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The Determination of Energetic Potential of Waste Wood Biomass Coming from Dębica Forestry Management Area as a Potential Basis for Ethanol Biofuels of II Generation

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Summary. The goal of this study was to determine the heat of combustion (top calorific value) and the determination of fuel value (bottom calorific value) of waste wood biomass of potential raw material for the manufacture of ethanol biofuels of second generation. There determined the energy potential of waste wood biomass, which may be obtained for energy purposes from the territory of Dębica Forest Management Area. The highest heat of combustion and calorific value among the studied five species of forest wood: pine, birch, oak, ash and poplar featured pine – 21,3 MJ/kg (19.1 MJ/kg), and the lowest oak – 18.5 MJ/kg (16.58 MJ/kg). From the above results, that the calorific value (similarly to heat of combustion) of pine is approx. 15% The fuel value of wood obtained yearly by the Dębica Forest Management Area over 6 years (2005-2011) is 38, 6 PJ.
Key words: biomass, ethanol, biofuels of II generation, heat of combustion, top calorific value.

INTRODUCTION

The quick economic development, which took place in the second half of the twentieth century, brought about a modification in the use of energy raw materials. A new model of global economy was shaped, which is mainly based on oil and earth gas, with decreasing use of black coal. The energy industry has the biggest share in emission of greenhouse gases into the atmosphere. In Poland the manufacture of electric energy is based mainly on black coal (60.8%), lignite (34.9%), earth gas (1.6%) and renewable energy sources (in total 2.8%) [4,8,9,10]. Unfortunately the energy sector based on oil and coal causes excessive emissions of the so called greenhouse gases, mainly CO_2 [11,14]. For that reason in recent year more and more emphasis is put on efforts to limit the emission of undesirable gases. The European Union published several documents, that order a gradual replacement of mineral fuels with renewable ones. The 2001/77/CE directive states, that until 2020 the share of renewable energy in the total balance of consumed energy shall be 20%.

In Poland since 2007 it has been legal to manufacture fuels and introduce them into free circulation. Manufactured are biofuels of first generation, that is mainly biodiesel and bioethanol, and they are introduced as biofuels and fuel additives. In 2014 the average share of biofuels and fuel bioadditives of the total fuel consumption amounted to at least 7.1%, considering energy value in relation to Diesel fuel and petrols. Simultaneously with the manufacture of first generation biofuels works have been started on new generation biofuels, the so called second generation. One of the objectives of the new biofuels was to manufacture them from nonfood sources. Bioethanol may be manufactured of forestry and agricultural biomasses, which include cellulose and lignocellulose. A very interesting idea seems to be the use of forestry wood waste.

For Europe the main sources of biomass with cellulose and lignocellulose content are forests. For that reason it is today important to assess the energy potential of wood waste biomass. This is also of local importance, because at locations with large resources of cellulose biomass in future will be constructed manufacturing facilities of second generation biofuels for transport. The development of the above fuels will cause partial independence from oil supplies and generate new jobs, and what is most important, it shall favourably influence the environment. At present the area of forests in Poland is 9,048 thousand hectares, which corresponds a forestation rate of 28.9% [5,6]. In 2011 the area of forests in Poland was 9,143.6 thousand hectares (according to GUS (Polish national statistical agency) – the condition as of 31.12.2011), which was equivalent to 29.2% forestation rate [6].

THE CHARACTERISTICS OF THE STUDIED DĘBICA FOREST MANAGEMENT AREA

The Dębica Forest Management Area is located in Podkarpackie Province, Districts of Dębica and Sędziszów – Ropczyce. The Forest Management Area includes two forest circuits – Dębica and Żdżary and is divided into eleven forestries. The total Forest Management Area comprises 11,126 hectares (forest area 10,941 hectares). In addition the Dębica Forest Management Area supervises forests, which do not belong to the State Treasure, of total area of 7,617 hectares – Fig. 1. The main forest species are : pine 50.5%, beech 29.3 %, fir 7.9 %, oak 6.7%.

