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Effect of Core Puncture Diameter on Bio-Char Kiln Efficiency

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***Abstract*—**Biochar has been used as a soil amendment since it has high porous structure and has proper nutrients and chemical properties for plants. Product yields produced from biochar kiln are dependent on process parameters and kiln types used. The objective of this research is to investigate the effect of core puncture diameter on biochar kiln efficiency, i.e., yields of biochar and produced gas. Corncobs were used as raw material to produce biochar. Briquettes from agricultural wastes were used as fuel. Each treatment was performed by changing the core puncture diameter. From the experiment, it is revealed that the yield of biochar at the core puncture diameter of 3.18 mm, 4.76 mm, and 6.35 mm was 10.62 wt. %, 24.12 wt. %, and 12.24 wt. %, of total solid yields, respectively. The yield of produced gas increased with increasing the core puncture diameter. The maximum percentage by weight of the yield of produced gas was 81.53 wt. % which was found at the core puncture diameter of 6.35 mm. The core puncture diameter was furthermore found to affect the temperature distribution inside the kiln and its thermal efficiency. In conclusion, the high efficient biochar kiln can be designed and constructed by using the proper core puncture diameter.

***Keywords*—**Anila stove, biochar, soil conditioning materials, temperature distribution.

I. Introduction

BIOCHAR is an organic matter produced via the carbonization along with the thermal stabilization of biomass. Biochar has been used as a soil amendment, improving the soil physical and chemical properties for the better crop production. The properties of biochar are different from the other organic matters of thermochemical conversion processes. It is stable carbon-rich form of non-fully carbonized product, providing the long-term carbon storage in soil [1], [2]. The alkalinity of biochar is useful to acidic sandy soil, which helps to neutralize the soil acidity, increase the soil pH and improve the nitrification [3], [4]. The pores of biochar help to improve the soil structure. The high surface area contributed by the pores can increase the water holding capacity of soil and maintain the soil nutrients, which is preferable to microorganism habitation and activity [3]. The negative surface charge of the biochar, resulting from the biochar cation discharge into the soil, can improve the cation exchange capacity (CEC) [3]-[5]. Furthermore, the CEC of soil has been found to increase with the pH, the surface area, and the charge density in soil [5].

The biochar can be made from general biomass materials produced by pyrolysis. The different processing conditions of pyrolysis play important roles in the biochar quantity and quality, evaluated by the product yield and physicochemical properties of biochar, respectively [6], [7]. The pyrolysis process used for the biochar production can be categorized into 3 types in general, i.e., slow, intermediate, and fast pyrolysis [3]. These types are different in the temperature, heating rate and residence time of the process. In the slow pyrolysis, the biomass is heated inside the kiln with the low temperature ranging from 400 to 500 °C for a long time span varying between 30 min to 3 h while the fast pyrolysis depends on the moderate to high temperature heating approximately 850 to 1,250 °C for the short time span varying between 1 to 10 s with high heating rate. The intermediate pyrolysis has the process conditions in between the slow and fast pyrolysis, operating with the temperature of 500 to 650 °C and residence time of 300 to 1000 s [8].

The product yields of biomass pyrolysis depend on these types of pyrolysis process. The fast pyrolysis produced more liquid product (bio-oil) than the slow pyrolysis, i.e., 75 wt. % and 30 wt. %, respectively, while the slow pyrolysis produced more solid (biochar) than the fast pyrolysis, i.e., 35 wt. % and 12 wt. %, respectively. For the intermediate pyrolysis, the liquid and solid products are in between the slow and fast pyrolysis, i.e., 50 wt. % and 25 wt. %, respectively [9]. This study focuses on the highest yield of biochar and consequently the slow pyrolysis was selected as the process for producing the biochar.

Several studies have investigated the effect of the process parameters, such as pyrolysis temperature, heating time, heat rate, particle size, and gas flow rate, on biochar obtained from different agricultural residues [1]-[3], [6], [7], [10], [11]. The process parameters strongly influence not only the yield of biochar but also the biochar quality. For small scale biochar production used in fieldwork, the easy construction and removal of biochar kiln is required. The techniques of small scale biochar production are not widely available along with the design information and the discussion of the effect of process parameters on the productivity and quality of biochar, as it has been provided for industrial production [10].

