Production of Bio-Oil from Soapnut seed by Microwave Pyrolysis

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Abstract. Biomass is one of the potential source of renewable energy to meet the need of alternative fuels. Biomass can be converted into useful energy by thermochemical conversion processes such as gasification, combustion and pyrolysis. Microwave pyrolysis a non-conventional method of heating for the production of pyrolytic bio-oil, char and gas. In this work, soapnut seed is used for the bio-oil production by microwave pyrolysis. The experimental setup used in this work consists of a microwave oven of 2.45 GHz frequency with maximum input power of 800W. In this work, temperature distribution and pyrolytic products yield from the pyrolysis of soapnut with respect to microwave power input are studied. The microwave pyrolysis experiments are conducted at power densities of 8 W/gm, 7 W/gm & 6 W/gm for 20 minutes. The experimental shows that the bio-oil yield (50 wt %) is the highest at 7 W/gm. The flash point, viscosity and calorific value of the pyrolytic bio-oil are measured and presented. The results indicated that the bio-oil produced by the microwave pyrolysis can be upgraded and used as a potential fuel for IC engines

Keywords: microwave pyrolysis; soapnut; power density; bio-oil; bio-char.

1. Introduction

Renewable resources are considered as alternative energy sources for the production of bio-fuels and bio-energy. An extensive volume of researches is being carried out around the globe on biomass energy conversion systems. Biomass resources can be classified into edible and non-edible resources. The present need for food resources minimize the usage of edible resources for the production biofuels.

Pyrolysis is a process in which the biomass feedstock is decomposed in the absence of oxygen to liquid, solid and gaseous products. Considerable researches in conventional pyrolysis is available and the modernistic researches are on non-conventional type of pyrolysis. Microwave pyrolysis is a non-conventional method of pyrolysis in which electromagnetic waves that are produced at a specified frequency heats the feedstock (AV Bridgewater et al) [1] [2].

Soapnut tree (Sapindus mukorossi) is a deciduous tree which is majorly found in India. The tree can grow to the height of 82 feet and width of about 5 feet. The tree is cylindrical and straight, the flowers are small and greenish white whereas the fruits are round shaped (Fig 1a). At initial stage of growth the outer shell is golden yellow and after dried it is brown in colour.(Fig 1b). It is well established that the soapnut seeds are rich in saponin content which makes it be a natural detergent that implies its...
application for cleaning purposes. However, there is no commercial exploitation of fruits of soap nut is made extensively. In chemical industry the pulp is considered as the raw material whereas the kernel is left out without any specified usage. A single soapnut tree produced about 125 kg of seeds annually [3] , which can be used as the source of bio-energy and biofuel production [4] [5]. Hence, the objective of the present work is to utilize soapnut seed as the feedstock in microwave pyrolysis. The specific objectives of the present work are i) to characterize the soapnut seed for its proximate and elemental compositions, ii) to use soapnut seed as the feedstock in microwave pyrolysis for producing bio-oil and iii) to determine fuel properties of soapnut bio-oil.

2. Materials and Methods

2.1 Soapnut seed

In this work, the Soapnuts are procured from the local market in Puducherry and it is manually broken using an iron mortar-pestle to separate the seed from the outer cover. The soapnut seeds are milled into a fine powder of approximately 2 mm.

2.2 Characterization of soapnut seed

2.2.1 Proximate and elemental analysis. The proximate composition (moisture, volatiles, fixed carbon and ash content) is found using a muffle furnace. The elemental composition, carbon, hydrogen, nitrogen, sulphur and oxygen contents) is measured using Elementar CHNS analyser in Pondicherry University. The results of proximate analysis and ultimate analysis are shown in Table1. The high volatile matter (74.33%) and lower ash (2.81%) contents of soapnut seed shows that it is potential feedstock for pyrolysis.

2.2.2 Thermogravemetric Analysis soapnut seed, The thermogravimetric Analysis (TGA) of the soapnut seed is carried to determine its thermal decomposing behaviour in nitrogen atmosphere. TGA analysis is carried out in Simultaneous Thermal Analyser (STA) (Make: Netzsch - STA 449 F3 Jupiter) in
Pondicherry University in which temperature is regulated from room temperature to 800°C at 20°C/min as heating rate in nitrogen gas atmosphere using 50 mg of sample in Al₂O₃ crucible holder.

| Proximate analysis (as received, wt. %) | Soapnut seed |
|----------------------------------------|--------------|
| Moisture content                       | 5.36         |
| Ash Content                            | 2.81         |
| Volatiles                              | 74.33        |
| Fixed Carbon                           | 17.5         |

| Ultimate analysis (dry basis, wt. %) | |
|--------------------------------------|---|
| C                                    | 51.62 |
| H                                    | 6.45  |
| N                                    | 2.52  |
| S                                    | 0.25  |
| O                                    | 39.16 |

2.3 Microwave pyrolysis of soapnut seed

2.3.1 Microwave pyrolysis experimental setup. Microwave pyrolysis of soapnut seed is carried out in a domestic microwave oven made by LG microwave oven, India. Fig 2 shows the experimental microwave pyrolysis set-up. A regulator is used to vary the input power from 100 W to 800 W. The pyrolysis is carried out in a microwave resistant quartz three-neck round bottom flask of 250 ml capacity. Two allihn condensers are connected to the round bottom flask. A Nitrogen gas cylinder with pressure regulator is connected to the one neck of the round bottom flask. Holes are drilled at appropriate places to connect the condenser, thermocouples and nitrogen inlet. To find the reaction temperature a K-type thermocouple with temperature with AUDRINO microcontroller is used. Two conical flasks were used to collect the bio-oil [6].

