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Methane fermentation of the maize straw silage under meso- and thermophilic conditions

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ABSTRACT

Under conditions of low funding for the production of "green energy" in Poland, it became necessary to search for other – cheaper sources of biomass and the development of more efficient technologies. The maize straw is waste material arising in the production of grain. Therefore currently has no wider application and the cost of acquisition is several times lower than in case of maize silage. This paper presents the results of research on biogas efficiency of the maize straw silage, the dynamics of the fermentation process and the decomposition time of biomass under the meso- and thermophilic conditions. Moreover, the exploitation costs of a biogas plant working on this substrate and maize silage have been compared.

It has been proved that thermophilic fermentation is significantly shorter (17%) than mesophilic and permits to increase biogas production (8.6%) and methane content (9.3%). In turn, mesophilic fermentation has more stable pH changes in comparison with the thermophilic technology. However, it is related to inhibition of the propionic acid, which can be of great importance in case of continuous fermentation. On the basis of energetic calculations it was shown that the substitution of the maize silage with the maize straw silage allows for nearly three-fold costs reduction and thus increase of the biogas plant profitability.

1. Introduction

Intensive development of civilization in the world has led to a sharp increase in energy consumption, reaching in 2013 the value nearly three times higher than 50 years ago [1]. Due to the need of intensification of energy generation from renewable sources, as well as the need for dissemination of the methods to reduce the emission of greenhouse gases into the atmosphere, increasing importance begins to play production and use of agricultural biogas. According to the Iniyan and Sumathy forecasts the energy from renewable sources will constitute 25% of the total energy demand in India in 2020 [2]. A similar tendency, although in much lower dimension also can be observed in Poland, where the number of biogas plants in the years 2001–2010 increased 10 times [3]. And still, the biogas potential is used only marginally [4].

Nowadays the most commonly used substrate for methane fermentation process in Central Europe is maize silage [5]. However, due to the conflict "energy vs. food", the risks arising from the crops monoculture and growing prices of this substrate, the alternative sources of biomass are increasingly looked for [6]. This conflict has taken a particular form in Mexico, where people went to the streets because allocation of maize for energy purposes, increased the price of tortillas [7]. Therefore, an alternative is even the use for energy purposes the waste materials from herbal industry [8], food industry and agriculture [9] or farming at the areas unsuitable for crops intended for human consumption [10]. Huge importance for the profitability of biogas investments under Polish conditions (low subsidies to the prices of "green" energy) has also the development of more efficient technologies, cheaper than western ones, use of heat produced during biogas combustion [11]

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List of abbreviations

Mg	Megagram
FM	Fresh Mass
TS	Total Solids
VTS	Volatile Total Solids
kW	Kilowatt
MW	Megawatt
MWh	Megawatt-hour
VFA	Volatile Fatty Acids
HRT	Hydraulic Retention Time

and digestate pulp management, i.e. as a high-grade field fertilizer [12].

In the face of these challenges, an interesting substrate may be maize straw silage which despite relatively low efficiency from Mg of dry mass (350–400 m^3) is characterized by a high ratio of methane yield of the substrate price [13]. This is mainly due to the fact that the maize straw has a higher dry mass than maize silage and is three times cheaper. Moreover, this substrate is a waste material arising in the production of grains, with no wider application in agriculture and industry. Thus, anaerobic digestion, next to composting, which apart from organic matter mineralization and volume reduction [14] allows waste hygienisation [15] is an environmentally friendly method for management of organic waste materials [16]. Moreover, anaerobic digestion, despite the composting process [17], allows not only matter but also energy to be recovered from bio-waste [18].

