Pyrolysis Of Saudi Arabian Date Palm Waste: A Viable Option For Converting Waste Into Wealth

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Abstract: Saudi Arabia has about 23 million palm trees and it is the second largest producer of dates. The biomass from the trimmed branches of palm trees amount to more than 200,000 tons/year. This biomass waste can be used to produce many commercial products. There are several relevant technologies for conversion of biomass and solid wastes into higher value products. The starting point of the project is the pretreatment of palm solid wastes. Thermogravimetric analysis has been done to understand the pyrolysis behavior of palm date wastes. A fluidized bed (FB) has been designed and to study hydrodynamics and develop optimum conditions for the pyrolysis of palm wastes. A novel fluidized bed test rig has been designed and fabricated to carry out the pyrolysis of palm wastes. The pyrolysis is used to produce activated carbon and the waste can also be readily converted to liquid phenolic products. Liquid products are particularly interesting because they have a higher energy density and can be used to produce adhesives as well as biofuels for use in power generation and transport sector. Experimental results have indicated potential opportunities of using the date biomass waste as a potential fuel in the Kingdom of Saudi Arabia.

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1. Introduction

Saudi Arabia is a land also famous for date Saudi Arabia is has one of the most abundant oil reserves in the world but it is also well-known for date production. Palm tree is regarded as one of the oldest trees in the world. A recent estimate showed that the Kingdom has about 23 millions palm trees that can produce about 780 thousand tons of dates per year [1]. Due to the presence of date processing industry, a large amount of date palm biomass waste is also generated. Excess amount of date palm leaves can cause environmental hazards such as fire, bait for insects and diseases [2]. Joardder [3] produced bio-oil and activated carbon from date palm seeds in a fixed bed reactor using pyrolysis technique. The project led the formation of value-added products using local waste materials via novel techniques. The whole concept of this research is presented in Figure 1. Thermo-chemical process serves as a potential method for the conversion of biomass into energy. Thermogravimetric technique has been used by a number of researchers to identify the devolatization behavior as well as determining the kinetic parameters of various biomasses [4-9]. The kinetics of the pyrolysis process was previously investigated and it was concluded that the temperature and heating rate are the controlling parameters (Hussain [10]). Prior knowledge of reaction kinetics is important for a successful utilization of the biomass as a feedstock in any thermo-chemical process. Since the country is blessed with huge reserves of oils, not much work has been devoted to utilize this potential source of energy that is renewable in nature.

2. Material And Methods

The main objective of this research work is to reveal new thermo-chemical characteristic data of date palm biomass. For this, thermogravimetric analyses were used to investigate the combustion and pyrolysis behavior of date palm biomass such as seed, leaf and stem. It is very crucial to evaluate the proximate and ultimate analyses of the date palm biomass prior to its application in thermo-chemical processes. Also, the kinetics of pyrolysis and combustion of the date palm biomass has been investigated. The proximate and ultimate analyses for the date biomass wastes are shown in Table 1 and Table 2.

Figure 1: The utilization concept of palm date waste

Table 1: Proximate analysis of date palm biomass (wt %).

Biomass	Moisture	Volatile matter	Ash	Fixed carbon
Seed	5.1	75.1	9.8	8.1
Leaf	5.3	77.5	12.1	6.1
Stem	18.1	52.1	20.2	8.1

Table 2: Ultimate analysis of date palm biomass (wt %).

Biomass	C	H	N	S	O
Seed	44.1	6.1	0.9	0.6	48.3
Leaf	50.4	6.3	1.1	0.4	41.8
Stem	38.1	5.2	0.8	0.3	55.6

Pyrolysis characteristics of the date palm biomass were investigated by thermogravimetric analyzer (TGA). The samples were collected from local farmers, washed, dried and then grinded to give a mean diameter of around 100 µm. The thermogravimetric analyses were carried out at the Analytical Core Laboratory of King Abdullah University of Science and Technology (KAUST) (Instrument: Netzsch TGA with MS, TG 209 F1). The loss of weight of various samples was measured over time at a constant heating rate. The temperature range was from 25 ºC to 700 ºC with heating rates of 10 ºC/min and 25 ºC/min in two mediums: Helium and Helium/Oxygen/Nitrogen. During the process of pyrolysis and combustion, the initial weight was recorded continuously as a function of temperature and time.

3. Results And Discussion

Date seed and leaf are characterized to contain high volatile matter and low ash components compared to leaf stem. High volatility makes these biomasses attractive for combustion process [11]. On the other hand, high moisture content deteriorates the chemical properties of the biomass materials as observed in case of leaf stem. Thermogravimetric analyses of date biomass wastes are shown in Figures 3-5.

