Biogas production from algal biomass

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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.

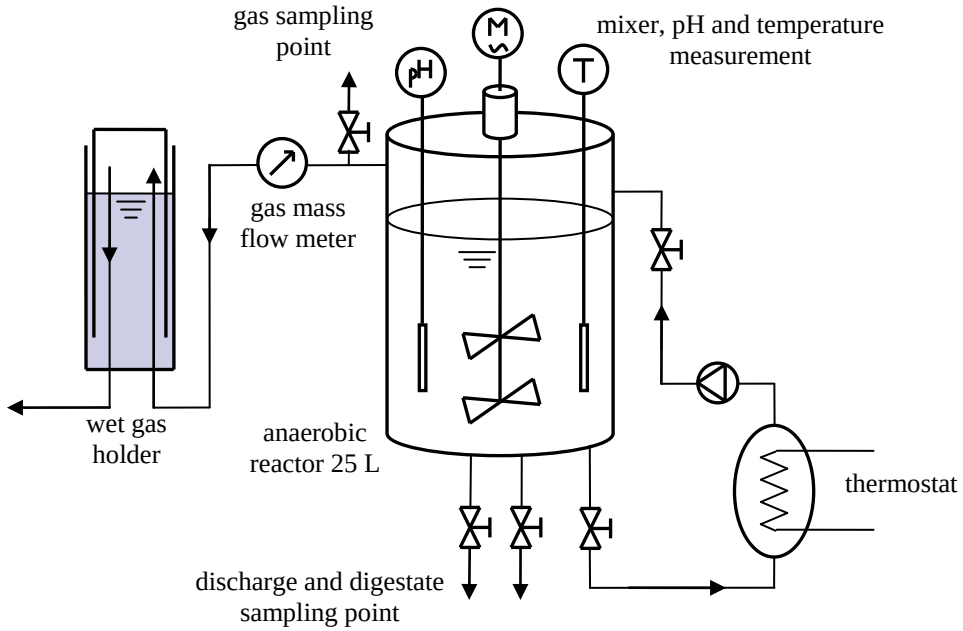

Fig. 1 Batch anaerobic pilot plant schematic

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 and food industry wastewaters in pilot scale. For the experiment, four types of biomass with different composition (MaB 1 to MaB 4) were used. MaB 1 is biomass composed mainly of living microalgal cells and MaB 2 is composed mainly of bacteria and dead microalgal cells (i.e. dead biomass stored in tank approximately for a month), both these types originated from treatment of municipal wastewater (WWTP Brno - Modřice). MaB 3 and MaB 4 compose mainly of living microalgal cells, MaB 3 originates from treatment of food industry wastewater (malt-house Bernard - Rajhrad) and MaB 4 originates from treatment of municipal wastewater (the same as MaB 1 and 2)

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

Component	Digester												Dry matter [%]	Organic matter [%]
	A_M	B_M	C_M	D_M	A_F	B_F	C_F	D_F	A_{MM}	B_{MM}	C_{MM}	D_{MM}		
Inoculum (IN)	1	2	1	2	2	1	2	5	2	1	2	1	3.08 ± 0.05	54.65 ± 0.51
Primary sludge (PS)	0	1	0	1	0	0	0	0	0	0	0	0	7.79 ± 0.02	59.82 ± 0.43
MaB 1	1	1	0	0	0	0	0	0	0	0	0	0	0.64 ± 0.01	52.04 ± 0.85
MaB 2	0	0	1	1	0	0	0	0	0	0	0	0	0.58 ± 0.02	73.16 ± 0.60
MaB 3	0	0	0	0	1	1	3	9		0	0	0	0.89 ± 0.01	54.66 ± 0.48
MaB 4	0	0	0	0	0	0	0	0	1	1	3	0	1.17 ± 0.01	58.11 ± 0.65

