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THERMAL CHARACTERISTICS OF WOOD-BASED MIXTURES BIOMASS

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Abstract: *In this paper, five different mixtures of wood (sawdust of soft- and hardwood and bark), agricultural (straw) and food (husks from sunflower seeds) residues are considered. They were processed into fine waste and then transformed into pellets. The higher and lower heating values were determined, firstly by experimental means using the XRY-1C Oxygen Bomb Calorimeter. By means of two equations and the initial mass-based composition, the heating values were then calculated. The experimental results are close to the calculated ones, validating the equations used and the elemental composition. For the thermal characterization of the combustible mixtures, there were determined, by using the combustion calculations, the theoretical air volume, the theoretical combustion products volume, the combustion products enthalpy and the combustion temperature. From the experimental data, the combustion time has been also evaluated.*
Keywords: *biomass, wood, heating value, combustion products enthalpy, combustion temperature*

1. INTRODUCTION

Biomass ranks as the fourth source of energy in the world, representing approximately 14% of world final energy consumption, a higher share than that of coal (12%) and comparable to those of gas (15%) and electricity (14%) [1]. Alternative biomass fuel is obtained from lignocellulosic biomass that includes forest and agricultural residues (trunks, branches, straw, vines, trees), food residues (fruit seeds), industrial residues (wood chips or sawdust, bark, pulp and paper processing) and municipal wastes (waste from gardens and parks) [2, 3]. Due to the various sources, biomass varies in composition, quality and quantity. The biomass is transformed into briquettes and pellets, improving thus some properties, like energy density increase, moisture content decrease and handling properties enhancing. When biomass is converted into compact briquettes, the moisture content must be 10% to 18% (20%) and the granulation up to 5 mm [2]. Biomass pellets are produced in pellet mills by pressing the biomass through cylindrical shaped press channels in which the biomass is exposed to high pressure and heat that arises from the high friction between the biomass and the press channel walls. Fuel pellets are frequently made from beech, spruce and straw, which represent the three most common classes of biomass used for fuel pellet production, i.e. hardwoods, softwoods and grasses, respectively [4]. Wood pellets are used for space heating in households, public and other large buildings and in all sizes of combustion plants: pellet stoves and small boilers in single family houses, small block central heating, medium and large district heating plants and large power plants [5]. The combustion properties of biomass pellets are evaluated by use of calorimeters [6]. The use of a cone calorimeter can trace combustion properties and the whole combustion behavior of biomass pellets [3]. The authors [3] have reported relationships between physical properties of wood pellets and combustion behavior. In what regards the heating value, bark has a lower heating value than wood [7]. Some physical properties (bulk density, true density and durability) of different biomass pellets and their relationship with moisture content, particle size of biomass and die thickness were determined by Theerarattananoon et al. [8]. Biomass differs from coal in what regards energy content and physical properties. Comparative to coal, biomass has generally less carbon, more oxygen and hydrogen, larger volatile matters and lower heating value. It behaves similarly to low-rank coals [1].
The objectives of the paper were to study the thermal characteristics of five lignocellulosic biomass mixtures made from beech and fir sawdust, pear bark, husks of sunflower seeds and wheat straw, which are the heating value, the air and combustion products volumes, the combustion products enthalpy, combustion temperature and

time.

2. MATERIALS AND METHODS

Five biomass types, which are beech and fir sawdust, pear bark, husks from sunflower seeds and wheat straw were used as raw materials for the study. The beech and fir sawdust was obtained on a 4 kW circular saw; the pear bark, the husks and straw were grinded by using a 1.7 kW hammer mill with 2.5 mm sieve openings. The grindings were stored in sealed plastic bags at room temperature.

The moisture content of the biomass was determined in different ways. For the beech and fir sawdust, a Feutron moisture meter (Model F10) was used. The air temperature was 20 ^oC. For the other biomass types, two samples of about 2 g of each one were dried in an oven (Feutron) at 103 ^oC for 24 h. The samples were weighed several times a day until a constant weight was achieved. The moisture content was calculated on dry basis as follows:

$$MC = \frac{m_1 - m_2}{m_2} \times 100 [\%] \qquad (1)$$

where m_1 is the mass of the moist biomass (g) and m_2 is the mass of dry biomass (g).

