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Experimental investigation on gaseous emissions from the combustion of date palm residues in laboratory scale furnace

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HIGHLIGHTS

- Emissions characteristics during DPR combustion tests were investigated.
- The ignition delay and reaction time are independent of DPR nature.
- DS may be the promising biofuel for the design of combustion processing system.
- The design of secondary air supply to prevent CO and VOC emissions is crucial.

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ABSTRACT

Emissions characteristics from the combustion of five date palm residues, DPR, (Date Palm Leaflets, Date Palm Rachis, Date Palm Trunk, Date Stones and fruitstalk prunings) in a laboratory scale furnace were investigated. Release of gaseous products such as CO_2, CO, VOC, NO_x and SO_2 were measured at 600–800 °C. The main goal was to analyze thermal behaviors and gaseous emissions in order to select the most convenient biofuel for an application in domestic boiler installations. Regards to biofuel characteristics, date stone have the highest energy density (11.4 GJ/m^3) and the lowest ash content (close to 1.2%). Combustion tests show that among the tested date palm residues, date stone may be the promising biofuel for the design of combustion processing system. However, a special attention to the design of the secondary air supply should be given to prevent high emissions of CO and volatile matters.

1. Introduction

Renewable energies are destined to play a very important role in the future world energy balance. Among these energies, biomass production and utilization is growing considerably since it offers the possibility to provide partial substitution of fossil fuels. Several biomass resources are used in energy recovery system to generate electricity and heat through thermochemical process such as combustion (Bridgwater, 1994).

Tunisia, like the developing countries, needs to identify and to exploit all their available biomass resources in the context of national sustainable development. Main sources of biomass in Tunisia include agriculture waste such as olive and date palm wastes. Although the energetic valorization of olive waste has received considerable attention (Chouchene et al., 2010a), few investigations on date palm residues combustion were found in literature.

Palm trees are abundant in several regions in the south of Tunisia. Country palm plantations cover an area of 32,000 ha, approximately containing 4.2 million trees (Rhouma, 2005), with a production increasing from 86,050 tons during 1993–1994 company to 100,000 tons during that of 2005–2006. In 2003, 36.2% of Tunisian dates were exported, which represent 42,010 tons (Saafi et al., 2008).

Each year, some of the leaves of the date palm, which are composed by the rachis (DPR) and the leaflets (DPL), become dry and need to be removed from the tree. Moreover, after many decades of cultivation, some of the date palms need to be substituted due to the decline of their production yield. Thus, the trunk (DPT), the rachis (DPR) and the leaflets (DPL) can be a potential source for energy recovery in heat generation installation. Fruit stalk prunings (FP) and date stones (DS), mainly generated by the production processing of based-date products in industrial sector, could also be used for energy recovery. Estimations of annual amounts of these residues are not easily available.

Al-Omari (2009, 2006) particularly examined the potential of date stones and palm stalks as an energy source. Al-Omari

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investigated the conversion of both date palm residues to thermal energy via combustion at different experimental conditions in a small scale furnace with a conical solid fuel bed. The obtained results were given as function of time for the mass of solid fuel in the bed, the rate of change of this mass due to fuel addition and fuel combustion, the temperatures at the top of the fuel bed and at the furnace exit and the rate of heat transfer to the cooling water jacket. For a date stones feed rate of 100 $g\,s^{-1}$, the rate of heat transfer to the cooling water was about 10 kW. The author noted that these biomasses are technically a viable alternative in the heat generation installations. Comparison with coal in the same conditions shows that date stones contain much volatile compounds as coal and under sufficiently high amounts of air, the heat transfer rates per unit mass of the fuel were in the same order of magnitude than for tested coal (Al-Omari, 2006).

In a recent work, we have provided kinetic characteristics of the five samples of date palm wastes making the purpose of this paper (El may et al., 2012). Investigation shows that these kinds of biomasses can be interesting raw materials for energy production. The same interest was made by Sait et al. for three kind of Saudi date palm biomass (seeds, date leaf and leaf stem). The authors concluded that these biomasses can become useful source of energy production (Sait et al., 2012). It seems therefore necessary to have reliable knowledge concerning thermal behavior and gaseous emission of these biomasses in laboratory scale furnace during combustion.

Many studies were performed in order to characterize and quantify gaseous emissions resulting from biomass combustion (Alves et al., 2010; Kannan et al., 2005; Kouprianov and Permchart, 2003). It is a required step when aiming to use a biomass as a feedstock in energy recovery installation. For this purpose, combustion tests were performed on the five date palm residues (DPR, DPL, DPT, FP and DS) in a laboratory scale furnace at different temperatures with monitoring gas emissions analysis in the exhaust. The aim is to assess the combustion behavior of the different residues and to compare the potential use of the different residues for bioenergy production.

