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Energy biomass characteristics of chosen plants

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A b s t r a c t. The chosen energy plants species: willow, mallow and *Miscanthus* are presented. Result of analysis of combustion heat and heating value of these species biomass indicate on possibility of their utilization as fuel for combustion and energy and heat production.

K e y w o r d s: plants, biomass, heating value

INTRODUCTION

In recent years, dynamic development of modern technology of utilization of renewable energy sources (RES), including biomass produced in agriculture, was observed worldwide. Worldwide biomass ranks fourth as an energy resource, after coal and oil. In all its forms, biomass currently approximately 14% of the world energy needs. Biomass is the most important source of energy in developing nations, providing; 35% of their energy. In developed countries, biomass energy use is also substantial. In the European Union biomass contributes between 20 and 40 mln t of oil equivalent to the annual energy consumption (Sotannde, 2010; Werther *et al.*, 2000).

The use of biomass to provide partial substitution of fossil fuels, has an additional importance as concerns global warming since biomass combustion has the potential to be CO_2 neutral. This is particularly the case with regard to agricultural residues or energy plants, which are periodically planted and harvested. During their growth, these plants have removed CO_2 from the atmosphere for photosynthesis which is released again during combustion (Werther *et al.*, 2000).

In a structure of renewable resources leading position in Poland has biomass. Currently in Poland biomass is obtained from forestry, wood-processing plants, maintenance of municipal green areas and in small amounts of organic fraction of segregated municipal wastes. In a close future supplement of the biomass balance can be obtained from short-rotation plantations (SRP) of willow coppice – *Salix* spp., *Miscanthus* - *Miscanthus x giganteus*, Virginia mallow – *Sida hemaphrodita* Rusby) and other crops (Stolarski *et al.*, 2008).

Territorial range of *Salix* genus presence is very wide and spreads from tropics and sub-tropics to cold arctic regions of the northern hemisphere. In Poland, it can be found in tree form in Wiślane and Elbląg marsh-lands. As an energetic plant, it has also been cultivated on arable land for several years. The most popular species of energetic willow are *Salix viminalis* and *Salix purpurea*. However, the most commonly cultivated forms are many crossbreeds based on these two varieties, while single variety cultivations are quite uncommon.

Biomass of wood originating from willow field plantations can be harvested annually or in two-, three- or four-year cycles for a period of 20-25 years.

Estimated yield of willow coppice on soils of Eastern Europe ranges from 13.8 to 18.1 t ha^{-1}, depending on variety, soil conditions, harvest cycle and agricultural procedures. (Borzęcka *et al.*, 2008; Fischer *et al.*, 2005).

Willow can be burned and chipped as any other wood. Moreover, briquettes and pellets can also be produced, however, it requires drying chips until their water content ranges form 12 to 13% for briquettes and 15-17% for pellets. The other efficient method of fast growing willow forms utilization is methanol production, however starting such a production is very expensive. Other, very important, way of willow utilization is using it in environment protection. Soils degraded and devastated by mining, industry and transport can be biologically reclaimed by means of cultivation of, resistant to soil acidification and capable of removing heavy metals from soil, willow. This method is

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also used in reclamation of sewage sludge from waste water treatment plants and sedimentation tanks as well as post-mining heaps. Moreover this plant is used in protection of watercourses from infiltration of fertilizers and pesticides washed off from fields and for stabilization of land endangered by erosion.

Virginia mallow (*Sida hermaphrodita* Rusby) originates from North America, where it is found growing wild. Recently possibility of its utilization for energetic purposes (mainly stems and leaves harvested in autumn – winter period after vegetation stops), has drawn researches attention (Antonkiewicz, 2005). Yield of dry weight of Virginia mallow stems varies depending on agro-ecological conditions. Its yield can reach 9 000 kg ha^{-1} when grown on sewage sludge and up to 17 000 kg ha^{-1} when cultivated on III class mineral soil. Advantage of this specie is possibility of obtaining biomass containing various amounts of moisture depending on needs. Biomass harvested in autumn, at the end of vegetation, may contain significant amounts of moisture, while moisture in biomass harvested in winter decreases to about 20%, mass (Borkowska and Styk, 2006).

