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Ascertaining of optimum pyrolysis conditions in producing refuse tea biochar as a soil amendment

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Abstract

Refused tea is a waste product of tea processing. Manufacturing of biochar from organic waste is an emerging technology where biochar can be used as a soil amendment for environmental remediation and carbon sequestration. As such the aim of this study was to determine the optimum pyrolysis conditions in producing refuse tea biochar for the said uses. Three refused tea samples were collected randomly from the bulk from tea processing factory in Gampola area of Sri Lanka and basic physical and proximate analysis were done. Initially, refused tea was packed tightly in the pyrolytic reactor which was designed to pyrolysis refused tea and pyrolysis was carried out by using five combinations of temperature (300, 350, 400, 450, 500 ^{o}C) and four retention times (15 min, 30 min, 45 min and 1 hour). The physical and chemical characteristics of biochar were analysed in line with the biochar quality standards proposed by International Biochar Initiatives (IBI). Results showed that the yield of biochar varied with the residence time for a given temperature treatment. The chemical, physical and morphological properties of biochar are largely influenced by the residence time for a given temperature treatment. Temperatures between 450^{o}C and 500^{o}C, and residence time between 45 and 60 minutes showed the highest biochar mass recovery. This research revealed that refuse tea can be effectively converted to biochar between 450 to 500 oC temperatures subjected to a residence time of 45 to 60 minutes. It also showed that higher volatilization rates at optimum temperature and residence time combination can be positively used for up scaling the pyrolysis reactor.

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1. Introduction

In agricultural eco systems, intensive farming has been focused mainly on monocultures required of considerable amounts of inorganic fertilizers. Nutrient cycles often go into imbalanced situations when high amounts of inorganic fertilizers are used. To counter-balance such it would be an appropriate the practice of blending with organic fertilizers or/and innovative raw materials such as refused tea bearing organic nature.

Handling and disposal of absolute refuse tea (ART) are worldwide constraints in the tea industry. Therefore a significant number of research studies have been conducted to examine the potential of absolute refuse tea for soil fertility improvements as well. Pyrolizing of refused tea for energy recovery and biochar producton are emerging technologies. Development of high quality biochar using tea refuse has been proposed as one of the alternative way of resource recovery and safe disposal. Biochar is a carbon rich product obtained from thermal decomposition of organic materials in absence of oxygen[1].

Researchers have shown that addition of biochar to soil reverses soil fertility decline, improve crop yields, and improve plant response to fertilizer[2]. It has also been suggested that biochar may have the potential to reduce leaching of pollutants from agricultural soils. This property of biochar is explained by the strong adsorption affinity of biochar for soluble nutrients such as ammonium[1], nitrate[3], phosphate and other ionic solutes.

The aims of this study are to (i) determine the optimum material handling and material mass balance for slow pyrolysis of refuse tea (ii) determine the optimum thermal conditions for slow pyrolysis of refuse tea (iii) characterize biochar produced according to the guidelines/test categories of International Biochar Initiatives (IBI).

2. Methodology

Quality of the produced biochar and the performances of the reactor were analyzed at Soil and Water Engineering Laboratory, Department of Agricultural Engineering, Faculty of Agriculture, University of Peradeniya, Sri Lanka.

Three Absolute Refuse Tea (ART) samples were collected randomly from the bulk from a black tea post-processing factory in Gampola area. The heating energy required to achieve higher temperature to produce biochar from refused tea were given by placing the pyrolytic reactor in a Muffle furnace, type 6000 - model F 6018. The reactor was consisted of following components as shown in figure 1.

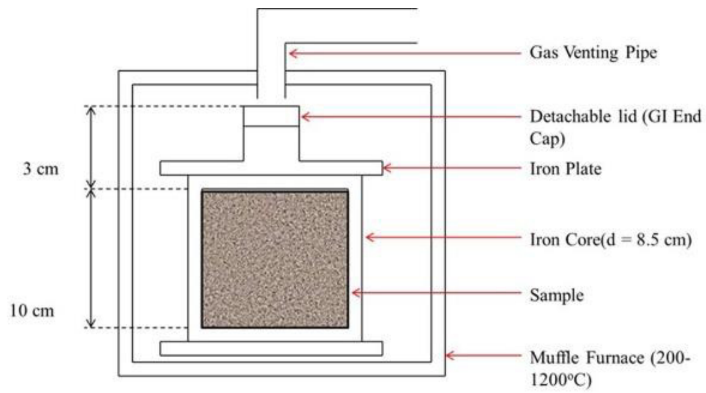

Figure 1: A schematic diagram of the reactor

Refuse tea was packed tightly in the pyrolytic reactor by compressing, minimizing amount of air entrapped in the reactor. Then, the lid was placed on the top and tightened to avoid air exchange between in and out. Once the muffle furnace reached the set temperature, the reactor was kept inside the furnace. Pyrolysis was carried out by using five combinations of temperature (300, 350, 400, 450, 500 ºC) and four retention times (15 min, 30 min, 45 min and 1 hour).

