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Evaluation of date palm residues combustion in fixed bed laboratory reactor: A comparison with sawdust behaviour

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A B S T R A C T

Combustion tests of five date palm Tunisian residues, namely: Date Palm Leaflets (DPL), Date Palm Rachis (DPR), Date Palm Trunk (DPT), Date Stones (DS) and Fruit-stalk Prunings (FP), were performed in a laboratory scale furnace. Gaseous emissions such as CO_2, CO, VOC, NO_x and SO_2, were analysed at 600 °C under 30–60 NL/h flow rate. Obtained results were compared with sawdust combustion behaviour in order to select the most convenient biofuel for an application in domestic boiler installations.

Combustion tests show that ignition delay and combustion time reaction are independent of the date palm residue. However, gaseous products emission rates and factors are correlated to the sample characteristics such as carbon, nitrogen and sulphur contents as well as fixed carbon and volatile matters contents. In order to optimize date palm residues combustion by decreasing unburnt gaseous emissions, special attention should be given to the design of the secondary air supply.

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1. Introduction

Expectation for the world energy demand and supply shows that fossil fuels such as oil, coal and natural gas will be depleted within the next 40–50 years [1]. Therefore, among renewable energies, biomass production and utilisation is growing considerably since it offers the possibility to provide partial substitution of the non-renewable energy sources. In addition to the economic advantage, use of biomass for energy production incorporates many environmental benefits such as reduced CO_2 emissions from fossil fuels combustion [2].

In Tunisia, thousands tons of biomass in the form of olive residues, wood waste, date palm residues and many other agriculture residues are generated every year. These resources could be easily used in energy production for replacing fossil fuels. Although energetic valorization of olive waste has received considerable attention [3–5], few investigations on date palm residues combustion were found in literature.

Date palm tree (see Fig. 1) is a typical cultivated tree in the arid and semi-arid regions of the world. It is especially abundant in several regions in the south of Tunisia [6–8](Fig. 2).

Each year, important quantities of palm leaves, which are composed by the rachis (DPR) and the leaflets (DPL), become dry and are removed or fall from trees. Moreover, after many decades of cultivation, several date palms need to be substituted due to the decline of their production yield. Thus, the trunk (DPT) generated can be a potential source for energy recovery. After the date fruit harvesting, important quantities of fruit-stalk prunings (FP) are generated. Date stones (DS) are by-product usually produced from processing of based-date fruits in industrial sector. Estimations of annual amounts of these residues are not easily available.

The main application for date palm residues in literature was found in wastewater treatment. For example, Date Stones and Palm-Trees Waste were tested for the removal of Cu(II) and Methylene Blue from aqueous solution [9,10]. Results showed that these residues are effective and alternative materials for wastewater management in industrial processes.

Recently, thermogravimetric analyses under inert and oxidative atmospheres of five date palm residues have revealed that thermal degradation profiles are similar among the samples, except for date stone. Among the studied samples, date palm trunk was the most reactive material under both atmospheres, whereas date stone was the less reactive fuel [8]. Sait et al. have also determined pyrolysis and combustion kinetics of three date palm residues using thermogravimetric analysis [11]. Kinetics data have been obtained for thermal degradation for seed, leaf and leaf stem. Gasification of

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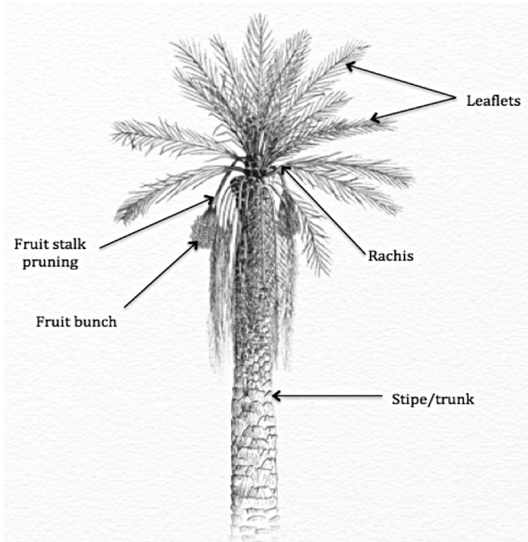

Fig. 1. Overview of a date palm tree.

date stones char has been investigated with carbon dioxide in a controlled environment using thermogravimetric analyzer (TGA) at temperatures ranging from 800 to 1000 °C [12]. The activation energy for date palm biomass char was found to be moderate as compared with other biomasses.

