BIOGAS PRODUCTION FROM FRESH MAIZE BIOMASS

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Abstract. There is a need to find acceptable energy crops for biogas production for the climatic and soil conditions in Latvia. The average annual dry matter yields from maize vary from 12 to 16 $t \cdot ha^{-1}$ under the climatic conditions in Latvia. Biogas yield from fresh maize biomass was investigated in dependence on the harvesting time of maize. The maize varieties Tango and Celido were harvested in September 8, September 20 and October 8. For biogas investigations 6 laboratory fermenters of 5 litres volume, operating in batch mode were used. Green maize biomass was mixed with water and animal manure for enhanced anaerobic treatment process. The biogas yield from biomass samples varies from 476 $l \cdot kg_{VOS}^{-1}$ to 570 $l \cdot kg_{VOS}^{-1}$. There were not verifiable advantages in volumes of biogas between the samples harvested in different periods found. The average methane content was in the range from 49.6 % to 59.3 % in biogas from different samples of maize biomass.

Keywords: anaerobic digestion, biogas, energy crops, maize, methane.

Introduction

According to EC directives the renewable energy share in gross energy consumption should increase from 32.5 % in 2005 up to 40 % in 2020 for Latvia [1]. The renewable energy share in gross energy consumption was only 29.9 % in 2008 in Latvia, therefore new alternative energy resources should be utilized to reach the appointed targets in the energy sector. Additional renewable energy supply can be provided by increasing of the area of intensive energy crops providing high dry matter (DM) yields [2]. Energy crops used for biogas production should provide high dry matter yield and high methane output per area unit. Energy crops should be easy to cultivate, i.e., to be tolerant to weeds, pests, diseases, drought and frost, have good winter hardiness and be able to grow with low nutrient input. For the agroecological conditions of Latvia such energy crop can be maize, having the annual dry matter yields from 10 to 16 $t \cdot ha^{-1}$. Maize is preferable for energy production as it belongs to C_4 type plants featuring less need for plant nutrients (nitrogen, phosphorus, potassium) uptake per unit of dry matter produced compared to C3 type plants sunflower and sugar beet [3]. The investigated photosynthetic efficiency for C_4 plants was 2.0 % compared to 1.4 % for C_3 plants [4]. The advantage of C_4 crops is less water requirement for plants dry mater production, for example, maize, sorghums (*Sorghum* spp), sudangrass and others had a mean transpiration ratio of ≈300 kg water kg^{-1} dry biomass, as compared to ratios ≈500-900 kg water kg^{-1} in the C_3 crops [5-6]. Most efficient utilization of maize is supply of green maize biomass directly to biogas plants for heat and power energy production. The periods of fresh raw material supply to biogas plants can be prolonged by introduction of early ripe and late ripe sorts in the crop rotations, and by different harvest time of maize. The purpose of the investigation is biogas yield obtainable in anaerobic digestion process from fresh maize biomass harvested in different plant vegetation periods.

Materials and methods

The soil for the proposed maize crops was ploughed in the autumn in 2007. The soil was rolled down and tilled afterwards by a vertical power harrow in spring 2008. Two maize hybrids "Tango" (average-early, FAO 210), and "Celido" (Mid-early, FAO 270) were sown in sandy loam soil (pH_{KCl} – 6.7, P – 112 $mg \cdot kg^{-1}$; K – 99 $mg \cdot kg^{-1}$, organic matter content – 19 $g \cdot kg^{-1}$) on May 06, 2008. Fertilization of plants was provided by mineral fertilizers (148 $kg_N \cdot ha^{-1}$, 34 $kg_P \cdot ha^{-1}$ and 75 $kg_K \cdot ha^{-1}$). Treatment with herbicides (0.25 $kg \cdot ha^{-1}$) was provided for weed control. The maize samples were harvested in September 8, September 20 and October 8. The maize samples were weighted and the average biomass DM yield was calculated for both varieties in each harvesting time.

All 6 samples of fresh maize biomass were chopped in 5-10 mm pieces and analysed for moisture and organic matter content. The fresh maize material was mixed with inoculums (fermented cow manure) and water before anaerobic digestion. The moisture content and organic matter content were analysed using standard methods.