Equal parts of each biomass were mixed into five combinations of 1.5 g each one. For each combination there were made three samples. The components and mixtures masses were measured with two balances of different precision, a technical balance (Kern, 0.01g) and an analytical balance (Vietzke, 0.1 mg).

The biomass mixtures were transformed into pellets by using a hand-driven press with the die size of 12 × 40 mm (hole diameter × length). The pellets were afterwards weighted.

The biomass pellets were submitted to the experimental determination of the heating value by using the XRY-1C Oxygen Bomb Calorimeter (Shanghai Changji Geological Instruments).

The dry-basis (db) and ash-free (a-f) composition of hard- and softwood, husks of sunflower seeds and wheat straw that was used in following calculation is indicated by [9] and that of bark is indicated by [10], respectively. Bark composition varies slightly according to different authors [1, 10 and 11]. The initial mass-based composition (i-b) was calculated.

The composition of the biomass mixtures was calculated considering the number of components participating in the mixture.

Based on the pellets composition, two equations for the determination of the higher and lower heating values (HHV and LHV) were used [12, 13], which are

$$Q_{i1} = 33900 \cdot c + 119850 \cdot \left(h - \frac{o}{8} \right) + 10470 \cdot s - 2500 \cdot u \qquad (2)$$

$$Q_{s1} = 33900 \cdot c + 142350 \cdot \left(h - \frac{o}{8} \right) + 10470 \cdot s \qquad (3)$$

$$Q_{i2} = 33900 \cdot c + 120120 \cdot \left(h - \frac{o}{8} \right) + 9250 \cdot s - 2510 \cdot u \qquad (4)$$

$$Q_{s2} = 33900 \cdot c + 142710 \cdot \left(h - \frac{o}{8} \right) + 9250 \cdot s \qquad (5)$$

The theoretical air volume and the theoretical combustion products volume were calculated from the stoichiometric combustion equations [12], by using the biomass mixtures composition. It was made the assumption that combustion runs in theoretical conditions, thus the excess-air coefficient is $\lambda = 1$.

The combustion time was calculated for each biomass mixture based on the time intervals indicated by the experimental records obtained during the heating values measurements. The time interval between two temperature measurements during the main period (combustion) is 30 s.

Combustion products enthalpy was determined according to the energy conservation law applied to 1 kilogram of fuel burned in a furnace [12] and accordingly, the combustion temperature was obtained by using H-t diagram that was represented for each biomass mixture.

3. RESULTS AND DISCUSSION

The average value of the moisture content for each biomass type is presented in Table 1.

The masses of the biomass pellets are shown in Table 2.

The experimentally determined higher and lower heating values are indicated in Table 3.

Table 1: Moisture content

Biomass	Moisture content (%) (mean ± SD)
Beech sawdust	7.6
Fir sawdust	8.8
Pear bark	17.355 ± 0.355
Husks of sunflower seeds	2.98 ± 0.48
Wheat straw	6.024 ± 4.575

Table 2: Biomass masses

Biomass mixture	Biomass components	Mass (g)		
		Sample		
		S_1	S_2	S_3
M_1	Beech sawdust (50%) Pear bark (50%)	1.4233	1.4279	1.4172
M_2	Beech sawdust (33%) Fir sawdust (33%) Pear bark (33%)	1.4289	1.4948	1.4599
M_3	Beech sawdust (50%) Husks of sunflower seeds (50%)	1.4993	1.4911	1.4913
M_4	Beech sawdust (50%) Wheat straw (50%)	1.47	1.4627	1.4633
M_5	Fir sawdust (33%) Husks of sunflower seeds (33%) Wheat straw (33%)	1.4919	1.4997	1.4739

Table 3: Experimental heating values

Biomass mixture	Higher heating value (MJ/kg) (mean ± SD)	Lower heating value (MJ/kg) (mean ± SD)
M_1	17.143 ± 0.14	16.703 ± 0.13
M_2	17.014 ± 1.2	16.576 ± 1.18
M_3	17.542 ± 0.07	17.102 ± 0.07
M_4	17.056 ± 1.86	16.617 ± 1.33
M_5	17.65 ± 0.22	17.209 ± 0.22

The dry-basis (db) and ash-free (a-f) composition of hard- and softwood, husks of sunflower seeds and wheat straw, as indicated by [9] and of bark, as indicated by [10], respectively is shown in Table 4, comparative to the initial mass-based composition (i-b) that was calculated.

