DE GRUYTER OPEN

DOI: 10.1515/aree-2017-0004

Acta Regionalia et Environmentalica 1
Nitra, Slovaca Universitas Agriculturae Nitriae, 2017, pp. 24–29

BIOMASS OF MICROALGAE AS A SOURCE OF RENEWABLE ENERGY

Natalia GŁOWACKA[1, 2]*, Ján GADUŠ[1], Ján SLOBODNÍK[3]

[1]Slovak University of Agriculture in Nitra, Slovak Republic
[2]Environmental Institute, s. r. o., Koš, Slovak Republic
[3]BioRent, s.r.o., Sládkovičovo, Slovak Republic

Algae represent a potential source of energy via anaerobic digestion. The aim of the study was to obtain the possible potential of green microalgae, which could replace the commonly used corn silage for the production of biogas in the future. The intensive construction of new biogas plants stations across Europe and the lack of arable land suitable for the cultivation of biomass for energy purposes are the fundamental reasons behind looking for the alternative raw materials for energy production as a substitute for commonly used input materials. When comparing green microalgae with conventional crops the high productivity potential (high oil content) as well as the possibility of their production during the whole year can be noticed. It is necessary to find the effective way to produce biomass from green microalgae, proper for energy conversion, while ensuring the economic and environmental aspects. The interim research results mentioned in this article indicate that microalgae present appropriate alternative material for the process of anaerobic digestion.

Keywords: microalgae, biomass, biogas, productivity, anaerobic digestion

Climate change, global warming, and rising prices for oil and petroleum products caused by the reduction of energy security are the main reasons why researchers are currently focused on renewable energy from microalgae (Mobin et al., 2014). Microalgae have the potential to be a substitute for traditional crops (rapeseed, corn silage) due to rapid growth and their high photosynthetic efficiency. Algae biomass can be cultivated in a number of different types of photobioreactors, water reservoirs or greenhouses. As examined by Tsai, Chen and Ramaraj (2017), microalgae were universally accepted as the ideal solution for monitoring of the greenhouse gas emissions. The research has shown the perfect uptake of CO_2 (the amount of 159 $mgL^{-1}.day^{-1}$ with 93% of CO_2 consumption efficiency) (Tsai, Chen and Ramaraj, 2017).

Microalgae – production of biomass

Microalgae are the simplest autotrophic organisms (mostly microscopic) with undemanding requirements for growth and increasing growth rates depending on the environmental conditions created in the growth medium. The key factors to control the growth of algae are: water, light, CO_2, temperature and optimum ratio of N : P : K. During the most important growth phase of algae growth – the exponential phase – there can be observed the doubling of biomass in less than 3.5 hours. The microscopic algae can be used to utilise the waste carbon dioxide (CO_2), 1 kg of dry biomass of algae will use approximately 1.83 kg of CO_2 (Brennan and Owende, 2009). Microalgae can be considered as a suitable substrate for anaerobic digestion due to high productivity and reduced need for the use of arable land. One of the most important factors for the overall success of microalgae cultivation is the selection of a suitable genus of algae (Bruton et al., 2009). The selection of optimal and proper types of algae results in a more effective conversion of biomass into methane. When selecting an appropriate genus of microalgae, it should be noticed that one of the most important parameters is the characteristic structure of the cell wall of microalgae, which determines the efficiency of the anaerobic process. Some species lack a cell wall, some microalgae have a wall consisting of a protein without cellulose or hemicellulose, and these parameters are the key ones to easier biodegradability. When selecting microalgae species for anaerobic digestion, it is necessary to take into account other parameters, for instance, productivity and sensitivity to contamination. If the selected species of microalgae have strong cell walls and are resistant to the anaerobic digestion process, algae biomass should be first processed before being used as a raw material in a biogas plant.

Due to the high photosynthetic efficiency and intense growth in the context of cultivation of microalgae, there is an ongoing study of green microalgae as a promising feedstock for the production of fuels and chemicals. The cultivation of algae biomass for the production of biofuels is an interesting biomaterial for researchers worldwide (Sarkar et al., 2015).

