Test of a modified small-scale biochar kiln

Lalita Petchaihan¹, Numpon Panyoyai¹, Tipapon Khamdaeng¹ and Thanasit Wongsiriamnuay¹∗

¹Division of Agricultural Engineering, Faculty of Engineering and Agro-Industry, Maejo University, 63 Chiangmai-Phrao Road, Nonghan, Sansai, Chiangmai, 50290, Thailand.

E-mail: t.wongsiriamnuay@gmail.com

Abstract. The conventional kilns were used for biochar production, but it took more than 7-9 hours for processing, and its process temperature was not uniform because some of the material could be converted into biochar and used lots of heat source input resulting in low production efficiency. Then the objective of this research was to improve the biochar production by using modified biochar kiln by reducing the temperature distribution. A 50-liter kiln with a modified core was needed in this research. This core was heating source for the pyrolysis process. The heat source came from the combustion of biomass. The core pipe was core puncture diameter for releasing product gas between a process, and it was core puncture diameter in 3 sizes (i.e., 3.18 mm, 4.76 mm and 6.35 mm). Seven kilograms of corn cob rice husk and longan peel were loaded in the biochar kiln using three kilograms of fuel. The physical and chemical properties of biochar were analyzed such as water content, pH, electrical conductivity (EC) using scanning electron microscope (SEM), and Energy-dispersive X-ray spectroscopy (EDX). The element and mineral compositions were also analyzed, including C, N, O, K, and P. It was found that most of the materials were converted into biochar at uniform temperature with the modified core. The temperature inside a kiln with the heat insulation the modified core was around 400-600°C better than the common core (100-700°C) and it took only 3 hours for the process. In terms of products obtained from pyrolysis condition, the average temperature positions inside the kiln were found to be 430 ± 583°C, 271 ± 512°C, and 189 ± 503°C and consisted of biochar yield were found to be 45.7, 34. 3 and 31.4 wt.% for rice husk, corn cob, and longan peel, respectively. Gas yields were found to be 68.6, 68.6, and 48.6 wt.% for longan peel, corn cob, and rice husk, respectively. Ash yields were found to be 10.0, 5.7, and 5.7 wt.%, for longan peel, corn cob, and rice husk, respectively. The biochar properties from corn cob rice husk and longan peel were beneficial, resulting in being useful for the soil amendment. It had suitable properties for improving the deteriorated soil structure conditions.

1. Introduction

Biochar is produced from biomass, or decomposed organic matter derived from nature such as wood waste, leaves or scraps of agricultural residue such as corn cobs, bean stalks, nuts, fruit peel, [1], wheat straw, bagasse, [2], pine tree biomass, willow biomass, maize cobs, rice husk, rice straw and miscanthus biomass [3-11]. There natural materials go through a minimum combustion process with temperature and air controls which is Pyrolysis. There are two methods of separation: Slow Pyrolysis
and Fast Pyrolysis. Slow thermal decomposition is slow burning by decomposition of organic matter in hours and uses to the temperature between 350-600 °C in an anaerobic condition.

Biochar yield from corn cobs, corn and maize cobs [5, 9, 12]. Rice husk physiochemical properties were analysed under slow pyrolysis at different temperatures 300-700 °C [13]. The results indicated that porosity, ash content, electrical conductivity (EC), and pH value [4-8, 10, 11, 14] of both EFB and RH biochars were increased with temperature; however, yield, cation exchange capacity (CEC) [4, 8, 9], SEM, H, C, and N contents were decreased with increasing pyrolysis temperatures. The Fourier transforms IR spectra [15]. The physical and chemical properties of biochar had an alkaline reaction (pH 7.0 –7.8) and could be used for neutralization of acid soils, which account for 45% in Poland [16]. The mineralization occurs when C/N ratio in the decayed organic substance is 20–30/1, whereas nitrogen content ranged from 1.2 to 1.8% [17]. The analysis of the content of carbon (C), hydrogen (H), nitrogen (N) and sulphur (S) and the different characterization techniques including BET, FTIR, XRD, SEM [4], and TGA were done Briefly, BTS exhibited heterogeneous surface structures and comparatively larger specific surface area [18]. The nanostructures of the longan seed and mangos teen skin derived porous carbons were investigated by the field emission scanning electron microscope (FE SEM, ZEISS Ultra.) [19].

