Resources, Conservation and Recycling 92 (2014) 145–150

Contents lists available at ScienceDirect

Resources, Conservation and Recycling

journal homepage: www.elsevier.com/locate/resconrec

Techno-economic and environmental assessment of an olive stone based biorefinery

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ARTICLE INFO

Article history:
Received 23 March 2014
Received in revised form
16 September 2014
Accepted 16 September 2014

Keywords:
Biorefinery
Olive stone
Ethanol
Xylitol
PHB
Furfural

ABSTRACT

Olive tree cultivation is spreading worldwide as a consequence of beneficial effects of olive oil consumption. Olive oil production process and table olive industries are the major sources of olive stones. Currently, this by-product is used in direct combustion to produce energy as electricity or heat. However, there are other possibilities for taking full advantage of a renewable source of interesting compounds. In this work the techno-economic and environmental assessment of two biorefinery schemes and its comparison with the direct combustion (base case) of this residue are presented. The first biorefinery scheme describes the integrated production of xylitol, furfural, ethanol and poly-3-hydroxybutyrate (PHB). The second biorefinery scheme considers the production of xylitol, furfural, ethanol and PHB integrated to a cogeneration system for producing bioenergy from the solid residues resulting from the mentioned processes. The results showed that in the first biorefinery scheme, the net profit margin is approximately 53%, while the second present a net profit margin of 6%.

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1. Introduction

Currently, most energy and chemicals are derived from fossil raw materials, although there are several environmental, economic and social concerns related to their extraction and use. These facts have increased the interest in the use of renewable raw materials. The replacement of the fossil raw materials either fully or partially is an objective in many countries, including Spain. Since the fossil supply in this country is almost entirely of foreign origin, is of special interest the use of local biomass such as agricultural, forest, agro-industrial and industrial wastes, due to its low cost and large availability.

Because of the reported beneficial effects of olive oil consumption, the olive tree cultivation has been propagated worldwide and it is nowadays present in countries as diverse as the United States, Argentina or Australia. Currently, this crop presents a global cultivated area of almost 10 million hectares with an annual production of approximately 18 million tons of olives. Olive oil and pitted table olive production are the most important agrifood industries in the Mediterranean countries, with Spain being the largest producer in the world. One important by-product generated in olive oil extraction and pitted table olive production is olive stone. Olive stone represents 10–30% (wt) (Garrido-Fernández et al., 1997) of the fruit, which implies an annual production of approximately three million tons. For instance, in the 2009/2010 season, the olive oil and table olives world production were 2.97 and 2.37 million tons, respectively (The International Olive Council, 2012). In the same season, approximately 0.17 million tons and 2.1 million tons of stone from table olives and olive oil industries, respectively, were produced. Currently, the main use of this by-product is the direct combustion to produce energy as electricity or heat (Romero-García et al., 2014).

Apart from its use as raw material for producing heat and electricity, crushed olive stones have also been considered as raw material for other kind of value-added products. For instance, olive stones contain extracts with high antioxidant capacity (approximately 5.5% dry basis), containing mainly hydroxytyrosol and tyrosol (Fernández-Bolaños et al., 1998). These antioxidants have application in the food, cosmetic, functional food and nutraceuticals