The successful cultivation of microalgae requires the knowledge about ecology of microalgae in order to ensure the precise conditions for their growth. It has been calculated (Benemann, 2013) that the amount of total dry matter production of microalgae in the world represents

Contact address: Mgr. Natalia Głowacka, Slovak University of Agriculture in Nitra, Faculty of European Studies and Regional Development, Department of Regional Bioenergy, Slovak Republic, e-mail: xglowacka@uniag.sk; Environmental Institute, s. r. o., Koš, Slovak Republic

the value of 15,000 $t.year^{-1}$. The biomass of microalgae is not collected only from the natural environment (water), but also from the artificial cultivation equipment (reservoirs) and photobioreactors.

The basic requirements for the cultivation of microalgae are:

- Light exposure – specific duration and frequency can influence concentration of biomass, cell density as well as the content of fatty acids and proteins.
- Temperature and pH control – it determines the reaction of intracellular enzymes, which affect the concentration of biomass.
- Oxygen elimination – microalgae produce oxygen proportionally to their growth (should be removed).
- Supply of CO_2 – the efficient capture of carbon dioxide is an important and crucial part of system design for algae growth.
- Circulation of the culture – affects the elimination of oxygen, distribution of light, reduction of the organic matter.

Green microalgae are one of the most promising sources for chlorophyll, due to the fact that cultivation of microalgae helps in minimizing the impact of global warming, because of CO_2 mitigation (Miazek and Ledakowicz , 2013). The rate of biofixation of CO_2 by *Chlorella* sp. was tested and the results showed the values of 700 mg $L^{-1}.d^{-1}$ (Adamczyk et al., 2016). The tolerance of CO_2 concentration can divide microalgae into two groups, as follows: sensitive to CO_2 (less than 2–5%) and tolerant to CO_2 (5–20%) (Miyachi et al., 2003). Green microalgae have an excellent capability to grow during utilisation of high concentrations of CO_2, which is the reason why microalgae are perfect to be used for biofixation process (Ji et al., 2016).

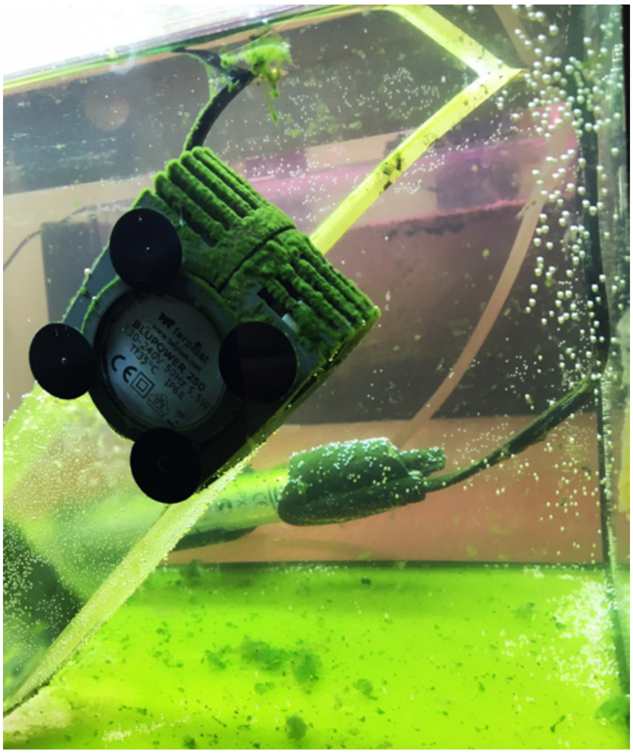

Figure 1 Cultivation of biomass from *Acutodesmus dimorphus* (Turpin) P. Tsarenko in a bioreactor
Source: author

Material and methods

The algal culture media has to provide the most essential inorganic elements, which are the components of algal cells. The crucial elements contain nitrogen (N), phosphorus (P), potassium (K) and iron (Fe). The estimation of the minimal nutritional requirements can be calculated using the molecular formula specified for microalgal biomass: $CO_{0.48}H_{1.83}N_{0.11}P_{0.01}$ (Chisti, 2007).