After the sample was heated for a given residence time at each temperature, the reactor was taken out. Then, the reactor was quenched by immersing in a water bath to avoid further oxidation of produced biochar. The quenching time varied depending on both pyrolyzing temperature and retention time. Thereafter, the biochar was collected from the reactor, weighed, and packed in plastic bags for subsequent analysis. The properties of biochar were analyzed using proximate analysis, mentioned in Table 1.

Table 1: Analytical parameters and methods

Analytical parameter	**Method/ Instrument and Condition**
Moisture Content	ASTM Method D3173
Ash	ASTM Method D3174
Carbon content	Experimental method
Bulk Density	Laboratory Method
pH	pH meter
Electrical Conductivity	Thermo orient Model 145A

Biochar characterization and quality estimation were done based on Standardized Product Definition and Product Testing Guidelines for Biochar standards, by International Biochar Initiative (IBI, 2012).

The characterization procedure has three categories of tests;

Category A) - Basic Utility Properties,

Category B) - Toxicant Assessment,

Category C) - Advanced Analysis and Soil Enhancement Properties.

3. Results, Discussion, Conclusions and Recommendations

The amount of biochar obtained by pyrolyzing at 300ºC for 15 minutes were comparatively low and the color of biochar was pale brown which was different from the quality biochar color (shiny black) and some amount of raw material was remained as shown in Figure 2. The partial pyrolysis was due to comparatively low temperature with short residence times a combination that was not sufficient to breakdown organic compounds like Lignin, Cellulose and Hemi-cellulose material of the raw material.

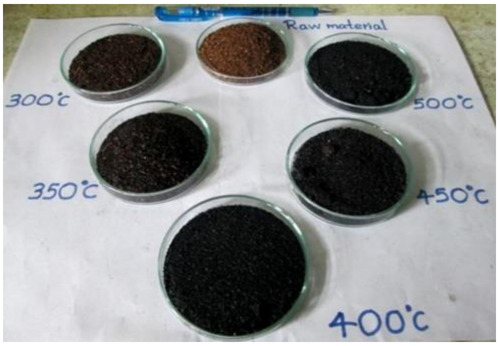

Figure 2: Comparison of pyrolytic products made at the retention time of 15

minutes

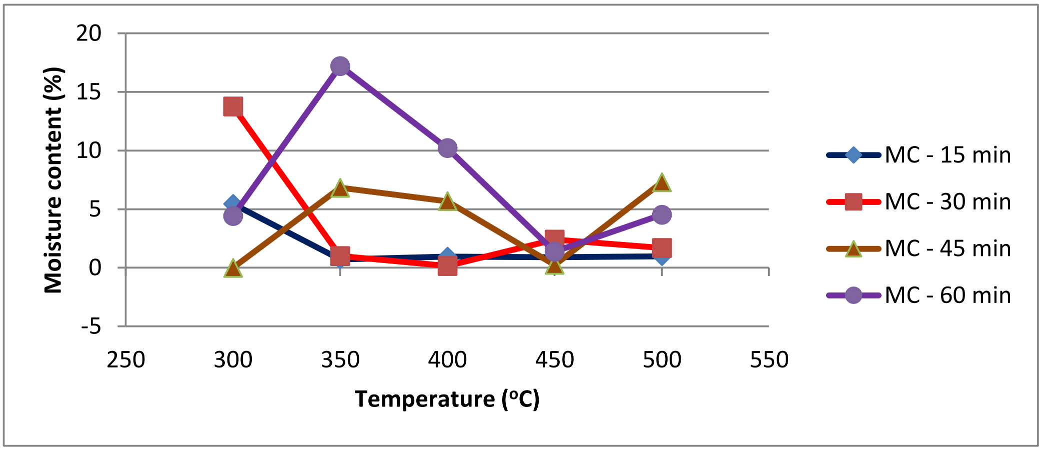

Figure 3: Comparison of moisture content variation

Basic utility properties shall be tested before applying the biochar into soil. The test category-A parameters are mandatory requirements set by IBI under basic utility properties.

