

Energetic aspects of oak and larch pellets obtained from sawdust waste improved by torrefaction

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Abstract. This paper aims to present the energetic problems of two lignocellulosic biomasses in the form of pellets. The main energetic characteristics of lignocellulosic biomass, such as calorific value, ash content, and calorific density are presented as a comparison between oak and larch sawdust biomass. Methodology and installations for torrefaction and determining the main calorific features are presented. From an experimental point of view it was shown that the oak and larch pellets obtained within the paper had small differences in density, but after the torrefaction treatment they considerably increased the calorific value. There have been observed increases of up to 30% of the calorific value, both for oak and larch sawdust. The final conclusion of the paper is that although the role of vegetal biomass has diminished significantly in the last few years, it has not yet said its last word. The role of lignocellulosic biomass, as a sustainable fuel, will increase as fossil fuel amounts will be diminish, and when the world's population will realize that fossil fuels are exhaustible and that others type of fuels have to be replaced instead.

Keywords: larch, oak, biomass, torrefied pellet, calorific value

1 introduction

Energetic of resource is a science that deals with energy types but also with combustible materials from which the energy is obtained. That is why there can be say that there is an energetic of coal (as a way of obtaining coal energy), of wood, oil, natural gas, and energetic of vegetal biomass. Determining the energy content of fuels differs from a fuel type to other, through methodology and equipments. This difference is especially quantifiable between solid and gaseous fuels. Liquid and solid fuels generally have the same principles of energy content measurement, the differences being insignificant [1-5]. Today there is a conventional energy (electricity, gas, oil and fossil coal) and unconventional one or renewable one (geothermal, wind, solar, atomic, biomass, etc.). The calorific energy is the energy that offers the heat, and is given by electricity, natural gas and fossil fuels. Heat can be given to people in the form of hot air, whether it blows into spaces or heating the cold air from it (when it comes to heating the living or working areas with radiators) or heating certain surfaces to be used in the food preparation, or in industrial processes for heating the press plates, etc. Electricity is produced from coal, solar panels, wind power, in atomic power plants, hydropower plants, etc. The calorific energy is obtained by combustion of natural gas, coal, oil and lignocellulosic biomass, but also by heating with electric resistors (plates and plateaux). The natural gases have won the consumers preferences due to a clean combustion in comparison with coals and oil, respectively due to a low pollution of the atmosphere. More precisely, for the same quantity of burned product, the natural gases release into the air a half the toxicity produced by coals. Also, the combustion of natural gases doesn't release sulphur dioxide or nitrates [6-8]. However the main problem is that natural gases do not regenerate so fast and the reserves will be soon finished. That's why in the present time the natural gases are just the solution of transition period to fuel regenerative resources.

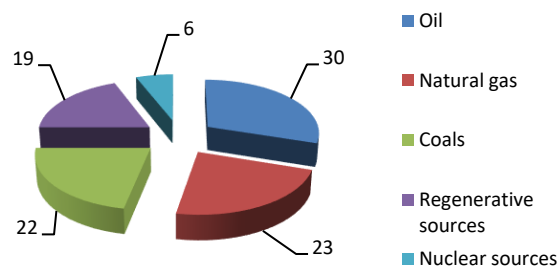


Fig 1. Worldwide energetic resources [9]

Even if nowadays the natural gas has the supremacy in the fuels used for domestic purposes for preparing food and heating the homes, the reducing of fossil fuels amount will necessarily lead to finding alternative energy sources, including biomass, which is available to all countries, even of the highly developed ones. The biomass is part of non-conventional energy resources following by wind, solar, geo-thermal and water energy. This will increase year by year and is expected to be the majority in the coming years alongside other renewable energy sources (Fig 1).