The above mentioned components were used to perform four batch test of biogas production in total three series (e.g. total twelve batch tests). Digestion proceeded in a batch mode at 36 °C with pressure approximately 0.5 kPa above atmospheric pressure and without pH regulation (except as otherwise provided). 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_M	B_M	C_M	D_M	A_F	B_F	C_F	D_F	A_{MM}	B_{MM}	C_{MM}	D_{MM}
m_{IN} [kg]	4.3	6.1	3.5	5.7	9.66	6.00	4.34	3.40	8.32	5.26	3.86	15.5
m_{PS} [kg]	0	1.2	0	1.1	0	0	0	0	0	0	0	0
$m_{MaB.1}$ [kg]	20.7	14.7	0	0	0	0	0	0	0	0	0	0
$m_{MaB.2}$ [kg]	0	0	18.5	15.2	0	0	0	0	0	0	0	0
$m_{MaB.3}$ [kg]	0	0	0	0	15.32	19.00	20.66	18.88	0	0	0	0
$m_{MaB.4}$ [kg]	0	0	0	0	0	0	0	0	11.68	14.74	16.10	0
$m_{subst.}$ [kg]	25.02	22.02	22.00	22.00	24.98	25.00	25.00	22.28	20.00	20.00	19.96	20.00
$DM_{subst.}$ [%]	1.06	1.72	0.97	1.59	1.64	1.36	1.23	1.19	2.04	1.72	1.57	2.53
$OM_{subst.}$ [% DM]	53.34	55.30	63.91	60.57	56.64	56.13	55.83	55.72	56.24	56.71	56.98	55.30
$OM_{subs.}$ [kg]	0.142	0.209	0.136	0.212	0.232	0.190	0.172	0.148	0.229	0.195	0.179	0.280
Loading [kg OM·m^{-3}]	5.71	9.58	6.18	9.66	9.28	7.60	6.88	5.92	11.45	9.75	8.97	14.00

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 few hours after the start of the experiment, temperature stabilized at approximately 36 °C and remained constant through the whole experimental period. The temperatures in digesters were: 36.2 ± 0.2 °C (A_M); 36.7 ± 0.1 °C (B_M); 36.7 ± 0.1 °C (C_M); 36.5 ± 0.1 °C (D_M); 35,9 ± 0,1 °C (A_F), 36,3 ± 0,1 °C (B_F), 36,0 ± 0,1 °C (C_F), 35,3 ± 0,4 °C (D_F); 35,7 ± 0,1 °C (A_{MM}), 36,4 ± 0,1 °C (B_{MM}), 36,0 ± 0,1 °C (C_{MM}), 36,4 ± 0,1 °C (D_{MM})

Values of pH were regulated only in reactor B_F due to fast decrease at the beginning of experiment. Values of pH were the most stable for reactors A_{MM} to D_{MM}, pH was 7.0 to 7.3. In reactors A_M to D_M the pH was approximately 6.5 to 7.5 with exception for reactor B (pH 7.5 to 8.0). Reactor D_F and A_F pH was 7.0 to 7.6. Reactor C_F pH started to drop after 250 h and after 500 h the pH stabilised on pH 5.6. Reactor B_F pH dropped quickly to 6.3 during first few h, addition of NaOH recovered the pH but after 500 h the pH was low again (pH 6.2).

Biogas production

For biomass from municipal wastewater treatment the specific biogas production (Fig 3) was highest in digester C while the specific production in digester B and A was at the end of experiment period similar. Biogas production in reactor C did not reach stationary phase, but in other reactors the process was close to the stationary phase. Specific biogas production at the end of the experiment was 169 L·kg^{-1} OM in the digester A, 168 L·kg^{-1} OM in the digester B and 330 L·kg^{-1} OM in the digester C. The lowest biogas production was in the digester D (specific biogas production of 64 L·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. Higher biogas production in digester C is result of substrate being composed mainly of dead cells (e.g. easily digested compared to living microalgal cells).