Biochar was added to soil using. The concept for obtaining an organic fertilizer containing biochar and its application in the processes of biological transformation of waste was presented. [20].

The Anila stove is a simple technology for converting biomass to char at household level. The stove has been designed and built. The stove consists of two metal barrels. The outer barrel is filled up with biomass and the inner is with firewood. [9]

Currently, there are various methods of production char. There are many factors that affect the production. And the key factor in the production of biochar is the kiln design, designed to be used in the process of slow pyrolysis is a modification of the iron tank. By using engineering principles in design. The objective of this work was to study on the production from agricultural residue, the physical and chemical properties of biochar and testing of a modified small-scale biochar kiln core puncture 3 sizes (3.18, 4.76 and 6.35 mm) and agricultural residue from corn cob rice husk and longan peel.. Changes in the physical and chemical characteristics of biochar that suitable properties for soil improvement.

2. Materials and methods

2.1. Biochar feedstocks

Agricultural residues used in this research were corn cob, rice husk, and longan peel which were obtained from Chiang Mai, Thailand. They were dried until their moisture contents were less than 10% [21].

2.2. Design biochar kiln

Developed from Anila-type (IBI Biochar) the biochar kiln was made of carbon steel with a dimension of 500 mm × 380 mm (height × diameter) and had a unit capacity of 50 L (Figure 1.). The lid and bottom of the kiln were cut at its centre with the diameter of 115 mm. The core of the biochar kiln was located at the centre of the kiln. The core was made of carbon steel pipe with thickness of 2.5 mm, inner diameter of 115 mm, height of 470 mm, and core puncture diameter of 3.18, 4.76, and 6.35 mm. The dimension of the core and the locations of the core puncture were detailed.
2.3. Production Biochar

Seven kilograms of feedstock was loaded into the biochar kiln around the core for each experiment. The lid was tightly closed with the heat insulation and the thermocouples were set in (Figure 1.) The biochar kiln was placed on the sieve platform before fuel was loaded in the core. The three kilograms of fuel was used. Fuel was divided into three equal portions and was slowly filled for each hour. The fuel was ignited from the top of the core. The combustion of fuel continued for 3 h. Following the process of slow pyrolysis, the feedstock was thermo-chemically decomposed and transformed into biochar. After the process finished, the outputs (i.e., biochar, non-biochar, and ash) were sorted out.

2.4. Characterization of biochar

Biochar yield were calculated form Balance of mass. Wherewith \( W_f \) and \( W_o \) are the amount of dry weight of the biochar and biomass, respectively [22].

\[
\text{Yield Biochar (\%) = } \left( \frac{W_f}{W_o} \right) \times 100
\]

Where \( W_o \) is the initial weight of the raw material and \( W_f \) is the mass of either biochar.

The moisture content of biochar could be done by analysing according to ASTM D1762-84 standard at 105 °C temperature for 2 hours [23], then measured acid-base (pH) using the analysis according to DIN ISO 10390 with 1:5 (W:V) biochar to 0.01 M CaCl\(_2\)-solution, 60 min shaking, measuring directly in the suspension and electrical conductivity (EC) analysis by DIN ISO 11265, adding 1:10 (W:V) H\(_2\)O to the sample, shaking for 60 min, followed by filtration of the solution. (According to EBC standard). Surface morphology Scanning electron microscope (SEM) and Energy-dispersive X-ray spectroscopy (EDX)