The initial loss in weight of the samples from temperature 25°C to 115°C was due to evaporation of moisture content, which was about 7 wt% for date seeds and leaf, whereas it was about 13 wt% in case of stem. Sudden drop in biomass weight after 200°C was attributed to the release of volatile matter. For instance, the volatile matter was released in three steps during the pyrolysis of seed, while leaf and stem showed two step pyrolysis behavior. After this final degradation temperature, there was gradual decrease in weight loss. This was attributed to the burning of remaining solid residue or char, which progressed until 700°C.

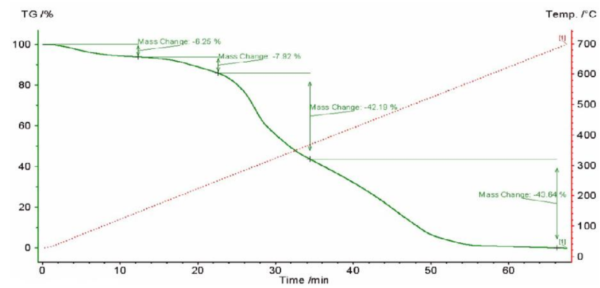

Figure 3: TGA plot for pyrolysis behavior of seed component of date biomass waste

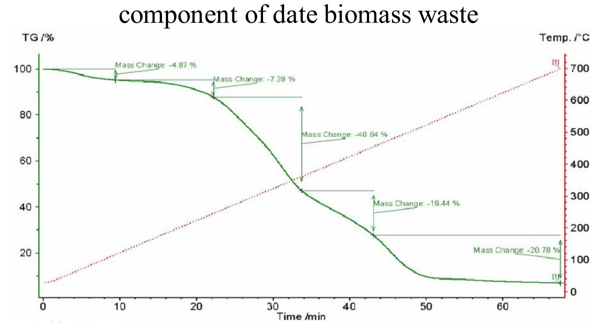

Figure 4: TGA plot for pyrolysis behavior of leaf component of date biomass waste

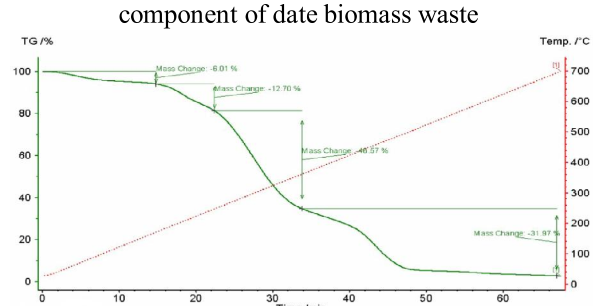

Figure 5: TGA plot for pyrolysis behavior of stem component of date biomass waste

The TGA analyses suggest that date palm seed and leaf would be good source of energy because of high volatile content. Also, it would be difficult to ignite or combust leaf stem when used as a fuel. The combustible components in the two date palm biomass samples (seeds and leaf) have almost similar elemental composition, particularly the H/C ratio. The ash content of the leaf and stem biomass was found to be higher. This may influence the burning rate during combustion and can even cause fouling and agglomeration behavior. Additionally, biomass with high ash content results in poor combustion behavior and increases disposal cost.

Since the stem has high moisture content, it cannot be used as fuel directly in thermo-chemical processes such as pyrolysis, combustion and gasification. High moisture content affects the burning rate, increases the energy requirement, reduces the combustion temperature to lower value and finally leads to lower system efficiency. In case of pyrolysis process, the moisture content in the feedstock should be lower than 10 wt% to gain product quality (Bridgwater, 2011). The type of conversion technology or process also depends on the amount of moisture content in the biomass (McKendry, 2002). The moisture content of the seed and the leaf are well below the threshold value required to combust the fuel. So, their pyrolysis and combustion characteristic of seed and leaf are better than stem. In particular, the initial degradation temperature or the ignition temperature was low in case of seed and leaf. This may indicate trouble-free burning of date seed and leaf biomass. If stem has to be used as a fuel, it has to be dried to a desired moisture value. This incurs the cost of drying.

From a commercial view point, the wastes from date palm would be better to handle as one component rather than separating it into seed, leaf or stem components. For possible use of date biomass wastes in boilers, it is better to handle it as a single component. The TGA analysis of a sample containing seed, leaf and stem is shown in Figure 6.The TGA suggest release of highest amount of volatile matters and moisture during this temperature range (0-700°C), which causes series of chemical reactions in the de-volatilization of fuel releases CO, CO_2, H_2O & hydrocarbons (i.e. CH_4; C_2H_4; C_2H_6) in the product gas.