In our experiment, the biomass of microalgae *Acutodesmus dimorphus* (Turpin) P. Tsarenko was cultured and grown in the laboratories of the Environmental Institute, Koš (Slovakia) within the biotechnological process conducted in an enhanced Bold's Basal medium (Andersen, 2005) with all basic parameters mentioned above. For the cultivation of algae, there was used a 10-liter bioreactor, which was later replaced by a 100 L bioreactor (10 L of algae suspension was added to 90 L of culture medium) while maintaining the optimum temperature between 25–28 °C. The temperature generated in a bioreactor can affect the chemical composition of algal cells. In order to create the most favourable conditions for the growth of algae, the pH was controlled in the range of 7.0–7.3. Mixing and circulation (CO_2 supply) of algal cultures in the bioreactor were important to remove high levels of oxygen, which is

Figure 2 Flocculation and harvesting of biomass from *Acutodesmus dimorphus* (Turpin) P. Tsarenko
Source: author

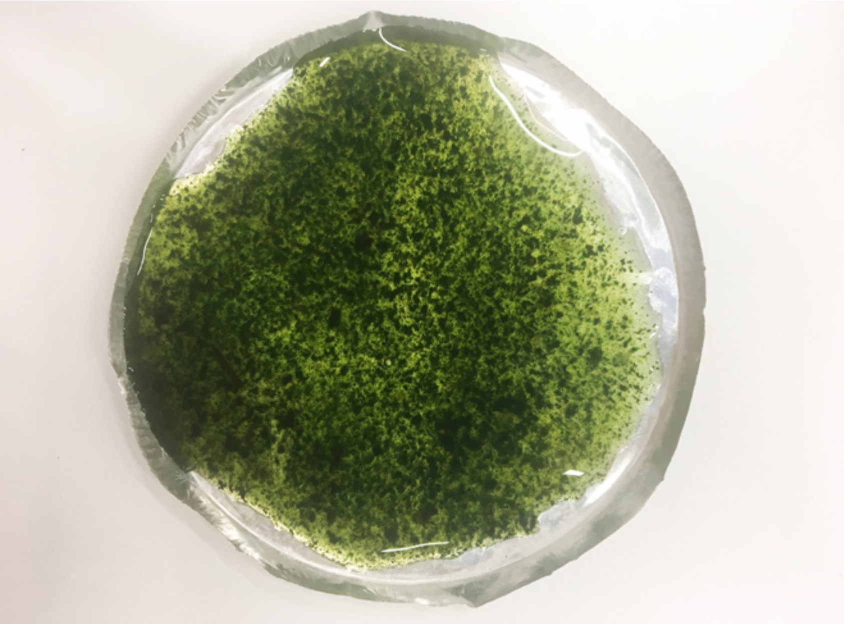

Figure 3 Sample material of microalgae *Acutodesmus dimorphus* (Turpin) P. Tsarenko (3.28% dry matter)
Source: author

harmful to algae. The level of light was kept at the desired ratio in order to control the process of photosynthesis, 16 : 8 (light : dark) (Głowacka et al., 2016).

For the purpose of realisation of the comparative tests of biogas yield of different mixtures of input materials, there were designed, produced, and installed the experimental fermenters for batch tests in the workplace of the Department of Regional Bioenergy in Kolíňany. The fermenters have the following basic parameters: stainless steel tank, with a net volume of 100 L, with electric water heating, with a digital temperature control and an electric low-speed mixer with the possibility of adjusting the mixing time and the breaks (12 cycles per day lasting from 20 to 30 minutes).

The structure of fermenters allows the implementation of batch tests to determine the yield of biogas production of mixed input materials (biomass). The quantity of the produced biogas was continuously measured and recorded through the automatic recording (using RIGAMO software). The fermenter was equipped with valves allowing sampling substrate during the experiment to the implementation of chemical analysis, as well as to analyse the composition of the produced biogas (see diagram Figure 4).

