Biogas production from algal biomass from municipal wastewater treatment

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Introduction

Microalgae have the ability to fix carbon dioxide, nutrients and store the solar energy into their cells via photosynthesis which makes them interesting as an alternative energy source (for example biogas) and for wastewater treatment. Compared to the conventional technologies for green fuel production, microalgae have higher growth rates and their growth does not compete with crops for human or animal nutrition. Treatment of wastewater with microalgae results in production of large amounts of biomass that needs to be disposed. One of the suitable technologies for microalgal biomass disposal is anaerobic digestion producing valuable biogas and solid residue that can be used as a fertilizer. This paper presents the results of anaerobic digestion of biomass composed of microalgae and bacteria (MaB) used for treatment of municipal wastewater. [1, 2]

Materials and methods

The anaerobic digestion was carried out in a batch laboratory anaerobic digesters consisting of:

- enclosed anaerobic digester;
- mixer;
- thermostatic tank with recirculation pump;
- wet gas holder;
- pH and temperature logger; and
- gas mass flow meter.

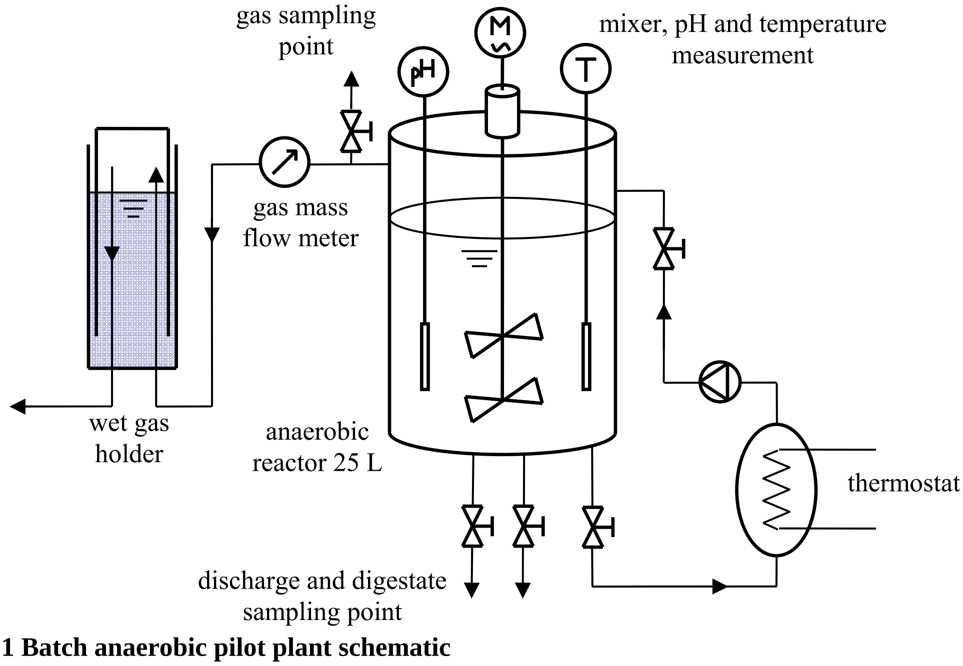

Fig. 1 Batch anaerobic pilot plant schematic

Each anaerobic digester has a volume of 25 L (usable volume of 22 L); thermally isolated shell; mixer; valves used for gas sampling, digestate sampling, discharging of the digester and for connecting the thermostatic tank; and a wet gas holder. The pH and temperature was monitored with Magic XBC (GRYF HB, spol. s r.o) with except for the digester A which was equipped with WTW MULTI 3420S and Electrode SenTix 940-3. Flow of produced biogas was measured by Bronkhorst F-101D-070-AGD-33-V mass flow meter located at the inflow to the wet gas holder. (see Fig. 1 and Fig. 2 for schematic and photo of the anaerobic digesters).

Fig. 2 Photo of the anaerobic laboratory digesters

Primary sludge and the anaerobic inoculum was sampled at the full-scale anaerobic mesophilic digester treating primary and excess biological sludge at the municipal wastewater treatment plant in Brno-Modřice, Czech Republic. Microalgae and bacteria biomass used as a substrate for anaerobic digestion previously served for pilot treatment of municipal wastewater in pilot scale. For the experiment, two types of biomass with different composition (MaB 1 and MaB 2) were used. MaB 1 is biomass composed mainly of living microalgal cells and MaB 2 is composed mainly of bacteria and dead microalgal cells.