To achieve the maximum biochar yield efficiently, the biomass must have sufficient energy (heat generation) for decomposition under the proper temperature conditions while

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the restriction of exposure of the biomass to oxygen has to be optimized. In this study, the biochar kiln was therefore prepared with the different core puncture diameters (3.18 mm, 4.76 mm, and 6.35 mm) in order to investigate the biochar yield and temperature distribution inside the kiln.

II. Materials and Methods

A. Biochar Kiln Preparation

Biochar kiln consisted of kiln, core of the kiln, flue and sieve platform as shown Figs. 1 and 2. The kiln was made of carbon steel with diameter of 384 mm, height of 467 mm, or the carbon steel tank with unit capacity of 50 L. The lid and the bottom of the tank were trimmed at its center to make the hole with diameter of 111.1 mm. The flue pipe was made of carbon steel with diameter of 114.3 mm. The biochar kiln was placed on the sieve platform prior to igniting. The air could flow from the bottom to the top of the kiln via the core.

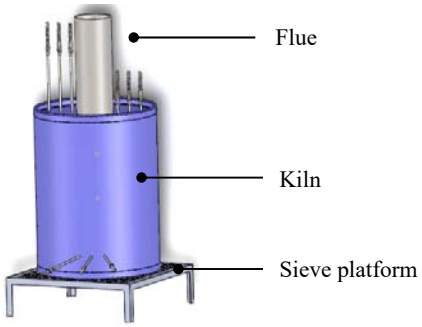


Fig. 1 Biochar kiln composition

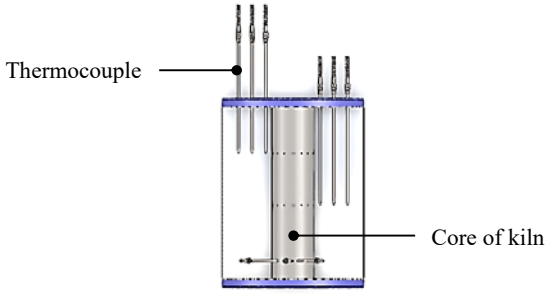


Fig. 2 Position of thermocouple attachment

The core was used to contain the fuel briquettes and served as combustion chamber. The core was located at the center of the kiln and was made of carbon steel pipe with thickness of 3.6 mm, inner diameter of 110.7 mm and height of 467 mm. The core diameter was recommended to be approximately 1/3 times to the kiln diameter. Heat could be transferred from the core to inside of the kiln by conduction and radiation. Nine stainless steel K-type thermocouple probes with the temperature range of 0 to 1,000 °C were placed inside the kiln, in radial positions at 52 mm, 124 mm, and 190 mm from the kiln center and in longitudinal directions at 50 mm, 200 mm, and 340 mm from the bottom of the kiln, as shown in Fig. 2. The real-time temperatures were acquired and stored using data logger (Wisco Online Datalogger OD04). To achieve the desired pyrolysis temperature and its distribution, the different core puncture diameters of 3.18 mm, 4.76 mm, and 6.35 mm were determined. The distance of each row of the core puncture illustrates in Fig. 3. The distance of each core puncture at the same row was 3 mm.

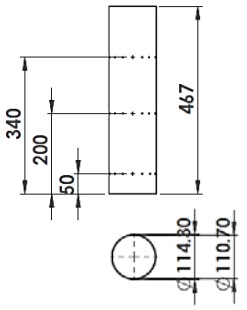


Fig. 3 Core dimension in millimeter

B. Experimental Procedure

The corncobs were sun-dried for about 5 days. The moisture content of corncobs before processing was less than or equal to 10% wet basis (wb). Seven kilograms of corncob were used in each treatment and were loaded in the biochar kiln around the core. The lid was tightly closed and the thermocouples were set. The biochar kiln was placed on the sieve platform. Three kilograms of fuel briquette made from the scraps of rubber tree were loaded in the core. The fuel briquette was ignited from the top of the core. The flue was set up in order to carry away smoke and circulate the air from the core. The combustion of fuel briquettes continued approximately for 3 hours. Following the process, the slow pyrolysis with low temperature and less air supply occurred inside the kiln. The corncobs were thermo-chemically decomposed and transformed into biochar.