3. Results and discussions

3.1. The effect of core punctures diameter type on the biochar yield

The biochar yield of core puncture diameter type in the biochar production from different agricultural residue was measured, Figure 2. It was found that the core puncture diameter of 3.18 mm would result in the greatest amount of yield. The results showed that biochar yield from rice husk gave the highest yield of 45.7 wt.% while those from corncob and longan peel were 34.3 wt.% and 31.4 wt.%, respectively. Increasing the temperature caused the amount of biochar to be reduced, and the reduction of biochar due to the breakdown of compounds such as cellulose and hemicellulose, as well as the burning of organic materials at increased pyrolysis temperatures. [24]. However, the result also depended on the density of agricultural residues that were also tested. The result showed that the amount of gas yield from longan peel had the highest gas yield of 68.6 wt.% while those from...
corn cob and rice husk were 68.6 wt.% and 48.6 wt.%, respectively. The results of ash yield from longan peel gave the highest yield of 10.0 wt.% while those from corn cob and rice husk were 5.7 wt.% and 5.7 wt.%, respectively.

| Core Puncture Diameter Type (mm) | Yield (wt.%) | Temperature (℃) |
|---------------------------------|--------------|-----------------|
| 3.18                            | Gas yield    | 0               |
| 3.76                            | Non Biochar  | 20              |
| 6.35                            | Ash yield    | 40              |
| 6.35                            | Biochar yield| 60              |

**Figure 2.** The weight percent of yields from biochar production corn cob (a), rice husk (b), and longan peel (c) for each core puncture diameter type.

| Core Puncture Diameter Type (mm) | Yield (wt.%) | Temperature (℃) |
|---------------------------------|--------------|-----------------|
| 3.18                            | Gas yield    | 0               |
| 3.76                            | Non Biochar  | 20              |
| 6.35                            | Ash yield    | 40              |
| 6.35                            | Biochar yield| 60              |

**Figure 3.** The pyrolysis temperature of biochar kiln from biochar production corn cob (a), rice husk (b), and longan peel (c) for each core puncture diameter type.

3.2. The effect of core punctures diameter type on the pyrolysis temperature
The results of the temperature distribution test were obtained from testing at the midpoint inside the biochar kiln which was the temperature radiation between fuel to agricultural residue or biomass
around the core in Figure 3. The above results, the core puncture diameter type, would affect the temperature distribution within the biochar kiln. Showed that the core puncture diameter of 3.18 mm resulted in the best temperature distribution as specified in the theory of pyrolysis in the production of biochar in the range 350-600 °C [1]. The production of biochar by slow pyrolysis method, the maximum average temperature was not more than 500 °C. For organic materials, after heat processing or combustion process, biochar with chemical composition obtained but could be changed according to the type of raw materials used to make biochar was for improving soil conditions [25]. Generally, plant growth was the highest with addition of biochar produced at a pyrolysis temperature of 500°C [20]. The results from the test would be in the average temperature range according to the test duration of 3 hours, the highest temperature of biochar production from 3 types of agricultural residue (i.e. corn cobs, rice husk and longan peel) were 512 °C, 583 °C, and 503 °C respectively. Therefore, when designing a larger core puncture diameter, the temperature inside the biochar kiln increased as the result of the core puncture diameter of 76.4 mm which gave the ranges 675 °C, 674 °C, and 604 °C, respectively. While the core puncture diameter of 35.6 mm gave the temperatures in the range of 630 °C, 652 °C, and 685 °C respectively. As mentioned above, when the temperature, it affected the properties of biochar yield and gas yield. [26].

3.3. Characterization of biochar
The results showed that the pH increased as the temperature increased in the pyrolysis process, mainly due to the separation of alkaline salts from organic substances, [27]. The pH properties of agricultural residue were shown in Table 1. Corn cob biochar, (3.18, 4.76, and 6.35 mm), rice husk (6.35 mm), and longan peel (4.76 mm and 6.35 mm) gave pH between 7.07-8.79 which were suitable properties for acid soil improvement. Biochar sachets from rice husk (3.18 mm and 4.76 mm) and biochar from longan peel (3.18 mm) gave pH values between 6.42-6.93, which was suitable for alkaline soil improvement.