Tab. 1 Ratio of dry matter of mixture components; dry and organic matter of mixture components

Component	Digester				Dry matter [%]	Organic matter [%]
	A	B	C	D		
Inoculum (IN)	1	2	1	2	3.08 ± 0.05	54.65 ± 0.51
Primary sludge (PS)	0	1	0	1	7.79 ± 0.02	59.82 ± 0.43
MaB 1	1	1	0	0	0.64 ± 0.01	52.04 ± 0.85
MaB 2	0	0	1	1	0.58 ± 0.02	73.16 ± 0.60

The above mentioned components were used to perform four batch test of biogas production. Digestion proceeded in a batch mode for 588 h at 36 °C with pressure approximately 0.5 kPa above atmospheric pressure and without pH regulation. Mixer was switched by time: 2 minutes of mixing with period of 12 minutes. Each rector was fed with mixtures of different composition (see Tab. 1 for composition of mixture in each digester and Tab. 2 for digesters loading and weight of each component).

Tab. 2 Weight of each mixture components and digesters loading

	A	B	C	D
m_{IN} [kg]	4.3	6.1	3.5	5.7
m_{PS} [kg]	0	1.2	0	1.1
$m_{MaB\ 1}$ [kg]	20.7	14.7	0	0
$m_{MaB\ 2}$ [kg]	0	0	18.5	15.2
$m_{subst.}$ [kg]	25.02	22.02	22.00	22.00
$DM_{subst.}$ [%]	1.06	1.72	0.97	1.59
$OM_{subst.}$ [% DM]	53.34	55.30	63.91	60.57
$OM_{subs.}$ [kg]	0.142	0.209	0.136	0.212
Loading [kg OM·m^{-3}]	5.71	9.58	6.18	9.66

Produced biogas was analyzed using gas chromatograph Master GC; each the component was weighted with Kern DE 60K20N scales with resolution of 20 g; dry matter (DM) was determined after drying to constant weight at 105 °C and organic matter (OM) after ignition at 550 °C.

Results and discussion

Conditions in digesters

Within six hours after the start of the experiment, temperature stabilized at approximately 36 °C and remained constant through the whole experimental period (Fig. 3). The temperatures in digesters were: (A) 36.2 ± 0.2 °C; (B) 36.7 ± 0.1 °C; (C) 36.7 ± 0.1 °C; and (D) 36.5 ± 0.1 °C.

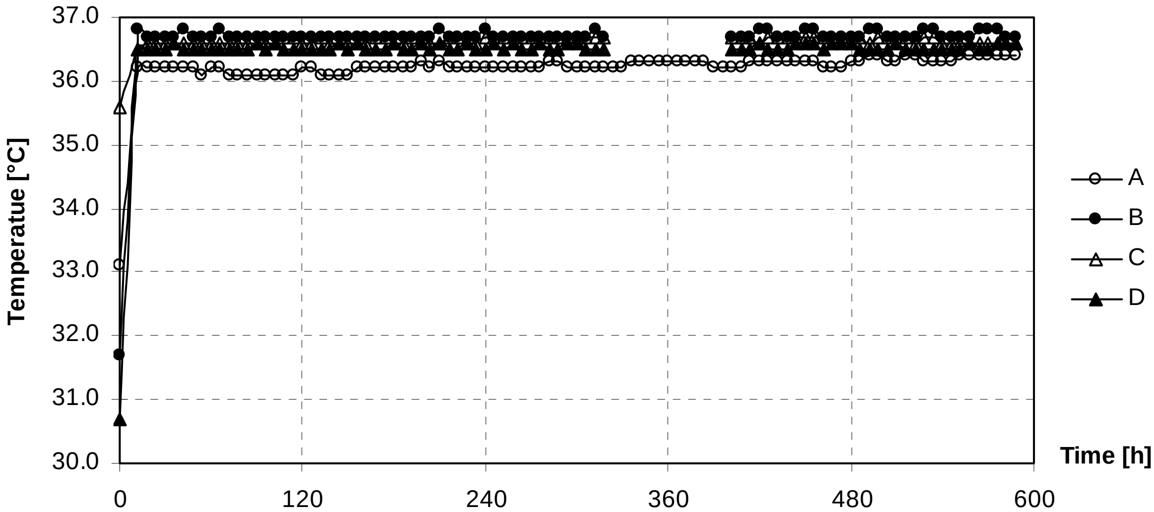

Fig. 3 Temperature in digesters during 588 hours of experiment

Values of pH in digester A and B significantly differed from those in digesters C and D. The reason for this difference is given by very low pH of the MaB 2 biomass (approximately 3.5) while the biomass MaB 1 had a neutral pH (approximately 7.5). After 300 hours of digestion the pH values stabilised at: (A) 7.2 ± 0.0; (B) 7.6 ± 0.2; (C) 6.8 ± 0.0; a (D) 6.9 ± 0.0, see Fig 4.

