an equal amount of biomass and inoculums in each reactor. The average methane content, varying from 47.2 % in the reactor R2 up to 52.2 % in the reactor R1, was sufficient for stable operation of the cogeneration unit.

The biogas and methane production in reactors with inoculum and barley straw is shown in Figure 2.

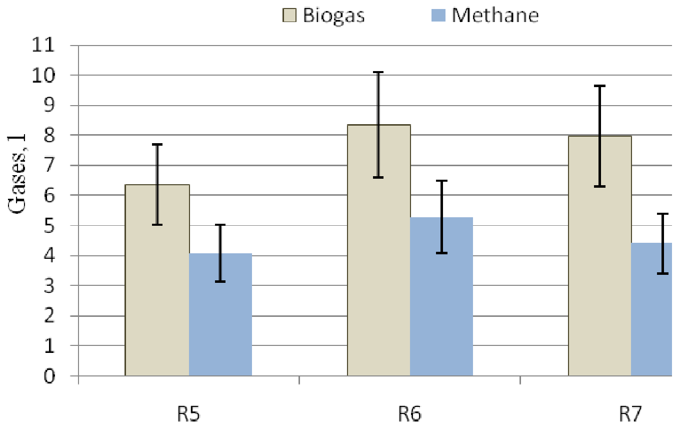

Fig. 2. **Biogas and methane release from reactors R5-R7 with barley straw and inoculum**

Barley straw substrates have the highest volatile solid content 5.91 % compared to all other substrates at the start of anaerobic fermentation. High organic load does not lead to acidification of substrates with barley biomass and the final pH values were 7.05, 7.18 and 7.25 in the reactors R5, R6 and R7, respectively. Balanced C:N ratio of substrates was established in the result of co-digestion of barley straw having high typical carbon to nitrogen (C:N) ratio 45 – 56:1 [4] with inoculum from fermented cow manure having low C:N ratio of 9-20:1 [5]. The methane content in biogas was 64.3 %, 63.3 % or 55.3 % in the reactors R5, R6 or R7 respectively, confirming stability of methanogenic processes in the reactors.

The biogas and methane production in reactors with inoculum and algal biomass is shown in Figure 3.

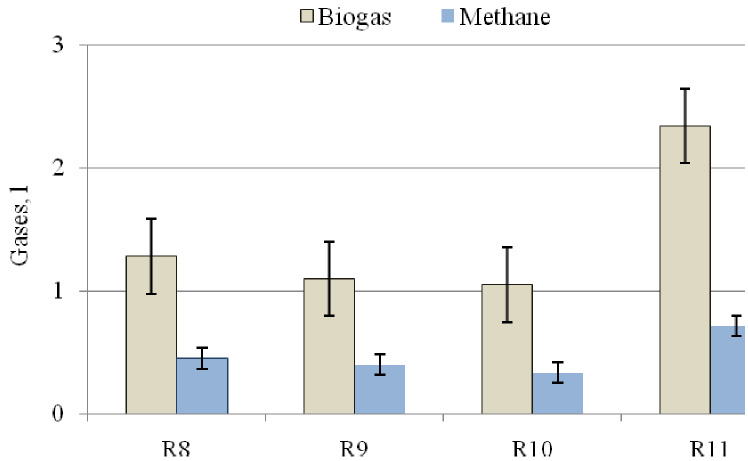

Fig. 3. **Volumes of biogas and methane produced in reactors R8-R11 containing algal biomass and inoculum**

The biogas and methane yield in the bioreactor R11 was twice as high as in the other reactors. This evidence can be explained by the slightly increased volatile solid content and/or by better adaptability of bacteria association to sea salts embodied in algal biomass. Some inhibiting processes obviously take place in the reactors R9 and R10, most likely due to unbalanced substrate C:N ratio as co-digested algal biomass and inoculum have low C:N ratio. Typical C:N ratio for algal biomass is 6-7:1 [6] and inoculum (fermented cow manure) in the range of 9-20:1 [5], therefore, algal biomass substrates in the reactors R8-R11 may have C:N level below 15-30:1, the ratio reported as optimal for anaerobic fermentation [5 – 7]. The average methane content in biogas was varying from 30.7 % in the reactor R11 up to 36.2 % in the reactor R9 and was sufficient for utilization of biogas in boiler houses, but it was too low for stable operation of the cogeneration unit.

The investigated average specific biogas and methane yields from added biomass, with subtracted gases released from inoculum according to equations (1) and (2) are shown in Figure 4.