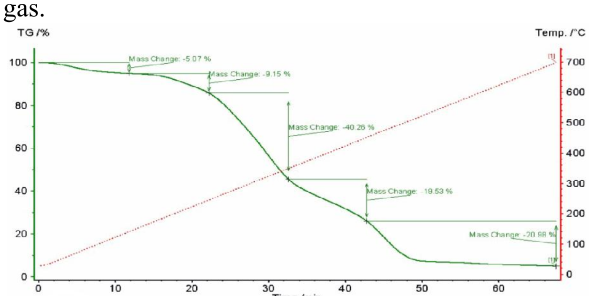

Figure 6: TGA plot for pyrolysis behavior of the combined seed, leaf and stem component of date biomass waste

One of the important aspects of this study is to produce pyrolysis oil from the date wastes. Pyrolysis oil can be converted renewable phenol that can potentially replace the petroleum-based phenol. This research utilizes Saudi Arabian date biomass waste as a renewable material resource using thermo-chemical process to produce valuable products such as phenol, formaldehyde and wood adhesives. The major advantages of this research include a new process of extracting phenolic compounds from date wastes and the high purity of phenolic compounds. Since the total global consumption of phenol is of the order of 20 million metric tons which is worth USD 20.0 billions, the commercial potential of this research is very high.

Fast pyrolysis is used to convert date biomass wastes into a mixture of liquid chemicals that can be separated directly from the pyrolysis oil and be subjected to further processing to produce adhesives. The extracted pyrolysis oil contained up to 80.1 wt% of phenol and phenolic compounds and can be used to prepare phenol formaldehyde resin. The pyrolysis reactor is expected to have great potential of commercialization for economic reasons. The design of the pyrolysis reactor is shown below in Figure 7.

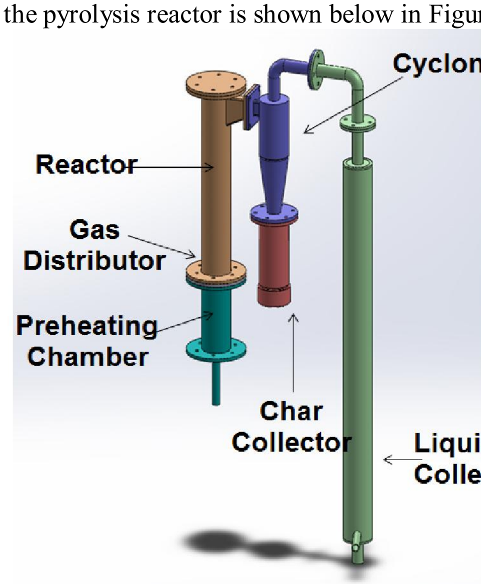

Figure 7: Design of Pyrolysis Reactor

The fluidized bed pyrolysis reactor consists of feed container, screw feeder, fluidized bed reactor, gas preheating chamber, fluidizing gas supply system, solid gas cyclone separator, char collector, water cooled condenser, ice-cooled liquid collector, thermocouple and temperature controller, fluidizing gas flow meter and electric cylinder tube heater. The control parameters include the size of the feed, the size of the silica sand, the feed rate, the flow rate of nitrogen and the temperature of fluidized bed. These parameters are optimized to run the pyrolysis process at maximum efficiency and high conversion rate of the biomass to pyrolysis oil.

Once we have obtained the pyrolysis oil, it is subjected to further processing to convert it to high-value products such as phenol. The process of converting pyrolysis oil to phenol is described as a flow diagram in Figure 8. The phenol formaldehyde (PF) resin formulation variables include the phenol-formaldehyde mole ratio (F/P), and the phenol replacement by oil-palm-based phenol. A 50% sodium hydroxide is used as catalyst. The sodium hydroxide to phenol mole ratio is 0.5. High purity formaldehyde and phenol are used in the preparation of PF resins. Figure 9 shows the quantification of chemical compounds in extracted pyrolysis oil.

