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ORIGINAL PAPER

The use of the white poplar (*Populus alba* L.) biomass as fuel

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Abstract We determined the calorific value of white poplar (*Populus alba* L.) woody biomass to use it as firewood. The value of 19.133 MJ kg^{-1} obtained experimentally shows that the white poplar can be quite successfully used as firewood. Being of a lower quality in comparison with usual beech firewood, the white poplar has similar calorific value. The white poplar has a calorific density of 30.7 % lower than that of current firewood. That is why the price of this firewood from white poplar is lower accordingly. Also, the prognosis of calorific value on the basis of the main chemical elements, being very close to the experimental value (+2.6 %), indicates an appropriate value can be achieved to be used for investigation with the chemical element analysis.

Keywords Calorific value · Chemical elements · Prognosis · White poplar

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Introduction

White poplar *Populus alba* L. is a fast-growing species (FGS), similar to species such as willow or acacia that can reach the age of 35–40 years at maturity in temperate regions (Brilli et al. 2014). FGS are used for biomass production because they yield over 20 t ha^{-1} for the dry biomass (Meriloa et al. 2006). The term FGS has the same meaning as short rotation coppice (SRC) or short rotation forest (SRF). White poplar should be grown in full sun and tolerates almost any soil, wet or dry (Christersson 2010). This species represents a potentially large source for timber, veneer, plywood, matches, pulp, composites and paper/cellulose (Kishi and Fujita 2008). Over 50 % of the total wood obtained from exploitation is waste, in the form of branches, tops, or sawdust, which may be used as sustainable and renewable fuel (Verma et al. 2009; Verlinden et al. 2013; Liang et al. 2006). Generally, woody biomass is a renewable fuel because the amount of carbon dioxide resulting from burning is equal to that absorbed during tree growth. Some species including white poplar are also used to reduce phreatic groundwater pollution. White poplar groves in meadows and riverside coppices cover over 200,000 ha in Romania and are a valuable source of nectar and pollen for beekeepers (Lunguleasa 2010). Another species of the poplar family, European aspen (*Populus tremula* L.), grows favorably under climatic condition of the Baltic region, being cultivated since 1999 in Estonia (Grantina-Ievina et al. 2012). Currently, Romanian forest covers a total area of 6.4 million ha, representing 26.7 % of the country area. This corresponds to the European average of 31 % forest cover (varying by country from 1 % in Cyprus to 71 % in Finland) and 0.27 ha of forest per Romanian inhabitant.

The overall use of round logs in the world is 3271×10^6 m^3 $year^{-1}$. About 55 % of it is used directly as fuel, such as split firewood, especially in developing countries. The remaining 45 % is used as industrial raw material, but about 40 % is used as primary or secondary process residues, suitable only for energy production, for example in superior products as briquettes and pellets (Gavrilescu 2008; Lunguleasa 2012; Lunguleasa et al. 2010; Nielsen et al. 2009). Terrestrial biomass contains $25{,}000 \times 10^{18}$ J of carbon dioxide and annual terrestrial biomass accumulates carbon dioxide at a rate of 3000×10^{18} J $year^{-1}$ (Jehlickova and Morris 2007). Though recently more briquettes and pellets have been made from woody biomass or in combination with coal and/or plastics (Aznar et al. 2006; Kostanaki and Vamvuka 2005; Kazagic and Smajevic 2009; Wijaya and Zhang 2011) with many improvements as carbonisation or torrefaction (Chen et al. 2011, 2012; Teuch et al. 2004), firewood still holds a prominent place in the developing or transition countries for heating or cooking (Bhattacharya and Abdul 1989; Boutin et al. 2007).