Table 4: Elemental composition

	Hardwood		Softwood		Bark		Husks of sunflower seeds		Wheat straw	
	db/ a-f	i-b	db/ a-f	i-b	db	i-b	db/ a-f	i-b	db/ a-f	i-b
Carbon (%)	50.5	46.157	51	46	52	42.975	51.5	49.451	50	44.08
Hydrogen (%)	6.1	5.576	6.15	5.548	5.51	4.554	5.9	5.665	6.2	5.467
Oxygen (%)	42.8	39.119	42.25	38.11	36.065	29.806	41.9	40.232	43.1	38.0039
Nitrogen (%)	0.6	0.548	0.6	0.542	0.56	0.463	0.5	0.48	0.6	0.529
Sulphur (%)	0	0	0	0	0.045	0.037	0.2	0.192	0.1	0.0881
Chlorine (%)	-	-	-	-	0.14	0.116	-	-	-	-
Water content (%)	-	7.6	-	8.8	-	17.355	-	2.98	-	6.024
Ash (%)	-	1	-	1	5.68	4.694	-	1	-	5

The elementary composition of the biomass mixtures was calculated considering the number of components participating in the mixture. It is shown in Table 5.

Table 5: Biomass mixtures composition

	M_1	M_2	M_3	M_4	M_5
Carbon (%)	44.566	45.044	47.804	45.1225	46.511
Hydrogen (%)	5.065	5.226	5.6205	5.5215	5.56
Oxygen (%)	34.4625	35.678	39.6755	38.5615	38.782
Nitrogen (%)	0.5055	0.51767	0.514	0.5385	0.517
Sulphur (%)	0.0185	0.01233	0.096	0.0441	0.0934
Chlorine (%)	0.058	0.058	-	-	-
Water content (%)	12.4775	11.2517	5.29	6.812	5.935
Ash (%)	2.847	2.23133	1	3	2.3334

The heating values were calculated with relations (2)-(5) and the mean values are shown in Table 6.

Table 6: Calculated heating values

Biomass mixture	Higher heating value (MJ/kg) (mean ± SD)	Lower heating value (MJ/kg) (mean ± SD)
M_1	17.023 ± 0.0064	16.407 ± 0.0011
M_2	16.42 ± 0.0014	15.957 ± 0.00081
M_3	17.157 ± 0.0006	16.876 ± 0.000041
M_4	16.3 ± 0.00091	15.972 ± 0.00034
M_5	16.792 ± 0.00071	16.482 ± 0.000095

The experimental and calculated higher and lower heating values are represented in Figs. 1 and 2.

