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Full Length Article

Torrefaction of olive tree pruning: Effect of operating conditions on solid product properties

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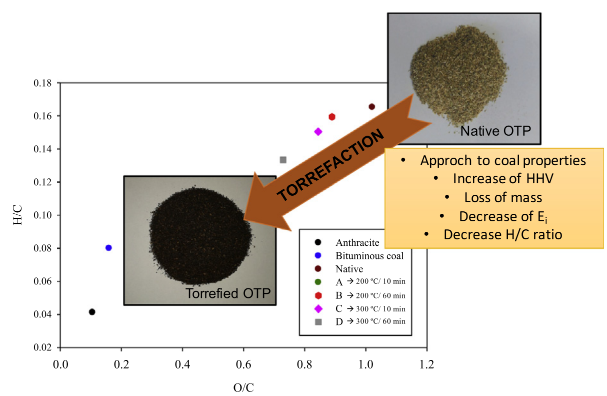
HIGHLIGHTS

- Fuel properties of the olive tree pruning were improved by torrefaction.
- Changes in properties of solid are mainly sensitive to torrefaction temperature.
- Higher heating value increased from 17.32 MJ/kg to 20.50 MJ/kg.
- The hemicellulose is the component more affected during the torrefaction.
- Effect of torrefaction on pyrolytic behavior of material was investigated.

GRAPHICAL ABSTRACT



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ABSTRACT

In this work, the effect of experimental conditions of torrefaction on properties of olive tree pruning was investigated. This study has demonstrated that fuel properties of olive tree pruning were improved by torrefaction. For example, torrefaction at 300 °C during 60 min provided to raw biomass an increase on the ratio of fixed carbon to volatiles (from 0.23 to 0.39) and it improved its fuel quality. Elemental analysis revealed that the composition of olive tree pruning moved from lignocellulosic biomass to coal (for example, from O/C and H/C ratios of 1.02 and 0.17 for raw biomass to 0.90 and 0.15 for torrefied sample at 300 °C during 10 min). Also, as a result of torrefaction, a more homogeneous solid with higher heating value was obtained. However, bulk density of solid did not change significantly after torrefaction process. In addition, SEM analysis indicated that the olive tree pruning surface structure was broken and destroyed by torrefaction process. Also, the thermogravimetric analysis of native and torrefied samples in nitrogen atmosphere showed a strong degradation of hemicellulose and, also, in severe torrefaction conditions, a modification on the thermal stability of cellulose. Finally, an investigation on the pyrolysis kinetics of native and torrefied samples was presented. Lower energy activation values of main lignocellulosic pseudo-components were obtained for torrefied samples.

1. Introduction

A great amount of wastes are produced by olive cultivation and olive oil production. These wastes require a particular management for decreasing their environmental impact. In Spain, olive-oil industry annually generates a total of 3,200,000 t of olive waste

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(approximately, 840,000 t of olive mill solid waste, 360,000 t of olive stone and 2,000,000 t of olive tree pruning) [1]. The olive tree pruning is the most abundant generated waste (around 62% of the total residues). It is obtained from the olive tree pruning process and it includes leaves, branch and some pieces of trunk.

In the last years, new strategies to replace fossil fuels as the main primary global energy by sustainable fuels has been developed motivated by the need of a more sustainable society. In this point, biomass appears as one of the most important renewable energy sources. Thus, the olive tree pruning waste produced by the olive-oil industry is highly valued as an energy source, mainly in rural areas of southern Spain. This is a material that consists predominantly of lignocellulosic fibers (between 58 and 88%). Direct combustion of this material can meet technical and economic problems mainly associated with its high moisture content, high volatile matter content, hygroscopic nature, low energy density/heating value (low fixed carbon content), etc. These properties are responsible of a negative effect on logistics (transportation, storage and handling) and low combustion efficiency [2].

