Ascertaining Optimum Pyrolysis Conditions for Biochar Production from Maple Sawdust

Abstract

Sawdust is a bi-product from wood processing industries. In the recent time, pyrolysis of organic waste is an emerging technology where biochar can be produced and used for carbon sequestration. In that respect, the aim of the present work was to ascertaining optimum pyrolysis conditions in producing sawdust biochar (SBC) for the said uses. The raw material was collected from Belad furniture industry because of their specialization in furniture work and large volume availability. The proximate and ultimate analysis of 3.56% moisture, 1.49% ash content, 72.32% carbon and 0.19% surphur confirmed its good candidature for biochar production. The pyrolysis experiment was carried out by using six combination each of temperature (400, 450, 500, 550, 600 and 650 ^{o}C), nitrogen flow rates (0.5, 1.0, 1.5, 2.0, 2.5 and 3.0L/mins) and residence times (10, 20, 30, 40, 50 and 60mins). Analysis of resulted biochar was done according to IBI standard. Results showed that the three factors decrease the yield of biochar at their increasing values. SBC yield being optimum at temperature of 400 ^{o}C, 10min residence time and 1.0L/min nitrogen flow rate.

1.0 Introduction

Recognition of biomass as a major world renewable energy source is indeed gaining more attention day by day. Its consideration as pyrolysis feedstock was based on three cardinal views: firstly, its renewable source that could be sustainably developed in the future; secondly, it appears to have positive environmental impacts resulting in no release of CO_2 and thirdly, it appears to have significant economic potential provided that fossil fuel prices increase in future (Cardenas et al., 1998). The energy recovery from biomass can be achieved either by direct combustion in which the recovery is low or pyrolysed to obtained valuable products (biochar, bio-oil and biogas). Pyrolysis of biomass was ancient as the production of charcoal in the pre-colonial era except recently when the physical and chemical processes as well as pyrolysis conditions were investigated to determine their roles in the array of products.

There has been much research on the properties/yields of biochar generated under different pyrolysis conditions. However, most of the previous research mainly focused on the feedstock types and pyrolysis temperature with little concern to residence time and gas flow rate on the distribution of pyrolysis products and where such exists, interest was on bio-oil. The objective of this present research was to explore appropriate reaction conditions to convert maple sawdust to biochar by slow pyrolysis including the effect of pyrolysis temperature, sweeping gas flow rate and residence time on the yield of biochar.

2.0 Materials and Methods

2.1Treatment of Biomass

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The maple sawdust was obtained from Belad furniture located at old Jebba Road, Oyun, Ilorin, Kwara State, Nigeria. Although, the industry specialized on hardwood, yet, utmost care was taken to avoid mixture with other classes of wood sawdust. It was crushed using a crusher and sieved to 2-3mm particle sizes. Proximate and ultimate analyses were immediately conducted to ascertain its candidature as good feedstock for biochar production

2.2 Experimental Design

The entire experiments were conducted in three main phases to study the effect of temperature, flowrate and residence time on the yield of pyrolysis products with keen interest on biochar. The first series of experiment was conducted using a fixed bed reactor to determine the effect of temperature on the pyrolysis product yield. The temperature was varied from 400 to 600 ^{o}C while other conditions remained constant. In the second phase, nitrogen flow rate was studied and varied from 0.5 to 3.0L/min at interval of 0.5 while the last of the series of experiment was conducted to determine the implications of varying residence time on the distribution of pyrolysis products.

2.3 Pyrolysis Experiment

For each experiment, 20g of preprocessed sawdust was measured and placed through a crucible into a pyrolyser housed in a muffle furnace. The reactor was degassed by purging gas to create inert environment. Bio-oil produced during pyrolysis was collected through the condenser attached to the pyrolyser. Biochar was the solid particle remained in the crucible after the experiment. Calculations of the yields were based on the differences between the biomass weight before and after the pyrolysis.

3.0 Results and Discussions

3.1 Feed stock Proximate and Ultimate Analysis

In any pyrolysis process, the percentage of moisture, ash level, volatile matters, fixed carbon and other chemical components will have a strong impact on the conversion of biomass to pyrolysis products. Although, almost any form of organic material can be carbonized, however, both the conversion efficiency and quality of the products are strongly dependent on the nature of the feed stock. The proximate analysis of the sawdust shows that it contains moisture Content of 3.56% (dry basis), Volatiles matters (66.63%wt), hydrogen (14.36%wt) and Oxygen (9.94%wt). The difference in the values reported in literature (Fagbemi et al., 2017), could be affiliated to either as received, dry ash free basis and origin of the feedstock. 28.32 % fixed carbon content and 60.6% volatiles provide measure of the ease with which the biomass can be ignited or oxidized. The values of sulphur is 0.19% and thus the sawdust can be accepted to be the future source of sustainable green energy because it contains less sulphur and nitrogen (Tripathi et al., 2015).