2 Background

Kambo and Dutta [1] studied the methodology of raw material improving. Biomass obtained from *Miscanthus* spp., in native form, pre-treated by torrefaction and densified in pellets was analyzed from the point of view of resistance and energy properties, in order to improve the properties. The density and energetic density of torrefied pellets increased from 834 kg/m³ and 15.7 GJ/m³ to 1036 kg/m³ and 26.9 GJ/m³. Akinrinola [7] stated that the heat treatment of torrefied biomass in Nigeria (resulting from 2 woody species and two other crops) promised to improve many fuel characteristics, regardless of whether it is used for energy generation or is used in the domestic field.

Ahn et al [10] used sawdust of two woody species *Larix kaempferi* C and *Liriodendron tulipifera* L to obtain pellets, and for the improvement of durability and calorific power it used lignin powder as an additive. Peng et al [11] demonstrated that the best pellets are obtained from the finest particles. An exhaustive analysis of untreated and torrefied pellets by Kumar et al [6] identified the benefits of using pellets even in combination with coal, but it was observed that from an economic point of view, further studies are still needed.

The main parameters of the pelletizing and torrefaction process are analyzed by Rudolfsson et al [12], focusing on the particle size, their moisture content, and the length of the pellet extrusion channel. The research carried out by Oh et al [13] on the pelletisation of the torrefied sawdust of two woody species revealed the Larch species (*Larix Kaempferi* C) compared with the yellow poplar species (*Liriodendron Tulipifera* L). Nhuchhen and Basu [14] found a method of replacing very expensive nitrogen with pressurized air for the heat treatment of torrefaction by replacing the continuous inlet nitrogen heat pipe with a poorly pressurized batch reactor. In the same direction as the previous authors, Kudo et al [15] replaced the inert gas that produced a weak adhesion of the shale with wet saturated steam. The tensile strength of the pellets obtained by this method increased 5 times. Peng et al [16] recommend that the biomass might be torrefied and then compressed in order to obtain pellets with higher characteristics, respectively high hydrophobicity and energy density.

As one of the main conclusion of the researches in the field of heat treatment of sawdust or torrefaction, it is observed that although it is very efficient, nitrogen flow treatment is expensive and requires sophisticated installations and large quantities of nitrogen, which is why new and simpler methods of thermal treatment are tried, which leading to appropriate effects.

Objectives: The paper aims to increase the energetic properties of the biomass of larch and oak species by heat treatment at high temperatures without air intake during treatment. The effective density of the pellets, the calorific power, the caloric density, the energy efficiency, the rate of energy release are taken into consideration, and the influence of moisture content on the calorific value of the two wood analyzed species will be studied as determinant factor.

2 Experimental

2.1 Materials and method

Two types of lignocellulosic biomass in the form of sawdust were used, namely sawdust of larch and oak, and their correspondingly pellets. Waste sawdust was taken from a circular saw machine. The main characteristics that have been determined were: density, calorific power, and ash content. Lignocellulosic biomass in the form of sawdust taken from a circular saw has also undergone to a torrefaction process in a oven without air admission, with different temperatures of 200, 220, 240, 260, 280, and 300 0C, in order to improve its calorific value.

The density of pellets was determined as the ratio between mass and volume (at the same moisture content). If the pellets are considered as a perfect cylinder (their ends were sanded to obtain a perfectly cross section perpendicular to length), the density determination relationship is followed (Eq. 1):

$$\rho = \frac{4 \cdot m}{\pi \cdot d^2 \cdot l} 10^6 \quad [kg / m^3] \quad (1)$$

Where: m is mass of pellets, in g; d- diameter of pellets, in mm; l- length of pellets, in mm.

The installation used for determining the calorific value of the wooden biomass was the explosive burning (bomb) calorimeter type XRY-1C, produced by Shanghai Changji Geological Instrument Co., from China (Fig. 3). Before testing, the calibration of the calorimetric bomb was performed with benzoic acid with a known value of calorific value (26 463 kJ/kg). With this value of calorific value, the calorimetric coefficient noted with k of calorimeter will be obtained, using the normal procedure of determination and equation of CV determination (Eq. 4).

$$CV = \frac{k \cdot (t_f - t_i) - q_i}{m} \cdot 10^{-3} \quad [MJ / kg] \quad (4)$$

where:

CV is calorific value, in MJ/kg; k - calorific coefficient of calorimeter, in kJ/Celsius; t_f –final temperature, in Celsius degrees; t_i -initial temperature, in Celsius degrees; m -mass of sample, in kg; q_i –supplementary heat obtained by cotton and nickel wire burn, in MJ.