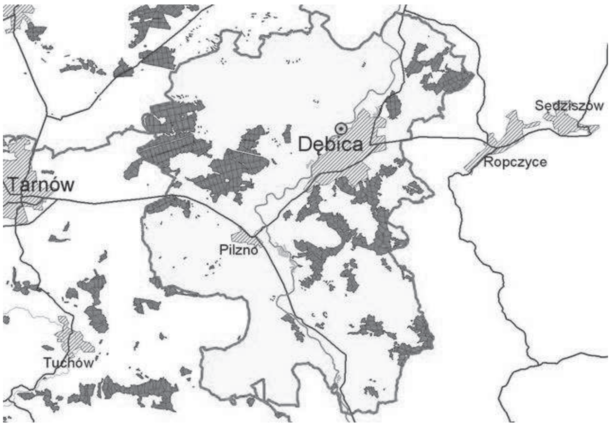


Fig. 1. The natural and geographic location of the Dębica Forest Management Area

CHARACTERISTICS OF WOOD WASTE BIOMASS WITH REFERENCE TO ITS ENERGY PROPERTIES

Wood waste biomass displays the most favourable parameters in relation to volume among the types of biomass used for energy purposes. The cost of energy obtained from wood waste biomass is decisively lower as compared with traditional sources. If we adopt the cost of energy obtained from wood at the level of 6.03 gr/KWh (gr =1/100 PLN) as 100% in particular conditions, then the cost of energy obtained from burning of coke is 169% of that value, from burning of liquid gas and earth gas 246 % and 170-195% of that value respectively, and from burning of black coal 94 % of that value, without the cost of transport [12,13,17].

The share of particular components with wood waste biomass differs depending on species (Table 1). Particularly worth noting is the difference when comparing wood of conifers and deciduous trees. This aspect is reflected both in the cost of transport, effectiveness of wood burning process as well as mineral content of ash remained after burning.

Table 1. Percentage share of wood, green mass and bark with particular wood waste biomass species [2]

Wood waste biomass	Wood [%]	Green mass [%]	Bark [%]
Deciduous trees	60-75	15-20	10-20
Conifers	70-80	10-15	10-15

By using the PER (Pure Energy Ratio) expressed as relations between obtained energy and consumed energy we are able to determine the economic value of a particular fuel. For coal the value of this ratio is included between 10 and 15, for oil it amounts to 20, and for phytomass and fuels manufactured from it is between 0.5 and 1.5 [1]. The low value of this coefficient results from high energy outlays related to use, forestation, transport and processing of these raw materials.

Wood waste biomass features in comparison with other traditional fuels two undoubted advantages:

- the unceasing reproducibility of wood in forests,
- its availability in our geographic conditions [2].

According to studies the calorific value of dry forest wood biomass is on the average lower with approx. 20% as compared with calorific value of black coal and with approx. 50% lower than calorific value of fuel oil (37.7 MJ/kg) and earth gas 36.8 MJ/m³) [3].

Average humidity of deciduous wood directly after clearing reaches 80 %.

Wood waste biomass burns easily and is a valuable fuel, if dried properly. Wood dried outdoors in a natural way contains 15-20% total humidity. When burning wood with excessive content of humidity problems can occur with igniting, that is its ignition time will be longer and it will be more difficult to reach proper boiler efficiency [15]. In Fig. 2 was presented the relation between wood calorific value and total humidity.

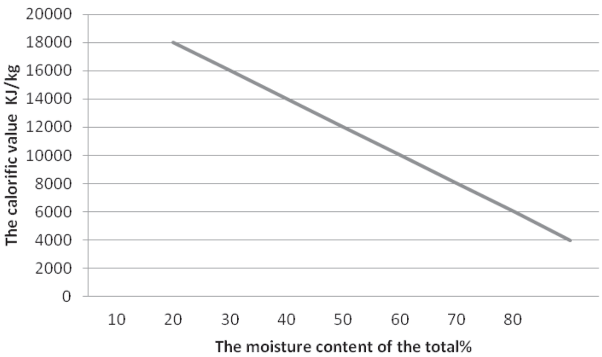


Fig. 2. Calorific value as function of total humidity content in wood (Voltz 1995)

CHEMICAL COMPOSITION OF WOOD WASTE BIOMASS

Generally the chemical composition of particular wood species is similar, and consists of (dry mass): coal (48-51%), oxygen (42-45%), hydrogen (6-7%), nitrogen (0.01-3%)

Besides wood, the wood waste biomass is composed of green mass (leaves, branches, needle cover) and bark. Ashes in bark constitute 1-1.5%, and in wood 0.4 -0.7%. Ashes include nutrients, which occur in the form of microelements and oxides, like: K_20, Na_2O, P_2O_5, CaO, MgO. The content of selected microelements is presented in Table 7. Besides the specified components the wood waste biomass includes: resins, tannins, waxes, fats, alkaloids and mineral salts [2].

Due to large content of volatile parts (80-85%) wood ignites easily. Most part of volatile components are emitted at temperatures 250-350°C, but the process of thermal decomposition of wood starts at approx. 210°C.