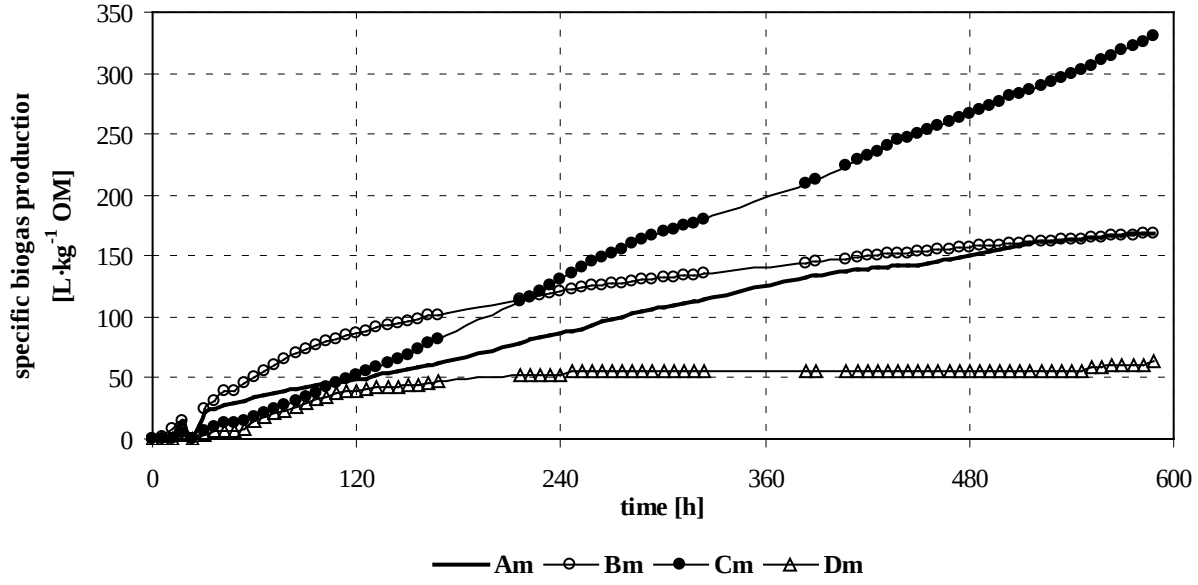

Fig. 3 Specific biogas production for biomass from municipal wastewater treatment (first series)

For biomass from food industry wastewater treatment the specific biogas production (Fig 4) was highest was highest in reactor A. The specific biogas production in this reactor was 126.0 L·kg^{-1} OM after 1140 h of testing. Graph also shows that even after 48 days of testing the biogas production did not reach the stationary phase. Second highest biogas production was in reactor C with specific biogas production of 91.9 L·kg^{-1} OM after 1140 h, process was close to stationary phase at the end of testing. Reactor B and D biogas production was not ideal due to low pH. Values of pH

dropped significantly at the beginning of experiment in reactor B which had negative effect on microbial culture and biogas production. Reactor D production was zero most of the days and was produced only on some days.

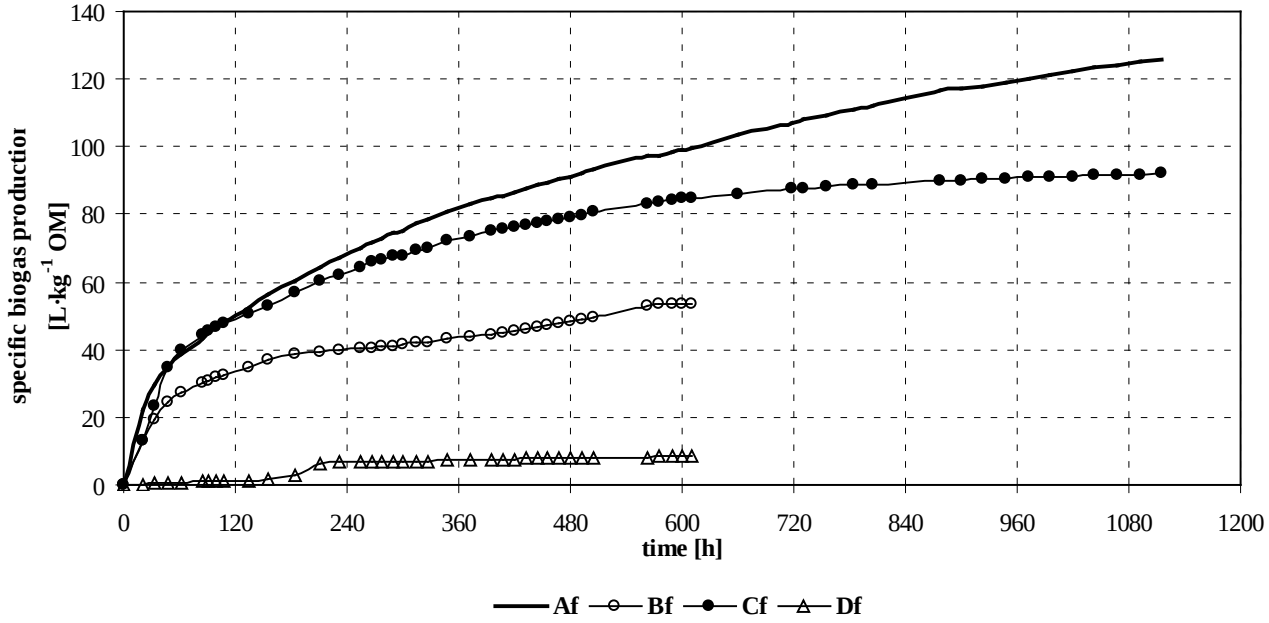

Fig. 4 Specific biogas production for biomass from food industry wastewater treatment