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http://dx.doi.org/10.1016/j.resconrec.2014.09.008
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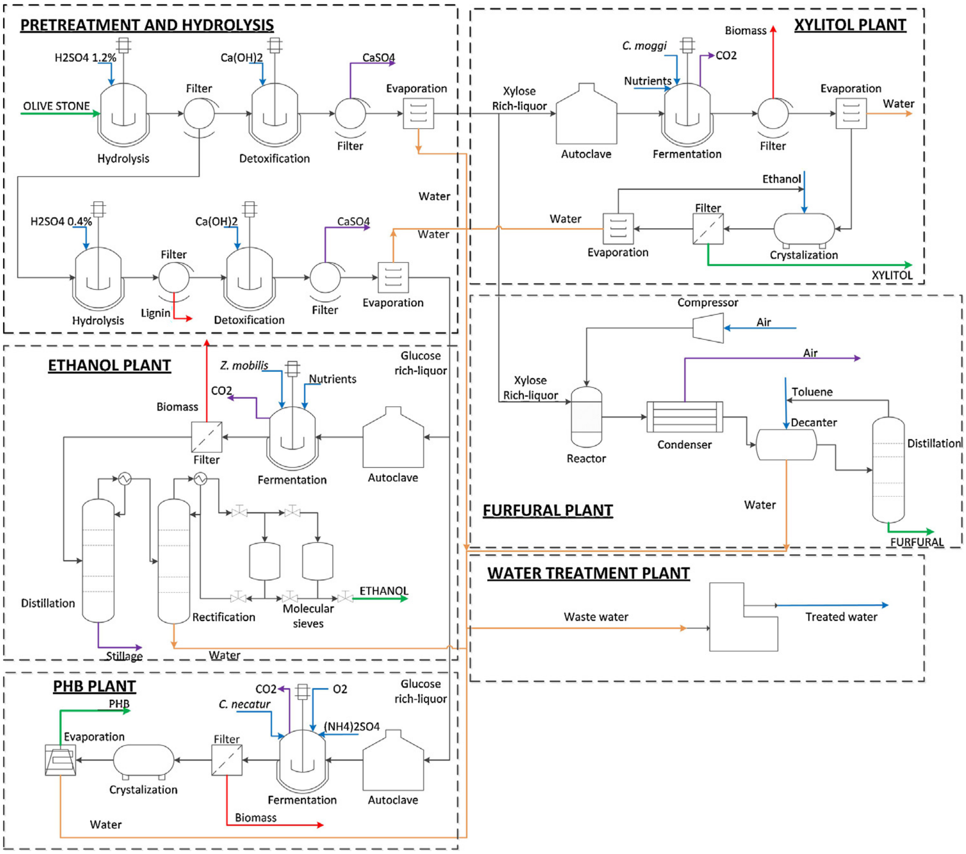

Fig. 1. Process flowsheet for scenario 1.

industries (Spizzirri et al., 2011). Hydroxytyrosol is able to inhibit or retard the rate of growth of a broad range of bacteria and fungi (Elbir et al., 2012). The extraction of phenolic compounds offers a double advantage. Firstly the recovery of the bioactive products with antioxidant capacity and high value-added, improves the economic viability of the process. Besides, the toxicity of the subsequent prehydrolyzed can be reduced, increasing the yield of the enzymatic hydrolysis or fermentation steps. On the other hand, olive stone is a lignocellulosic material with reducing sugar and lignin content of approximately 50% and 40%, respectively. This reducing sugar fraction allows obtaining different value-added products. For instance, in this work four products are considered: ethanol and furfural, because of being renewable fuels; xylitol, because of its application in the nutraceutical industry; and PHB in order to evaluate the production of an alternative polymer.

In this work the direct combustion of the olive stone (base case) and two biorefinery scenarios are techno-economic and environmentally assessed. The first biorefinery scenario presents the integrated production of xylitol, furfural, ethanol and poly-3-hydroxybutyrate (PHB). In the second scenario, the additional production of bioenergy from the solid residues integrated to de production of xylitol, furfural, ethanol and PHB is considered.

2. Materials and methods

2.1. Raw material

Olive stones were supplied by the olive-oil mill factory “S. C. A. Unión Oleícola Cambil” located in Jaén, Spain. The stones were separately removed from the olive pomace with an industrial pitting machine, with a 6 mm sieve separator, which is the standard size in this industrial process, soaked in water, washed to free them from any adhering flesh, air-dried and then dried for 24 h at 50 °C. The composition of the raw material was determined according to NREL (National Renewable Energy Laboratory, Golden, CO, USA) analytical methods for biomass.

2.2. Scenarios description

In this work a base case and two biorefinery scenarios were techno-economic and environmentally assessed. The base case considers the current use for this raw material: power production through a direct combustion process. In this scheme, the olive stone is submitted to a combustion process at 850 °C and 60 bar. The resulting stream goes through a gas turbine where the pressure decreases up to 1 bar to produce electricity. The first biorefinery scheme for producing xylitol, furfural, ethanol and PHB is presented in Fig. 1. In this process, the raw material is submitted to pretreatment and hydrolysis, where the xylose and glucose rich fractions were extracted. Then the xylose-rich fraction was destined to produce xylitol (80%) and furfural (20%). On the other hand, the glucose-rich fraction was used to produce ethanol (80%) and PHB (20%). Finally, in the second biorefinery scheme, the solid residues resulting from xylitol, furfural, ethanol and PHB processes, which are lignin and biomass, are used to produce power and heat through a cogeneration system (see Fig. 2).

2.3. Simulation process

For the base case as well as for the two biorefinery schemes, flowsheet synthesis was carried out using process simulation tools. The objective of this procedure was to generate the mass and energy

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