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SYNTHESIS OF BIOCHAR PRODUCTION FROM WOOD WASTES USING SEMI-INDIRECT NON-ELECTRIC PYROLYTIC REACTOR

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ABSTRACT

In this study, two different wood wastes were selected based on their availability at different locations in Tamil Nadu for the production of biochar and *Prosopis julifera* was used as combustion fuel. The properties of wood waste and combustion fuel was studied and selected wood wastes had higher volatile content (80%) for pyrolysis conversion and *Prosopis julifera* had a higher heating value of 20.13 MJ/kg, which enables good combustion to provide heat energy for the production of biochar. The biochar production was optimized with the different mass ratio of *Prosopis julifera* (0.25, 0.50, 0.75 and 1.0 kg). The optimization of biochar production was carried out in a semi-indirect non-electric pyrolytic reactor had a capacity of 1 kg. The maximum optimized yield of biochar obtained from casuarina wood (*Casuarina spp*) was 36% and 35% from sawdust of teak wood (*Tectona grandis*) with a mass of 0.75 kg combustion fuel. Characterization of biochar shows the presence of higher total organic carbon content (84-87 %).

KEY WORDS: *Prosopis julifera*, Casuarina wood, Sawdust, Biochar, Pyrolytic reactor

INTRODUCTION

Climate change and increasing greenhouse gas emission limelight the reduction of fossil fuel consumption by means of utilizing renewable energy sources such as biomass (McKendry, 2002). Energy derived from renewable energy sources provides almost zero greenhouse gas emissions (Demirbas, 2005). Wood is one of the widely used renewable energy sources, which is converted into solid, liquid and gaseous fuels through various conversion processes. However, a huge amount of wood waste available in the country is wasted and makes disposal and environmental problems (Kim and Song, 2014).

Pyrolysis is one of the green technology to convert this waste biomass into carbon-rich biochar (Bridgewater, 2003). In pyrolysis, biomass is heated in the absence of oxygen at a particular temperature and produces char, bio-oil and gaseous products (Diebold, 2003). Depending upon the process temperature, heating rate and residence time the pyrolysis process is classified as slow and fast pyrolysis (Laird, 2008). Slow pyrolysis is a simple and viable process for producing farm-based biochar on a small-scale (Song and Guo, 2012).

Biochar has excellent properties and this can be helpful in crop production and climate change mitigation (Qambrani *et al.,* 2017). It is a solid black carbonaceous material and acts as a soil amendment, which improves the physical and chemical properties of soil and this leads to improve crop yields (Jeffery *et al.,* 2011). While biochar can be synthesized from different varieties of biomass under various process conditions and production processes and also have various properties (Antal and Gronli, 2003), hence which have different effects in soil. Singh *et al.* (2010) observed a significant difference between the various biomass obtained from wood, leaf, manure, poultry litter and paper mill sludge at 400 and 500 °C pyrolysis temperatures in terms of CEC, pH, ash content, acidity, lime equivalent, surface basidity and nutrient content. However, Mukherjee *et al.* (2011) reported that biochar produced from different feedstock such as pine, grass and oak at various pyrolysis temperatures had diverse surface chemistry signified by various properties. Meanwhile, biochar has the potential for carbon sequestration (Matovic, 2011) and mitigating the emission of greenhouse gases (Rondon *et al*., 2007). In this context, the present study is focusing on the production and characterization of biochar from different wood wastes using a semi-indirect non-electric pyrolytic reactor.

MATERIALS AND METHODS

Description of pyrolytic reactor

The semi-indirect non-electric pyrolytic reactor (Prabha *et al.,* 2015) was used for biochar production. The capacity of the reactor was 1 kg. The reactor (Fig. 1) consists of two chambers for the combustion and pyrolysis process with a grate and chimney. The combustion chamber provides the heat energy for producing biochar and the pyrolysis chamber is used for converting the wood wastes into biochar. The combustion and pyrolysis chambers had adiameter of 18 cm each and a height of 24 and 18 cm, respectively. In the combustion chamber, a grate is attached to the bottom of the chamber for supplying the stochiometric air to the combustion process. A grate of 32 holes (each hole of a diameter of 6 mm) was provided at the bottom of the pyrolysis chamber to transfer the heat from the combustion chamber to the pyrolysis chamber. Also, a chimney was provided on the top of the pyrolysis chamber to exhaust the flue gas. Both chambers were well insulated with glass wool to avoid conductive heat loss during biochar production.