Burning of woody biomass is a complex physical and chemical process. The reaction of woody biomass combustion is reversible to that of biomass generation, as seen in Eq. 1 and Fig. 1.

$$C_xH_yO_z + (x + y/4 - z/2)O_2 = CO_2 + (y/2)H_2O + Ash + Thermal\ energy \quad (1)$$

Woody biomass ignition needs a flame and oxygen. An average temperature of 300 °C is necessary for dry wood (10–15 % moisture content (MC)) to reach a flash condition. Firing needs a certain amount of air, namely about 0.6 kg oxygen for 1 kg of absolutely dry wood. Ultimately wood combustion itself is a chemical process of wood decomposition into its main chemical elements. The main chemical elements contained in the woody fuel are: carbon (C), hydrogen (H), sulfur (S), nitrogen (N), oxygen (O) and minerals from ash (As). The air has a more complex composition, but it is assumed that the combustion air has the following composition: Nitrogen (N) 79 % and oxygen (O) 21 %. As burning is progressing, wood catches fire and burns the formed gases. Maximum efficiency is reached only when the burning is complete, i.e. when the final products are obtained such as carbon dioxide, water vapor and the mineral form of ash, according to Eq. 2.

$$C + H_2 + O_2 + N_2 \rightarrow H_2O + CO_2 + N_2 \quad (2)$$

Incomplete combustion is evidenced by the presence of carbon in the ash residues and emissions of carbon monoxide (Shi et al. 2013) and hydrogen gases (Eq. 3).

$$\mathrm{C + H_2 + O_2 + N_2 \rightarrow soor + H_2O + CO_2 + CO + N_2} \quad (3)$$

It is considered that the main chemical elements of wood burning are: C, O, H and S, according to the following exothermic reactions (Eq. 4).

$$\begin{aligned} &C + O = CO_2 + 0.394\,MJ\,mol^{-1} \\ &S + O_2 = SO_2 + 0.297\,MJ\,mol^{-1} \\ &2H_2 + O_2 = 2H_2O + 0.242\,MJ\,mol^{-1} \\ &CO + 1/2O_2 = CO_2 + 0.283\,MJ\,mol^{-1} \\ &CH_4 + 2O_2 = 2H_2O + CO_2 + 0.803\,MJ\,mol^{-1} \end{aligned} \quad (4)$$

The other exothermic reactions during woody biomass combustion (especially in the second stage) are illustrated by Eq. 5:

$$\begin{aligned} &C + 2H_2 \rightarrow CH_4 \\ &H_2O + CO \rightarrow CO_2 + H_2 \\ &3H_2 + CO \rightarrow CH_4 + H_2O \\ &4H_2 + CO \rightarrow CH_4 + 2H_2O \\ &CH_2S + 6F_2 \rightarrow CF_4 + 2HF + SF_6 \end{aligned} \quad (5)$$

Combustion proceeds in a number of basic steps, namely:

- Evaporation of water;
- Ignition;
- Thermal decomposition of chemical elements (with primary air insertion);
- Combination of chemical elements to form some combustible gases;
- Burning of combustible gases (with secondary air insertion);
- Combustion of carbon.

The main parts of a hot water boiler, which demonstrate the two areas of primary and secondary air intake and also all combustion products, are shown in Fig. 2.

The determination of woody biomass calorific value with an explosive combustion bomb is a cumbersome method that requires a long time (about 1 h) and supplies of expensive materials that are difficult to obtain such as