The energetically density (ED) is determined by keeping into account the caloric power of the pellets and density, with the following relation:

$$ED = CV \cdot \rho \quad [MJ/m^3] \quad (5)$$

where; CV-calorific value, in kJ/kg; ρ - oven-dry density of pellets, in kg/m³.

On the basis of the combustion time, calorific value and oven-dry mass, the burning rate was also determined (Eq. 6).

$$BR = \frac{CV}{t} \cdot m_0 \quad [kJ / min] \quad (6)$$

where:

BR- burning rate (KJ/min); CV - calorific value, expressed on dry basis, KJ/kg; m_0 - oven-dry mass of sample, g; t - the combustion time for each sample, min.

BR value is obtained as an arithmetic mean of 8 experiments, with different values of time and calorific value.

Because the moisture content is one of the main factors of calorific value influence, a dependence relationship for 0% and a certain other moisture content M_c value [17] can be add (Eq. 7):

$$LCV_{M_c} = \frac{CV \cdot (100 - M_c) - 2.44 \cdot M_c}{100} \quad [MJ / kg] \quad (7)$$

where: LCV_{M_c} -low calorific value, at a certain moisture content, in MJ/kg; CV- calorific value, for 0% moisture content, in MJ/kg; M_c -moisture content, in %.

The influence of moisture content on the calorific power is very complex and depends on the wood species, but also on the type of the calorific power, respectively if it is the superior calorific power (HCV) or inferior one (LCV). In order to determine this influence, two different moisture contents of the samples from untreated pellets were used, respectively of 20 and 50%. From these tests the high and low calorific power were determined, thus obtaining two straight lines, in the xOy plane ($CVOM_c$), equations that intersect the vertical axis CV at the same point, and the horizontal axis M_c at two different points. The arithmetic mean of horizontal intersections will be called Limitative M_c .

To determine the ash content of the biomass, the general method of standardized determination was used (as ASTM E1755-01 [18]). According to this method, the milled and dried material (dried to 0% moisture content) is calcined at a temperature of 650°C in a laboratory calibrated oven, for a period of at least 3 hours. The milled samples for calcination were put on a metallic crucible resistant to elevated temperature of 650 Celsius degrees, and the weighting was made on an analytical balance with a 3-decimal precision. When determining the ash content, it will be taken into consideration that the sample is completely dried and also it keeps into consideration the cleaned and empty non-melting crucible mass, as in Eq. 8 [19-21].

$$A_c = \frac{m_{a+c} - m_c}{m_{s+c} - m_c} \cdot 100 \quad [\%] \quad (8)$$

where: m_{a+c} -mass of calcinated ash, considering also the crucible mass, in g; m_{s+c} - mass of sample considering also the crucible mass, in g; m_c - mass of empty crucible, in g.

The experimental process from the paper involves two parts. In the first phase the sieved sawdust is thermally treated (torrefied) in a calcination furnace STC 18.26 (Romania) at successive temperatures of 200, 220, 240, 260, 280 and 300 °C (Fig. 2) in a low oxygen environment (without air admission). The periods of sawdust torrefaction were 3, 5 and respectively 10 minutes, for each temperature and wood species [22-24]. During this step some changes of the sawdust sample colour occur [25-27], coupled with the emerging of odour and smoke at high temperatures.

The percent mass loss (PM) of the sawdust was calculated with the help of Eq. 9:

$$PM = \frac{m_i - m_f}{m_i} \cdot 100[\%] \quad (9)$$

Where: m_i is the initial mass of sawdust sample, before torrefaction (g), and m_f is the final mass of sawdust sample after torrefaction (g).