The temperatures were acquired through the process. The steady-state temperatures at the nine locations in the biochar kiln were selected.

The kiln was let to cool down after the process finished. The completed biochar was sorted out from the raw corncobs and non-completed biochar. The outputs of the process, i.e., completed biochar, raw corncobs, non-completed biochar, and fuel ash, were weighed using digital weighing scale with accuracy ±0.1 g. The outputs were classified into 3 groups as follows, biochar (completed biochar), non-biochar (raw corncobs and non-completed biochar), and ash (fuel ash).

C. Parameter Calculation

The yield of biochar was calculated as follow:

$$\%\ \text{Biochar Yield} = \frac{\text{Weight of Biochar}}{\text{Weight of Total Solid Yields}} \times 100 \quad (1)$$

The gas produced by pyrolysis was inferred from the loss of total weight after the process, i.e.

$$\%\ \text{Produced Gas} = \frac{\text{Weight of Inputs - Weight of Total Solid Yields}}{\text{Weight of Inputs}} \times 100 \quad (2)$$

where weight of inputs was 10 kg which included the 7 kg of

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corncobs and 3 kg of fuel briquettes.

The experiment was repeated 3 times to calculate the average of the yields of biochar and produced gas for each core puncture diameter.

III. Results and Discussion

The temperature distributions were assessed in the biochar kiln. The temperature distributions in radial direction of the biochar kiln were measured at the height of 50, 200, and 340 mm from the bottom of the kiln for each core puncture diameter.

Figs. 4-6 show the variations of temperature along the radial locations of the biochar kiln with the core puncture diameter of 3.18, 4.76, and 6.35 mm, respectively. The similar trend is noted for each core puncture diameter. The highest temperatures for each height were found at the inner locations and decreased outwards the center of the kiln. The temperatures at the middle part of the biochar kiln (height of 200 mm) were higher than those at the top and base of the kiln (height of 340 and 50 mm), respectively.

The large quantities of biochar occurred at the middle part of the kiln. The range of temperature of the middle part of the kiln with the core puncture diameter of 3.18, 4.76, and 6.35 mm was 419.2 to 691.7, 384.9 to 612.3, and 361.6 to 575.8 °C, respectively, which were in the temperature range of the slow to intermediate pyrolysis process. The greater diameter of core puncture resulted in the lower temperature range. Although the lower temperature range was obtained at the core puncture diameter of 6.35 mm, the temperature distribution from the core to inside of the kiln was more uniform (lower in the temperature gradient) than the other core puncture diameters.

The weight of total solid yields (i.e., biochar, non-biochar, and ash) and produced gas for each core puncture diameter is shown in Table I. The percentages of the biochar yield and produced gas were respectively determined using (1) and (2). The comparison of biochar yield and produced gas between each core puncture diameter averagely over three experiments is presented in Fig. 7.

The effect of the core puncture diameter on the biochar kiln efficiency, i.e., the yields of biochar and produced gas, was first investigated on the present specific-designed kiln. The optimized core puncture diameter was determined.

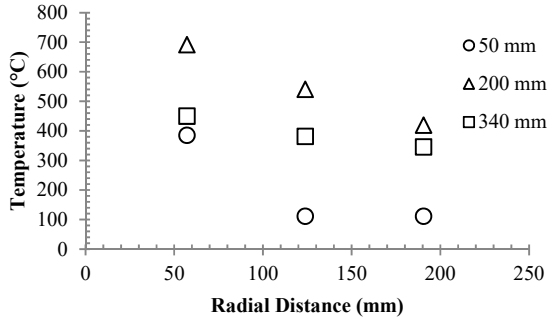


Fig. 4 Temperature distribution in radial direction of the biochar kiln at the height of 50 mm, 200 mm, and 340 mm from the bottom of the kiln with core puncture diameter of 3.18 mm