One of the plants which may be a source of biomass is *Miscanthus* (*Miscanthus x giganteus*), sometimes in literature called 'Chinese grass' or 'elephant grass'. For many years it was treated as exotic decorative plant. It was only beginning of 80's when first 1 ha plantations in Germany and Denmark, and later in Switzerland, Holland and Hungary were established. Outside Europe, this grass is cultivated in some countries in Asia, Africa and South America.

Also in Poland research on introduction and cultivation of *Miscanthus* genus are conducted. These plants are of the great interest among farmers, who have hopes with their introduction.

Depending on the habitat conditions in terms of central Europe from 1 ha of plantations can be obtained from 17.7 to 21.8 t dry matter. This grass is maintained for 15 years in one place (Borzęcka *et al.*, 2008; Fischer *et al.*, 2005).

Among the various conversion technologies, combustion is the most common and developed way of converting biomass fuels to energy (Werther *et al.*, 2000; Williams *et al.*, 2001). The design and operation of biomass combustion systems significantly relies on biomass characteristics such as the heating value, moisture content, elemental composition, ash properties, *etc*. (Sheng and Azevedo, 2005).

The heating value defines the energy content of a biomass fuel and is one of the most important characteristic parameters for design calculations and numerical simulations of thermal systems no matter how biomass is used, direct combustion or co-firing with other fuels *eg* coals (Werther *et al.*, 2000; Williams *et al.*, 2001).

Generally, the heating value of a fuel may be reported on two bases, the higher heating value or gross calorific value and the lower heating value or net calorific value. The higher heating value (HHV) refers to the heat released from the fuel combustion with the original and generated water in a condensed state, while the lower heating value (LHV) is based on gaseous water as the product.

The heating value of a biomass fuel can be determined experimentally by employing an adiabatic bomb calorimeter, which measures the enthalpy change between reactants and products. However, the measurement is a complicated and time-consuming process that requires the set-up, measurement and calculation procedures (Sheng and Azevedo, 2005). In contrast, the conventional analysis *ie* proximate and ultimate analyses, is a basic fuel characterization and can be carried out more easily, quickly, and cheaply by using common or modern laboratory equipments.

The aim of this work was to determine the energy characteristics extracted from selected biomass energy plants *ie*:
- annual shoots of Virginia mallow (*Sida hermaphrodita* Rusby),
- annual shoots of willow coppice (*Salix viminalis* L.),
- grass straw of *Miscanthus* (*Miscanthus x giganteus*).

MATERIALS AND METHODS

In Department of Power Engineering and Vehicles in Lublin, research, which goal was determination of combustion heat and calculating heat value of chosen species of energy plants, has been undertaken, indicating this way, a possibility of their utilization for combustion and heat and energy production. The research material was collected randomly from the field of energy crops, following the end of the growing season. The materials with large particle sizes were ground using a knife mill (equipped with a 3 mm sieve), followed by a thorough homogenization. Fuels were then divided into 5 separate samples in such a way as to constitute a subgroup of repetitions. Determination of moisture content was conducted with conformity to EN 14774-3 (2009) norm by means of: electric dryer with air exchange unit, equipped with thermometer with measurement range to 120°C and elementary scale 1°C; laboratory ware, electronic and analytical mechanical scale. The sample used for the determination is the general analysis test sample with a particle size of 1 mm or less, prepared according to CEN/TS 14780 (2005). On the prepared samples were carried out three determination. Research, which goal was determination of combustion heat, was conducted by means of KL-12 calorimeter, which is intended for measuring combustion heat of solid fuels. Measuring method is in conformity with requirements of Polish norm PN-EN 14918 (2009). The research sets the measurements of changes of temperature of the water, which is coating the calorimetric bomb where a sample of the fuel (1 g) is being burnt completely under the atmosphere of oxygen at the pressure of 30 bar. On the base of received values of heat of combustion the caloric values of the tested fuels were calculated, according to the adequate standards. Moreover, in Central Laboratory of Power Research and Testing Company Laboratory 'Energopomiar' Ltd. in Gliwice, which is certified Testing Laboratory, accredited determination of Virginia mallow biomass chemical composition was carried out. Following analytical methods were utilized:

1. Carbon content – Q/ZK/P/15/09/A.
2. Hydrogen content – Q/ZK/P/15/09/A.

RESULTS AND DISCUSSION

Obtained results of combustion heat and calorific value of investigated energy plants are presented in Table 1. Moisture content of investigated material ranged from 7.6%, mass for stems of Virginia mallow and *Miscanthus* to 9.7%, mass for willow coppice (which was air dried in room temperature prior to analysis). Conducted research showed that wood of willow coppice had the greatest heat value which was 17 688 kJ kg^{-1}, biomass of Virginia mallow characterized with similar heat value of 17 167 kJ kg^{-1}, the smallest heat value had biomass of *Miscanthus* 16 577 kJ kg^{-1}, with similar moisture content. Based on statistical analysis of the results of research of calorific value, there were significant differences between the measured characteristics at the level of $\alpha = 0.05$, in the all analyzed cases.

In literature, there is a lot of data concerning energetic parameters of willow coppice and *Miscanthus*. Obtained results of research on combustion heat value and heating value of willow coppice and elephant grass biomass correspond to research results presented by other authors (Table 2). There are few reports in literature characterizing energetic parameters of Virginia mallow.

Obtained results of authors own research, as well as quoted data, lead to a conclusion that investigated plants can be considered biomass having high heating value (Table 2).

Biomass is composed of elements C, H, O, N, S, and Cl, where the former three are the major, representing up to 97-99% of the biomass organic mass. C and H are oxidised during combustion by exothermic reactions (formation of CO_2 and H_2O). The content of C and H contributes positively to the heat of combustion, the content of O negatively. H also influences the heat value due to the formation of water (Obernberger *et al.*, 2006).

For the purpose of comparison, obtained results of chemical composition of Virginia mallow biomass were compared to results of research on *Miscanthus* and willow coppice (Table 2). All chosen plants characterized with fairly high carbon content, which for willow coppice and Virginia mallows was 44% on average and 41% for Giant miscanthus. Content of hydrogen was at similar level and for willow coppice and Virginia mallow was 5.8, and 5.3% for *Miscanthus*, while oxygen content was 38% on average. Presented data shows that chemical composition of biomass of chosen energy plants is favourable in terms of their combustion. However, relatively high content of oxygen lowers its heating value.

Chemically, biomass is made up of similar components *ie* cellulose, hemicellulose, lignin and a small portion of solvent extractives (volatile substances). The chemical components of biomass, except cellulose, have different chemical structure and composition; consequently, the heating values of these components may vary a lot among different biomass species. The high content of volatile substances that cause biomass, compared to coal, are easier to ignite and to

T a b l e 1. Results of combustion heat and heat value of chosen species of energy plants

Parameters	Willow coppice		Virginia mallow		*Miscanthus*	
	Value determination	Average	Value determination	Average	Value determination	Average
Heat of combustion (kJ kg^{-1})	18 811	18 915a	18 237	18 300b	17 911	17 837b
	18 968		18 246		17 859	
	18 967		18 382		17 469	
Heat value (kJ kg^{-1})	17 605	17 688a	17 160	17 167c	16 735	16 577c
	17 754		17 074		16 579	
	17 706		17 267		16 427	
Moisture content (%, mass)	7.6	7.6	7.5	7.6	7.9	7.9
	7.5		7.6		7.8	
	7.7		7.6		7.9	

Different letters means that there are significant differences between the measured characteristics at the level of $\alpha = 0.05$.