For biomass from municipal wastewater treatment (second series) the specific biogas production (Fig 5) was highest in digester A. The specific biogas production in this reactor was 185.6 $L \cdot kg^{-1}$ OM after 1344 h of testing. Graph also shows that even after 57 days of testing the biogas production did not reach the stationary phase. Second highest biogas production was in reactor B with specific biogas production of 93.4 $L \cdot kg^{-1}$ OM. Biogas production did not reached the stationary phase similarly to the reactor A. Compared to the reactor B slightly lower biogas production was achieved in reactor D with substrate being only anaerobic inoculum diluted with water. The specific biogas production in reactor D was 75.2 $L \cdot kg^{-1}$ OM and the process also did not reach stationary phase. The results from reactor D implies that the anaerobic inoculum itself contributes significantly to the production of biogas in other reactors. Reactor C biogas production was minimal with specific biogas production only 3.4 $L \cdot kg^{-1}$ OM after 501 h.

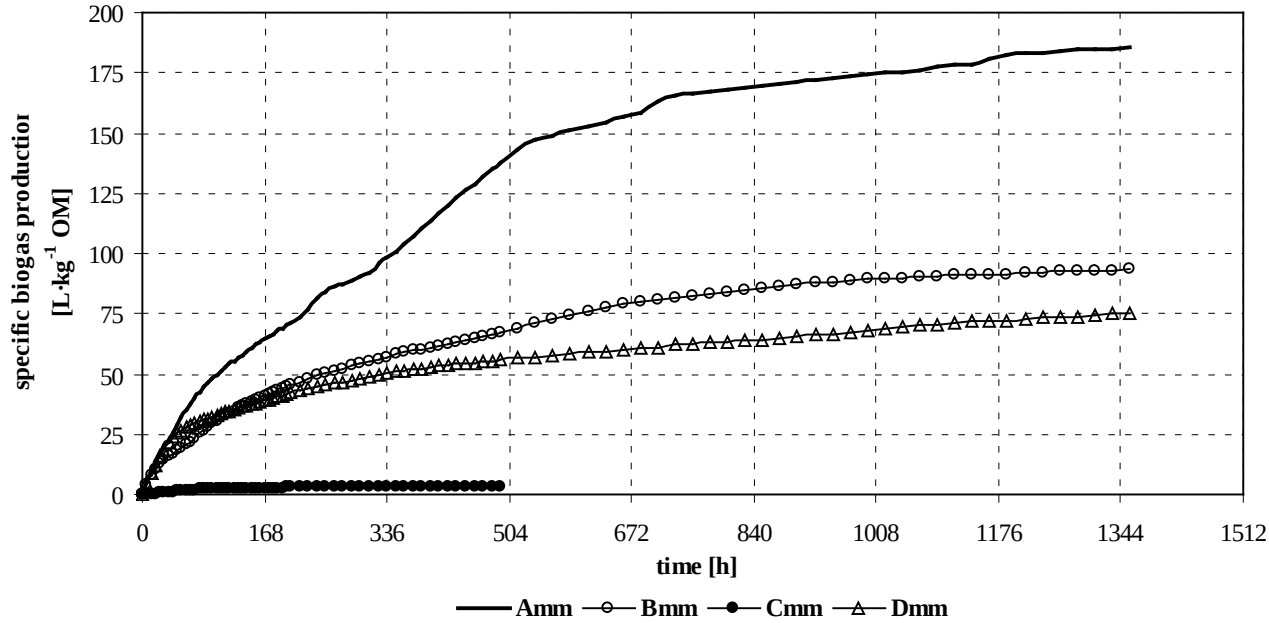

Fig. 5 Specific biogas production for biomass from municipal wastewater treatment (second series)