3.2 Effect of temperature

Conventionally in pyrolysis process, three distinct phases are produced. One of the key factors that determine the distribution among the three products is temperature. At nitrogen flow rate of 1.0L/min, residence time of 10min, heating rate of 10^{o}C/min and particle size of 3.0mm, the

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effect of temperature was studied. As shown on figure 1, the yield of biochar decreased from 39.2% to 20.1% corresponding to 400 to 650 °C. Higher biochar yields are typically generated at low temperature or low heating rate (Alhassan et al., 2017) while under higher temperature or fast heating rates, the process produces high yields of either liquid or gas (Baumlin et al., 2006).

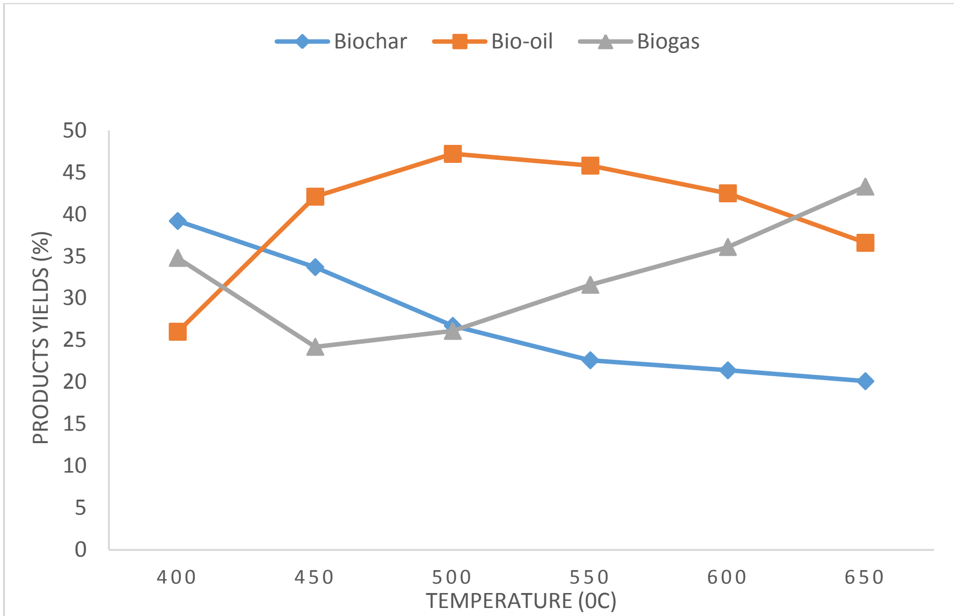

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Figure 1: Effect of Temperature on sawdust pyrolysis

This could probably due to decomposition of the lignocellulosic material at this temperature range (Intani et al., 2016). When the pyrolysis temperature further increased from 600- 650 °C, the biochar yield only decreased from 21.4% to 20.1%. This result indicated that most of the volatile fraction had been earlier removed at lower temperatures. Previous study on the biomass pyrolysis have shown that the increased temperature leads to decreased biochar yield, primarily due to gasification reaction occurring at the higher temperature (Encinar et al., 2015). The higher pyrolysis temperature also resulted in more liquid cracking, resulting in more production of gaseous product and lower yield of tar and/or biochar (Zanzi, 2014). The initial increase in the bio-oil yield from 26.0% to 45.8% corresponding to 400 to 500 °C could be as a result of degradation of lignin content of sawdust which usually occurs at such a high temperature. Further increase in temperature to 650 °C led to reduction of bio-oil yield to the tune of 36.6%. This can be attributed to the secondary reaction of pyrolysis vapors at elevated temperature (Jung et al., 2008). More decomposition of biochar and cracking of bio-oil at elevated temperature contributed to biogas formation.

3.3 Effect of Nitrogen flow rate on product yields

The purpose of the carrier gas (purging or sweeping gas) is to remove the volatiles from the pyrolysis environment during the biomass pyrolysis process. In other word, to avert secondary reaction of the primary biochar with the released volatiles in the reaction zone.

At 400 ^{o}C and residence time of 10min, six combinations of Nitrogen flow rates were studied (0.5, 1.0, 1.5, 2.0, 2.5 and 3.0L/min). The biochar yield of 30.7% was achieved when the nitrogen flow rate was set at 0.5L/min.