Torrefaction is a pre-treatment for further processing that pretends eliminate technology barriers of biomass in its utilization as energy source. It consists in exposing biomass to an inert atmosphere at low temperature (200–300 °C) and a low heating rate (residence time of 10 min – 1 h) to converts biomass into a charcoal-like carbonaceous material with better properties [3–9]. The product obtained strongly depends on the experimental conditions applied during the process. In general terms, hemicellulose is partially or totally decomposed. Water and some volatile organic compounds (VOCs) with low calorific values are released from the native biomass enhancing the heating value/energy density of the torrefied material. Also, torrefied materials presents better physical characteristics as grindability, and therefore, makes biomass friable and more easily pulverize like coal in milling processes decreasing energy consumption for grinding [9] or hydrophobicity, and consequently, storage life without fuel degradation is increased or handling and storage cost is decreased. In this way, the torrefaction is a very promising technology for obtaining new solid fuels, whose properties range between biomass and coal.

Many studies of torrefaction had focused on different agricultural byproducts, such as pine sawdust [10], palm kernel shell [11], rice straw [12], olive wastes [13–15]. For example, an interesting study conducted by Volpe et al. [14] on pyrolysis and torrefaction of two types of olive wastes (olive trimmings and olive pulp), proposed the use of combination of mass loss and H-content as indicators of gross calorific value of solid product or Martín-Lara et al. [15] presented a kinetic analysis of the decomposition of olive tree pruning during torrefaction process.

Recent advances in torrefaction and other pre-treatment techniques can be found in reviews of Madanayake et al. [16] or Chen et al. [17].

The main objective of this paper is to investigate the thermochemical transformation via torrefaction of olive tree pruning produced as a forestry residue of the olive cultivation. The difference with our previous published work [15] is the focus on effect of operating conditions on solid product properties.

2. Materials and methods

2.1. Material

Olive tree pruning (OTP) was collected from 70 years old trees of the ‘Picual’ olive variety in the Spanish province of Jaén, Spain. The sample was ground using an analytical mill (IKA MF-10). The milled material was then sieved using a high vibratory sieve (CISA) and the fraction between 0.25 and 1 mm particle size was selected for the analyses and thermal treatments.

2.2. Torrefaction procedure

Several tests were proposed to investigate the effect of the temperature and residence time on the OTP torrefaction process. To accomplish this, OTP was torrefied under different temperature conditions in an electric muffle furnace model Nabertherm L3/11B180 with an operational temperature range of 30–3000 °C.

A total of four experiments (by duplicated) were performed, two at 200 °C (lowest temperature in torrefaction process) and residence times of 10 and 60 min and two at 300 °C (highest temperature in torrefaction process) and residence times of 10 and 60 min, using an inert atmosphere of N_2 (the nitrogen flow was regulated at 4 L/min). In each experiment, 5 g of OTP were placed on a ceramic crucible forming a thin layer. After a required time to move oxygen from oven and until nothing of oxygen is left in the oven chamber, the crucible was introduced in it with a heating rate of 15 °C/min. After the specified residence time period (counted from the sample temperature reached the torrefaction temperature), the crucible was removed from the oven and saved in a desiccator. When the solid was cooled, it was weight and stored in plastic sealed buckets for further analyses.

Table 1 shows temperatures and residence times for obtained torrefied samples. Thus, native sample was olive tree pruning without any thermal pre-treatment of torrefaction and A, B, C and D samples are the torrefied solids.

2.3. Physico-chemical characterization of native and torrefied samples

2.3.1. Proximate analysis

Proximate analysis is defined by ASTM as the determination by standard methods of moisture, volatiles, fixed carbon and ash. The moisture content has been determined following the UNE-EN-3 14774 using a drying oven with a temperature of 105 ± 2 °C. The ash content has been calculated according to the UNE-EN 14775, which is used for solid biofuels. The volatile content has been performed following the procedure outline in the UNE-EN 15148, appropriate for solid biofuels. Finally, the fixed carbon content was determined by difference with the other components.

2.3.2. Elemental analysis

The elemental composition (C, H, N, S, O) analysis of native and torrefied samples was performed using an elemental analyzer Fison’s Instruments EA 1108 CHNS. It is based on a flash combustion of organic samples, which allows the simultaneous determination of percent carbon, hydrogen, nitrogen and sulfur in 15 min.

2.3.3. Bulk density

The bulk density is represented as the ratio of the dry weight of solid sample and the volume occupied by it. It was determined following the procedure described in the UNE-EN 15103.

Table 1
Temperature and residence time during thermal pretreatment of torrefaction for all torrefied olive tree pruning samples.

Sample	Temperature (°C)	Residence time (min)
Native	–	–
A	200	10
B	200	60
C	300	10
D	300	60