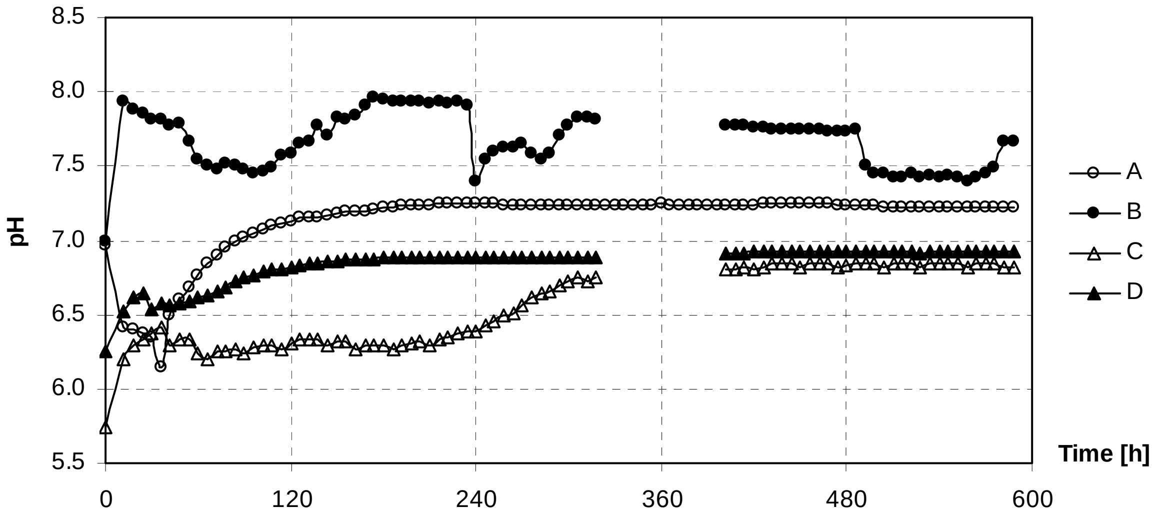

Fig. 4 pH in digesters during 588 hours of experiment

The three days gap without measurements of pH and temperature was caused by drop-out of logging PC, but the values were stabilized at that time so the time course of both pH and temperature is obvious.

Biogas production

Compared to digesters A and D, biogas production was higher in digesters B and C (Fig. 5). The difference in production of biogas is even higher when the biogas production is expressed as specific biogas production in litres of biogas per kilogram substrate (Fig. 6). The highest specific biogas production was in digester C while the specific production in digester B and A was at the end of experiment period similar. Specific biogas production at the end of the experiment was 169 $L\cdot kg^{-1}$ OM in the digester A, 168 $L\cdot kg^{-1}$ OM in the digester B and 330 $L\cdot kg^{-1}$ OM in the digester C. The lowest biogas production was in the digester D (specific biogas production of 64 $L\cdot kg^{-1}$ OM). Anaerobic process in the digester D was inhibited; however, the cause could not be determined due to similar process conditions in digesters D and C.