Fig. 1. Semi-indirect non-electric pyrolytic reactor

Experimental procedure

The three different wood wastes *viz*., *Prosopis julifera*, casuarina wood (*Casuarina spp*) and sawdust of teak wood (*Tectona grandis*) were used in the present study. *Prosopis julifera was* used as a combustion fuel. Casuarina wood (*Casuarina spp*) and sawdust of teak wood wastes (*Tectona grandis*) were utilized for biochar production. The pyrolysis process was initialized by igniting the combustion fuel. The air supply for the combustion was provided from the bottom opening of the combustion chamber. After five minutes the fuel material was started to burn hotter and release smoke. The wood waste started to decompose due to the heat produced from combustion. After 30 minutes to 1 hr the wood waste was completely converted to biochar emitting the volatile substances and enhancing the non-volatile carbon at atemperature of above 400 °C. At the time of closure of the process, a trace amount of gases with little smoke is released indicating the completion. After that the chimney was removed and the pyrolysis chamber was covered with the lid. In order to prevent the conversion of biochar into ash, the bottom opening of the combustion chamber was covered with another lid. The reactor was cooled down after some hours and then biochar was taken out from the reactor.

Biochar yield (kg) = (weight of biochar/weight of biomass) × 100

Characterization of wood wastes and biochar

The proximate composition of wood wastes and biochar was analyzed according to American Society for Testing of Materials (ASTM) standards (D3172 for fixed carbon, D3173 for moisture, D3174 for ash, and D3175 for volatile matter), whereas the bulk density was measured based on the procedure of ASTM E-873-06. The calorific value of wood wastes was found in a bomb calorimeter (M/s. Aditya, India) by using the ASTM D-2015 procedure. The total organic carbon present in the biochar was determined through ASTM D4373-02. In addition, the pH and EC of biochar were measured based on the procedure suggested by Rajkovich *et al*. (2012).

RESULTS AND DISCUSSION

Characterization of selected wood wastes

The different characteristics of selected wood wastes were shown in Table 1. The bulk density of wood

Table 1. Properties of wood wastes

Wood wastes	Bulk density (kg/m³)	Calorific value (MJ/kg)	Moisture content (%)	Proximate composition (dry basis) (%)		
				Volatile matter	Ash content	Fixed carbon
Prosopis julifera	395	20.13	7.36	81.52	1.40	17.08
Casuarina wood (*Casuarina spp*)	910	18.43	10.35	80.26	1.45	18.29
Sawdust of teak wood (*Tectona grandis*)	220	17.10	5.98	79.35	4.20	16.45

waste varied from 220 to 910 kg m^{-3}. A high bulk density of 910 kg m^{-3} was found for casuarina wood and a low bulk density of 220 kg m^{-3} was found in the sawdust. The calorific values of selected wood waste ranged from 17.10 – 20.13 MJ kg^{-1}. The higher calorific value was found in *Prosopis julifera* and lower in sawdust. The selected wood waste had higher volatile content (79.35 – 81.52 %) and lower ash content (1.40 - 4.20). Biomass with high volatile and low ash content must favor the pyrolysis technique (Bridgwater *et al.,* 1999). The proximate composition of *Prosopis julifera* and casuarina wood was on par with the results reported by Chandrasekaran *et al.* (2021). They reported that the volatile matter, ash content and fixed carbon content of *Prosopis julifera* was 80.66 ± 2.26, 1.37 ± 0.34 and 17.97 ± 1.96 % and for casuarina wood 77.14 ± 2.63, 1.83 ± 0.64 and 21.03 ± 1.76, respectively. The fixed carbon content was varied as 16.45 – 18.29 %. Parthasarathy and Sheeba (2017) reported the volatile matter of sawdust (*Tectona grandis*) as 76 %. Chen *et al.* (2003) analyzed the properties of pine sawdust for pyrolysis conversion and denoted that the calorific value and fixed carbon of sawdust was 18 MJ/kg.