Each experiment directed to detection of the yield of biogas was carried out in the period of 30 days.

As the contribution to the search for possible alternative input materials

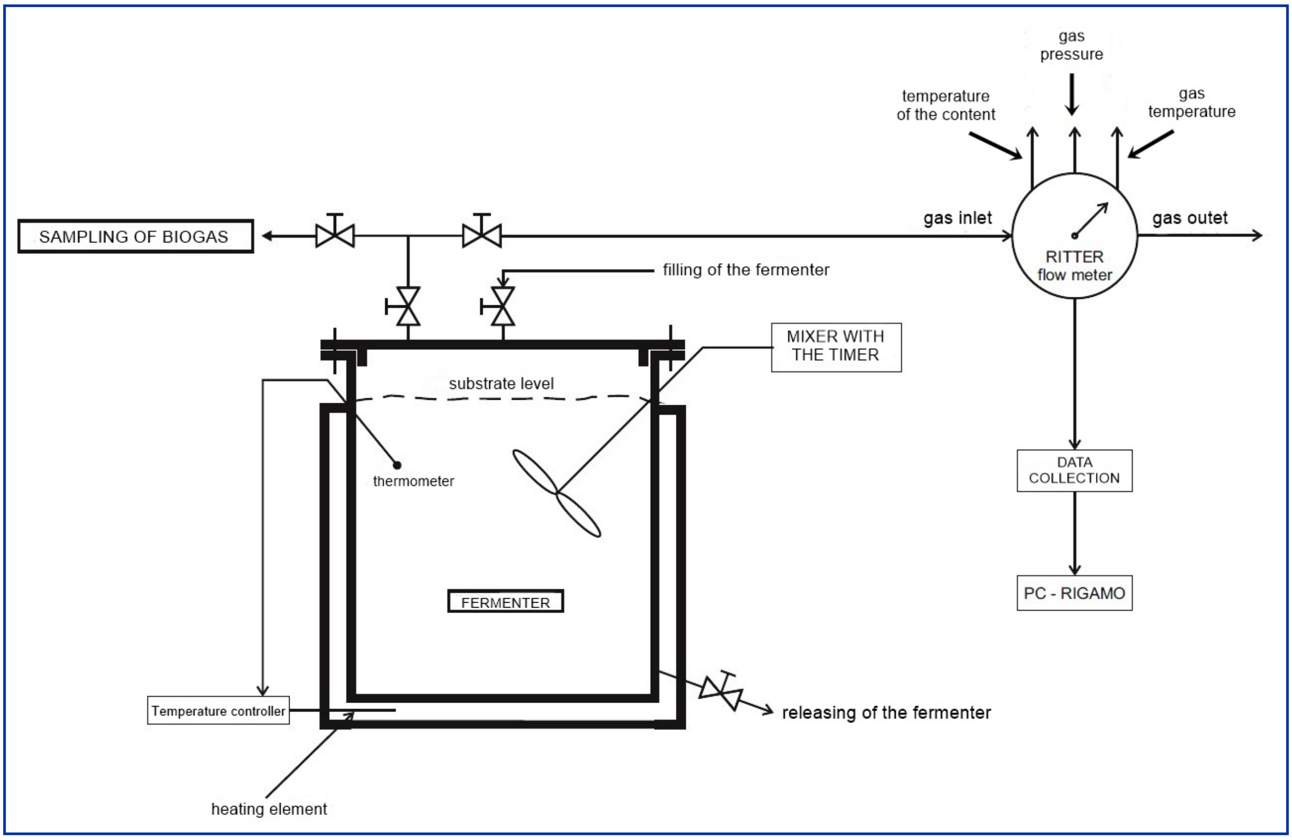

Figure 4 The technological scheme of the experimental fermenter 100 L
Source: author

Figure 5 The arrangement of 100 L fermenters with Ritter gas meters
Source: author

Figure 6 The substrate: the inoculum + microalgae after filling of the fermenter
Source: author

Table 1 The characteristics of microalgal slurry of *Acutodesmus dimorphus* (Turpin) P. Tsarenko.