OBJECTIVE AND SCOPE OF THE WORK

The goal of this study was to determine the heat of combustion (top calorific value) and the determination of fuel value (bottom calorific value) of waste wood biomass of potential raw material for the manufacture of ethanol biofuels of second generation. There will be determined the energy potential of waste wood biomass, which may be obtained for energy purposes from the territory of Dębica Forest Management Area. The obtained results shall be used in the above Forest Management Area in order to develop a long term waste wood management strategy. The wood biomass studied in order to determine energy parameters was dried to reach the technical humidity of 8%.

APLLIED METHOD

The goal of the study was the determination of energy potential of waste wood biomass, which is a potential raw material for the manufacture of ethanol biofuels of II generation of cellulose biomass obtained from wood in the Dębica Forest Management Area. The basis for the determination of these parameters was the determination of heat of combustion when burning wood samples coming from the above Forest Management Area. The study included the following species of wood present in the Dębica Forest Management Area: Scots pine (Pinus sylvestris), warty birch (Betula pendula), English oak (Quercus rubra), ash (Fraxinus tremula), poplar (Populus tremula). The material was collected without bark from top part of bolt or log. Then the material was comminuted and dried using H SPT-200 Vacuum Drier to reach the technical humidity of 8%.

DETERMINATION OF HEAT OF COMBUSTION AND CALORIFIC VALUE OF FIVE FOREST WOOD SPECIES

The study was performed in compliance with Polish standards PN-86/C-04062 and PN-81/G-04513 Solid fuels, determination of heat of combustion and calorific value in force [16,17]. Heat of combustion was determined using automatic KL-10 calorimeter manufactured by „Precyzja Bit" company. The diagram of the calorimeter is presented in Fig 3.

DETERMINATION OF TOP HEAT OF COMBUSTION (CALORIFIC VALUE)

The determination of heat of combustion in the calorimeter is based on the simplified equation of thermal balance of the calorimeter presented below:

$$Q_c^a m_{pal} + Q_d m_d = (m_w c_w t + m_s c_s)\,\Delta t = K\Delta t$$

where:
Q^a_c – heat of wood combustion related to the analytical sample,
m_{pal} – weight of wood sample,
Q_d – heat of combustion of steel wire,
m_d – weight of wire,
m_w – weight of water in calorimetric vessel,
c_w – specific heat of water,
m_s – weight of solid bodies of calorimeter – bomb and vessel,
c_s – specific heat of solid bodies,
Dt – corrected temperature increase,
K – constant, thermal capacity of calorimeter.

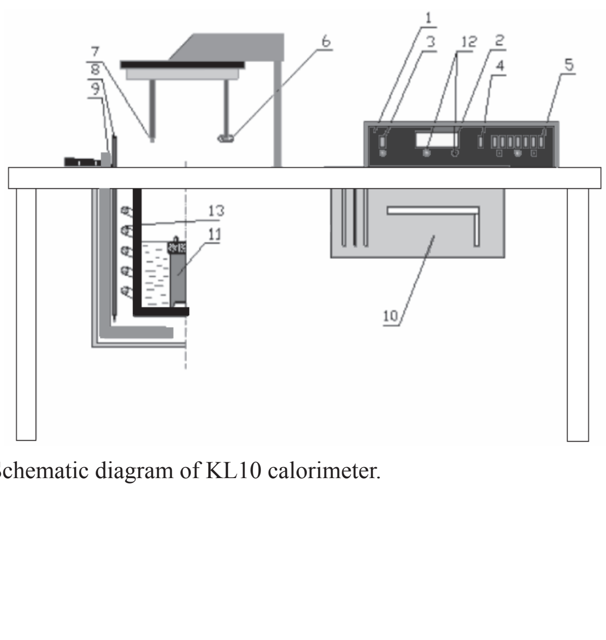
Heat of combustion was determined by the calorimeter using the following relation:

$$Q_c^a = \frac{K\Delta t}{m_{pal}}$$

Calorific value was calculated on the basis of the previously determined heat of combustion. The calorific value was referred to the analytical condition and calculated using the formula below:

$$Q_w^a = Q_c^a - \frac{m_{H2O}}{m_{pal}} \cdot r\ ,$$

where:
Heat of evaporation r = 2500 kJ/kg. The sum of water weights related to fuel humidity and weight of water from burning of hydrogen included in fuel is the quantity of water after condensing, that is analytical humidity expressed in humidity kg/ wood kg.



where:
1. control unit,
2. display of heat of combustion,
3. computer system computer system,
4. digital display,
5. agitator,
6. calorimetric bomb,
7. electric switch,
8. thermometer,
9. signalling diodes,
10. start of measurement,
11. water mantel thermometer,
12. agitator of water mantel,
13. coil.