The PM values presented in the paper represent an average of 12 measurements, for each thermal treatment time, temperature, and sawdust species.

In the second step, the torrefied wood sawdust has been compressed in cylindrical pellets (about 10 mm diameter, 0.5-0.8 g mass, and 9-11 mm length) with the help of a handle press (Fig. 2b). At least 12 pellets were obtained from each white and thermally treated wood sawdust batch. Two different categories of pellets, made of larch (*Larix decidua*), and oak (*Quercus robur*) were analyzed.

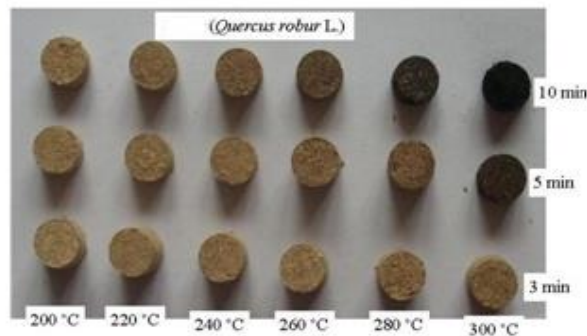


Fig 2. Color of torrefied pellets for oak

Improving of calorific value after thermal treatment was determinate, based on the calorific value before and after treatment, with aid of the next relation (Eq. 10):

$$I_{CV} = \frac{CV_{at} - CV_{bt}}{CV_{bt}} \cdot 100 [\%]$$

where: I_{CV} - Increasing of Calorific value (CV), in %; CV_{at} -calorific value, after torrefaction, in kJ/kg; CV_{bt} – calorific, value before torrefaction, in kJ/kg.

2.2 Results and discussion

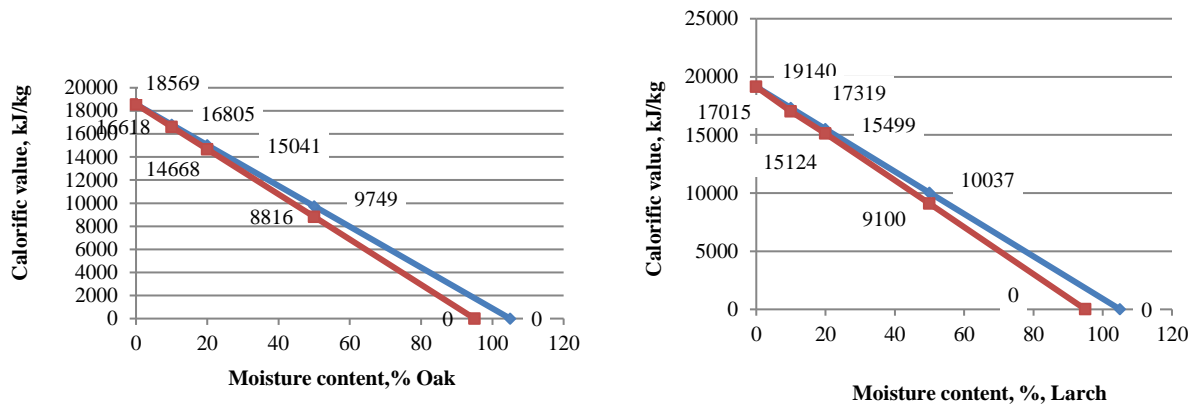
Moisture content of sawdust and pellets was 10%, being determined by method of weighing and drying, as was stipulated by EN 14774-1:2009 [28]. Density of pellets, determined as a ratio between mass and volume, was about 1010 kg/m³ for oak specie and 1012 kg/m³ for larch specie. For the two analyzed species (oak and larch) the time of burning and calorific values (HCV and LCV) were obtained when un-treated pellets were used (Table 1).

