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Experimental and economic study of a gasification plant fuelled with olive industry wastes

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ABSTRACT

Spain is the first olive oil maker worldwide. Yearly, the olive oil industry generates large amounts of by-products: olive pomace, tree pruning, pits, leaves and branches. This work presents the experimental and feasibility study of a pilot plant for the conversion of olive tree pruning and olive pits into electrical and thermal power. The pilot plant is composed of a downdraft gasifier, gas cooling-cleaning stage and spark ignition engine with a modified carburetor. The experimental results showed satisfactory cold gas efficiency (in the range of 70.7–75.5%) and good lower calorific value of the producer gas for both raw materials (4.8 and 5.4 MJ kg^{-1}). Moreover, the plant achieved acceptable values for the electric and CHP efficiency: 15% and almost 50%, respectively. Finally, the investment achieved reasonable profitability index with a payback period of 5–6 years. As a result, the energy recovery potential from the olive industry wastes may represent a good opportunity to promote distributed generation systems.

Introduction

Olive oil production has been an established practice in the Mediterranean region for more than 7000 years. Currently, there are around 11,000 olive mills in EU (European Commission, 2012): roughly 2000 are located in Spain and almost 1000 in the south of Spain (MARM, 2012). In 2012, the olive oil production in EU represented around 73% of the world's total (European Commission, 2012). According to Table 1, Spain, Italy and Greece accounted for about 97% of the EU olive oil production (FAOSTAT, 2012).

In consequence, the olive oil industry wastes represent one of the most important renewable energy sources in Andalusia (AEA, 2012). Currently, there are 1.5 million hectares of olive grove in this region (García-Maraver et al., 2012). In the last harvest, around 4.6 million tons of olives were recollected in Andalusia (AEA, 2012; IOOC, 2012): roughly 4.3 million tons were used to make olive oil and the rest for table olives.

During the olive oil extraction process (OOEP) some by-products are generated in the mill (Table 2): leaves and branches from the olive cleaning activities, olive pits and pomace (Malheiro et al., 2013; AEA, 2012; Cruz-Peragón et al., 2006). On the other hand, yearly solid wastes are also generated in the olive grove during the pruning activities (Table 2).

Table 2 depicts the characteristics and properties of the olive oil industry wastes. It can be seen that the olive tree pruning, pits and exhausted pomace are the wastes with high *LHV* and low ash content. However, the main disadvantage of the tree pruning is the logistic costs (cutting and transport) from the olive grove to the mill. It should be noticed that the exhausted pomace is the residue obtained after a drying process of the virgin pomace (MORE, 2008). Nowadays, leaves and branches are only used as animal feed or compost due to the high ash content.

Practically, the olive pits are used for thermal applications (house boilers) and exhausted pomace in biomass power plants (Infopower, 2011). Otherwise, leaves and branches don't have energy applications and its disposal increases the treatment costs for the mill owners. It is important to notice that only a low percentage of tree pruning harvested is currently used for pellet production. Thus, these wastes may be used for CHP applications via thermochemical processes: combustion, gasification or anaerobic digestion (Basu, 2010; Biomass Technology Group, 2012; Higman and van der Burg, 2008).

Recently, the usage of olive oil wastes for CHP applications has been studied in several works. Most of the articles presented the modeling and simulation results for different CHP applications (García-Maraver et al., 2012; Damartzis et al., 2012; Mertzis et al., 2014); while other works developed an economic approach for different CHP scenarios using olive oil by-products (Celma et al., 2007; Celma and López-Rodríguez, 2009; Celma et al., 2013). Finally, the study and validation of some experimental CHP plants (for small-scale generation) were presented in Lee et al. (2013), Simone et al. (2012), Centeno et al. (2012), Mamphweli and Meyer (2009), and Henriksen et al. (2006).

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Nomenclature

C_b	annual biomass cost (€ y^{-1})
c_i	biomass unit cost (€ kg^{-1})
C_{mo}	annual M&O cost (€ y^{-1})
c_{mo}	M&O unit cost (€ kW^{-1} h^{-1})
Cmo_f	fixed annual cost of M&O (€ y^{-1})
CW	civil work cost (€)
c_{wd}	waste disposal unit cost (€ kW^{-1} h^{-1})
d	nominal discount rate (%)
E	annual energy production (kWh y^{-1})
ER	equivalence ratio (–)
HHV	high calorific value (MJ kg^{-1})
INV	total investment cost (€)
INV_f	fixed investment cost (€)
LHV	lower heating value (MJ kg^{-1})
$\dot{m}$	mass flow (kg s^{-1})
n	mole flow (kmol s^{-1})
NPV	net present value (€)
p	electric energy price (€ kW^{-1} h^{-1})
P	power (kW)
PI	profitability index (–)
PV	present value (€)
PV_{IN}	present value of cash inflows (€)
PV_{OUT}	present value of cash outflows (€)
r_b	annual increase rate of C_b (%)
r_g	annual increase rate of the energy price (%)
r_{mo}	annual increase rate of C_{mo} (%)
T	annual plant running time (h y^{-1})
V_u	useful lifetime of the pilot plant (y)
X	pressure ratio (–)
y	Mass fraction (%)