Parameter	TS (%)	VS (%)	VS (%TS)	COD (mg.L^{-1})	NTOT (mg.L^{-1})
Microalgae	3.28	2.94	93.41	45,000	115

for biogas production, the species *Acutodesmus dimorphus* (Turpin) P. Tsarenko, cultivated in laboratory conditions at the total amount of 2,300 ml has been chosen for the research of biomass – concentrated microalgae. The prepared starting material is shown on Figure 3. The fermenter was filled with the inoculum taken from the biogas plant in the volume of 97 L where the microalgae were added (Figure 6). The experiment was conducted during 30 days.

After closing of the fermenter, it was set to auto mode control heating at 40 °C ±1 °C, as well as the automatic recording mode of the cumulative biogas production. The value of biogas production was recorded every hour. The processed outputs of individual endpoints are shown in the following tables and graphs.

Results and discussion

The cumulative production of biogas is shown in the graph (Figure 7). The total amount of biogas produced from the substrate in the fermenter during 30 days of experiment was 289.6 L of biogas, where the separated inoculum (97 L) has produced 124.8 L of biogas. The content of biogas is shown in the graph (Figure 8).

The experiment has confirmed that concentrated microalgae are a suitable raw material for biogas production with the method of wet fermentation. The acceptable average levels of methane in the biogas have been achieved – it was 50.38% by volume, as well as low levels of hydrogen sulphide in the amount of 105.83 ppm. Thus, the biogas would require the minimum desulphurisation (to a value below 100 ppm) prior to use in the cogeneration unit.

During the 30 days of the experiment in the experimental fermenter, the total achieved production of biogas reached 289.6 L, representing the average daily production of 9.653 L.day^{-1}. The average pH in the fermenter was 6.93 and the temperature was 39.37 °C throughout the duration of the experiment.

The content of dry matter (TS%, DM) of the concentrated microalgae was 3.28%, the doses of dry matter (DM) and the organic dry matter (ODM) of microalgae in the fermenter were as follows:

Dose of DM = 0.0754 kg DM of microalgae

Dose of ODM = 0.0705 kg ODM of microalgae

The average total production of biogas (BP) per unit of dry matter of the microalgae biomass was:

Biogas production = 2.186 $m^3.kg^{-1}$ DM

Biogas production = 2.338 $m^3.kg^{-1}$ ODM

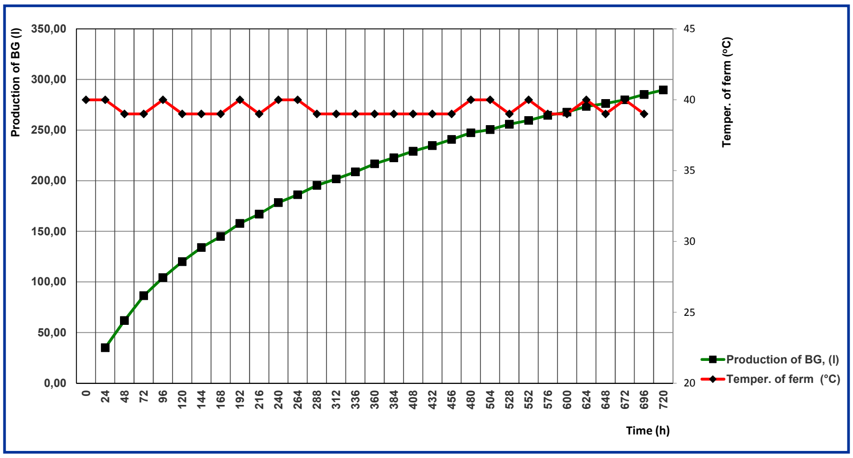

Figure 7 The cumulative production of biogas during experiment with microalgae *Acutodesmus dimorphus* (Turpin) P. Tsarenko
Source: author