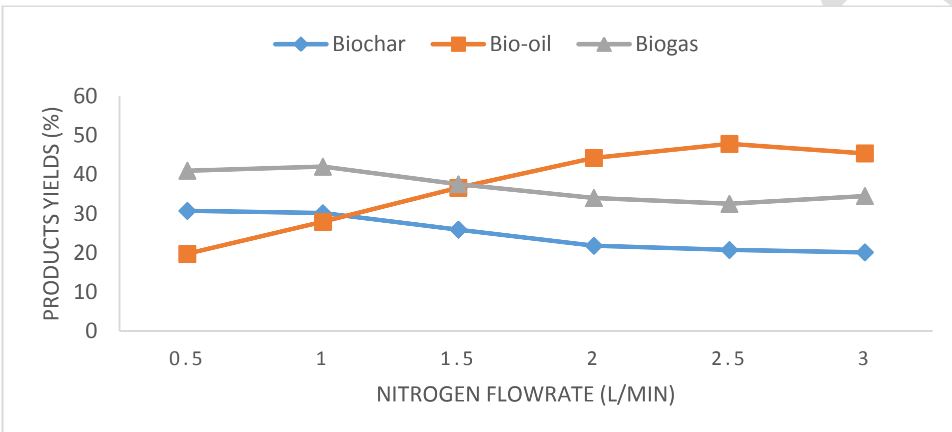

Figure 2: Effect of sweeping gas flow rate on sawdust pyrolysis

A close value of 30.9% of biochar was also achieved at flow rate of 1.0L/min and subsequent increase of Nitrogen flow rates from 1.5L/min to 3.0L/min drastically reduced the yield of biochar from 25.9% to 20.1%. It would be reasonable to suggest that at lower nitrogen flow rate, the velocity of the sweeping gas was slightly lower to transfer the hot vapors into the condensation section, hence, more yield of biochar. The yield of bio-oil increases from 19.7% to 47.8% corresponding with increasing Nitrogen flow rate from 0.5 to 2.5L/min. Blanco et al (2013) suggested that the sweeping Nitrogen gas had removed the hot vapor quickly and reduced the residence time of hot vapors. As such, it had contributed to the higher mass of bio-oil obtained. Gercel (2013) had reported that the minimization on the secondary reaction was achieved by higher velocity of the sweeping gas that transferred the hot vapors into the condensed bio-oil. However, the bio-oil seemed reduced when the Nitrogen flow rate was increased from 2.5 to 3.0L/min. This could be due to insufficient condensation of the hot vapors by the cooling apparatus improvised to the system. Erta and Alma (2013) support the assertion.

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The decreased trend of bio-oil over increasing flow rates (2.5 – 3.0L/min) seemed to increase the production of biogas. It could also be suggested that certain volume of condensable gases had transferred and escaped the condensation due high velocity of the sweeping gas.

3.4 Effect of Residence Time on Pyrolysis Product Yields

To investigate the effect of residence time on the pyrolysis of maple sawdust, a slow pyrolysis was conducted at optimum conditions of other parameters: temperature 400 ^{o}C and 1.0L/min nitrogen flow rate. Figure 3 shows the percentage of pyrolysis products obtained from varying residence times on sawdust pyrolysis

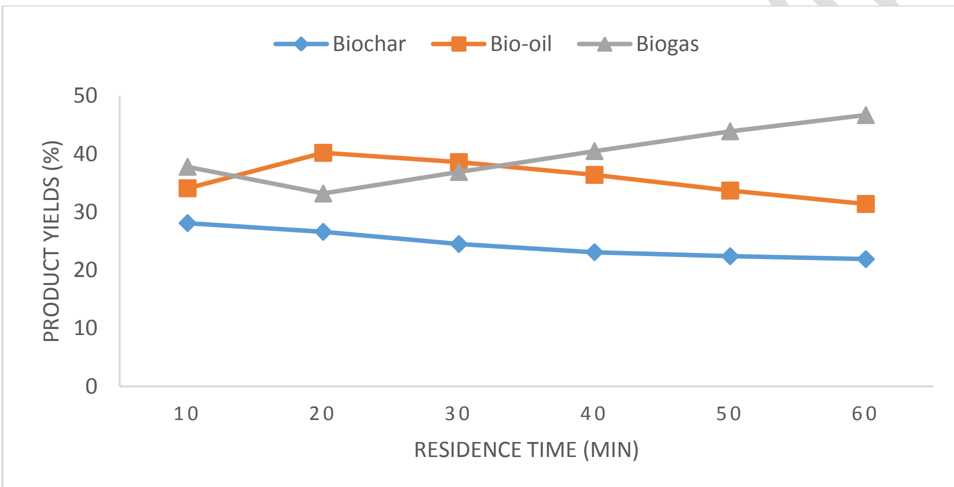

Figure 3: Effect of residence time on sawdust pyrolysis

The yield of biochar, as can be seen from the graph, portrayed a negative correlation as the residence time increases. In order word, biochar yields decreases (28.1 – 21.9%) with increasing residence time (10 – 60mins). With the negative trend, it is logical to state that greater mass would be volatilized during longer pyrolysiss conditions (Zhao et al., 2018). However, the close value of biochar yields at 50min (22.4%) and 60min (21.9%) suggest the constant value of biochar yield trend for subsequent pyrolysis beyond this research value. The shorter residence time of the volatiles in the reactor caused relatively minor decomposition of higher molecular weight products (Sensor, 2002).

Conclusion

The present research revealed the effect of pyrolysis conditions most especially temperature, sweeping gas flow rate and residence time on the yield of biochar. As compared to the previous understanding of temperature as the major driver of pyrolysis process, residence time and gas flowrate also showed substantive effects on the product distribution. Shorter residence and low flowrate were observed to favor the production of biochar at the expense of other products.

COMPETING INTERESTS DISCLAIMER:

We have declared that no competing interest exists. It was funded only by the personal effort of the authors.

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