Anaerobic digestion was provided in laboratory scale digesters, each in the volume of 5 litres. Each digester was equipped with a heating device for automated regulation of temperature inside of the digester at 37 ± 1.0 ˚C. Digesters were equipped with sensors for automated registering of pH and gas volume data in computer. Anaerobic treatment of substrates was provided in batch mode without mixing or recirculation. Methane, hydrogen and other gases was measured in biogas by a special instrument. The digestion process was provided within 2 month period until production of biogas ceases.

The energy output obtainable in the anaerobic digestion process from the energy crops area calculates as following:

$$E = m_F\ k_{DM}\ k_{OM}\ k_D\ k_L\ V_{BN}\ LHV_{BN}\ , \tag{1}$$

where E – energy obtainable from unit of energy crop area, $MJ \cdot ha^{-1}$;
m_F – fresh biomass harvested, kg ha^{-1};
k_{DM} – fraction of dry matter in harvested fresh biomass;
k_{OM} – fraction of dry organic matter in dry matter of biomass;
k_D – biodegradation ratio of organic matter during anaerobic digestion process,
k_L – coefficient of losses of dry organic matter during biomass pretreatment and storage;
V_{BN} – volume of biogas (temperature $T = 0$ ˚C, pressure $P =$ 101.3 kPa, dry gas) obtainable from organic matter in anaerobic digestion process, $Nm^3 \cdot kg^{-1}$;
LHV_{BN} – lower heat value for 1 m^3 of biogas at normal conditions, $MJ \cdot Nm^{-3}$.

Lower heat value of biogas at normal conditions in dependence on the methane content in biogas calculates as following [6]:

$$LHV_{BN} = 0.359\ p_{CH_4} - 0.024\ , \tag{2}$$

where p_{CH4} – percentage of methane content in biogas, %.

If the actual parameters of the produced biogas (actual volume and actual lower heat value) are known for actual digester, than the value V_{BN} calculates as follows:

$$V_{BN} = \frac{LHV_B\ V_B}{LHV_{BN}} = k_V\ V_B\ , \tag{3}$$

where V_B – volume of produced biogas at actual conditions (actual temperature, pressure, fully saturated with water vapour) in output of digester before gas counter, m^{-3};
LHV_B – lower heat value of biogas in actual conditions (actual T, P, fully saturated with water vapour) before gas counter, $kJ \cdot m^{-3}$;
k_V – coefficient for conversion of actual biogas volume into normalized (T = 0 ˚C, P = 101.3 kPa, dry gas) biogas volume.

The coefficient k_V for conversion of biogas with the methane content 60 %, fully saturated with water, in normalized biogas volume is shown in Table 1 [6].

Electricity power produced by the cogeneration plant per unit of energy crop area calculates as follows:

$$P_e = \frac{E\ k_e}{3.6\,n_y\ k_p}\ , \tag{4}$$

where P_e – electric power produced by cogeneration plant per 1 ha of energy crop area, $kW \cdot ha^{-1}$;
E – energy obtainable from unit of area, $MJ \cdot ha^{-1}$;
k_e – share of electric energy in total energy produced by cogeneration plant;
n_y – number of days in a year (n_y = 8760);
k_p – ratio of cogeneration plant idle time in relation to working time during one year period.

Table 1

Coefficient k_V for conversion of biogas actual volume to normalized biogas volume

Actual biogas pressure, kPa	Coefficient k_V for conversion of biogas (CH_4 = 60 %, fully saturated with water vapour) actual volume into normalized biogas volume (T = 0 ˚C, P= 101.3 kPa, dry gas), for actual temperatures:					
	35 ˚C	29 ˚C	24 ˚C	18 ˚C	12 ˚C	7 ˚C
101.3	0.837	0.866	0.893	0.918	0.928	0.941
102.3	0.846	0.875	0.902	0.927	0.937	0.951
103.3	0.855	0.884	0.911	0.936	0.946	0.961
104.3	0.863	0.893	0.920	0.945	0.956	0.97
105.3	0.872	0.902	0.929	0.954	0.965	0.979
106.3	0.881	0.910	0.938	0.964	0.974	0.988
107.3	0.889	0.919	0.947	0.973	0.984	0.998
108.3	0.898	0.928	0.956	0.982	0.993	1.007
109.3	0.907	0.937	0.965	0.992	1.002	1.017
110.3	0.916	0.946	0.974	1.001	1.012	1.026

