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Pyrolysis of Date palm waste in a fixed-bed reactor: Characterization of pyrolytic products

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ABSTRACT

The pyrolysis of several Tunisian Date Palm Wastes (DPW): Date Palm Rachis (DPR), Date Palm Leaflets (DPL), Empty Fruit Bunches (EFB) and Date Palm Glaich (DPG) was run using a fixed-bed reactor, from room temperature to 500 °C, with 15 °C/min as heating rate and −5 °C as condensation temperature, in order to produce bio-oil, biochar and syngas. In these conditions, the bio-oil yield ranges from 17.03 wt% for DPL to 25.99 wt% for EFB. For the biochar, the highest yield (36.66 wt%) was obtained for DPL and the lowest one (31.66 wt%) was obtained from DPG while the syngas production varies from 39.10 wt% for DPR to 46.31 wt% DPL. The raw material and pyrolysis products have been characterized using elemental analysis thermogravimetric analysis (TGA), Fourier transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM). The syngas composition has been characterized using gas analyzer.

1. Introduction

In view of the continuously rising of the environmental problems and the increasing of energy demand in the worldwide in general and in Tunisia in particular, the utilization of sustainable renewable energy (wind, solar thermal and photovoltaic, hydraulic, biomass, … etc) has become a scientific and industrial trend in the last few decades. Among these energy sources, biomass – including several resources: municipal solid wastes, lignocellulosic wastes, industrial wastes and several organic wastes – constitute a precious source of energy since it can be transformed directly into biofuels, useful as liquid fuel for transport, for heat and power production, as source of hydrogen and it can provide also minimization of the waste disposal (Bonelli et al., 2001).

In this context, lignocellulosic biomass, which is the most abundant and available on earth, represents a sustainable choice for the production of fuels and raw materials since it can be converted into biofuels, biomolecules and biomaterials. Its renewable character, low cost and essentially zero balance in terms of carbon dioxide emissions are among the most important advantages from its utilization (Bertero et al., 2014). Thus, it is a promising alternative to limit fossil fuels consumption and so atmospheric pollution.

In Tunisia, one of the most available lignocellulosic biomass is “Date Palm residues” which are produced yearly in huge quantities (around 200,000 tons per year; CRDA, Kébili, 2011) since the economy is based on agriculture activities and mainly on dates one. These by-products generated yearly by Date palm trees processing activities can generate many environmental problems (combustion, landfilling, … etc). These Date palm wastes are usually valorized as organic fertilizer (through composting), as biocombustible, as animal feed or also in the manufacture of decorative objects. Traditional methods such as composting and incineration are not suitable to process these organic wastes as they contain small concentrations of nitrogen for composting and a considerable amount of solid grains and smoke would be released to pollute the environment during incineration (Tsai et al., 2007). However, innovative practical methods of biomass conversion into biofuels like pyrolysis process could be more suitable for these lignocellulosic residues.

Pyrolysis is a thermal cracking of biomass in an inert medium, at temperatures between 300 and 700 °C. This leads to the production of useful liquid biofuel (bio-oil), solid biocombustible (biochar) and

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renewable syngas. Many studies of pyrolysis process showed that the cracking reactions depend on pyrolysis parameters which determine the yields and the properties of the final products.

In last few decades, there has been an enormous amount of research in the area of the pyrolysis technology applied to lignocellulosic biomass due to its several socio-economic advantages (Jahirul et al., 2012). In fact, pyrolysis process have been investigated in the literature for several lignocellulosic biomass such as for rice husk (Tsai et al., 2007), switchgrass (Imam and Capareda, 2012), safflower seed press cake (Angın, 2013), birch wood (Khelfa et al., 2013), *Arundo donax* (Bartoli et al., 2016a) and pyrolysis of a-cellulose (Bartoli et al., 2016b) sawdust (Kumar et al., 2017), corn cob and corn stover (Ravikumar et al., 2017).

Concerning the application of pyrolysis to date palm residues, some works have been published in recent years. The major parts of these studies focused on the preparation of biochar that can be used as a soil amendment or as a low cost adsorbent for organic and non-organic pollutant removal. For example, Mahdi et al. (2015) were studied the palm date seed using slow pyrolysis process at different pyrolysis temperatures (350, 450, 550 and 650 °C) whereas Hadoun et al., 2013, investigated the pyrolysis of date stem (empty fruit bunches) in order to produce activated carbon. Other studies investigated the thermal behavior of date palm wastes via TGA and compared it with other lignocellulosic waste (El May et al., 2012, 2014; Babiker et al., 2013). The other parts focused on the preparation of activated carbon from date palm seed at final temperature 600 °C; the obtained activated carbon was valorized for the Cu(II) and methylene blue removal from aqueous solution (Belala et al., 2011). Few studies were focused on the production of biofuels (bio-oil, biocoke and syngas) from date seeds (Joardder et al., 2012). Thus, few published data evaluating the potential use of date palm by-products as a renewable energy source were found in literature.

