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Factors affecting the quality of pellets made from residual biomass of olive trees

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ABSTRACT

In the Mediterranean areas of southwest Europe, olive tree pruning residues generate substantial amounts of residual biomass. Pelleting this biomass supposes the conversion of a residue difficult to manage into an energy resource especially indicated to be used in the areas where these groves exist.
The final quality of pellets varies depending on the raw material properties and the manufacturing process. Consequently, in this paper the raw materials were chemically characterized before pelletization under different conditions in a semi-industrial pellet mill. In addition, the physical and mechanical parameters of the pellets produced were analyzed in order to determine the optimum pelletization conditions for each raw material by using IBM SPSS Statistics 20 software and considering the European requirements for non-industrial pellets.
The aim of this work is to investigate the influence of the main densification parameters (moisture content, compression and temperature) and raw material (leaves, pruning, and wood) on the quality properties of pellets from the different olive tree pruning residues.
In general, low moisture content (9%), short compression lengths (20–24 mm) and temperatures higher than 40 °C were the best pelleting conditions for the residual biomass from olive trees, although these parameters varied between the raw materials analyzed.

1. Introduction

The increasing price of fossil fuels, the energy dependency derived from their use, and the increasing environmental concerns, have made it necessary to develop an energy system with a more renewable energy matrix and a consequently reduction of greenhouse gases. One important renewable energy source is biomass, which can be used for heat, electricity, and transportation [1,2]. In recent years, the production of thermal energy by means of biomass on a small scale has shown a clear trend toward densified biofuels (pellets) [3]. This is due to their homogeneous size, which facilitates an automatic or semi-automatic treatment, and because its use resolves the disadvantages of the traditional domestic use of biomass, such as the low thermal efficiency [4,5]. The use of densified biofuels also reduces the costs associated with handling, storage and transportation, due to the increase in bulk density associated with the densification process.

In general, the quality of the pellets depends on the properties of the feedstock and quality management of the manufacturing process [6]. Considering that only woody pellets from forestry residues have already successfully established technologies and markets for production and consumption in some European countries, it is necessary to focus on studying the pelletization of agricultural biomass, which is periodically planted and harvested and has a great energy potential especially in rural areas [7,8].

In the Mediterranean areas of southwest Europe, agricultural activities are very important, and great amounts of residues are produced from these activities [5,9]. This is the case of olive tree pruning residues, which give rise to significant amounts of residual biomass in the areas where these groves exist [9]. Despite the generation of large quantities of agricultural residues, the current level of their utilization as fuel is low. Generally, agricultural residues are produced locally and they often have a low bulk density [10,11]. Other important factors which influence the level of energy usage of agricultural residues are the local availability, the fact that they are dispersed over a relatively large area, the costs associated with the treatments needed for their proper removal [5], and the lack of sufficient information concerning the combustion and emission characteristics of these residues. This information is important for the design and efficient operation of combustion systems that are fully adapted to the biomass of each region.

The final quality of pellets varies depending on the raw material properties and the manufacturing process [12]. The variables dependent on the pelletization process can be controlled to optimize production

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efficiency and improve the quality of the finished product [11] according to the specific biomass studied.

Hence, the aim of this paper is to analyze the mechanical, physical and chemical characteristics of three different types of residual biomass from olive trees that were pelletized under different operating conditions: initial moisture, diameter and compression length of the pellet mill die, and temperature of the pelletization process. With this purpose, the operational conditions have been optimized according to the final properties of the pellets produced. In addition, the quality parameters are discussed and compared with the EN 14961-2 [13] in order to check if the pellet samples fulfill the guidelines established for non-industrial use, which are the most restrictive.

2. Materials and methods

2.1. Characterization of the raw materials

Olive pruning residues (leaves, prunings and wood) were obtained from an olive grove near Granada, Spain. Olive leaves (OL) were obtained from an olive oil production plant in February 2012 with a moisture content of 24.4% (w.b.), prunings (leaves and small branches) (OP) were harvested as a whole in March 2012 with a moisture content of 26.7% (w.b.) and olive wood (OW) was collected as logs in March 2012 with a moisture content of 23.2% (w.b.).

The biomass was stored for 3 months uncovered, until its moisture content decreased to approximately 15% (w.b.). Then it was stored for a month in the laboratory in order to dry it progressively. Representative samples of the raw materials were analyzed before being pelletized in order to obtain the values of the properties that are dependent on the raw material itself. The methodology is described below, and the results obtained are compared with the guidelines established for non-industrial pellets summarized in Table 1 according to the European Standard EN 14961-2 [13].

2.1.1. Particle size distribution

5 kg of the milled material was screened through 2.5 and 4 mm circular holes and the distribution for classes <2.5 mm, 2.5–4 mm and >4 mm was calculated according to EN 15149-2 [14].