Fig. 3. Schematic diagram of KL10 calorimeter.

Using stoichiometric equations we are able to calculate, that from 1 kg hydrogen we can obtain 9kg water, that is 9h, which can be presented using the formula below :

$$\frac{m_{H2O}}{m_{pal}} = 9h^a + W^a \, \frac{kgH_2O}{kgpaliwa}$$

As a result we obtained the relation for calculating calorific value, when we know the heat of combustion

$$Q_w^a = Q_c^a - r(9h^a + W^a)$$

From the above relations results, that in order to determine the calorific value it is necessary to know the content of hydrogen and analytical humidity in the studied fuel.

TEST RESULTS

In Fig. 4 we presented test results for the determination of calorific value and calculation of heat of combustion of studied forest wood species at absolute humidity of 8%.

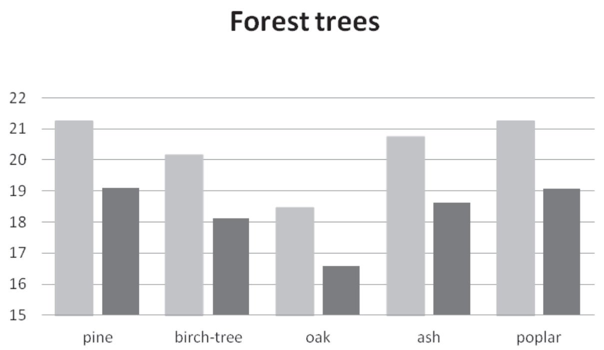


Fig. 4. Comparison of heat of combustion and calorific value of studied forest trees at humidity of 8%

The highest calorific value among the studied wood waste biomass shows pine (Pinus sylvestris) – 19.1 MJ/kg, and a lower one oak (Quercus rubra) – 16.58 MJ/kg. From the above results, that the calorific value of pine (as well as heat of combustion) is approx. 15% higher as compared with calorific value of oak. A probable cause, that pine wood gives more energy than oak wood is the fact, that it contains more volatile oils and resins, which considerably increase its calorific value [2].

The calorific value of wood depends on its type, humidity and processing form. Despite the fact, that wood transactions are settled almost exclusively in volume units – cubic meters, generally its calorific value is determined by its specific mass. For example a cut down pine has density of 700 kg/m³, but in totally dry condition its density falls to 480 kg/m³.

For energy purposes it is best to use dry wood, however sometimes the waste wood biomass stored for energy purposes features different humidity. A material, which has already been dried, for example in periods with heavy rains or in winter can become moist and will feature a lower calorific value. To illustrate, what the influence on calorific value of wood from forest trees humidity can have, taking into consideration the already obtained test results, theoretical calculations of calorific values of particular wood species at assumed humidity of 20, 30 and 40% respectively were performed. The results of calculation were presented in Table 2 and in the figure was presented the influence of humidity on calorific value of wood species at humidity of 8 %.

Table 2. Humidity impact on calorific value of particular wood species.

Type of wood	Bottom calorific value [MJ/kg]			
	at 8% humidity	at 20% humidity	at 30 % humidity	at 40 % humidity
Pine	19,10	16,805	14,895	12,985
Birch	18,11	15,938	14,127	12,316
Oak	16,59	14,595	12,936	11,278
Ash	18,63	16,393	14,530	12,667
Poplar	19,08	16,794	14,886	12,977

In compliance with statistical information made available by the Dębica Forest Management Area, knowing the percentage share of particular wood species in the whole waste wood biomass obtained yearly by the above management area was calculated the total calorific value for all species that constitute the forest stand of the above

Table 3. Energy potential of waste wood biomass obtained in subsequent years by the Dębica Forest Management Area .

Energy potential of wood obtained in subsequent years				
Year	Quantity of wood obtained in the subsequent years [m³]	Calorific value of wood [MJ]	Calorific value of wood [GJ]	Electric energy [MWh]
2005	40 737	3880570588	3880570.59	1077936.27
2006	52 838	5033301145	5033301.14	1398139.21
2007	58 405	5563608641	5563608.64	1545446.84
2008	70 102	6677854515	6677854.51	1854959.59
2009	62 266	5931404086	5931404.09	1647612.25
2010	59 806	5697066662	5697066.66	1582518.52
2011	60 890	5800327543	5800327.54	1611202.1
In total	405 044	38584133179	38584133.2	10717814.8
Average yearly result	**62 944**	**5995989766**	**5995989.77**	**1665552.7**

management area. The results are presented in Table 3 below.