Optimization of biochar production from wood wastes

Pyrolysis of wood waste (1 kg) was carried out in a semi-indirect non-electric pyrolytic reactor with different mass ratio (0.25, 0.5, 0.75 and 1.0 kg) of *Prosopis julifera* (combustion fuel). The results of batch experiments are shown in Table 2. The maximum yield of biochar from casuarina wood and sawdust (Fig. 2) were found as 36 and 35 percent with 0.75 kg of *Prosopis julifera.* The mass of combustion fuel increased from 0.25 to 0.75 kg should increase the yield of biochar and further increasing of mass ratio leads gradual decrease in the biochar production. The mass ratio of combustion and pyrolysis fuel was 0.75:1. The residence time for biochar production was optimized as 45 min to 1h. The yield of biochar from wood wastes are vary based on the types of wood, as well as process conditions (Guida *et al.* (2020) and Tomczyk *et al*. (2020)). Similade A. Adeodun et al., (2022) studied the pyrolysis of stored wood wastes and optimization of process parameters for higher

Casuarina wood Sawdust

Fig. 2. Biochar produced from wood waste

Table 2. Optimization of biochar production

Pyrolysis fuel	Mass of combustion fuel, kg	Biochar yield, kg	Efficiency of biochar yield, %	Ash, kg
Casuarina wood (*Casuarina spp*)	0.25	0.10	10	0.085
	0.5	0.26	26	0.10
	0.75	0.36	36	0.12
	1.0	0.35	35	0.15
Sawdust of teak wood (*Tectona grandis*)	0.25	0.10	10	0.095
	0.5	0.19	19	0.11
	0.75	0.35	35	0.13
	1.0	0.33	34	0.16

Table 3. Properties of biochar

Biochar	Bulk density (kg/m^3)	Moisture content (%)	Proximate composition (dry basis) (%)			pH	EC, $ds\ m^{-1}$	Total organic carbon (%)
			Volatile matter	Ash content	Fixed carbon			
Casuarina wood (*Casuarina spp*)	264	6.53	17.38	0.80	81.82	8.56	0.24	87
Sawdust of teak wood (*Tectona grandis*)	203	5.71	15.60	2.27	82.13	7.95	0.21	84

biochar yield. The results revealed that the optimum yield of biochar obtained as 33.6, 29.4 and 18.5 % from hardwood sawdust (*Anogeissus leiocarpa* (African Birch)), soft wood sawdust (*Casuarina equisetifolia* (Whistling Pine tree)), and mixed sawdust with a residence time of 2 hours, respectively.

Characterization of Biochar

The physical and chemical properties of biochar studies are listed in Table 3.

The wood waste biochar had lower bulk density and application of these low density biochar in soil tends to reduce the soil bulk density. The lower bulk density of soil can improve better moisture retention and greater plant root penetration in soil. Based on the feedstock and pyrolysis process condition, the bulk density of biochar can vary in the range of 200 – 800 kg/m^3 (Downie *et al.,* 2009). The produced biochar had higher fixed carbon (81.82 and 82.13%) with lower ash content (0.80 and 2.27%). Rogovska *et al.* (2014) reported that the fixed carbon, volatile and ash content of mixed hard woods was 78.1, 13.5 and 7.7%. The biochar had alkaline pH of 7.95 and 8.56. Gaskin *et al.* (2008) stated that most of the biochar had alkaline pH. The total organic carbon content of biochar was 84 and 87 %. Depending upon the feedstock, biochar have a total carbon content of 400 to 900 g/ kg (Gaskin *et al.,* 2010).

CONCLUSION

In this research, biochar was produced from the pyrolysis of wood waste in the semi-indirect non-electric pyrolytic reactor by combusting *Prosopis julifera* with different mass ratio. The mass ratio of combustion fuel was optimized for higher recovery of biochar. The maximum yield of biochar (35-36%) was found with the mass of combustion and pyrolysis fuel in the ratio of 0.75:1 kg. The properties of biochar were studied and results indicated that the obtained biochar had lower bulk density and higher total organic carbon content. These experimental results revealed that the selected wood waste had high potential for the production of biochar and characterization study shows that the obtained biochar can improve the plant growth by enhancing the soil nutrient proprieties.

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