Few investigations have mentioned the combustion of date palm residues. Al-Omari has examined the potential of date stones and palm stalks as an energy source [13,14]. The author investigated the conversion of both date palm residues to thermal energy via combustion at different experimental conditions in a small scale furnace using a conical solid fuel bed. He noted that these biomasses are technically a viable alternative in the heat generation installations. Comparison with coal in the same experimental conditions showed 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 [13].

Evaluation of pollution emissions is a required step when aiming to use a biomass as a feedstock in energy recovery installation. Although, many studies were performed in order to characterize and quantify gaseous emissions resulting from biomass combustion [15–17], few investigations on date palm residues combustion were found. To the best of our knowledge, only our previous study interested to the measurement of gaseous and particulate pollutants during combustion of date palm residues [18]. This study particularly interested on particles emissions showed that date palm biomasses have impact on environment. Particles emitted during their combustion are mainly constituted of fine and ultrafine particles. For all samples studied, 99% of particles emitted are with diameters below 1 μm. Combustion of DS produces the lowest content of $PM_{0.1}$, leads to the lowest emissions factors of aerosols, and generates fewer tars than the other date palm residues.

The main objectives of this present work are to assess the combustion behaviour of different date palm residues and to compare the potential use of the different residues for bioenergy production with sawdust combustion behavior. For this purpose, combustion tests were performed on five residues (DPR, DPL, DPT, FP and DS) in a laboratory scale furnace at 600 °C with analysing exhaust gaseous emissions.

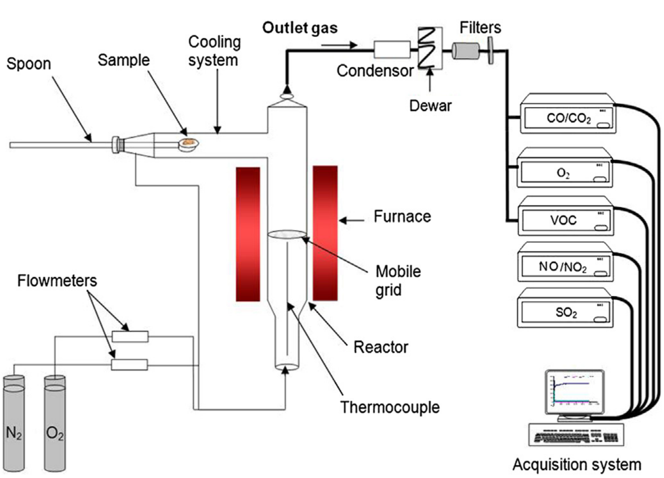

Fig. 2. Experimental set-up for the combustion of date palm residues.

2. Materials and methods

Date palm residues were provided from different varieties accumulated in south of Tunisia. Five different residues from Deglet Nour variety were collected from Djerid region (an oasis of Tozeur) for this study. They were dried under natural conditions during 2–3 days to reduce their water contents. 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), fruit-stalk 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.

In order to assess the characteristics and the combustion behavior of date palm residues, a conventional biomass was used as a reference. Hence, natural pine sawdust 0.5–0.7 mm particle size was selected for the present investigation.

Ultimate analyses corresponding to the elemental compositions of the five samples were carried out by Service Central d'Analyses (Vernaison, France) according to the relevant XP CEN/TS 15104 standard method. Carbon, hydrogen and nitrogen compositions were performed by combustion at 1050 °C using an elemental analyzer. Oxygen and sulfur were determined by pyrolysis at 1080 °C and combustion at 1350 °C, respectively.

Proximate analysis measurements were conducted using a thermogravimetric analyser (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.

The high heating values (HHV) was measured following XP CEN/TS 15103 standard methods, using an adiabatic oxygen bomb calorimeter (IKA). The energetic potential of the different biomasses was estimated basing on the calculation of the low heating values (LHV), bulk density (BD) and the energetic density (ED) that is the potential of energy available per biomass volume.

Combustion tests were carried out in a vertical laboratory scale furnace. The device includes a fixed bed 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 beginning of the isothermal zone which length is estimated to 10 cm. A thermocouple is placed 5 mm under the grid for temperature recording.

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