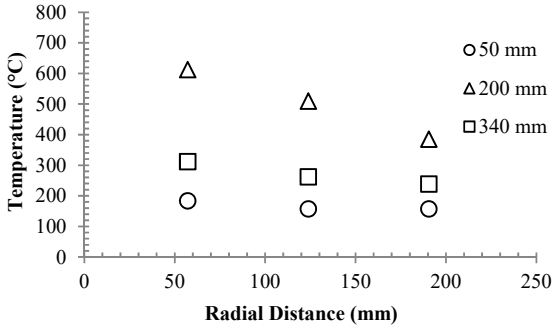


Fig. 5 Temperature distribution in radial direction of the biochar kiln at the height of 50 mm, 200 mm, and 340 mm from the bottom of the kiln with core puncture diameter of 4.76 mm

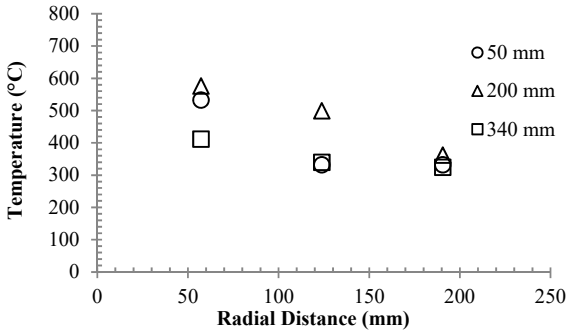


Fig. 6 Temperature distribution in radial direction of the biochar kiln at the height of 50 mm, 200 mm, and 340 mm from the bottom of the kiln with core puncture diameter of 6.35 mm

TABLE I
The Weight of Total Solid Yields and Produced Gas for Each Core Puncture Diameter

Core Puncture Diameter (mm)	Input Weight (g)		Output Weight (g)			
	Corncob	Fuel Briquette	Corncob		Ash	Produced Gas (g)
			Biochar	Non-Biochar		
3.18	7,000.0	2,999.9 ± 1.6	447.0 ± 57.3	3,461.2 ± 129.0	308.8 ± 34.2	5,782.9 ± 104.4
4.76	7,000.0	2,998.7 ± 1.3	686.2 ± 2.7	1,894.0 ± 20.1	264.3 ± 7.9	7,154.2 ± 32.0
6.35	7,000.0	3,001.8 ± 2.3	225.1 ± 8.1	1,451.3 ± 140.1	169.2 ± 35.4	8,156.3 ± 185.8

The biochar yield was plentifully obtained when the lower heating rate was applied [6]. The identical quantities of the fuel briquettes were continuously added into the core of the kiln during the experiments. The heating rate was thus not necessarily in this study. However, the temperature distribution inside the kiln significantly affected the product yields.

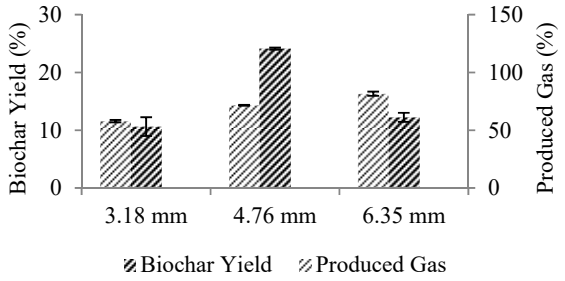


Fig. 7 Yields of biochar and produced gas (mean ± std) obtained from the experiments of the core puncture diameter of 3.18 mm, 4.76 mm, and 6.35 mm