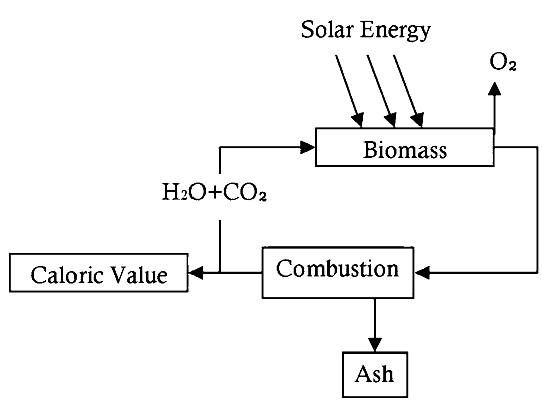

Fig. 1 The cyclic process of woody biomass combustion and generation

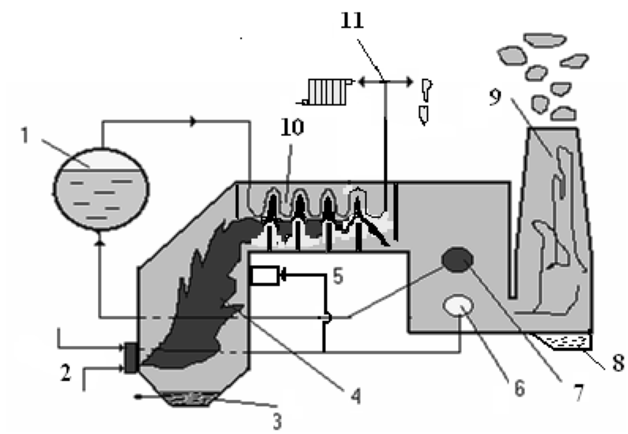

Fig. 2 Boiler for hot water: *1* bowl of preheated water; *2* primary air; *3* ash of grill; *4* flame; *5* preheated secondary air; *6* air duct; *7* water pipe; *8* flying ash; *9* chimney; *10* heat exchanger; *11* uses (radiator or hot water)

nickel-chrome wire. Therefore the estimates based on elemental chemical composition becomes a far simpler method of obtaining calorific value.

The main objective of our study was to determine the calorific value of woody biomass of White poplar obtained after harvesting and sawing into rough lumber. We also considered the prognosis of calorific value based on elementary chemical composition analysis. Moreover, we intended to obtain other calorific features in order to characterize the energy content of white poplar. We analyzed these parameters to determine whether *P. alba* L. was suitable for use as firewood.

Materials and methods

Poplar wood material was taken from a sawmill. The poplar logs were brought from three forest belts. The samples were in the form of columns with dimensions 200 mm × 20 mm × 20 mm. The samples were dried in a laboratory oven at (103 ± 2) °C to 10 % MC. We cut at least 10 fresh pieces of 0.6–0.8 g from each batch for determination of calorific value. The samples were dried in desiccators, then they were weighed to three decimals.

The preparation of the bomb calorimeter (OXY-1C/China) for testing began with weighing the wire and cotton thread. Next, nickel chromium was fixed in electrodes, cotton wire was fixed between a wood sample and nickel thread. Next, about 3 ml of water were introduced into the bomb, the lid was secured on the bomb body, 3 MPa of oxygen pressure were injected into the bomb. At this moment the calorimetric test was ready and the bomb could be inserted into the calorimeter to make possible the coupling to the electrodes and to begin the test. Data including sample name and mass, heat capacity of the calorimeter (determined usually with benzoic acid and expressed in kJ °C^{-1}), and mass and heat of cotton and metal wire were entered into the computer program (DIN 51900-1: 2000; ISO 1928:2009).

General relations of calorific values (MJ kg^{-1}) determination (used by computer software) are given in Eq. 6 (ASTM D3865: 2000).

$$CV = \frac{CC \cdot (t_f - t_0) - \Sigma E_i}{m \times 1000} \tag{6}$$

where, CC is the capacity of the calorimeter in kJ/ °C; t_f is final temperature in °C; t_0 is initial temperature in °C; ΣE_i is the sum of energies obtained from wire, cotton and sulfuric acid; m is the mass of samples in kg.

The calorimeter and the main parts of the bomb are presented in Fig. 3.

The experiments were conducted in a bomb calorimeter in order to determine the high calorific value (HCV) and low calorific value (LCV), both expressed in MJ kg^{-1}. Three basic steps are necessary to determine the calorific value:

- The initial period “fore”, which aims to determine the water temperature variations in calorimetric vessel due to heat exchange with the outside before firing. During this period, which usually lasts about 6 min, the temperature is read and recorded every minute with a precision thermocouple to 3 decimals. The last date of the initial temperature is actually the first main period and represents the initial temperature calculation t_0 expressed in °C;
- The principal period “main”, aims to estimate water temperature increases of the calorimetric vessel due to combustion of wood particles. To determine the final temperature is necessary to read the temperature every minute (usually 30–38 values). The final temperature is given by the maximum of temperature and is noted with t_f, being read in °C. Dropping in temperature means that it no longer receives heat from the bomb in the calorimeter;
- The final period, “after”, aims to determine the average water temperature variation inside the calorimetric vessel, due to heat exchange with the outside. In this period the computer displays and records temperature every minute, or about 5–8 times. After the ultimate values the test is finished by display of “end”.