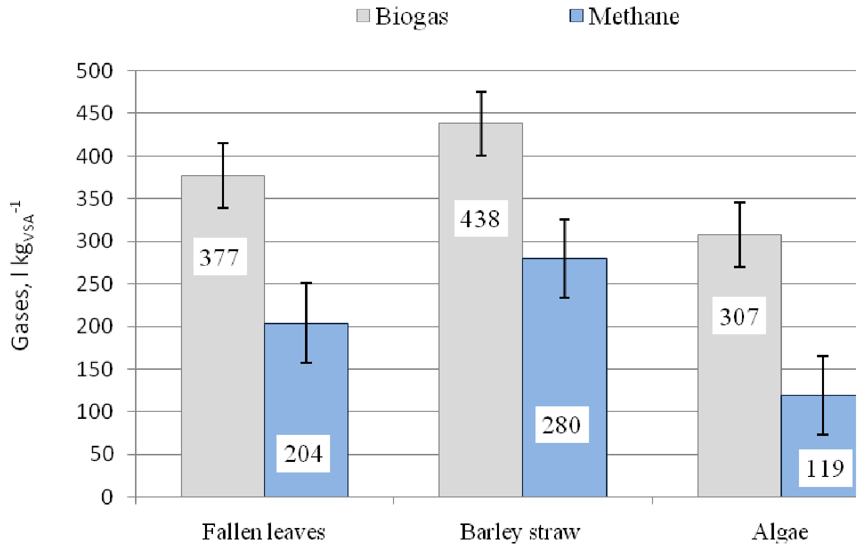

Fig. 4. **Average specific biogas and methane yield produced per 1 kg volatile solids of added biomass**

The average specific biogas production yield 377 ± 22 l·$kg_{VSA}^{-1}$with the average methane content 50.2 % was obtained from fallen leaves. Further improvement of biogas output from fallen leaves can be achieved through different pre-treatment techniques, e.g., fine shredding, steam heating and/or chemical treatment, improving lignine biodegradability.

High specific average biogas yields 438 ± 67 l·kg_{VSA}^{-1} and methane yields 280 ± 39 l·kg_{VSA}^{-1} were obtained from barley straw. The investigated average methane yield was by 18 % higher compared to methane yield reported for barley straw co-digestion with manure [6]. Possible reasons for such high biogas and methane yields were fine chopping of biomass, pre-treatment through soaking before fermentation, balanced organic load and C:N ratio, and high buffering capabilities of inoculum used in the reactors. The average specific methane content 50.2 % in the obtained biogas is suitable for heat and electric energy production purposes.

The low specific methane yield 119 ± 62 l·kg_{VSA}^{-1}released from algal biomass in the experiments was similar to the methane yield (143 l·kg_{VSA}^{-1}) obtained in anaerobic fermentation of algae sludge harvested from ponds and fermented at 35 ºC [7], but it was much lower compared to the assumed methane yield 275 l·$kg_{VS}^{-1}$from co-fermentation of marine macroalgae with poultry manure [8]. The methane output from algal biomass can be increased substantially if the substrate C:N ratio will be raised up to 20-30:1 [7]. Co-digestion of algal biomass with carbon rich biomass, e.g., chopped straw, leaves or waste paper to improve the nutrient balance in substrates and to increase the methane yield is recommended.

Conclusions

1. The average specific biogas yield 377 ± 22 l·kg_{VSA}^{-1} and methane yield204 ± 19 l·$kg_{VSA}^{-1}$was obtained in anaerobic fermentation of naturally fallen tree leaves collected in autumn.
2. A high specific biogas production yield 438 ± 67 l·kg_{VSA}^{-1} and methane yield 280 ± 39 l·$kg_{VSA}^{-1}$was observed during barley straw anaerobic fermentation, due to pre-treatment and balanced substrate C:N ratio.
3. The investigated average specific methane content, without incalculation of inoculum, was 54 %, 64 % or 42 % in biogas from fallen leaves, barley straw or algal biomass, respectively.
4. Further increase of biogas and methane output from leaves or straw biomass can be provided by thermal and/or chemical pre-treatment of biomass to improve biodegradability of lignine.
5. A low specific average methane yield 119 ± 62 l·kg_{VSA}^{-1} was observed from algal biomass, due to low substrate C:N ratio in the reactors.

6. Co-digestion of algal biomass with carbon rich biomass, e.g., straw, paper, leaves is recommended to increase the methane yield in anaerobic fermentation of algal biomass.

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