The higher temperature gradient represented the lower uniform temperature distribution which was found at the core puncture diameter of 3.18 mm (Fig. 4). Heat from the core could be transferred to corncobs by conduction and radiation. The heat transfer rate increased with the heat transfer area, resulting in the increasing temperature around the core of the kiln as shown in Fig. 4. The amount of ash increased with the increasing temperature. The pyrolysis of corncobs was then processed by the heat which was transferred by conduction, convection, and radiation. The smaller puncture diameter cannot properly release the produced gas from the pyrolysis of corncobs, resulting in the decreases in the heat convection of the produced gas and the uniformity of temperature distribution inside the kiln. Furthermore, the heated gas could not start to ignite some of corncobs inside the kiln for pyrolysis. The incomplete decomposition occurred resulting in the decrease in the biochar yield. The yield of non-biochar (raw corncobs and non-completed biochar) thus increased. The smaller core puncture diameter had higher yield of non-biochar (mean ± std) than the greater one, i.e., 3,461.2 ± 129.0 g, 1,894.0 ± 20.1 g and 1,451.3 ± 140.1 g (Table I) for the core puncture diameter of 3.18 mm, 4.76 mm, and 6.35 mm, respectively.

The produced gas increased with the core puncture diameter as shown in Table I. The higher uniform temperature distribution leaded to increase the produced gas, resulting in the decrease in the biochar yield. The volatiles of biomass were preferably cracked into the liquid and gas as high temperature reached [11]. As the core puncture diameter increased, the pressure reduction and continuous circulation of air inside the kiln might drive out the thermal volatiles rapidly and consequently cause the decrease in the biochar yield [8], [10]. The lower temperature gradient represented the higher uniform temperature distribution which was found at the core puncture diameter of 6.35 mm (Fig. 6). Therefore, the greater core puncture diameter had higher in gas release capability than the smaller one, i.e., 81.54 wt. %, 75.79 wt. %, and 57.82 wt. % for the core puncture diameter of 6.35 mm, 4.76 mm, and 3.18 mm, respectively, as shown in Fig. 7.

Following the experimental conditions, the maximum biochar yield was found to be equal to 24.12 wt. % (Fig. 7) at the core puncture diameter of 4.76 mm. The optimum core puncture diameter increased the biochar yield. At the core puncture diameter of 4.76 mm, the temperature distribution was averaged as a result of the proper heat convection of the produced gas inside the kiln. The heated gas could properly circulate and start to ignite the corncobs inside the kiln for pyrolysis. The optimum core puncture diameter helped to release the produced gas and restrict the entrance air appropriately. This appropriated flow rate allowed the volatile constituent of corncobs to initiate repolymerization process where volatiles were slowly driven out [8]. The biochar derived from corncob has been investigated in previous reports [7], [12]. The increase in the pyrolysis temperature resulted in the decreasing biochar yield. The biochar yields were found to decrease from 34.2 to 20.2 wt. % on increasing the pyrolysis temperature from 400 to 700 °C [12] and from 30.6 to 5.7 wt. % on increasing the pyrolysis temperature from 450 to 1,250 °C [7]. In this present study, the high biochar production was found at the temperature range of 384.9 to 612.3 °C (i.e., 24.12 wt. %).

The physicochemical and morphological properties of biochar were limited in this study. The pyrolysis temperature in range of 400 to 600 °C for straw and lignosulfonate was found to greatly affect both physiochemical properties and stabilities, i.e., increase in pH and aromatic carbon content [11]. For the crop residues, the pyrolysis temperature at 500 °C was suggested for biochar production [4]. The suitable pyrolysis temperature for high biochar production was adjusted depending on the difference of the type of biomass material and its composition. The physicochemical and morphological properties of the biochar based on this present study will be investigated in the future.

IV. Conclusions

The results of this study indicated that the core puncture diameter of 4.76 mm was optimum for producing the biochar, with the highest yield. The temperature distribution was assessed in this study. The air circulation and gas release capabilities of the kiln for each core puncture diameter could be indicated by the temperature distribution, which significantly affected the product yields. The increase in the air circulation and gas release capabilities revealed the uniform temperature distribution inside the kiln, resulting in the increasing produced gas and reducing biochar yield. The core puncture diameter of 6.35 mm had better utilize for cooking application due to its higher gas release. The biochar kiln with the core puncture diameter of 4.76 mm was, however, more efficient in biochar production than that with the core puncture diameter of 3.18 mm and 6.35 mm.

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