Table 1. Calorific values

Specie	Time of burning	Calorific value			Lineal equation	Limitative	
		HCV	LCV	CV		Mc, %	
Oak	25	18 564	18 563	18569	HCV=18569-176.4·Mc LCV=18569-195.1·Mc	105.2 95.1	100.1
Larch	29	19 135	19 132	19140	HCV=19140-150.8·Mc LCV=19140-279.4·Mc	126.9 68.5	97.7

The calorific value depends on the moisture content, and the two HCV and LCV values decrease as value with increasing in moisture content. It is observed that the HCV and LCV values are slightly different from each other; although the pellets used in the introduction into the calorimetric bomb were dried to constant mass (i.e. they had a moisture content of 0%). This is explained by the fact that about 3 ml of distilled water is introduced

into the bomb, which absorbs nitrogen compounds during the combustion, and which would have deviated from the normal values of CV (this is a recommendation of the calorimeter producing company).



100.

Fig 3. Calorific value for Oak and Larch

From the fig 4 it is observed that by increasing the moisture content, it will decrease the calorific power by consuming a higher amount of heat to dry the lignocellulosic material, such that at moisture content of about 109 °C, The caloric power for 0% (CV) is determined based on the methodology of finding the linear regression equation, the equations that are found in Table 1. Intersection of each equation with horizontal axis (Fig 3) determines the limitative moisture content. Medium values as 100.1% and 97.7% show as a value when no energies release, because energy of wood combustion is equal with energy to consume (to dry) water from wood. At 0% moisture content, the two values of equation merge into one, obtaining a point with the calorific value CV. The two regression equations for the high and low calorific power are also observed (Fig 3). The amount of heat which is released is equal to that consumed for burning maintenance. This is why the calorific energy efficiency issue occurs during combustion of fuel with certain moisture content [29-32] as it shows in Fig 4. On regard of this fact, Fig 4 shows that the calorific efficiency decrease with increasing of moisture content of oak biomass usually value of 10% moisture content offer a good efficiency of 95%.

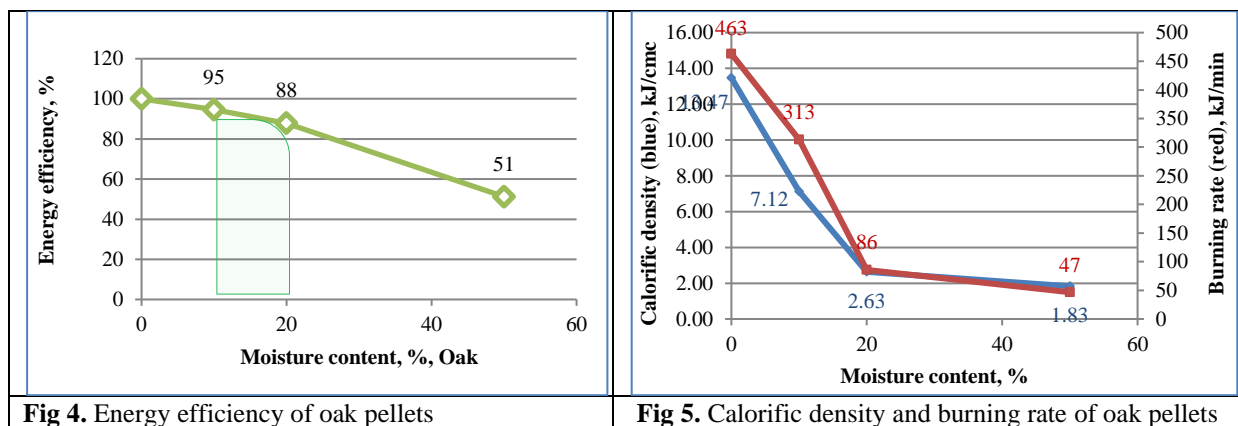


Fig 4. Energy efficiency of oak pellets

Fig 5. Calorific density and burning rate of oak pellets

Regarding the torrefaction activity of sawdust, it was noticeable that calorific density has extremely values 2-15 kJ/cm³, and burning rate also decrease with increasing of moisture content (Fig 5).

