Fuel 153 (2015) 431–436

Contents lists available at ScienceDirect

Fuel

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

Performance of a household boiler fed with agropellets blended from olive mill solid waste and pine sawdust

M. Lajili [a,*], M. Jeguirim [b], N. Kraiem [a], L. Limousy [b]

[a] Unité de recherche Etude des Milieux Ionisés et Réactifs (EMIR), IPEIM, Avenue Ibn Eljazzar, Monastir 5019, Tunisia
[b] Institut des Sciences de Matériaux de Mulhouse, University of Strasbourg, Université de Haute Alsace, 3 bis, rue Alfred Werner, 68093 Mulhouse, France

HIGHLIGHTS

- Agropellets were produced from Olive Mill Solid Waste (OMSW) blended with pine sawdust.
- Combustion performances and gaseous emissions were obtained during combustion tests in a domestic pellets boiler.
- Combustion efficiencies and pollutants emissions could reach European standards.
- OMSW agropellets may be an attractive alternative fuel for energy production in Tunisia.

ARTICLE INFO

Article history:
Received 30 October 2014
Received in revised form 3 March 2015
Accepted 4 March 2015
Available online 20 March 2015

Keywords:
Olive mill solid waste
Pine
Pellets
Combustion
Gaseous emissions

ABSTRACT

The main purpose of this present work is to study the combustion characteristics of a domestic boiler (12 kW) when fired with biofuels prepared by blending an industrial by-product (pine sawdust, PS) and an agro-industrial by-product (Olive Mill Solid Waste, OMSW). The boiler and combustion efficiencies as well as gaseous emissions were determined and compared to EU normalization standards (EN 303-5). It was found that the main exhaust gases (CO, CO_2 C_xH_y and NO_x) are emitted in acceptable concentrations comparing to other biofuels in the literature. The analysis of bottom ash compositions shows the presence of three oxides, namely CaO, K_2O and SiO_2 as well as a significant amount of unburned carbon. Hence, the boiler control through the primary and secondary air injections should be adapted to the different pellets properties. Additionally, both combustion efficiency and boiler efficiency results are encouraging for considerations of prepared agropellets as alternatives to woody biofuels.

1. Introduction

Energy demand and its resource exploitations are continually increasing due to population growth, increasing urbanization and the intense mechanization in the three economic fields (agriculture, industry and services) [1]. Moreover, as the major fossil fuel resources such as coal, petroleum and natural gas are being rapidly depleted, biomass resources are emerging as a promising renewable and sustainable solution [2]. Biomass can be defined as any substance in which solar energy is stored. Hence, plants are producing biomass by photosynthesis. Furthermore, biomass resources can be classified into three types [3,4]: (1) Wastes which are produced directly by agriculture, wastes due to agricultural processes, crop residues, mill wood wastes, urban wood wastes and municipal organic wastes, (2) forest products including wood, logging residues, trees, shrubs and wood residues, sawdust, bark and (3) energy crops such as herbaceous woody crops, grasses, short rotation woody crops, starch crops (corn, wheat and barley), (soybean, sunflower, safflower) sugar crops (cane and beet) and oilseed crops. For many developing countries (like Tunisia) industry consuming electricity is still fully dependent on fossil fuels [5,6]. However, the energetic balance of Tunisia, which was in a comfortable situation (production of fossil fuels is higher than consumption) until 1994 became in equilibrium around 2000. Unfortunately, since 2000, the increase of the electricity supply due to economic growth has yielded deficiencies in the balance of consumption and production. For this reason, non-edible residual biomass is considered in order to be well exploited for 2nd generation biofuels and bioenergy production in accordance with the directive 2003/30 EC [7]. Moreover, emerging and underdeveloped countries should establish a biomass action plan resolving the increased dependence on imported conventional energy and allowing for the achievement of the three main objectives related to competitiveness, sustainable development and supply security. Mainly the three sectors for

* Corresponding author.
E-mail address: Marzouk.Lajili@ipeim.rnu.tn (M. Lajili).

http://dx.doi.org/10.1016/j.fuel.2015.03.010
0016-2361/

which the exploitation of biomass should to prioritize are: heat production, electricity production and transport. In Tunisia's case potential biomass resources are principally agriculture wastes and agro-industrial byproducts. Indeed, Mediterranean countries are the major producers (more than 98% of produced oil all over the world) [8–10], and they are also the major consumers (77% of all produced oil) of olive oil. Indeed, all sorts of olive wastes are produced in huge quantities in Tunisia. Tunisia is classified as the second country (after Spain) in term of lands designated for olive trees and also as the fourth county in term of olive oil export. Indeed, Tunisia produces about 350,000–450,000 tons of solid wastes and 700,000–1,200,000 tons of olive mill wastewater (OMWW) [11]. It is worth noting that the totality of the oil presses in Tunisia follow a 3-phase decanting process. This means that from the treated olive paste obtained, after kneading olive grains to which is added some water, one obtains separately oil, olive mill solid waste and olive mill waste water. The water addition results in an increased moisture content in olive mill waste.

