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The possibility of using plants from hybrid constructed wetland wastewater treatment plant for energy purposes

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ABSTRACT

In recent years, constructed wetland systems are used widely for the purification of small amounts of wastewater because they provide very high effects of removing impurities. The existing research results show that constructed wetland systems can be used not only for highly efficient wastewater treatment, but at the same time in order to produce biomass for energy purposes.

The aim of this paper was to determine the possibilities of energy use of the plants: common reed, willow, Jerusalem artichoke, giant miscanthus, obtained from constructed wetland system.

The yield of common reed was the highest compared to the other plant species used in analyzed object and amounted to 13.6 Mg DM ha^{-1} and then 8.7 Mg DM ha^{-1} for willow. The lowest dry matter yield was 5.9 Mg DM ha^{-1} in the case of Jerusalem artichoke.

High Heating Value was similar in all analyzed plants (17.9–19.2 MJ kg^{-1}), the highest results were obtained from willow. Biomethane production during anaerobic digestion was the highest from common reed (108 m^3 Mg^{-1} FM) and the lowest from Jerusalem artichoke (66 m^3 Mg^{-1} FM). The methane concentration in biogas was rather low (50.9–54.9) comparing to other typical substrates for biogas production.

1. Introduction

Since the water resources both in Europe and Poland are relatively small, in recent years more and more attention is paid to water conservation methods. Therefore, in 1991 the Council of the European Community introduced the Directive No. 91/271/EEC (Urban Waste Water Treatment (91/271/EWG), 1991) concerning urban wastewater treatment. This document obliges the Member States of the European Union to provide all agglomerations with population equivalent above 2000 with sewage systems providing biological waste water treatment before discharging them into the water, so as to meet certain requirements related to the content of readily biodegradable substances. In areas where the construction of a collective sewerage system would not bring any benefits to the environment or would result in excessive costs, the Directive recommends the use of individual systems or other alternatives that ensure an adequate level of environmental protection. Those systems should provide a high level of wastewater treatment that would prevent pollution and degradation of water receivers and groundwater, as well as protect and improve the condition of aquatic ecosystems. In most households in rural areas in Poland, the so-called septic tanks are still being commonly used. Unfortunately, those tanks very often are leaky and create a huge threat to the environment (Obarska-Pempkowiak and Kołecka 2007). Favorable alternative of management of domestic sewage in relation to the use of septic tanks are the domestic sewage treatment plants i.e. objects that support up to 50 residents.

Nowadays, there are a lot of different solutions designed for sewage treatment plants. These are mainly the drainage systems that constitute a system of underground drains, discharging wastewater purified mechanically in a settling tank to the ground. According to Dragon et al. (2016), these systems are the most commonly used in Poland (63%) due to the low costs of installation. However, there is a still ongoing debate whether the sewage drainage can ensure effective elimination of pollutants, or serve only for the discharge of untreated sewage into the ground. Zhang

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et al. (2015) stated that systems with drainage unit cannot be accepted in the long term, because sewage discharged into the receivers are purified only by mechanical means. According to Jóźwiakowski et al. (2015), taking into account environmental criteria in order to preserve the principles of sustainable development, the possibility of using these solutions on a larger scale should be excluded.

A solution that is much safer for the environment is that of treatment installations based on the use of sand filters. Such systems are similar to the drainage systems in terms of their structure, but they are isolated from the natural ground by means of an impermeable geomembrane. Sand filters are a much better technological solution than filtering drainage, due to the higher effectiveness of pollutant removal (Kauppinen et al., 2014). Another type of domestic wastewater treatment systems are systems with biological bed and activated sludge, as well as systems combining those two systems into a hybrid system. Biological beds are systems in which wastewater (purified mechanically in the settling tank) flows through a bed filler layer built of a porous material (e.g. coke, crushed stone, gravel, plastic shaped blocks), on the surface of which biological membrane develops, consisting of microorganisms utilizing pollutants contained in wastewater as nutrients (Hoang et al., 2014). Whereas, activated sludge is formed by microbial communities that, with a suitable supply of oxygen, have the ability of mineralization of organic matter contained in wastewater. Thanks to the application of activated sludge and to the creation of alternating aerobic, oxygen-deficient and anaerobic conditions, it is possible to remove, with high efficiency, carbon compounds as well as biogenic compounds – nitrogen and phosphorus (Ratkovich et al., 2013). Still another type of domestic wastewater treatment plants are constructed wetlands. Their functioning is based on the use of the same physical, chemical and biological processes that take place in natural wetland ecosystems, with participation of various microbial groups and suitable selected plant species. Pollutant removal in constructed wetlands is related primarily with the functioning of a biological membrane formed in the course of wastewater passage through a ground layer, while plants play an auxiliary role in the process of purification (Gajewska et al., 2015).