As a general rule it is observed that with the increase of degree of torrefaction (given by the temperature and time of the thermal treatment) the mass loss will increase (Fig 6). Temperatures over 260 °C increase better the mass loss [33-36], and temperature of 300 °C represents the best one in this field. Assuming that the mass loss for the white sawdust is zero, the mass loss over the total temperature range for 3 minutes is 8.84%, for 5 minutes it is 16.95%, and for 10 minutes it is 40.24%. Almost similar values were obtained in the case of the larch specie; by this it was shown that during the torrefaction treatment, the woody species have an almost similar behaviour.

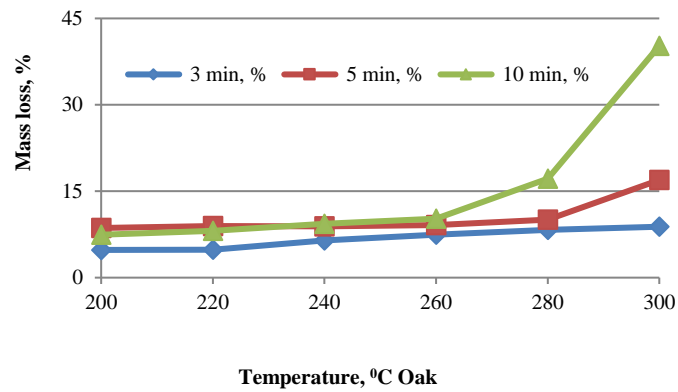


Fig 6. Mass losses of oak in time of torrefaction

Regarding about the influence of torrefaction temperature on calorific value of oak pellets, Fig 7 shows the increasing CV for 3 min with 14.5%, and with 15.5% for 10 min, taking as starting point the un-treated pellets.

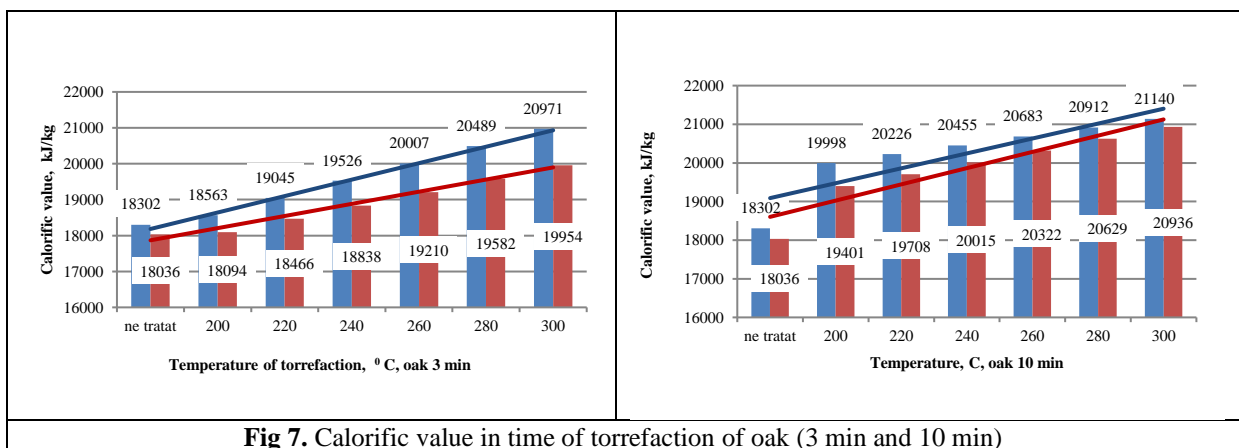


Fig 7. Calorific value in time of torrefaction of oak (3 min and 10 min)