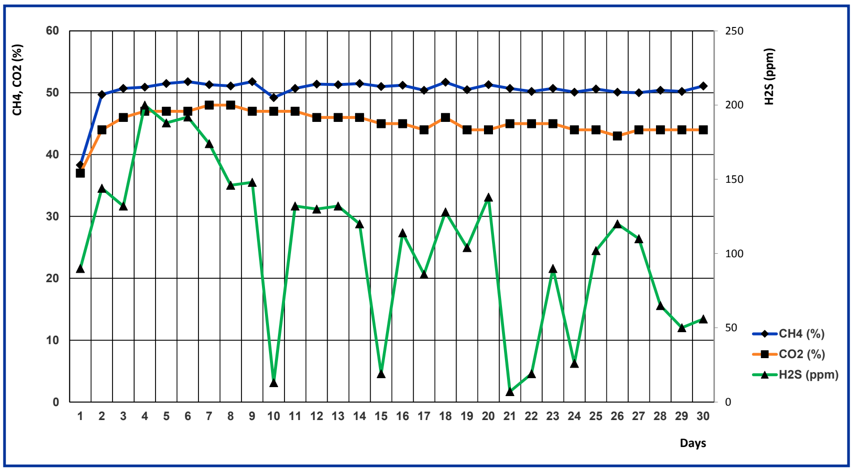

Figure 8 The course of methane, carbon dioxide and hydrogen sulphide in the produced biogas
Source: author

For comparison, there are listed the results obtained during the same experiment using 97 L of manure (composed of 80% of liquid pig manure and 20% of cattle manure). The results are shown in Table 2. The total production of biogas was 124.8 L of biogas, the calculated dry matter per unit of input material (dry matter content in the manure was DM = 1.17%) was obtained as the biogas production of 0.1099 $m^3.kg^{-1}$ of DM with the composition of the average methane content of 48.89%.

The most essential value that should be noticed in the table (Table 2) is the average production of biogas (TS), ($m^3 \cdot kg^{-1}$). The value is calculated per unit of dry matter; as we can see, the biomass of microalgae *Acutodesmus dimorphus* (Turpin) P. Tsarenko has produced 2.186 $m^3.kg^{-1}$ of biogas.

Biomass of microalgae is a very powerful material. The sooner people will accept its valuable impact on the environment, the better they will be able to resolve the significant problems and issues related to the environment (Chand et al., 2000).

Conclusion

The development of installations of biogas plants in the European Union is a constantly growing trend. It is therefore necessary to look for the suitable replacement for the commonly used input material, which is corn silage. Our experiment has shown that green microalgae can be quite a promising alternative. Microalgae biomass of *Acutodesmus*

Table 2 The average calculated values and the comparison of composition of the produced biogas from microalgae, manure and corn silage

Substrate (input)	Total biogas production (L)	Average dose of substrate (kg)	Average biogas production per unit of TS ($m^3.kg^{-1}$)	Average methane content (%)	Average carbon dioxide content (%)	Average hydrogen sulphide content (ppm)
Microalgae *Acutodesmus dimorphus* (Turpin) P. Tsarenko 2.3 L	164.8	0.0754	2.186	50.38	45.10	105.83
Manure 97 L	124.8	1.135	0.1099	48.89	43.10	95.27
Corn silage 3 kg	704.94	0.9876	0.7138	53.98	40.40	315.17

dimorphus (Turpin) P. Tsarenko was able to produce 2.186 $m^3.kg^{-1}$ of biogas while corn silage produced only 0.7138 $m^3.kg^{-1}$. We have achieved 50.38% of methane in the produced biogas by volume. Another important issue was the low content of hydrogen sulphide (105.83 ppm) in the produced biogas, which will result in the minimum process of desulphurisation (to a value below 100 ppm).