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

Digester C_M produced 330 $L \cdot kg^{-1}$ OM of biogas at concentration of substrate of 6.2 kg $OM \cdot m^{-3}$ which is above the average of other studies [4, 5]. Digesters A_F, A_{MM} produced similar amount of biogas compared to the productions in other studies digesting microalgae biomass. Achieved productions are significantly lower compared to digestion of sludge from municipal wastewater treatment plants. [4, 5, 6]

Biogas composition

Biogas composition was determined by two to four samples for each digester. In first series of tests with biomass from municipal wastewater treatment the biogas was sampled after 236 and 496 h. Biogas was sampled after 161 h, 567 h, 903 h and 1140 h from reactors with biomass from food industry wastewater treatment and after 213 h, 501 h, 884 h and 1344 h from reactors with biomass from municipal wastewater treatment (second series).

Similarly to other studies [7, 4, 8], produced biogas had a high methane content ranging from 61.5 % to 75.6 % at the end of experiment. With exception of digester B_F, biogas composition was relatively stable during the experiment (see Tab. 3).

Tab. 3 Composition of produced biogas [%]

Gas	Sampling №	Digester											
		A_M	B_M	C_M	D_M	A_F	B_F	C_F	D_F	A_{MM}	B_{MM}	C_{MM}	D_{MM}
CH_4	1st sampling	73.0	71.6	60.3	67.5	82.9	76.9	80.8	69.6	70.1	74.3	72.8	65.0
	2nd sampling	71.9	62.7	61.5	68.3	76.7	15.9	75.2	75.6	67.7	72.3	70.0	65.5
	3rd sampling	-	-	-	-	71.3	-	70.0	-	64.9	69.6	-	64.5
	4th sampling	-	-	-	-	70.0	-	63.8	-	63.4	66.3	-	64.2
CO_2	1st sampling	15.5	20.9	28.6	21.6	12.0	2.7	8.9	13.1	22.3	14.1	13.8	26.1
	2nd sampling	18.8	27.0	29.5	27.2	20.8	0.6	12.4	15.3	25.9	21.1	19.8	28.0
	3rd sampling	-	-	-	-	24.8	-	19.3	-	27.2	23.5	-	28.9
	4th sampling	-	-	-	-	28.0	-	19.0	-	25.9	22.2	-	27.1
O_2	1st sampling	0.5	1.3	0.9	1.5	0.4	1.3	0.3	0.4	0.2	0.3	0.3	0.2
	2nd sampling	0.5	1.3	0.7	0.7	0.2	7.0	0.6	0.5	0.2	0.2	0.3	0.3
	3rd sampling	-	-	-	-	0.3	-	0.3	-	0.2	0.3	-	0.2
	4th sampling	-	-	-	-	0.2	-	0.4	-	0.1	0.3	-	0.2
N_2	1st sampling	10.6	7.4	9.4	7.9	4.7	19.0	10.0	16.9	7.4	11.3	13.1	8.6
	2nd sampling	9.3	8.2	8.0	3.4	2.3	76.5	11.8	8.7	6.2	6.2	9.9	6.3
	3rd sampling	-	-	-	-	3.6	-	10.4	-	7.8	6.5	-	6.3
	4th sampling	-	-	-	-	1.9	-	16.8	-	10.6	11.3	-	8.4

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 (B_M and D_M) reached the stationary phase faster than the digesters without primary sludge but the biogas production after 588 h 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.

Results from other digesters shows that the most important parameter is the ratio of inoculum to microalgae-bacteria biomass. Results of two series of testing are similar with respect to suitable ratio of inoculum to microalgae-bacteria biomass: biogas production increases with increasing ratio of inoculum to microalgae-bacteria biomass.

The highest biogas yield achieved (digester C, 330 $L \cdot kg^{-1}$ OM) is above the average of other studies. This is given by the nature of the biomass (biomass composed mainly of dead cell of bacteria and microalgae). Biogas productions in other reactors with high ratio of inoculum to microalgae-bacteria biomass were similar to other studies. Biomass produced during treatment of municipal wastewater generally produces more biogas compared to the biomass produced during treatment of food industry wastewater.

Composition of produced biogas was comparable to the other studies ranging from 61.5 % to 75.6 %. Biomass produced during treatment of municipal wastewater generally produced biogas with lower methane content.

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