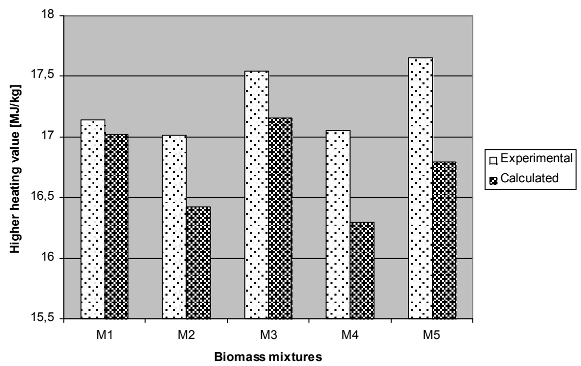

Figure 1: Experimental and calculated higher heating value

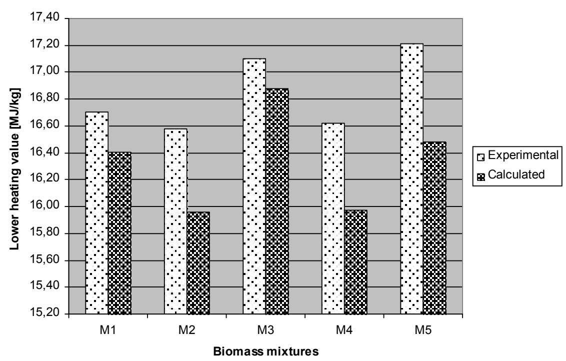

Figure 2: Experimental and calculated lower heating value

Biomass mixtures M_5 and M_3 have high experimental heating values, which can be explained by low moisture and ash content of sunflower seeds husks and high carbon, hydrogen and oxygen mass fractions of the same biomass type. Lower heating values have mixtures M_2 and M_4, due to the high moisture and ash content of bark, high ash content of straw and low carbon mass fraction of straw and bark. The calculated heating values are lower than the experimental ones. Mixture M_3 has the highest calculated heating value and mixture M_4, the lowest. The moisture content values of mixtures M_3 and M_5 are very close and their compositions are comparable. Larger differences between experimental and calculated higher and lower heating values are met at those mixtures that contain wheat straw (M_4: HHV-4.31%, LHV-3.88%; M_5: HHV-4.86%, LHV-4.22%). They can be explained by some moisture content variations between the moisture content measurement and the heating value measurement. According to Kamikawa [3] the lower heating value of softwood xylem and bark mixtures ranges from 15.47 and 16.78 MJ/kg. Straw has the gross calorific value of 15.354 MJ/kg [1].

In Fig. 3, the volume of combustion air is indicated and in Fig. 4, the combustion products volume. The results are similar. High volumes of air and combustion products are obtained for mixture M_3 that contains large amounts of carbon and hydrogen and low amounts of ash and moisture. Mixture M_1 has low volumes because the same components have opposed mass fractions to those of mixture M_3.

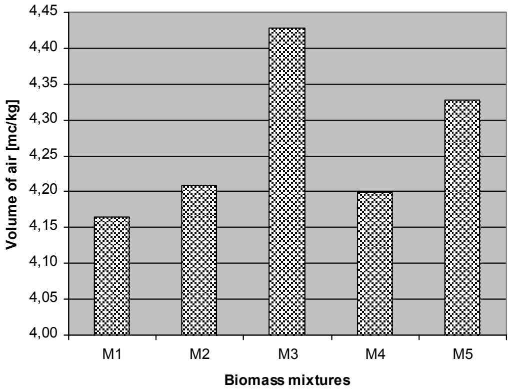

Figure 3: Volume of combustion air

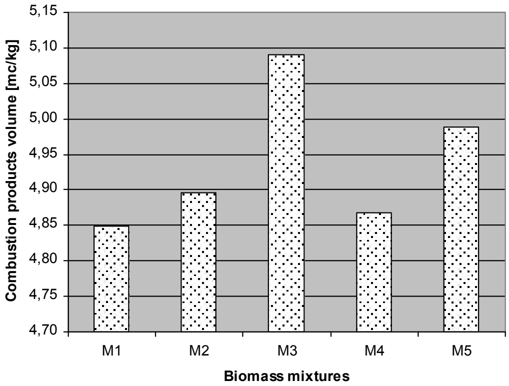

Figure 4: Combustion products volume

The combustion time is indicated in Fig. 5. There is a lower combustion time for mixture M_3 and a higher time for M_4. The combustion dynamics is inverse proportional to the heat of combustion. Kamikawa [3] made the observation that bark pellets showed slower combustion than wood pellets. If comparing the results of the burn-out time with the total amount of heat release, the reversed proportionality can be remarked too in [3]. Combustion products enthalpy is shown in Fig. 6. There is the same distribution of the biomass mixtures like in Figs. 1 and 2, showing a good correlation between the heating value and heat of the combustion products.