T a b l e 2. Heat of combustion, heat value and elemental composition of chosen species of energy plants

Energy plant	Moisture content (%, mass)	Heat of combustion (kJ kg^{-1})	Heat value (kJ kg^{-1})	Content (%, mass)		
				C	H	O
Willow coppice[1]	11.4	17 188	15 711	43.1	5.5	38.4
Willow coppice[2]	7.1	18 150	16 876	45.0	5.8	-
Willow coppice[3]	11.1	17 922	16 371	43.8	5.9	-
Virginia mallow[4]	9.5	17 420	15 377	45.4	5.61	-
Virginia mallow[5]	7.7	16 900	15 600	46.2	4.9	-
Virginia mallow[6]	8.1	18 746	17 003	-	-	-
Miscanthus[7]	14.2	16 800	15 273	41.5	5.4	37.1
Miscanthus[8]	6.2	17 975	16 450	48.2	6.1	-
Miscanthus[9]	9.8	16 326	14 945	43.4	5.2	37.8

[1,9]Hallgren *et al*., 1999; [2,8]Komorowicz *et al*., 2009; [3,7]Illeroup and Rathmann, 1996; [4]own research; [5]Kowalczyk-Juśko, 2008; [6]Borkowska and Styk, 2006.

burn, although the combustion is expected to be rapid and difficult to control. The high volatile matter contents are also expected to affect the overall combustion process (Werther *et al.*, 2000).

Unfavourable property of plant derived biomass is, reaching even 50%, moisture content. Additional problem is posed by its variability depending on type of plant and seasoning time. High moisture content can lead to poor ignition, reduce the combustion temperature, which in turn hinders the combustion of the reaction products and consequently affects the quality of combustion.

High content of moisture in biomass affects also costs of its acquisition. Biomass is often moved to the place where it is combusted from distant regions of the country, and this way higher weight of biomass increases costs of its transport. Borkowska and Styk (2006) noticed that, regardless to term of harvest, half of wicker biomass was water, while Virginia mallow harvested in winter contained 50% less moisture. This phenomenon allows reduction of transport costs as well as reduction of amount of energy necessary for drying.

As a new crop in the landscape, *Miscanthus* and Virginia mallow, which can attain a height of up to 4 m under European conditions, may have a significant visual impact especially, when fields remain un-harvested until February. On the other hand, tall stands of *Miscanthus* can serve as cover and habitat for birds and mammals (Lewandowski *et al.*, 2000). *Miscanthus* stands contain more large animals (mammals, birds) than other herbaceous crops (maize or reeds), possibly due to the greater diversity of canopy structure leading to a higher number and greater range of ecological niches (Lewandowski *et al.*, 2000).

Obtained results show that Virginia mallow is a plant which can be utilized for energetic purposes. Popularization of Virginia mallow would contribute to increase of energy plants cultivation diversity.

Biomass obtained from energy plants plantations is a prospective ecological raw-material for energy production. Production of heat energy based on biomass combusted in appropriate devices is economically grounded and, when compared to fossil fuels combustion, limits environment pollution. At the same time, it creates new jobs in a whole chain, starting from manufacturing appliances for combustion, through biomass production, its distribution, processing and finally energy production. Moreover, locally produced biomass makes one independent from external suppliers of fuel oil and natural gas (Kisiel and Stolarski, 2004).

Biomass of energy plants can be widely used. It can be combusted as is or after pellets or briquettes are formed of it. It can also be processed into biocarbon, or by means of methane fermentation into methanol.

CONCLUSIONS

1. Cultivation of characterized in this paper energy plants may yield biomass having advantageous energetic parameters. willow coppice, Virginia mallows and Miscanthus characterize with high value of combustion heat and high heating value. The highest calorific value was obtained for willow coppice 17 688 kJ kg^{-1} and the lowest for *Miscanthus* and Virginia mallows 16 577 and 17 688 kJ kg^{-1}, respectively.

2. Heating value of presented energy plants is lower than of coal (aprox. 25 000 kg^{-1}). It results from higher content of moisture in plant biomass and higher content of oxygen.

3. It is advisable that research on obtaining and processing of biomass from long-term energetic plant plantations as well as on cost optimization is continued.

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