These results give us a positive view into the future; they shows there is a way to replace the corn (maize) silage with algae biomass, which can be cultivated and harvested through the whole year, regardless of the weather conditions. The results of the present research will contribute to the further development of the comprehensive program to use all forms of renewable energy in the European area.

Microalgae can also be a perfect solution to utilise the agricultural waste and convert it into energy. Such reuse of technological waste forms a perfect opportunity to integrate the energy producing and consuming technologies of processing of by-products and waste. However, the barrier which can be met under the development of the algae biomass production technology, becoming a large-scale system still needs to be taken into consideration.

References

ADAMCZYK, M. – LASEK, J. – SKAWINSKA, A. – 2016. CO_2 biofixation and growth kinetics of *Chlorella vulgaris* and *Nannochloropsis gaditana*. In Appl. Biochem. and Biotechnol., 2016, no. 179, pp. 1248–1261.

ANDERSEN, R.A. (ed.). 2005. Algal culturing techniques. London : Elsevier Academic Press, 2005, 578 pp.

BENEMANN, J. 2013. Microalgae for biofuels and animal feeds. In Energies, vol. 6, 2013, no. 11, pp. 5869–5886.

BRENNAN, L. – OWENDE, P. – 2009. Biofuels from microalgae – A review of technologies for production, processing, and extractions of biofuels and co-products. In Elsevier, 2009. doi:10.1016/j.rser.2009.10.009.

BRUTON, T. – LYONS, H. – LERAT, Y. – STANLEY, M. – RASMUSSEN, M.B. 2009. A review of the potential of marine algae as a source of biofuel in Ireland. Dublin : Sustainable Energy Ireland, 2009, p. 88.

CHAND, R. L. – KUMAR, H. D. – MOHN, F. H. – SOEDER, C. J. 2000. Services of algae to the environment, Journal of microbiology and biotechnology. In J. microbiol. biotechnol., vol. 10, 2000, no. 2, pp. 119–136. ISSN 1017-7825.

CHISTI, Y. 2007. Biodiesel from microalgae. In Biotechnology Advances, vol. 25, 2007, no. 3, pp. 294–306.

GLOWACKA, N. – GADUS, J. – KISS, G. – SLOBODNIK, J. 2016. Potential of microalgae biomass for biogas production, 6th International Scientific Conference May 31–June 2, 2016 Tatranské Matliare, Renewable Energy Sources 2016 High Tatras, Slovak Republic, Volume of papers, pp. 16–21. ISBN 978-80-89402-82-3.

JI, M.K. – YUN, H.S. – HWANG, J.H. – SALAMA, E.S. – JEON, B.H. – CHOI, J. 2016. Effect of flue gas CO_2 on the growth, carbohydrate and fatty acid composition of a green microalga *Scenedesmus obliquus* for biofuel production. In Environ. Technol., 2016, pp. 1–8.

MIAZEK, K. – LEDAKOWICZ, S. 2013. Chlorophyll extraction from leaves, needles and microalgae: a kinetic approach. Int J Agric Biol Eng., 2013, no. 6, pp. 107–115.

MIYACHI, S. – IWASAKI, I. – SHIRAIWA Y. – 2003. Historical perspective on microalgal and cyanobacterial acclimation to low- and extremely high-CO_2 conditions. In Photosynth. Res., vol. 77, 2003, no. 2, pp. 139–153.

MOBIN, S. – ALAM, F. 2014. Biofuel Production from Algae Utilizing Wastewater, 19th Australasian Fluid Mechanics Conference, Melbourne, Australia.

SARKAR, O. – AGARWAL, M. – KUMAR, A. N. – MOHAN, S. V. 2015. Retrofitting hetrotrophically cultivated algae biomass as pyrolytic feedstock for biogas, bio-char and bio-oil production encompassing biorefinery. In Bioresour. Technol., 2015, no. 178, pp. 132–138.

TSAI, D. D.W. – CHEN, P. H. – RAMARAJ, R. 2017. The potential of carbon dioxide capture and sequestration with algae. In Ecological Engineering, vol. 98, 2017, pp. 17–23.