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Torrefaction of olive mill waste

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ABSTRACT

Two-phase olive mill waste (TPOMW) was converted via torrefaction into a carbon rich solid interesting as bioenergy feedstock. TPOMW was characterized and torrefied in an oven at temperatures ranging from 150 to 300 °C for 2 h. Mass and energy losses occurred during torrefaction were measured and the torrefied products were characterized including ultimate analysis, heating value measurements, accelerate solvent extraction (ASE) and FTIR in order to assess the effects of torrefaction on the physicochemical properties of TPOMW. Additionally, ash fouling evaluation was also performed through XRF analysis. The weight fraction of C, defined in percentage as wt.%, improved from 56 to 68 wt.% and the high heating value rose from 26.4 to 30.0 $MJ \cdot kg^{-1}$ as torrefaction temperature increased, reaching typical values of subbituminous coal and finding the best results at 200 °C in terms of maximizing the heating value and minimizing the energy losses. Accordingly, from FTIR analysis it was observed that the degree of coalification increased during torrefaction of TPOMW. ASE results shown that the residual olive oil in TPOMW was removed during torrefaction, being completely eliminated at 300 °C. The alkali index for TPOMW was found to be 0.66 kg $alkali \cdot GJ^{-1}$, which implied a high fouling tendency that could be mitigated through co-firing. Finally, t-TPOMW briquettes with good mechanical strength and energy density of 26.7 $GJ \cdot m^{-3}$ were produced using a hydraulic piston press. Results demonstrated that torrefaction allows transforming TPOMW into a coal-like material, which would imply a profitable way to manage these wastes.

1. Introduction

Motivated by the transition to a more sustainable society based on clean energy technologies, biomass emerges as one of the most important renewable energy sources. On the one hand, due to its environmental benefits, since bioenergy could imply a reduction in the carbon dioxide emissions and contributes to decrease the environmental impact caused by organic wastes. On the other, because it constitutes a key factor in the economic development of rural areas and enhances energy access [1,2]. Over the past decade, the bioenergy utilization increased from 8% of the world total primary energy supply to 10% today and it is expected to rise further to between 25% and 33% by 2050 [1]. However, an important transition required to achieve this vision is to use biomass more efficiently by deploying more efficient conversion technologies and better integrating bioenergy production into biomass value chains in other industries.

There is a considerable bioenergy potential from several sources, since a wide range of feedstocks can be used for bioenergy generation, like energy crops, biomass residues and organic wastes. In the northern European countries, is common to refer to wood biomass (e.g. bark, wood chips and

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sawdust). Nevertheless, the Mediterranean area has a great bioenergy potential from several agricultural residues, especially from the olive oil sector as they produce over 98% of the worldwide production [3].

The olive-oil extraction process generates large amounts of byproducts and wastes that require a specific management regarding minimization, valorization and mitigation of their environmental impact. The new technology for olive-oil extraction is a continuous centrifugate two-phase process that generates a liquid phase (olive oil) and an organic slurry called two-phase olive mill waste (TPOMW, or ‘alperujo’ in Spanish). In Spain (major olive oil producer country), alone this new system generates approximately 300,000 tons per year of TPOMW [4], which is a high polluting by-product due to its content in organic matter. Indeed, the pollutant power of TPOMW is very high (BOD 89–100 g L^{-1}, COD 80–200 g L^{-1}, being BOD and COD the Biological Oxygen Demand and the Chemical Oxygen Demand, respectively) as the TPOMW organic fraction includes sugars, polyalcohols, pectins, lipids and notable amounts of aromatic compounds that are responsible for phytotoxic and antimicrobial effects [5,6]. Nowadays, there is not an efficient elimination system of TPOMW due to its low energy density and its high moisture content, which makes it costly to transport, in combination with other technological limitations as low combustion efficiency [7]. Thus, it is imperative to find a proper disposal or utilization of viable management strategies.