Results and discussion

The green biomass yield and dry matter content in freshly harvested maize biomass is shown in Table 2. The investigated average fresh biomass yield was 59.82 t·ha^{-1} "Celido" that was by 10.01 t·ha^{-1} higher compared to maize hybrid "Tango". The investigated average dry matter content in fresh biomass of the maize hybrid "Tango" was 23.93 % or by 3.95 % higher compared to the hybrid "Celido". The parameters and results of anaerobic digestion of maize samples are shown in Table 2. The average organic matter percentage in total solids for the maize hybrid "Celido" was 94.2 % that was by 1.9 % lower compared to that in the maize hybrid "Tango".

The average substrate moisture was 98.5 % for the hybrid "Celido" samples and 98.0 % for the maize hybrid "Tango" before digestion process, see Table 2. Biogas production obtained from all digesters is shown in Figure 1. The average biogas yield from the maize hybrid "Celido" was 561 kg$_{VOS}^{-1}$ or by 53 l·kg$_{VOS}^{-1}$ higher compared to that obtained from the maize hybrid "Tango". The biogas yield was not affected significantly (p>0.05), if the biogas was obtained from different maize hybrids or from maize samples with different harvest time. Higher biogas yield obtained from the middle-early variety Celido (FAO 270) can be explained by higher dry matter content in biomass samples compared to the maize variety "Tango" with a shorter vegetation (FAO 210) period. Higher dry mass content in biomass results in higher lignine content usually, that has usually been the governing factor for biogas production.

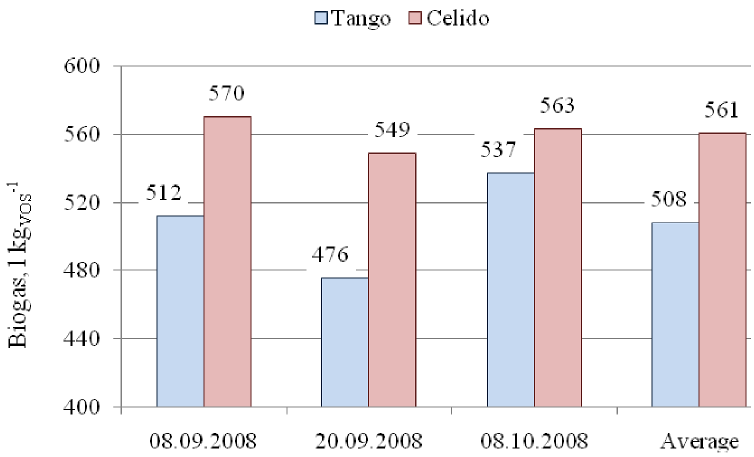

Fig. 1. **Biogas yield released from maize hybrids in anaerobic digestion process**

The investigated average methane content in biogas produced from the maize hybrid "Celido" was by 4.2 % higher compared to that obtained from the hybrid "Tango". The methane content is sufficient for biogas utilization in internal engines in cogeneration plants after removal of sulphurous substances. Biogas can be delivered also into the gas pipeline, if carbon dioxide is removed.