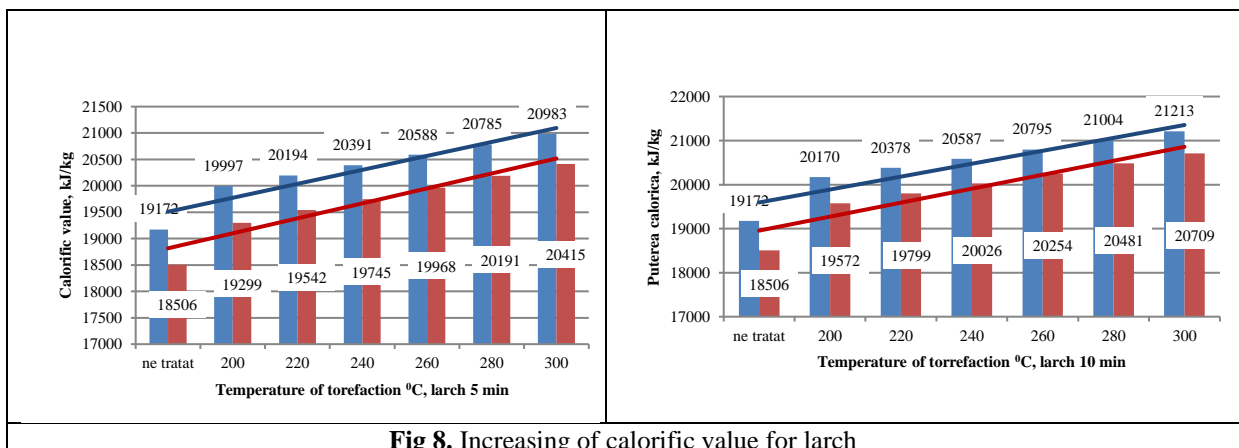


Fig 8. Increasing of calorific value for larch

Regarding the influence of the torrefaction temperature on the calorific value of the larch pellets, a CV increase of 9.4% for the 5-minute period and 10.6% for the 10-min period is observed. It should be noted that the 3-minute period offers an increase of less than 5% for both analyzed species.

Ash content was different for native biomass, being 0.42% for larch and 0.51% for oak. The torrefied sawdust had higher ash content, corresponding to the mass losses obtained by heat treatment [37]. Therefore maximum values of ash content for sawdust treated at temperatures of 300 °C as 0.58% for larch and 0.71% for oak were highlighted during laboratory tests.

If a comparative analysis is made of the properties of larch and oak biomass, it is observed that although they are two different species (softwood and hardwood) and have different densities (oak 775 kg / m³ and larch 521 kg/m³ at 10% moisture content), their energetic properties are quite appropriate. In this sense the densities of the pellets differ below 0.2%, the calorific powers of the white pellets differ below 3.1%, and the differences

in the increase of calorific power after torrefaction are under of 3.1% in favour of larch biomass. Similar differences were found for caloric efficiency, energy release rate and calorific density.

3 Conclusions

On a general way, woody biomass in the form of sawdust is environmentally friendly and gives to the world a neutral energy against the emissions of carbon dioxide. The CO₂ is sequestered inside the biomass during the growing process of trees (about 60-140 year) and forms a closed circuit, because the quantity of CO₂ which was absorbed by the plants during the growing process will be equal to which was raised during the complete burning process (in a few minutes or hours). It could say that the same quantity of CO₂ is raised when woody biomass is naturally discomposed in open spaces in few years, which is why the use of wood biomass in combustion for human needs is recommended.

From an experimental point of view it was shown that the oak and larch pellets obtained within the work had small differences in density, but after the torrefaction treatment they both considerably increased their calorific value. There have been observed increases of up to 12% of the calorific value after torrefaction, both for oak and larch sawdust. No exceptional differences were found between the calorific properties of the two species analyzed, although they are considered structurally different species.

Considering that the two wood species (oak and larch) are valuable species with main uses in the construction of furniture and veneers, it is recommended to use only the remnants from the manufacture of these products in the fabrication of normal or torrefied pellets.

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