In the literature, some previous studies have shown that wet biomass after a drying phase or semi-drying phase can be transformed to a biofuel showing some benefits such as the decreasing of CO_2 emissions [12,13]. Moreover, Heschel et al. [14] have shown that when using by-products characterized by low nitrogen content yields a significant decrease of NO_x emissions. Verma et al. [15] have tested a multi-fuel domestic pellet boiler (40 kW) under standard laboratory conditions using eight different biomass pellets. In addition, two boilers (35 kW) were tested in real conditions while firing with DINplus certified wood pellets. The most relevant results obtained by these authors were that wood pellets yielded the highest combustion efficiency (92.4%) followed by apple pellets (91.3%). The CO and dust emissions were the highest for peat and sunflower husk pellet, respectively. Whereas, straw pellets emitted the highest NO_x and SO_x. Miranda et al. [16] characterized the combustion of olive pomace and forest residue pellets. They carried out combustion tests in a pellet stove in order to analyze the emissions associated with each sample. They concluded that emissions are slightly worse with olive pomace pellet and that the blending process does not exceed in any case the limit of 50% of olive pomace.

It is to be highlighted that OMSW is a lignocellulosic material rich of hemicellulose, cellulose, and lignin. Demibras [17] showed the percentages of these constituents are respectively 23.6%, 24% and 48%. Several investigations have examined the thermal characterization and the combustion of olive oil by-products in a laboratory scale furnace [18–20]. Recently, Lajili et al. [21] studied the physico-chemical characterization and the thermal degradation of blended samples prepared from different mass fractions between pine sawdust and olive solid waste (containing a weak percentage in the range of 3–4% of residual oil). The results were encouraging when compared to standard normalizations [21]. In fact, the heating values, volatile matters (VM), fixed carbon (FC) and ash contents showed the possible occurrence of the clean combustion process. In order to validate the use of these samples as alternative biofuels, it seems important to perform combustion tests with a pellets stove or a multi-combustible boiler. The determination of the combustion efficiency, the boiler efficiency via a heat exchanger and the analysis of gaseous and particulate emissions will be of a great interest for further commercialization of the investigated biofuels.

In this sense, 4 different fuel samples were prepared: (1) a sample composed of 100% (PS), (2) a second sample is a blend of 75% (PS) and 25% of OMSW, (3) a third sample is composed of 50% (PS) and 50% of OMSW, and (4) the last sample is prepared from 50% (PS) and 50% exhaust olive mill solid waste (EOMSW). The EOMSW is an OMSW that undergoes a second oil extraction by chemical processes in seed-oil factories in order to extract its residual oil. The main goals of the present work are: (1) to study the thermal performance of an 8–12 kW wood pellet boiler when fired with agropellets prepared by blending different mass compositions of pine sawdust and olive mill solid waste (in raw and exhaust states), (2) to asses gaseous emissions such as CO, CO_2, C_xH_y and NO_x and ash composition resulting from the combustion of the different blends in the boiler, and (3) to compare the obtained results with the available standards and data in literature.

2. Materials and methods

The pine sawdust (PS) used was obtained from a wood factory situated in Alsace (Nollinger sawmill, France); whereas, the olive mills solid waste (OMSW) and the exhaust olive mill solid waste (EOMSW) were provided by the oil and soap factory of Zouila situated in the vicinity of the town of Mahdia (Tunisia). 10 kg of each type of 4 different samples 100PS, 75PS/25OMSW, 50PS/50OMSW and 50PS/50EOMSW were prepared. Initial moistures like abrasive components in lignocellulosic materials are crucial for obtaining good pellets (having good brightness, high hardness and durability). Hence, for all samples the initial moisture content was adjusted at the vicinity of 20%. Indeed, according to Serrano et al. [22], the optimum moisture for producing barley straw pellets should be in the range of 19–23% for the initial moisture and in the range of 6–8% after pelletization. They also concluded that, when adjusting the moisture content to 12% for samples containing pine as constituent, the mechanical durability of the pellets was improved. Moreover, they noted that due to the high lignin content in pine, the calorific value was improved. After meticulously mixing of the different constituents, blends were transformed into pellets using a KAHL 14/175 pelletizer. Given that optimal conditions are 50 Hz frequency and 65–75 °C temperature, a loss of moisture due to evaporation occurs yielding to moisture content ranging from 9% to 12%. After the latter stage, the prepared pellets were stored for 24 h under room conditions in order to stabilize their moisture and temperature. The obtained products are cylindrical pellets of 6 mm diameter and approximately 15 to 25 mm in length according to the used pelletizer die. The moisture content is calculated in wet basis (wb) according to EN 14774. The ash content is determined by sample combustion in a muffle furnace during 3 h at a temperature of 815 °C according to DIN 51719 standard. The higher heating value (HHV) is obtained after combustion of a sample under specific conditions (under an oxygen atmosphere of 35 bar) in an adiabatic bomb calorimeter IKA-C200 according to the EN 14918 standard. The lower heating value (LHV) is deduced from the HHV using the vaporization latent heat of water, the moisture content and the hydrogen content on wet basis according to:

$$\mathrm{LHV} = \mathrm{HHV} - L_V\left(9\frac{\%\mathrm{H}}{100} + \frac{\%M}{100}\right) \quad (1)$$

Ash content is determined by sample combustion in a muffle furnace during 3 h at a temperature 815 °C according to DIN 51719 standard.

Combustion tests are performed in an automatic feed domestic boiler Ökofen of 8–12 kW with a nominal power output set at 10 kW. Fig. 1 shows all components and accessories of the used device. The boiler fuel feed is performed using a screw conveyor after placing a sufficient quantity of pellets in the silo. The consumption of pellets is around 2–3 kg h^{-1} at the full load regime. Primary combustion air is fed naturally from the same side level of the grate; whereas, secondary air is convected using a mini ventilator under the fuel bed. The boiler heat feeds a water recovery system, which is connected to a heat exchanger. Ash residues are collected in the ash box under the grate.