In recent years, for purification of small amounts of wastewater, both worldwide and in Poland, the constructed wetland systems are increasingly being used because they provide very high effects of removing impurities (Gajewska et al., 2015; Vymazal, 2007). On the basis of the multi-criteria analysis it has been recognized (Jóźwiakowski et al., 2015) that use of those solutions is consistent with the fundamental principles of sustainable development. Previous experience has shown that those systems can neutralize domestic wastewater in rural areas with great success for many years (Vymazal, 2011; Melián et al., 2010). In Poland there is now the beginning of using these systems also in protected areas. The first three constructed wetland installations were built in 2014 in the Roztocze National Park and an another one in 2015 in the Polesie National Park (Jóźwiakowski et al., 2014, 2016).

According to Foladori et al. (2012), Vymazal and Březinová (2014) and Vymazal (2013), the removal of contaminants in the constructed wetland systems is related to the functioning of the biological membrane that is formed when wastewater passes through a ground layer, while the plants assist in the purification process. At the plant roots an oxygen rhizosphere is created, while in other parts of the layer there are anaerobic zones and poorly oxygenated ones. According to Birkedal et al. (1993), the plant roots and rhizomes allow to keep proper hydraulic conductivity of the layer and cause the looseness of its internal structure. The system of developed roots and rhizomes allows an intensive development and growth of the plants on the soil-plant layers, which can have a direct impact on high transpiration of water from the plant surface and show a significant reduction of the amount of sewage flowing out of the systems, and even the disappearance of the drain (Gregersen and Brix, 2001). The existing research results show that constructed wetlands can be used not only for highly efficient wastewater treatment, but at the same time in order to produce biomass for energy purposes (Cerbin et al., 2012; Posadas et al., 2014). The problem of environmental protection and biomass production are the subject of numerous scientific studies (Białobrzewski et al., 2015; Koyama et al., 2014; Posadas et al., 2014; Verma et al., 2014; Janczak et al., 2013; Cieślik et al. 2016).

This is mainly due to the wide range of possibilities for its development. One of such possibilities is the use of biomass for the production of compost, i.e. organic fertilizer rich in humus and nutrients for plants (Czekała et al., 2016; Lewicki et al., 2014; Starzyk and Czekała, 2014). Using more advanced technologies it is possible to use the plant biomass for energy purposes (Lu and Zhang, 2013). Such actions certainly bring an additional benefit to the environment, resulting from the use of renewable energy sources while maintaining extremely valuable sources of fossil fuels (Schneider and Kaltschmitt, 2000; Halbe et al., 2014; Kowalczyk-Juśko et al., 2015b).

Energy crops such as willow, Jerusalem artichoke, common reed and giant miscanthus are characterized by rapid growth, even on very poor soils (Gruenewald et al., 2007). It is the greatest advantage from the energy viewpoint. Large scale production of raw material will enable its use in direct combustion or for the production of solid biofuels such as pellets or briquettes (Nimmanterdwong et al., 2015).

One of the advantages of solid biofuels is the ability to use them in the farm of the producer or at a local scale. Another possibility is to use it for agricultural biogas production (Koyama et al., 2014; Dach et al., 2014). Biogas plants can use a wide variety of agro-food industry by-products as feedstock (Moss et al., 2014). It is necessary to look for new substrates for biogas production. One of them may be straw (Czekała et al., 2015; Ciotola et al., 2011). Regardless of which substrates are used in the biological decomposition processes, it is necessary to know their characteristics (Lewicki et al., 2014). Another aspect in favor of energy crops use is the withdrawal from the model system of the biogas plant working on maize silage and slurry (monoculture formation). Taking into account all those facts, the utilization of plants from sewage treatment plants for biogas production appears to be a rational solution.

Obtained research results may serve as an indication for municipalities on how to improve the energy efficiency of the local environment by using renewable energy sources – biomass produced along with simultaneous exploitation of the sewage treatment plants. So far, in the constructed wetlands in Europe and worldwide, commonly used were mainly common reed (*Phragmites australis* Cav. Trin. ex Steud.) and willow (*Salix viminalis* L.) (García et al., 2013; Vymazal, 2011, 2013). However, in the systems selected for research and described in this paper the following energy plants have been used – giant miscanthus (*Miscanthus* × *giganteus* Greef et Deu.) and Jerusalem artichoke (*Helianthus tuberosus* L.).

The aim of the paper was to determine the possibilities of energy use of the plants obtained from constructed wetland for wastewater treatment. In order to achieve the research objective the following research tasks have been carried out:

- collecting the plants from constructed wetland, four selected species of energy crops;
- study of energy value (Low Heating Value—LHV, High Heating Value—HHV) of the plants harvested after the second year of exploitation;
- study of biogas and biomethane potential tests of harvested plants.