Table 2

Parameters of anaerobic digestion of maize samples

Digester		D1	D2	D3	D4	D5	D6	Mean value ± standard error	
Parameters	Unit	Celido 8.09	Tango 8.09	Celido 20.09	Tango 20.09	Celido 8.10	Tango 8.10	Celido	Tango
Substrate composition	%	12 m 13 in 75 w	12 m 13 in 75 w	5 m 11 in 84 w	5 m 11 in 84 w	5 m 12 in 83 w	5 m 12 in 83 w	-	-
Fresh maize yield	$t \cdot ha^{-1}$	61.36	54.71	58.86	51.29	59.24	43.43	59.82 ±0.78	49.81 ±3.3
DM content (in freshly harvested maize)	%	17.68	21.26	19.32	23.84	22.93	26.67	19.98 ±1.55	23.93 ±1.56
OM content in DM	%	94.5	96.2	92.7	95.6	95.5	96.4	94.2 ±0.8	96.1 ±0.2
Total substrate weight	kg	3.913	3.955	4.342	4.269	4.125	4.003	4.127 ±0.124	4.076 ±0.098
Substrate moisture	%	98.2	97.0	98.8	98.4	98.4	98.6	98.5 ±0.2	98.0 ±0.5
Biogas yield	$l \cdot kg_{VOS}^{-1}$	570	512	549	476	563	537	561±6	508±18
Methane yield	$l \cdot kg_{VOS}^{-1}$	338	291	321	236	332	312	330±5	280±23
Aver. methane content	%	59.3	56.8	58.5	49.6	59.1	58.1	59±2.0	55±2.0
Max. methane content	%	78.4	66.4	73.9	52.1	78.2	73.3	76.8 ±1.5	63.9 ±6.2
OM conversion ratio	-	0.66	0.61	0.63	0.60	0.65	0.64	0.65	0.62
Biogas yield per area	$m^3\ ha^{-1}$	5844	5729	5787	5564	7303	5996	6314	5819
Energy per area	$GJ\ ha^{-1}$	115	108	113	92	143	116	124	106
Electric power	$kWh\ ha^{-1}$	1.59	1.49	1.55	1.26	1.98	1.60	1.71	1.46

Remarks: m – maize biomass, in – inoculum, w – water, OM – organic matter, DM - dry matter, VOS – volatilized organic solids.

The highest methane content 59.3 % was observed for the maize variety "Celido" harvested on September 8, Figure 2.

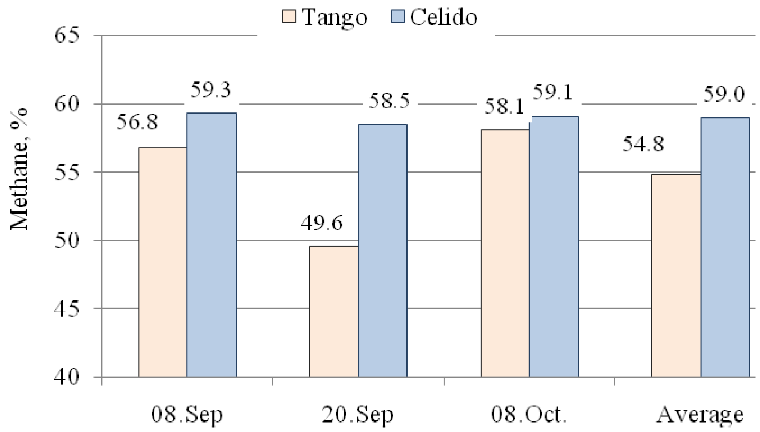

Fig. 2. **Methane content in biogas from two maize hybrid samples, harvested at different times**

Energy obtainable from unit of energy crops area is calculated help by equations (1) and (2), assuming, that there were not dry matter losses during harvesting and pretreatment (k_l = 1.0) and the biogas volume was measured at temperature 18 ˚C and at pressure 102.3 kPa (k_v = 0.927, see Table 1) biogas. Lower heat value is calculated by help of regression equation (2). The results of energy calculation for both maize varieties are shown in Figure 3.