The measurements are recorded and displayed on the final report of the computer software.

Also, in order to forecast these calorific values, two formulae from the scientific literature (Eqs. 7 and 8) are used, based on the calorific value of the main chemical elements. Based on the calorific value of each chemical element of wood, the formula introduced by Mendeleev (Lunguleasa et al. 2007) was used:

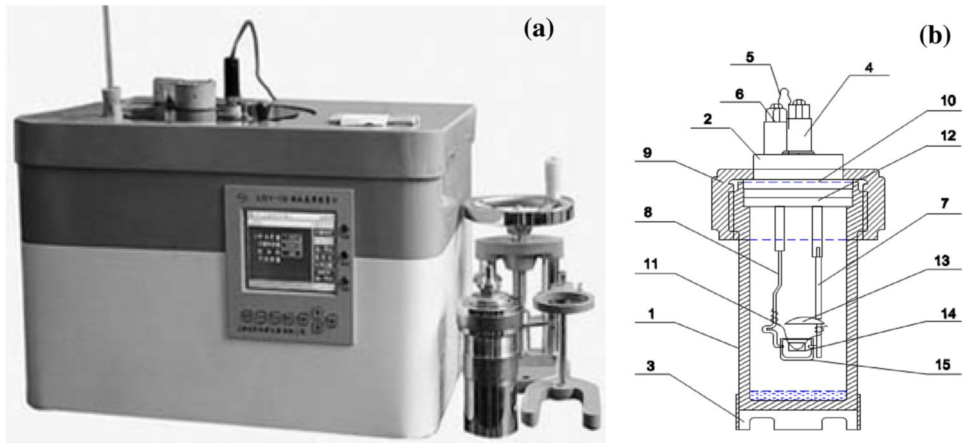

Fig. 3 Determining calorific value with bomb calorimeter OXY-1C. **a** calorimeter; **b** bomb: *1* body; *2* fixing lid; *3* support; *4*, *5* external electrodes; *6* lockable for oxygen introduction with valve; *7*, *8* inner electrodes; *9* screw cap; *10* garnish; *11* cotton thread; *12* gasket; *13* protective cover of flame; *14* wood sample; *15* metal crucible

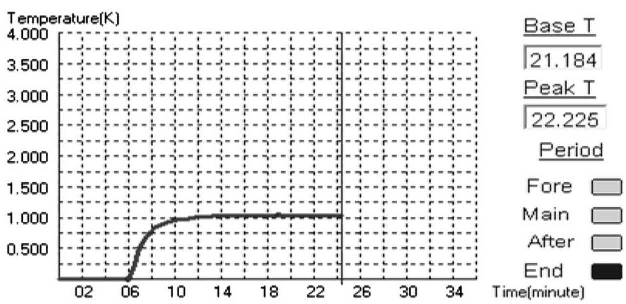

Fig. 4 Diagram-test for determining the calorific value

$$CV = 33.913\frac{C}{100} + 8.373\frac{H}{100} - 1.779\frac{O}{100} \quad (7)$$

Another formula was also taken into consideration, following Parikh et al. (2005) as referenced by Chen et al. (2011):

$$CV = 33.910\frac{C}{100} + 11.783\frac{H}{100} - 1.034\frac{O}{100} + 1.005\frac{S}{100} - 0.151\frac{N}{100} - 0.211\frac{As}{100} \quad (8)$$

where, *S*, *N*, *As* are the amounts of sulfur, nitrogen and ash (% dry weight, wt); 34.910, 11.783, 1.034, 1.005, 0.151 and 0.211 calorific value (MJ kg^{-1}) of carbon, hydrogen, oxygen, sulfur, nitrogen and ash.