In Tunisia, the thermo-chemical conversion of DPW, especially via pyrolysis processes, is still undeveloped. Thus, in order to advance the lignocellulosic thermal processing field in Tunisia, the present study can be viewed as a feasibility assessment of this innovative application to Tunisian DPW. Therefore, the object of this study is to investigate the main characteristics of the obtained products from the pyrolysis of these DPW in order to define their potential as renewable energy sources and raw materials for the chemical industry.

2. Materials and methods

2.1. Raw materials

Four samples of Tunisian DPW: Date palm rachis (DPR), Date palm leaflets (DPL), Empty fruit bunch (EFB), Date palm Glaich (DPG) used in this study were obtained from the National Institute of Arid Zone (IRA-Kebili, Tunisia) where the date palms occupy the first place in the agricultural activities of the region. All studied raw materials were finely crushed to small pieces with sizes from 2 to 4 mm in order to have homogenous products. Then, they were naturally air-dried in order to reduce their water content.

2.2. Pyrolysis process

Pyrolysis experiments of the DPW were conducted on a laboratory scale pyrolysis pilot plant (Fig. 1). The pyrolysis setup used in this study was described in detail in Ben HassenTrabelsi et al., 2014 and Zaafouri et al., 2016. under the same operational condition which are: 500 °C as final temperature, 15 °C/min and 300 g mass initial of the used sample. The percentage of bio-oil and biochar yields were determined by the following equations:

$$\text{Bio-fuel } (\%) = \frac{weight\ of\ char\ or\ Liquid\ (g)}{weight\ of\ dry\ raw\ material\ used\ (g)} \times 100 \quad (1)$$

Through the application of the principle of mass conservation, the gas production yield has been deducted as the difference between percentage of char and liquid yields from the total percentage of 100%.

$$Syngas\ (\%) = 100-(bio\text{-}oil)\%-(bio\text{-}char)\% \quad (2)$$

2.3. Physico-chemical and thermal analyses

The moisture content of DPW samples was measured with the method of (AFNOR XP CEN/TS 14774-3). The volatile matter (VM) content of DPW samples was measured according to ASTM method D-1762-84, 1990. Ash content was obtained using the standard methods AFNOR XP CEN/TS 14775; ASTM method D-1762-84 and ASTM, 1990. The fixed carbon content was obtained as follow:

$$FC = DM-(VM + Ash) \quad (3)$$

The lignocellulosic components (celluloses, hemicelluloses and lignin) of several studied DPW were determined according to the method used by Sun et al. (2003). Thermogravimetric analyses (TG-DTG) of the raw DPW were applied to determine thermal degradation behavior of biomass weight to the change in temperature by using Thermogravimetric analyzer (SIITG/DTA7200), under N_2 atmosphere in the temperature range 25–800 °C and heating rate of 10 °C/min.

2.4. Elemental, morphological and functional analyses

The elemental compositions (CHN-O) of raw DPW, bio-oil and biochar products were determined using an elemental analyzer (LECO CHNS TRuSpec); The O content was determined by difference. The morphology of DPW and their biochars were determined by scanning electron microscopy (*FEI Quanta 450 FEG apparatus*). Fourier transform

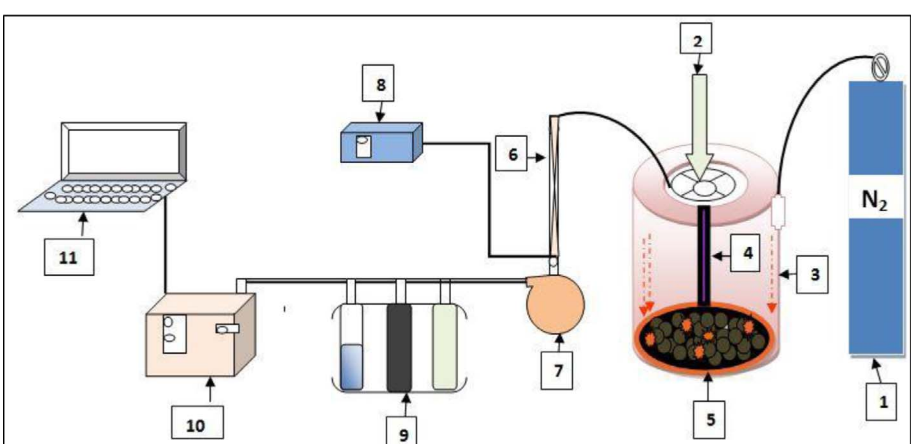

Fig. 1. Schematic diagram of the pyrolysis set-up: (1) Nitrogen cylinder; (2) waste; (3) Stainless steel fixed bed reactor with a total volume around 5 liters (height: 30 cm and ∅:15 cm internal diameter); (4) Thermocouple; (5) pyrolysis solid residue; (6) refrigerant; (7) Recovery ball for Bio-oil;(8) cryostat;(9) purification system; (10) syngas analyser; (11) computer.