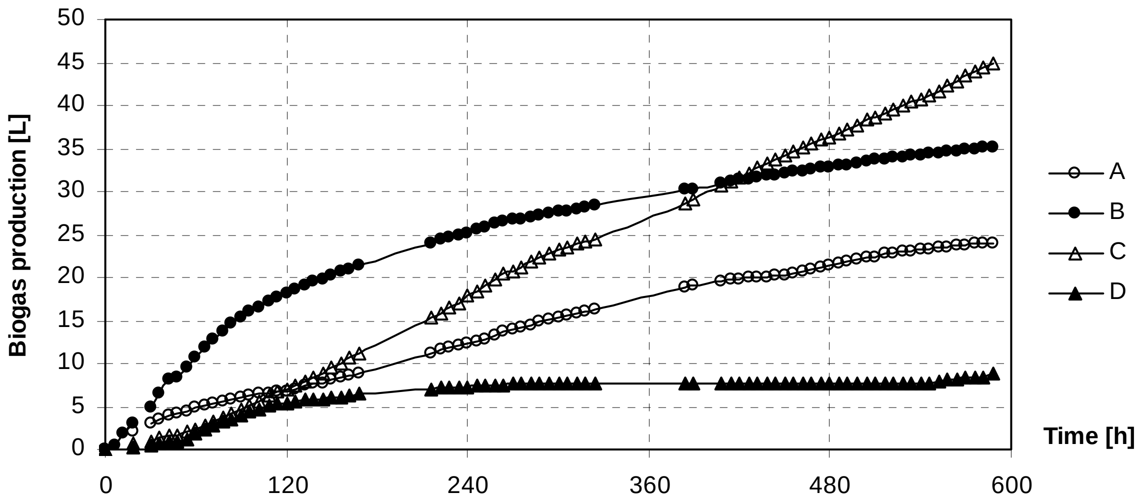

Fig. 5 Biogas production during 588 hours of experiment

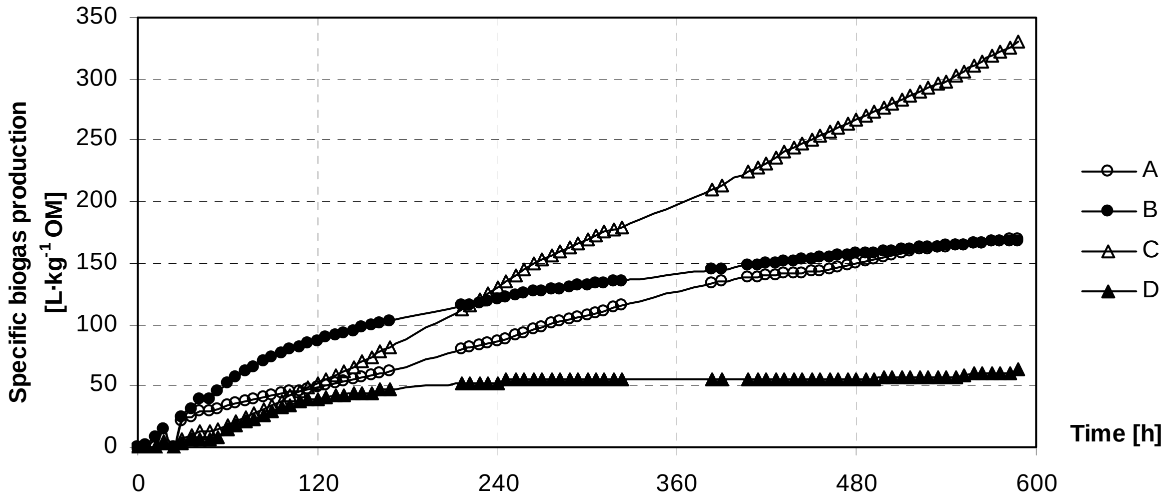

Fig. 6 Specific biogas production during 588 hours of experiment

The development of biogas production (Fig. 5 and Fig. 6) in digester C shows that even after 24 days the biogas production did not reached the stationary phase. Biogas production in digesters A and B was near the stationary phase at the end of the experiment.