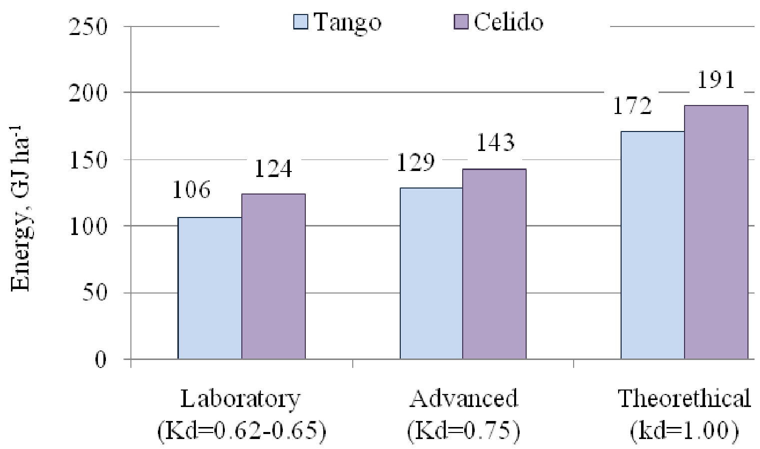

Fig. 3. **Biogas energy obtainable from 1 ha of maize area**

The calculated average energy per unit of area obtainable from the variety “Celido” is 124 GJ·ha^{-1}, that is by 19 GJ·ha^{-1} higher compared to the variety “Tango” in the same soil conditions. Electric power obtainable in the cogeneration plant from 1 ha of energy plant area is calculated according to equation (4). The degradation ratio in Figure 3 and Figure 4 represents different stages of biodegradation as follows: ratio obtained in laboratory (batch process without mixing, k_d = 0.62-0.65, see Table 2), ratio inherent for advanced technology (continued process with substrate mixing, k_d = 0.75) and theoretical ratio (all organic matter is degraded, k_d = 1.0).

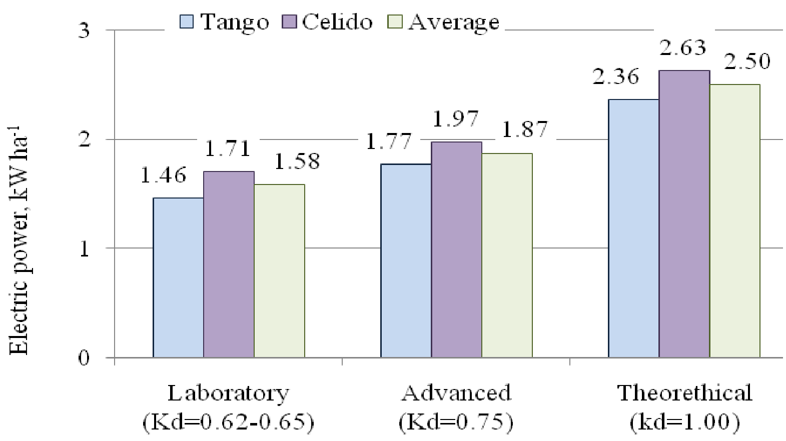

Fig. 4. **Electric power obtainable in cogeneration plant from 1 ha of energy plant area**

Electric power, obtainable in cogeneration plant per 1 ha energy crop area, based on the laboratory investigations, was 1.71 kW for the hybrid “Celido” and 1.46 kW for the maize hybrid “Tango”. Increase in electric power per area unit will be possible in connection with further improvement of the degradation ratio upwards to the theoretical ratio by help of fine cutting of raw biomass and/or by improvement of the anaerobic digestion process.

Conclusions

1. The investigated average dry matter yield was 12.0 $t \cdot ha^{-1}$ for the maize hybrid Celido and 11.9 $t \cdot ha^{-1}$ for the maize hybrid Tango, harvested during 30-day period.
2. The biogas yield was not affected significantly ($p>0.05$), if the biogas was obtained from different maize hybrids or from maize samples with different harvest time.
3. The average methane content in the harvest period was observed 59 % for the maize hybrid "Celido" and 54.8 % for the hybrid "Tango".
4. The calculated average energy per unit of area obtainable from the variety "Celido" is 124 $GJ \cdot ha^{-1}$, or by 19 $GJ \cdot ha^{-1}$ higher compared to the variety "Tango" in the same soil conditions.
5. Electric power, obtainable in the cogeneration plant per 1 ha energy crop area, based on the laboratory investigations, was 1.71 kW for the hybrid "Celido" and 1.46 kW for the maize hybrid "Tango"

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