Torrefaction is a mild pyrolysis process that can help to overcome some of the above mentioned limitations by converting biomass into an upgraded solid material with increased energy density and decreased oxygen content, therefore more suitable for energy generation. This method comprises thermal treating of material at temperatures from 200 to 300 °C so that neither great initial investment nor high operating costs are required [7–9].

The torrefaction products are volatile (carbon dioxide, carbon monoxide and possible traces of acetic acid, hydrogen and methane), condensable and non-condensable gases (water vapor, acetic acid, furfural, formic acid, methanol, lactic acid, phenol), and a carbon-enriched solid, which is the main torrefaction product, that retains between 75 and 95% from the departure energy content, depending on the processing conditions (pressure, temperature, residence time) and the feedstock [9]. Wannapeera and Worasuwannarak [10] studied the torrefaction under pressure of leucaena and found that the mass and energy yield was higher when raising the torrefaction pressure. Other authors [7,11–15] examined the influence of torrefaction temperature and residence time on the properties of torrefied materials obtained from different feedstocks and observed that, although both parameters affect the product distribution and the properties of the solid, the temperature had more effect on torrefaction than the residence time. Pimchuai et al. [7] study the torrefaction in nitrogen atmosphere of rice husks, sawdust, peanut husks, bagasse and water hyacinth at temperatures ranging from 250 °C to 300°, and found that the combustion properties of the torrefied materials were improved for the higher torrefaction temperatures investigated. Chen et al. [12] investigate the torrefaction behavior of lauan blocks and recommended the operation at 250 °C and 1 h in order to intensify the heating value as well as to avoid too much mass loss of the initial wood and its conversion into condensed liquid. On the other hand, Rousset et al. [16] evaluated the combined effect of the temperature and oxygen concentrations on the physical and chemical properties of eucalyptus grandis and from the results it was possible to confirm that the oxygen concentration become important on the properties and compositions of the solid from over 280 °C, being negligible at lower temperatures.

The torrefied material is comparable with a low rank coal and still retains some characteristic properties from the original biomass but present higher energy content and better stability against microbial degradation due to the improved hydrophobic properties. Besides, torrefied biomass is a fragile and low density porous product that has a higher dust formation capacity and lower mechanical strength than fresh biomass due to the loss of structural integrity from the breakdown of hemicellulose [9]. Consequently, these characteristics make it necessary to volumetrically densify the torrefied material in order to facilitate its handling and reducing transport and storage costs.

Among the variety of densification systems, pellet mill and briquette press are the most common technologies used for producing a uniform format feedstock product for bioenergy applications [17]. Studies of torrefied biomass densification have indicate that the pressure and the energy required during the briquetting process are reduced by a factor of two while the performance increases twice as compared to the densification process of fresh biomass [17]. Hence, torrefaction combined with briquetting or pelletizing could be an efficient option for treating agricultural wastes and produce bioenergy feedstock.

Despite torrefaction of diverse biomass resources can be found in the literature [12–14,18–21], there is still a gap of information in the implementation of this technique as an efficient management treatment to minimize and valorize problematic organic wastes, such as the TPOMW. In this work, the torrefaction method has been applied to TPOMW in order to study the viability of the process to produce bioenergy feedstock from the olive oil extraction waste. Different experiments were carried out at laboratory scale in order to determinate the optimum temperature of the process. Then, the torrefied materials were fully characterized in order to evaluate its potential as a biofuel. Finally, briquetting tests were performed to test the applicability of this technique to the torrefied TPOMW (t-TPOMW).

2. Materials and methods

2.1. *Materials*

Fresh TPOMW was supplied by Extremadura Agricultural and Food Technological Centre (CTAEX) during the olive campaign for 2012–2013. This material was sun dried on the field for two weeks. Then, the residual moisture content was obtained from the total mass loss after drying the fresh TPOMW in an over at 105 °C for 24 h, which was found to be 5.8 wt.%. The dried TPOMW material was milled in a grinder to attain homogeneity, since the olive pits were easy to detect among the dried pulp, sieved to obtain a particle size less than 0.5 mm