From Table 3 results, that the calorific value of wood calculated in [GJ] from the total of wood obtained yearly by the Dębica Forest Management Area over the period of 6 years (2005-2011) is 38584133.2 [GJ], as a result of the assumption, that 1MWh = 3600MJ, the obtained in this period biomass is equal to electric energy of 10,717,814.8 MWh over a period of six years, and expressed as average yearly quantity it is 1,665,552.7 MWh, which converted into [GJ] yields yearly 5,995,989.7 energy.

In Table 4 were summarised test results, which show, what is the calorific value of the biomass from all sorts of waste wood at the example of year 2010.

Table 4. Energy potential of all sorts of waste wood obtained yearly by the Dębica Forest Management Area at the example of year 2010.

Energy potential of waste wood		
Type of obtained assortment from waste wood	Year 2010 [m³]	Calorific value [GJ]
Dead wood from standing trees	3,465	478,170
Dead wood from lying trees	4,398	606,924
Dead wood from twigs	23,265	3,210,570
Dead wood from stumps and roots	129,417	17,859,546
In total	160,545	22,155,210

The calorific value of all assortments of waste wood obtained by the Dębica Forest Management Area at the example of year 2010 was 22,155,210 GJ.

CONCLUSIONS

1. The state owned National Forests (Lasy Państwowe) enterprise is able to deliver wood waste biomass for energy purposes in the form of different assortments such as: small dimensioned wood, rests from clearings, windfall wood, fuel wood and low quality pulp wood in case of natural disasters (hurricanes, floods, insect pest infestations), wood of higher quality for protection reasons, in order to prevent their depreciation in the forest.
2. Forest wood waste biomass is a perfect raw material for the manufacture of ethanol biofuels of II generation, because it is possible to obtain large quantities of biomass with cellulose and lignocellulose content.
3. The highest heat of combustion and calorific value among the studied five species of forest wood: pine, birch, oak, ash and poplar featured pine – 21,3 MJ/kg (19.1 MJ/kg), and the lowest oak – 18.5 MJ/kg (16.58 MJ/kg). From the above results, that the calorific value (similarly to heat of combustion) of pine is approx. 15% higher than the calorific value of oak. The probable cause of the fact, that pine wood has higher energy value than oak wood, is because pine has more volatile oils and resins which considerably increase its calorific value.
4. The fuel value of wood obtained yearly by the Dębica Forest Management Area over 6 years (2005-2011) is 38,584,133.2 GJ. This amount of energy equals 10,717,814.8 MWh electric energy. An average based on medium yearly result of 1,665,552.7 MWh is equal to 5,995,989.7 GJ energy.
5. The fuel value of all assortments of waste wood obtained by the Dębica Forest Management Area at the example of year 2010 totalled 22,155,210 GJ.

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OKREŚLENIE POTENCJAŁU ENERGETYCZNEGO DENDROMASY ODPADOWEJ POCHODZĄCEJ Z NADLEŚNICTWA DĘBICA JAKO POTENCJALNEJ BAZY DLA BIOPALIW ETANOLOWYCH II GENERACJI

Streszczenie. Celem pracy było oznaczenie ciepła spalania (wartości opałowej górnej) oraz wyznaczenie wartości opałowej (wartości opałowej dolnej) biomasy z drewna odpadowego potencjalnego surowca do produkcji biopaliw etanolowych II generacji. Następnie zostanie określony potencjał energetyczny dendromasy jaki można pozyskać na cele energetyczne z terenu

Nadleśnictwa Dębica. Najwyższym ciepłem spalania i wartością opałową wśród przebadanych pięciu gatunków drzew leśnych: sosna, brzoza, dąb, jesion i topola charakteryzowała się sosna – 21,3 19,1 MJ/kg (19,1 MJ/kg), natomiast najmniejszą dąb – 18,5 MJ/kg (16,58 MJ/kg). Wartość opałowa drewna pozyskiwanego corocznie przez Nadleśnictwo Dębica na przestrzeni 6 lat (2005-2011) wynosi 38, 6 PJ.

Słowa kluczowe: biomasa, etanol, biopaliwa II generacji, ciepło spalania, wartość opałowa.