Greek letters

α	rate of Spanish government support (%)
ΔP_j	relative pressure in the gasifier annular jacket (mm H_2O)
ΔP_n	relative pressure in the air nozzles (mm H_2O)
η	efficiency (%)
λ	fuel–air ratio (–)

Subscripts

act	actual
air	air
b	biomass
C, O, H	carbon, oxygen, hydrogen
cc	carbon conversion
cg	cold gas
e	electric
g	gasifier
ge	gas engine
pg	producer gas
stoi	stoichiometric
n	thermal

Abbreviation

CHP	combined heat and power
EFGT	externally fired gas turbine
EU	European Union
GC	gas chromatographer
ICE	internal combustion engine
M&O	maintenance and operation
MGT	micro gas turbine
OOEP	olive oil extraction process

Prior to this study, the authors presented the steady state performance parameters of different CHP technologies (MGT, EFGT and ICE) coupled to combustion or gasification processes (Vera et al., 2011, 2012, 2013). These works described the modeling and simulation approaches, but need to be validated in a real scenario (pilot plant or prototype). Thus, in order to confirm the simulation results presented in Vera et al. (2013), this study carried out the experimental and feasibility study of a pilot plant composed of the following devices: downdraft gasifier, gas cooling–cleaning stage and ICE. The CHP plant was fed with two types of olive industry wastes: pits and tree pruning. Once the steady state conditions were reached, the producer gas composition was measured and analyzed in order to be suitable for ICEs. The pilot plant studied was able to produce heat and electricity injected to the grid.

Methodology

Raw material

The pilot plant was built in an olive mill located in the city of Úbeda (Andalusia, Spain). Yearly, this mill is able to process around 10,000 olive tons. Table 3 depicts the quantity and properties of the residues generated (Cruz-Peragón et al., 2006; Malheiro et al., 2013). Waste disposal increases the treatment costs for the mill owners and, consequently, the rise in the olive oil prize.

The olive tree pruning needs to be transported from the olive grove to the mill and chipped up to the gasifier specifications.

It is important to highlight that the olive tree pruning and pits were tested in the gasifier. These raw materials are very suitable for the gasification process due to the low ash and moisture content together with the high LHV. The proximate and ultimate analysis is reported in Table 4 (Basu, 2010).

Fig. 1 shows the raw materials tested and analyzed in Table 4. The olive pit sample is presented after solar drying (left) and the olive tree pruning (right) after a chipping process. These pre-treatments must be required before the gasifier feeding process.

CHP plant

The pilot plant (technically called GAS 70 by the manufacturer) was installed and commissioned in an olive mill located in Úbeda (Spain) in the year 2012. The building time was around two months (excluding logistic times). Ankur Scientific Energy Technologies Pvt. Ltd (Ankur, 2014) was the power plant manufacturer. This company has successfully developed and commercialized a very wide range of biomass gasifiers ranging in size from as small as 5 kW_e to 2200 kW_e.

At nominal conditions, the GAS 70 plant is able to produce 70 kW of electrical power and 160 kW of thermal power (85 kW in the form of hot water and 75 kW of exhaust gases). Fig. 2 shows the pilot plant layout, four main parts can be observed: downdraft gasifier (block 1), gas cooling–cleaning stage (blocks from 2 to 10), waste water treatment (12, 13) and gas engine unit (11).

Table 1
Olive oil production in EU countries (2012).

EU country	Olive tree surface (ha)	Olives recollected (t)	Virgin olive oil (t)
Spain	2,503,675	7,820,060	1,585,200
Italy	1,144,422	3,182,204	543,000
Greece	913,800	1,873,900	331,200
Portugal	343,200	443,800	83,191
France	16,945	23,320	5200
Slovenia	892	1704	700
Croatia	17,200	31,423	596
Montenegro	2300	1557	500
Malta	6	5	2.52