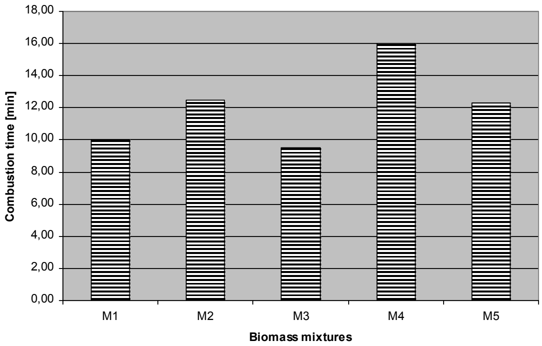

Figure 5: Combustion time

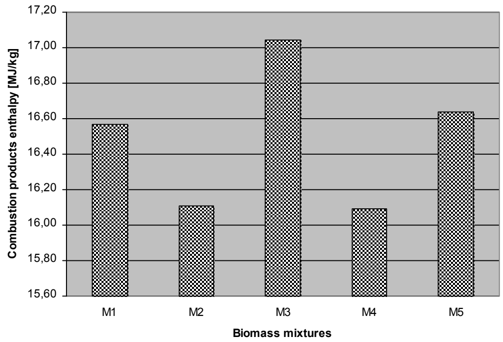

Figure 6: Combustion products enthalpy

In Fig. 7 H-t diagrams are represented. The curves are very close. Combustion temperature is presented in Fig. 8. It ranges from 1738 ^{o}C (M_2) to 1799 ^{o}C (M_1).

4. CONCLUSIONS

In this study we obtained thermal characteristics (heating value, air and combustion products volumes combustion products enthalpy, combustion temperature and time) of five lignocellulosic biomass mixtures, composed of beech and fir sawdust, pear bark, husks of sunflower seeds and wheat straw. The higher and lower heating values were obtained experimentally and were also calculated by use of the initial mass-based composition (ultimate analysis) of the mixtures. The results are very close, except the mixtures that contain wheat straw. Mixtures M_3 (beech sawdust and husks of sunflower seeds) and M_5 (fir sawdust, husks of sunflower

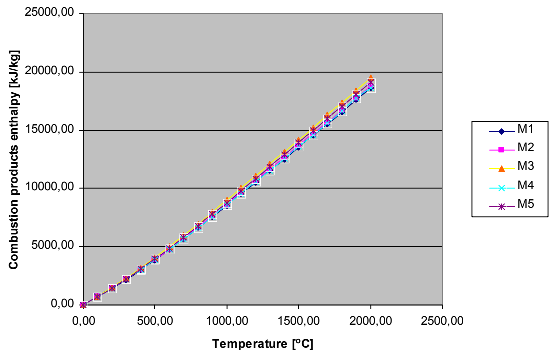

Figure 7: H-t diagrams

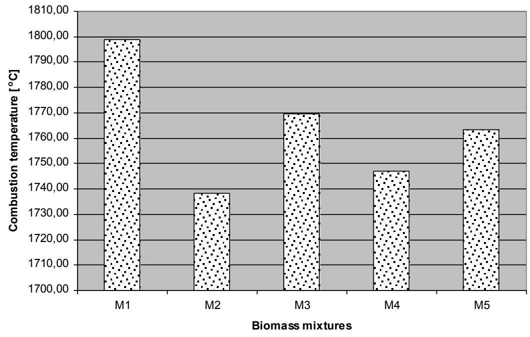

Figure 8: Combustion temperature

seeds and wheat straw) have high heating values because they have high carbon and hydrogen mass fractions and low moisture and ash content. Mixtures M_2 (beech sawdust, fir sawdust and pear bark) and M_4 (beech sawdust and wheat straw) instead, have low heating values. The volumes of combustion air and combustion products are similarly distributed on the five biomass mixtures, being influenced by their composition in the same way like the heating value. High volumes of air and combustion products are obtained for mixture M_3 and low volumes for mixture M_1 (beech sawdust and pear bark). The combustion time is inverse proportional to the heat of combustion. Thus, mixture M_3 has the lowest time and M_4 the highest time of combustion. The combustion products enthalpy is directly correlated with the heating value. The values of the combustion temperature are close. They range from 1738 ^oC (M_2) to 1799 ^oC (M_1).

Biomass derives from different renewable sources and varies therefore considerably in composition. The thermal characteristics of biomass enhance if the moisture and ash content is low and the carbon and hydrogen mass fractions are high.

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