2.1.2. Moisture, ash and volatile content

The EN 14774-1 [15], EN 14775 [16] and EN 15148 [17] test procedures were applied to three samples from each raw material to analyze their moisture, ash and volatile content respectively.

2.1.3. Elemental analysis

Three samples of each raw material were milled and mixed to obtain a homogeneous sample of about 7 mg to determine the percentage of carbon, nitrogen, sulfur and hydrogen, according to EN 15104 [18]. A Fisons Carlo Erba EA 1108 CHNSO detector type was used for this purpose.

2.1.4. Calorific value

The higher heating value (HHV) was determined three times for each raw material according to EN 14918 [19] by using a bomb calorimeter (Parr 6100) and the average value was calculated. The lower heating value (LHV) was calculated by correcting the HHV by the heat energy required to vaporize water due to hydrogen released during combustion (Eq. (1)). The hydrogen content values (%H_2) were determined by elemental analysis.

$$LHV = (HHV * 4.184 - 206 * \%H_2 - 23.05 * \%H_2O)/4.184 \quad (1)$$

2.1.5. Chlorine content

After the determination of the calorific value, the soluble chlorine content was calculated by using a Mettler Toledo compact titrator G20 with silver nitrate as reaction agent.

2.1.6. Ash fusibility

Ash fusibility was investigated using an imaging sintering point-testing equipment (Leco AF-700). Ash samples were prepared by igniting the fuels in a muffle furnace at 550 °C, and then shaped into pyramids. Ash fusion temperature measurements were carried out with a maximum temperature of 1500 °C, in an oxidizing atmosphere. The measurements were carried out following international standard procedures [20,21]. During the testing process, the deformation temperature (DT), softening temperature (ST), hemisphere temperature (HT) and fluid temperature (FT) were recorded according to the specific shapes of the ash cylinders.

2.2. Densification of the raw materials

Since a particle size smaller than 5 mm was necessary for the pelletization process, the granulometric values of the raw materials had to be reduced. Therefore, a Retsch MM301 hammer mill was used for 5 min at 25 Hz, as well as a sieve of 4 mm size. In some cases it was also necessary to wet the samples by sprinkling water on them to get homogeneous final moisture content for the tests (9, 11 and 13%).

The pellets were produced by means of a pelletizer Kahl 14-175. This pelletizer has a nominal power of 3 kW. Its production reached approximately 100 kg/h for OL and OP, while the production capacity was 50 kg/h for OW.

Three different flat dies that differed in the size of their cylindrical holes were used for the production of the pellets:

D1 diameter 6 mm; compression length 20 mm
D2 diameter 6 mm; compression length 24 mm
D3 diameter 8 mm; compression length 32 mm

Several runs of pellets were obtained to supply the pellet press continuously with the milled and sieved biomass. Once the process stabilizes, the temperature of the material increases due to the friction between the stationary flat die, the driven roller and the residue. Therefore, the pelletizing runs were carried out according to an experimental design with the factors (i) raw material moisture content before pelletizing, (ii) raw material composition in three ingredients: OL, OP and OW, (iii) diameter and compression length of the pellet die, and (iv) temperatures reached during the pelletization process (Table 2). The challenge in biomass pelletization is therefore to keep these parameters in the range where high quality pellets are produced, at a minimal energy input and at a high pellet mill capacity [22]. However, these parameters are a function of the properties of the raw material [23].

Table 1
Quality guidelines for non-industrial use pellets [13].

Parameter	Classification		
	A1	A2	B
Size (diameter and length) (mm)	D06: D ≤ 6 ± 1 and 3.15 ≤ L ≤ 40 D08: D ≤ 8 ± 1 and 3.15 ≤ L ≤ 40		
Moisture content (%)	M10: ≤10		
Ash content (%)	A0.7 ≤ 0.7	A1.5 ≤ 1.5	A3.0 ≤ 3.0
N (%)	N0.3 ≤ 0.3	N0.5 ≤ 0.5	N1.0 ≤ 1.0
S (%)	S0.03 ≤ 0.03	S0.03 ≤ 0.03	S0.04 ≤ 0.04
Cl (%)	Cl0.02 ≤ 0.02	Cl0.02 ≤ 0.02	Cl0.03 ≤ 0.03
Durability	DU97.5 ≥ 97.5	DU97.5 ≥ 97.5	DU96.5 ≥ 96.5
Bulk density (kg/m^3)	BD600 ≥ 600		
Lower heating value (MJ/kg)	Q16.5: 16.5 ≤ Q ≤ 19	Q16.3: 16.3 ≤ Q ≤ 19	Q16.0: 16.0 ≤ Q ≤ 19
Additives	≤2% (type and quantity to be specified)		

Durability has been defined in terms of percentage of whole pellets after testing.