Another factor influencing the profitability of the investment is the use of the technology – mesophilic or thermophilic one. The scientific community is not consistent as to the effect of the temperature of the process on the efficiency of the biogas substrate. Bojra et al. proved that in case of fermentation olive mill wastewater the thermophilic process is more efficient [19]. Similar results were obtained by Kinnunen et al. Using as a substrate Nannochloropsis micro alga [20]. Moreover, Kim et al. also while studying the differences between the meso- and thermophilic processes in various mixing systems and different number of stages, using a dog food as a substrate have found that, in many ways, higher temperature preferably affects methane fermentation process [21]. In turn, research conducted by Gołkowska and Greger, where the substrates were cellulose and maize silage, showed that greater stability and higher methane efficiency is characteristic in case of mesophilic process [22]. However an advantage of thermophilic fermentation is shortening the decomposition time of the biomass which was proved both in the aforementioned research and in case of dry fermentation of municipal waste [23] and maize straw [24].

The aim of the study was to compare the methane fermentation of the maize straw silage under meso- and thermophilic conditions by determining the dynamics of the process and the final efficiency of the biogas. Moreover, the expectable incomes obtainable from the sale of electricity and origin certificates have been summarized. The calculations included the costs of the substrates needed to power a biogas plant with a capacity of 250 kW operating on maize straw silage and traditional maize silage.

2. Materials and methods

The research experiments were carried out in the Laboratory of Ecotechnologies in the Poznań University of Life Sciences – the largest biogas laboratory in Poland (over 250 fermenters working in temporary or permanent mode). The analysis of the biogas efficiency of the substrate was based on a modified German norm DIN 38,414/S8 and standardized biogas guidance issued by the Association of German Engineers in Dresden VDI 4630. The efficiency of biogas production is defined as maximum amount of biogas and biomethane production during fermentation of analysed substrate under optimal, laboratory conditions Chemical analyses were made in accordance with the Polish Standardization System. Research methodology related to bio-waste was developed during several grants implemented throughout the 6th EU Framework Programme and Polish Ministry of Science and Higher Education in 2006–2012.

2.1. The origin of the substrate and fermentation inoculum

The maize straw silage has been obtained from Przybroda Agricultural-Orchard Experimental Farm belonging to the Poznań University of Life Sciences (PULS). The mesophilic fermentative inoculum was gained by separating the liquid fraction of the digestate pulp from operating agricultural biogas plant. Thermophilic inoculum was prepared by progressive increase of the temperature (1 °C/week) of the water jacket in a tank containing the mesophilic inoculum, the same as described above. In addition, the inoculum has been feeding with the plant biomass providing an access of nutrients in the soil for all groups of microorganisms involved in the methane fermentation process. After reaching the temperature of 55 °C inoculum was stored in a heated tank and feeding until the start of the proper experiment.

Both mesophilic and thermophilic inoculum had a similar share of dry organic matter in the fresh mass, which was 1.58% in case of mesophilic inoculum and 1.51% for the thermophilic one.

2.2. Methane production set-up

The experiment of biogas production was conducted through anaerobic digestion in the set of multi-chamber biofermentor (Fig. 1) constructed in the Laboratory of Ecotechnologies. This biofermentor is commonly used for testing biogas efficiency for large amount of biomass samples.

Methane fermentation was conducted in the glass reactors with capacity of 2 dm^3. The tested substrates were placed in the reactors and then flooded with sufficient amount of inoculum. The reactors purged with nitrogen (creation of anaerobic conditions) were placed in a water bath with temperature of 39 °C ± 1 (mesophilic fermentation) or 55 °C ± 1 (thermophilic fermentation) to ensure optimal conditions for the methane fermentation process. Biogas produced in each separate chamber was transferred to cylindrical store – equalizing reservoirs, filled in with liquid resistant for gas solubility. The samples were tested in 3 replications.

2.3. Physical and chemical analyses

In order to select the proper proportions between the tested substrate and inoculum, the following parameters were examined: Total Solids (PN-75 C-04616/01), Volatile Total Solids (PN-Z-15011-3), pH (PN-90 C-04540/01) and conductivity (PN-EN 27888: 1999). These parameters were essential for the calculation of the biogas efficiency of the substrates into the units m^3/Mg FM.; m^3/Mg TS; m^3/Mg VTS. Moreover, every day, for the entire duration of the experiment, the pH and conductivity of the fermentation samples have been analysed.

2.4. HPLC analyses

Samples were centrifuged, filtered with a 0.45 μm-membrane

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