2.3.2 Microwave pyrolysis experimental procedure. The round bottom flask containing soap nut seed powder of 100 gm is placed inside the microwave cavity. Before the starting the experiment, the flask containing biomass is exerted with N₂ gas for about 7 min to make sure it is a no-oxygen zone.

The nitrogen flow is continued till the completion of pyrolysis process. The outlet of the three neck flask is connected to the condensers. Water at room temperature is circulated in the condensers at a constant flow rate. The temperature variation inside the microwave cavity is studied using AUDRINO UNO microcontroller connected to AUDRINO software for temperature data analysis. At the end of experiments, bio-oil produced is collected and weighed. The solid bio-char in the quartz flask is collected and then weighed. The uncondensed gaseous particles are left to in atmosphere. The
percentage yields of bio-oil, bio-char and gas are calculated as shown in Eqn (1) to Eqn (3) respectively [7].

\[
\text{bio - oil yield (wt\%)} = \frac{\text{mass of bio-oil}}{\text{mass of biomass}} \times 100 \quad (1)
\]

\[
\text{bio - char yield (wt\%)} = \frac{\text{mass of bio-char}}{\text{mass of biomass}} \times 100 \quad (2)
\]

\[
\text{gas yield (wt\%)} = 100 - (\text{bio - oil yield} + \text{bio - char yield}) \quad (3)
\]
accounts to a mass loss of about 65%. The TGA analysis thus revealed that the soapnut has higher volatile matter content and it is a potential feedstock for microwave pyrolysis.

Fig 3 Thermogravimetric Analysis of Soapnut seed

3.2 Variation of temperature with respect to residence time

Fig 4 shows the variation of temperature during the microwave pyrolysis of soapnut seed at three different power densities. The maximum residence time of biomass is kept as 20 minutes. Power density is the ratio between the power input and the mass of the feedstock. Fig 6 shows that, the maximum temperature attained is almost same (550°C) at all the three different power densities. However, the time taken to attain the maximum temperature varies with power density, that is 7min, 16 min and 11 min respectively when the power density is 6W/gm, 7 W/gm and 8 W/gm. This may due to the type of polarisation, specific area and surface morphology which is similar to the studies done by Suriapparao et al., 2015. Even though the maximum temperature is attained within the shortest time of 7 min at 6W/gm power density, there is drop in temperature after 10 minutes. This dissipation of heat during pyrolysis comparatively takes higher reaction time for complete decomposition. At 7 W/gm power density the maximum temperature was 528°C, but the temperature is not maintained throughout the reaction time. It is noticed that the temperature of 400°C and 500°C is maintained for 13 min at 7W/gm and 16 min at 8W/gm. On comparing the time taken for attaining maximum temperature, the pyrolysis which is conducted at 8 W/gm required less reaction time than pyrolysis conducted at 7 W/gm. But pyrolysis at 7 W/gm exhibits better sustainability on maintaining the temperature [8]. At the end of the reaction the temperature is 261.25°C. The maximum temperature attained at 6 W/gm is 550°C within 7 minutes. Similar type of temperature profile is studied by [9] [10] in which the maximum temperature for complete pyrolysis took 35 minutes.
3.3 Product yields obtained by the microwave pyrolysis of soapnut seed

Fig 5 shows the bio-oil, bio-char and gas yields obtained by the microwave pyrolysis of soapnut seed at different power densities of 6 W/gm, 7 W/gm and 8 W/gm. The maximum bio-oil yield of 52% is obtained at a power density of 7W/gm. At this power density, the intensity of the electrons becomes stronger, this leads to a vigorous vibration of polar molecules.
production of bio-oil at this power density. The production of gas is high at 8 W/gm. It is been stated that, decreased pyrolytic oil yield for high temperature that results in production of high gas yield which might be caused by non condensable gases [11] [12] . It is noted that for 8 W/gm power density the temperature profile has more number of high temperature peaks resulting in higher gas yield. The bio-char yield is high at 6 W/gm power, even though a maximum temperature of 528 °C is attained by this reaction at the early stage of pyrolysis it is noted that there is reduction of temperature until the MW is off, thus lower temperature throughout the reaction resulted in higher yield of bio-char. [13] [14].

3.4 Properties of the produced pyrolytic bio-oil

Table 2 shows the properties of the produced bio-oil. The bio-oil is dark brown in colour with a smoky odour. The viscosity of bio-oil is around 10 times higher than diesel fuel. The flash point is comparable to diesel fuel. The water content determined using a separating funnel is 10-15%. The energy content is about 50% lower than that of diesel fuel. The bio-oil is acidic in nature [15]. The properties of the bio-oil obtained revealed that it has to upgraded in order to use it as a partial substitute for diesel fuel.

| Properties                        | Produced Saopnut seed pyrolytic-oil |
|-----------------------------------|-------------------------------------|
| Appearance                        | Dark brownish colour                |
| Kinematic viscosity at 40°C in cSt| 36.7                                |
| Flash point (°C)                  | 54                                  |
| Fire point (°C)                   | 74                                  |
| Water content (%)                 | 10-15                               |
| Gross calorific value (MJ/kg)     | 22                                  |
| pH                                | 5.2                                 |

4. Conclusion

Microwave pyrolysis of the soaput seed resulted with varying product yield fractions. The production of pyrolytic bio-oil is significantly high at 7 W/gm. The temperature profile for respective power densities enables to understand the feedstock’s reaction to the incident microwave irradiation. The properties reveals that bio-oil needs upgradation to utilize it as a partial substitute for diesel fuel.

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