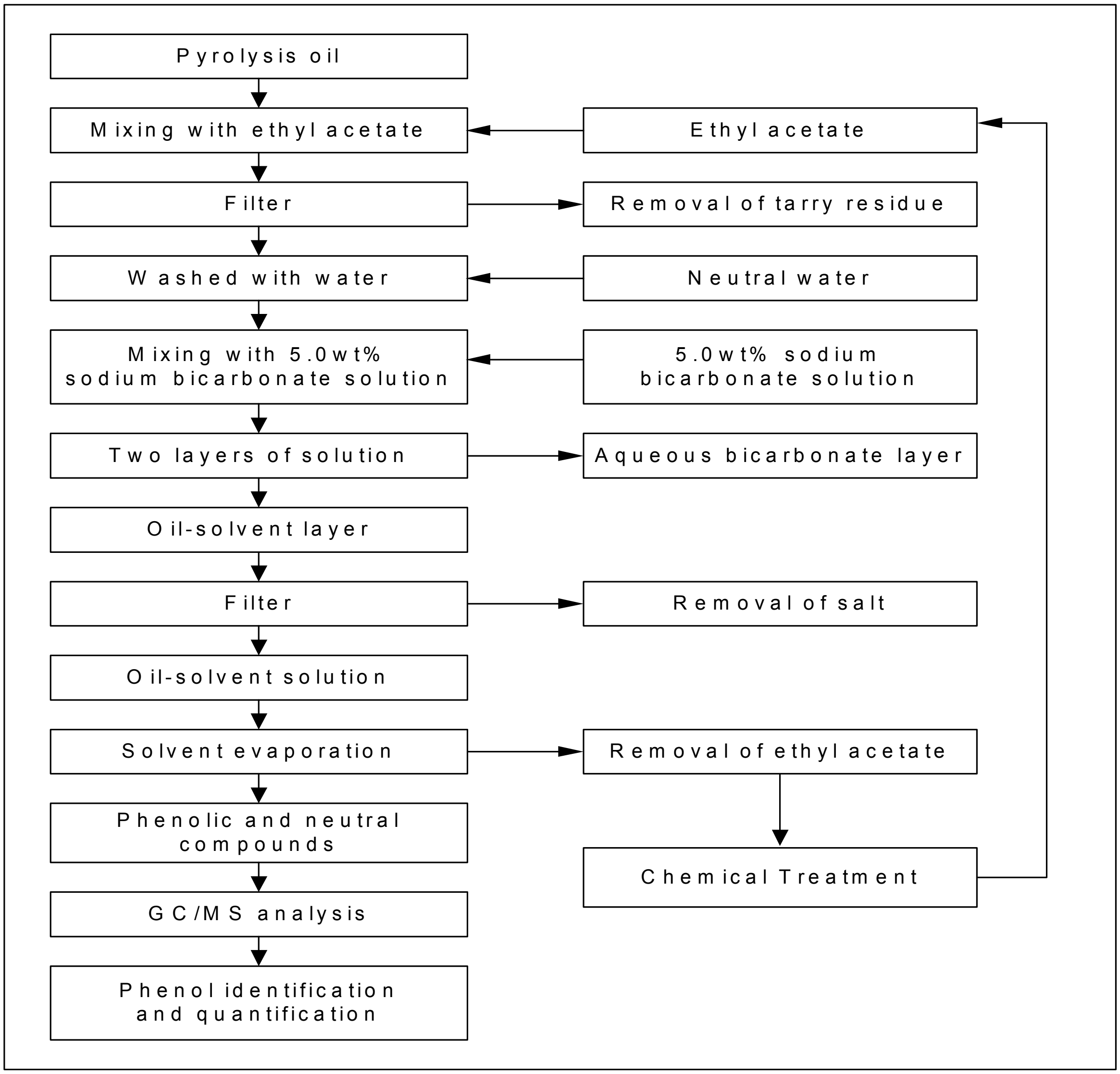

Figure 8: Flow sheet of extraction of phenol from the pyrolysis oil

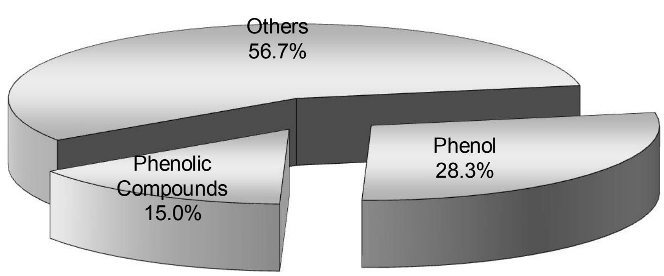

Figure 9: Quantification of chemical compounds in waste based pyrolysis oil

4. Conclusions

i. The increasing amount of organic solid waste generated has become a concern nowadays due to its impact on the environment. As organic solid wastes are renewable energy sources, instead of disposing the solid wastes at dumping sites or through incineration, it is much more beneficial to convert these wastes into some valuable products.

ii. Fast pyrolysis process has been projected as the most promising technology to derive pyrolysis liquid from solid biomass. The pyrolysis oil contains high concentration of valuable chemical compounds.

iii. The extracted pyrolysis oil is expected to have phenol and phenolic compounds which can be used to prepare phenol formaldehyde resin.

iv. The pyrolysis reactor is expected to have great potential for commercialization for economical and environmental purposes in Saudi Arabia.

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