The equilibrium moisture content of produced biochar was very low, except some retention times, as high pyrolysis temperature, water was vaporized as shown in Figure 3. It was less than moisture content in paddy husk char (5%) and saw dust char (7%) recorded by Ryu et al., (2005).

Table 2: Ash content variation

Temperature	Ash content			
	15 minutes	30 minutes	45 minutes	1 hour
300	11.49	25.85	20.65	45.13
350	32.42	12.38	38.88	9.02
400	42.01	26.63	52.74	16.87
450	34.12	30.42	39.77	26.35
500	51.70	29.83	37.31	27.24

According to the results shown in Table 2, average ash content of refuse tea biochar is greater than typical value (0-5 %) of ash content in wood, paddy husk and saw dust chars. Ash increases the soil pH, thereby increasing available phosphorous. And also, it improves the aeration in the crop root zone, increases the water holding capacity and level of exchangeable Potassium and Magnesium.

Figure 4 shows the mass recovery after pyrolysis at different residence times. According to the figure 4 temperatures between 450 °C and 500 °C showed the lowest mass recovery. Since, refuse tea is a biomass which composed of hemicellulose, cellulose and lignin, all these materials decompose between lower temperatures and lower residence times as compared with woody and lignified materials. Thus, it is evident that lower residence times are adequate at a range of temperatures between 350 °C and 500 °C.

The chemical, physical and morphological properties of biochar are largely influenced by the residence time for a given temperature treatment. At the temperatures between 400 °C and 500 °C and residence time of 30 to 60 minutes, refuse tea cannot be effectively converted into biochar due to higher mass losses. Material mass balance revealed that between 450 °C and 500 °C and the residence time of 45 and 60 minutes, refuse tea can be effectively converted into biochar.

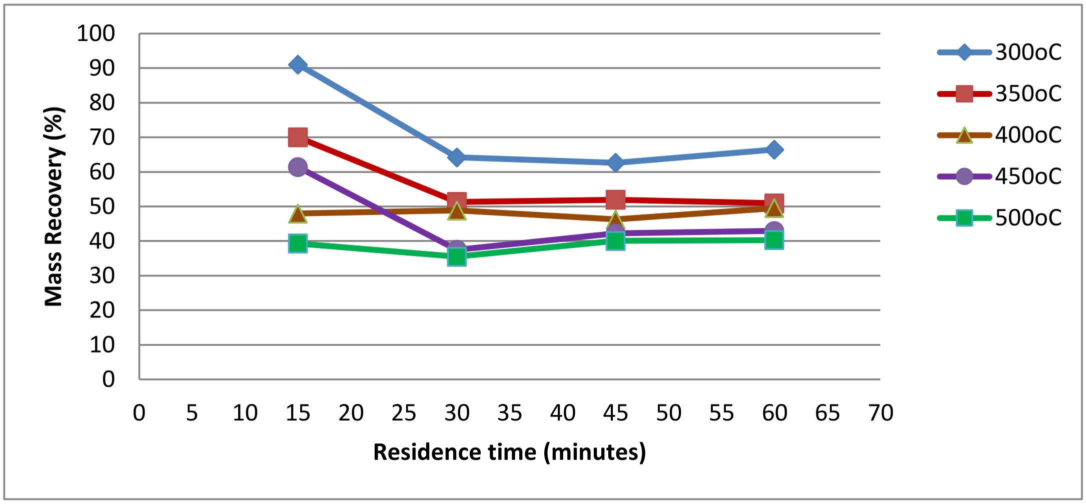

Figure 4: Mass recovery with the increase of residence time

The proximate analysis of produced biochar showed the fixed carbon content varied from 26% - 58%. The overall experiments showed that refuse tea biochar can be effectively manufactured by pyrolysing at 350 °C for 30 minutes which requires less thermal energy than conventional feedstock like wood or crop residue. This could have attributed by small particle sizes of refuse tea and leafy nature. Furthermore fast volatilization of organic mass at lower temperatures can be positively used in up scaling the pyrolysis reactor where the excess energy in pyrolyzed gas can be combusted for heat recovery.

The preliminary data obtained from this study can be used for designing and fabrication of large scale pyrolytic reactors which can be used for pyrolysis of refuse tea. This can be started with appropriate that shall develop to efficient pyrolytic reactors with additional testing.

Furthermore, effect of biochar on physical and chemical properties of soil should be examined after incorporating into soil for crop production.

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