Equations 7 and 8 are used for prognosis of the calorific value.

Each test was charted by computer software, with time on the horizontal axis and temperature on the vertical axis (Fig. 4). Any technical problem in working methods leads to automatic stopping of the test and resuming of it.

Results and discussions

The values obtained during testing (HCV and LCV for 10 % MC and CV_0, for 0 % MC) were tabulated and all lots were statistically verified for the values distribution. Regardless of the form of the tested samples (solid wood, sawdust, wood chips, briquettes or pellets), the calorific value is about the same (Lunguleasa 2012). The average values for 10 tests are listed in Table 1.

The calorific values of two different moisture contents of poplar biomass were determined in order to obtain the equations of two lines through two different points of each. These two lines (Fig. 5) are intersected in CV_0 and have a decreasing trend with increasing moisture content of biomass fuel ($HCV = CV_0 - 0.176$ MC; $LCV = CV_0 - 0.205$ MC). It also shows a low difference of values for different batches due to vegetation conditions, water and nutrients supply, soil type, tree location (north or south), etc., for which the average value is taken into account, in this case three values of CV_0, HCV_{10} and LCV_{10}. With the above linear equations other values for 30 and 50 % or other MC can be displayed (Fig. 5).

At a moisture content of poplar biomass above 90 %, the combustion efficiency is zero, because a higher quantity of heat is consumed to remove water than that quantity resulting from biomass burning. Hence an important conclusion follows, namely is to burn only dry wood (10–15 % MC), usually after 12–18 months of drying and proper storage. The practice of using wet wood after dry wood is also not recommended. Figure 5 demonstrates the relationship between firewood moisture content and amount of energy produced by biomass burning.

In thermal calculations the low calorific value LCV is commonly used (but CV_0 is also recommended), because

Table 1 Centralized values of calorific value for poplar fuel

Lots	Calorific value (CV_0) (MJ kg^{-1})	Higher calorific value (HCV) MC = 10 %	Lower calorific value (LCV) MC = 10 %
Batch 1	19.205 ± 0.51	17.188 ± 0.47	17.057 ± 0.39
Batch 2	19.120 ± 0.44	17.625 ± 0.41	17.098 ± 0.40
Batch 3	19.074 ± 0.40	17.282 ± 0.38	17.082 ± 0.44
Mean	19.133 ± 0.45	17.365 ± 0.42	17.079 ± 0.41

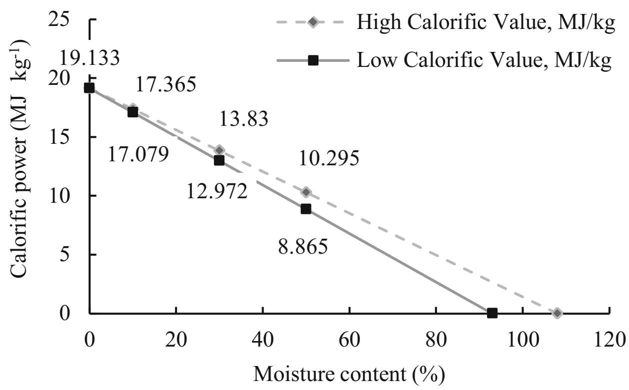

Fig. 5 Calorific value (CV_0, HCV, LCV) of poplar fuel related to moisture content

the high calorific value contains extra amount of energy of water vapor condensation that actually is eliminated along with the other combustion gases in gaseous emissions.

Using the previous forecast relationships (Eqs. 9 and 10) the prognosis values of CV_0 were obtained, shown in Table 2.

The differences between the expected and experiment values were slight and positive (+2.6 %) when projections were made using the Mendeleev formula, and both greater and negative (−7.9 %) when using the formula of Parikh et al. (2005). From this point of view the Mendeleev relations are recommended.

Another indicator of the analysis is the calorific density (CD) of the species (white poplar). This was obtained by multiplying species density and calorific value (MJ kg^{-1}):

$$CD = CV_0 \cdot \rho \qquad (9)$$

where, ρ is oven-dry density (kg m^{-3}), and CV_0 is calorific value (MJ kg^{-1}).