2. Methods

2.1. Samples preparation

Date palm residues were provided from different varieties accumulated in south of Tunisia. They were dried under natural conditions during 2–3 days to reduce their water content. The leaflets (DPL) were manually separated from the rachis and cut to 1–2 mm in width and 4–5 mm in length.

Date palm rachis (DPR), date palm trunk (DPT), fruitstalk prunings (FP), and date stones (DS) were separately grounded in order to have homogeneous products. After sieving, one common particle size, ranging from 1 to 2 mm, was selected for the four samples to carry on combustion tests.

2.2. Samples characterization

2.2.1. Proximate and ultimate analysis

Ultimate analysis corresponding to the elemental compositions of the five samples were carried out by Service Central d'Analyses (Vernaison, France) to determine the weight fraction of carbon, hydrogen, oxygen, nitrogen sulfur and chlorine. Proximate analysis measurements were conducted using a thermogravimetric analyzer (CAHN 121 thermobalance). The proximate TG method involves heating the sample (under N_2) at a rate of 10 °C/min to 110 °C then holding for 10 min to obtain the weight loss associated with moisture. The temperature is then ramped from 110 °C at a rate of 20 °C/min to 900 °C (under N_2) and held for 10 min to obtain the weight loss associated with volatiles release. Air is then introduced into the furnace chamber to oxidize the carbon in the char and the weight loss associated with this is the fixed carbon. The remaining material after combustion is the ash.

2.2.2. Evaluation of the potential combustion energy

The high heating values (HHV) was measured using an adiabatic oxygen bomb calorimeter (REKA). The energetic potential of the different biomasses was estimated basing on the calculation of the low heating values (LHV), the bulk density (BD) and the energetic density (ED) that is the potential of energy available per volume of biomass.

2.3. Combustion tests

Combustion tests were carried out in a vertical laboratory scale furnace (Fig. 1). The device includes a fused silica reactor (internal diameter 37 mm) placed in an electrically heated oven. A mobile fused silica grid is placed in this reactor at the start of the isothermal zone which length is estimated to 10 cm. A thermocouple is placed 5 mm under the grid to register the temperature.

Samples are introduced by mean of a long stainless steel spoon in which they are placed. In a typical experimental test, the reactor is heated until the selected temperature test. When the temperature is reached, pushing forward the spoon allows overthrowing the samples on the grid simulating the combustion of the biomass in a real boiler.

The device includes also gas cleaner (glass wool filter, dust filter) and a gas dryer. Measurement of gaseous pollutants was possible using online gas analyzers. Immediately after leaving the reactor, a part of the exhaust gas flow was aspirated toward a flam ionization detector (COSMA graphite 655: range 1–10,000 ppm) to quantify the volatile organic compound (VOC). The exhaust gases are cooled gradually when passing through the gas line. If the FID analyzer is placed at the end of the gas analyzing system, VOC will be under estimated due to condensation and deposition phenomena in the pipe. After being dried and cleaned, the rest of the exhaust gas flow passes through a set of analyzers where mole fractions of CO_2, CO, NO, NO_2 and SO_2 are measured by Rosemont infrared analyzers (BINOS 100 for CO and CO_2: range 0–6% and 0–10%, respectively; and NGA 2000 for NO, NO_2 and SO_2: range 0–1000 ppm). Paramagnetic analyzer (OXYNOS 100: range: 0–25%) is used to quantify oxygen. The exhaust gases are diluted before analysis to have gas concentrations in the range of each analyzer. Combustion tests were performed with three temperatures (600, 700 and 800 °C) under a gas flow rate of 30 and 60 NL/h.

In order to evaluate four characteristics on combustion performance, residence times of gas were calculated for the different experience conditions. Residence time was estimated according the following equation:

$$\text{Residence time} = (L * S)/F * (273/T_a)$$

where L is the length of the isothermal zone of reactor (m), S is the reactor section (m^2), F is the rate flow of gases (N m^3/s), and T_a is the average temperature of gases in the isothermal zone (K).

This leads to four sets of experiments with three residence times (see Table 1). The samples weights were close to 120 mg and each combustion test was triplicated to assure results reproducibility.

3. Results and discussion

3.1. Samples characteristics

Ultimate and Proximate analyses are given in Tables 2 and 3.