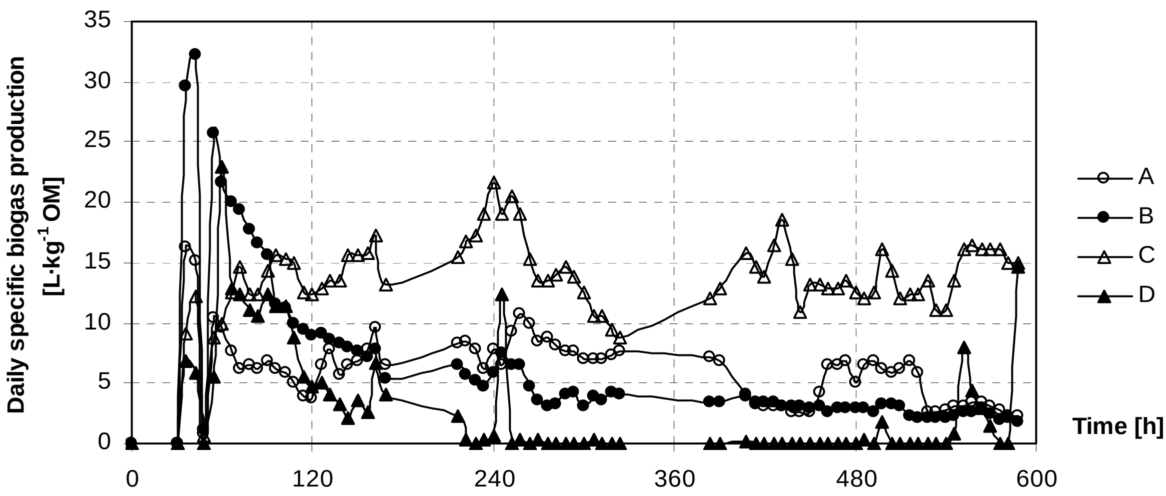

Fig. 7 Daily specific biogas production during 588 hours of experiment

The daily specific biogas production (Fig. 7) in digester C was increasing for the first 250 hours of experiment and remained approximately constant until the end of the experiment. Daily specific biogas productions in digesters A and B had a decreasing trend from the beginning of the experiment. Digester D daily specific production was zero almost during the whole experiment, biogas was produced only occasionally.

Theoretically microalgae biomass can produce up to 550 $L \cdot kg^{-1}$ OM when presuming all organic matter is decomposed [3]. Range of biogas production in other studies varies considerably:

- 160 and 170 L·kg^{-1} OM after 25 and 45 days, respectively, of digestion of non-pretreated microalgae as substrate. [4]
- 300 to 350 L·kg^{-1} OM after 25 days of digestion and 450 to 480 L·kg^{-1} OM after 45 days of digestion of microalgae with excess sludge. Digestion of microalgae without any additional substrate produced up to 110 L·kg^{-1} OM after 25 days of digestion and 260 L·kg^{-1} OM after 45 days of digestion. [5]

Digester C produced 330 L·kg^{-1} OM of biogas at concentration of substrate of 6.2 kg OM·m^{-3} which is above the average of other studies [4, 5]. Digesters A and B produced 169 L·kg^{-1} OM of biogas after 25 days of digestion which is similar to the productions in other studies digesting microalgae biomass. Achieved productions are significantly lower compared to digestion of sludges from municipal wastewater treatment plants. [4, 5, 6]

Biogas composition

Biogas composition was determined by two samples for each digester: first sample after 236 h of digestion and second after 469 h of digestion. Similarly to other studies [7, 4, 8], produced biogas had a high methane content ranging from 60 % to 73 %. With exception of digester B, biogas composition was relatively stable during the experiment (see Tab. 3).

Tab. 3 Composition of produced biogas

	CH_4		CO_2		O_2		N_2	
	236 h	496 h	236 h	496 h	236 h	496 h	236 h	496 h
A	73,0 ± 0,5	71,9 ± 0,3	15,5 ± 0,4	18,8 ± 0,4	0,5 ± 0,0	0,5 ± 0,0	10,6 ± 0,2	9,3 ± 0,1
B	71,6 ± 3,9	62,7 ± 0,7	20,9 ± 4,5	27,0 ± 0,4	1,3 ± 0,4	1,3 ± 0,0	7,4 ± 1,4	8,2 ± 0,1
C	60,3 ± 0,0	61,5 ± 0,3	28,6 ± 0,7	29,5 ± 0,2	0,9 ± 0,2	0,7 ± 0,1	9,4 ± 0,4	8,0 ± 0,1
D	67,5 ± 0,8	68,3 ± 0,5	21,6 ± 0,8	27,2 ± 0,3	1,5 ± 0,0	0,7 ± 0,0	7,9 ± 0,2	3,4 ± 0,1

Conclusions

The results of anaerobic mesophilic digestion of microalgae-bacteria biomass shows that substrate composition plays an important role in biogas production. Digesters with added primary sludge reached the stationary phase faster than the digesters without primary sludge; the biogas production after 588 hours of digestion was not significantly higher with the primary sludge. Thus, it may be more convenient to digest biomass without primary sludge because specific yield with added primary sludge is the same or lower than without added primary sludge. The highest biogas yield achieved (digester C, 330 L·kg^{-1} OM) is above the average of other studies; the content of methane in biogas is comparable with other studies. Due to inexplicit results it is not possible to determine which biomass (MaB 1 or MaB 2) is more suitable for digestion.

Composition of produced biogas was comparable to the other studies ranging from 62 % to 72 %. Specific biogas production in digester C was higher compared to other studies but did not reach the biogas production of digestion of sludge from municipal wastewater treatment plants.

Further research focused on determination of time needed to reach the stationary phase is needed. Additional research on digestion of biomass with different substrate to inoculum ratio will be conducted.

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