Regarding to the calorific density, if a density of 480 kg m^{-3} is used for poplar and a calorific value of 19.133 MJ kg^{-1}, then a calorific value of 9.183 MJ m^{-3} is calculated, compared to a value of 13.255 MJ m^{-3} for beech, with a density of 690 kg m^{-3}, but a higher value of CV_0 of about 19.210 MJ kg^{-1}).

If it is considered that White poplar is a fast growing species, there appears a new indicator for the evaluation of the heat capacity, considering the amount of wood obtained per ha (capacity forestry, C_pF), called calorific forestry (C_lF, MJ ha^{-1} $year^{-1}$). This indicator is determined by the formulae (Eq. 10):

$$C_lF = CV_0 \cdot C_pF \qquad (10)$$

Using the forest capacity for the White poplar of 20 t ha^{-1} $year^{-1}$ dry wood (Meriloa et al. 2006) and over 3.7 t $year^{-1}$ for European beech (Lunguleasa et al. 2007) it will result an indicator $C_lF = 38.26 \times 10^4$ MJ ha^{-1} $year^{-1}$.

The price of White poplar firewood at 40 € m^{-3} is lower than that of beech firewood (65 € m^{-3}). Keeping into account the different densities of these species we obtain 0.083 € kg^{-1} for poplar and 0.092 € kg^{-1} for beech, with a decreasing price of 9.7 % in the case of poplar. Comparison of White poplar versus Beech (*Fagus sylvatica* L.) firewood is shown in Table 3. White poplar shares some characteristics with beech firewood and others, and white poplar is suitable for use as firewood. Undesirable aspects of white poplar as firewood were identified as increased use of firewood due to more rapid burning and the requirement for increased storage area. Its lower price and higher calorific forestry index makes white poplar a good firewood. If the hybrid poplar were taken into account, all indicators would be much better (Grantina-Ievina et al. 2012).

Table 2 The prognosis calorific values of the White poplar

Calorific value CV_0, (MJ kg^{-1})	Chemical elements %, dry mass	Values	Differences related to experimental value
Experimental	C = 49.8 %; H = 9.7 %;	19,133	–
Equation Mendeleev	O = 38.9 %; N = 0.7 %;	19,646	+2.6 %
Equation 4. Parikh et al. (2005)	S = 0.05 %; As = 0.85 %.	17,616	−7.9 %

Table 3 Comparison between calorific characteristics of poplar and beech firewood

No	Indicator		*Populus alba* L	*Fagus sylvatica* L	Differences (%)
1	Calorific values (MJ kg^{-1})	CV_0	19.133	19.210	–0.4
		HCV_{10}	17.233	17.245	–0.06
		LCV_{10}	17.009	17.044	–0.2
2	Calorific density	(MJ m^{-3})	9.183	13.255	–30.7
3	Calorific forestry	(MJ ha^{-1} year^{-1})	38.26×10^4	7.1×10^4	+438.8
4	Specific amount of material	(kg MJ^{-1})	0.0526	0.0520	+1.1
		(m^3 MJ^{-1})	0.108	0.075	+44
5	Price	(€ m^{-3})	40	65	–38.4

Conclusions

As a general conclusion it should be noted that the White poplar can become a new resource of firewood despite its lower density. The reasons for it are the following:

- Acceptable calorific value of 19.133 MJ kg^{-1}, slightly lower than that of beech firewood (19.210 MJ kg^{-1}).
- Lower quality makes it usable as firewood and seldom for furniture, doors, etc.
- Being less dense (480 kg m^{-3}), it is cut easily and burns faster and obtains higher temperatures inside of firebox installation.
- It has a good calorific forestry (38.26×10^4 MJ ha^{-1} - year^{-1}), because the white poplar is a short rotation tree.
- It has a good price and becomes economically suitable.

Because of these strengths, the white poplar can be used as firewood for both residential stoves and central heating.

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