The EC test results Table 1, from the production of biochar at different core puncture diameter had an effect on the volume which was increased with the increased temperature. According to the tests, longan peel biochar had the highest EC value (0.11, 0.79, and 0.99 ds m⁻¹), followed by corn cob biochar (0.15, 0.37, and 0.41 ds m⁻¹) and bio-charcoal from rice husk (0.21, 0.27, and 0.39 ds m⁻¹), respectively [28], which were considered suitable for soil improvement.

The morphology of a biochar using high definition scanning electron microscope 15 kV electron beam energy was identified. This is caused by the interaction of atoms between the electrons of the beam and the sample of biomass [29]. A morphological study using a scanning microscope with magnification of 10 μm or 2000X showed that the core puncture diameter type affected the porosity in biochar are shown in Figure 6, 7 and 8, respectively porosities in the biochars from corn cob biochar, rice husk and longan peel.

| Biochar   | The core puncture diameter type (mm) | Biochar yield (wt.%) | Water Content (wt.%) | pH     | EC (ds m⁻¹) |
|-----------|-------------------------------------|----------------------|----------------------|--------|-------------|
| Corncob   | -                                   | -                    | 5.41                 | 5.18   | 0.15        |
|           | 3.18                                | 34.3                 | 1.51                 | 7.07   | 0.37        |
|           | 4.76                                | 28.9                 | 2.07                 | 8.40   | 0.41        |
|           | 6.35                                | 25.7                 | 2.27                 | 8.79   | 0.64        |
| Rice husk | -                                   | -                    | 7.665                | 5.81   | 2.44        |
|           | 3.18                                | 45.7                 | 2.930                | 6.42   | 0.21        |
|           | 4.76                                | 37.1                 | 3.130                | 6.59   | 0.27        |
| Biochar        | The core puncture diameter type (mm) | Biochar yield (wt.%) | Water Content (wt.%) | pH  | EC (ds m⁻¹) |
|---------------|-------------------------------------|----------------------|----------------------|-----|-------------|
| Longan peel   | 6.35                                | 40.0                 | 2.987                | 7.21| 0.39        |
|               | -                                   | -                    | 9.490                | 6.05| 2.45        |
|               | 3.18                                | 31.4                 | 2.820                | 6.93| 0.11        |
|               | 4.76                                | 24.3                 | 2.856                | 7.20| 0.79        |
|               | 6.35                                | 27.1                 | 2.896                | 7.67| 0.99        |

![Figure 4. SEM biochar results 2000X of corncob, rice husk, and longan peel.](image)

The results showed that different the core puncture diameters had effects from the temperature in the production of biochar, resulting in the biochar having increased porous area characteristics when the temperature increased. As the temperature increased, the amount of pore increased with the size of the core puncture diameter (6.35, 4.76, and 3.18 mm) respectively. As the porous biochar increased, it became was more suitable for the soil improvement [30], and also resulted increased carbon content (C) When comparing the amount of minerals from Energy-dispersive X-ray spectroscopy (EDX) such as element content of C, N, O, K, P, etc., it was found that the core puncture diameter of 3.18 mm could gave suitable amounts of element for soil improvement.
husk > corncobs > longan peel giving biochar yields in the ranges of 583°C, 512°C, and 503°C respectively. The amount of gas yield from the biochar production gave the order that longan peel > corncobs > rice husk giving gas yields that 3

The result of testing the design of different core puncture diameters and agricultural residue shows

| Element          | The core puncture (mm) | C K  | N K  | O K  | K K  | P K  |
|------------------|------------------------|------|------|------|------|------|
| Corn cob         | 3.18                   | 73.24| 11.11| 8.85 | 0.16 | 0.13 |
|                  | 4.76                   | 91.01| 1.98 | 11.34| 0.34 | 0.15 |
|                  | 6.35                   | 85.59| 3.53 | 7.86 | 0.11 | 0.04 |
| Rice husk        | 3.18                   | 39.60| 16.89| 38.97| 0.11 | -    |
|                  | 4.76                   | 27.47| 10.52| 52.62| -    | -    |
|                  | 6.35                   | 31.71| 4.54 | 56.33| 0.07 | 0.10 |
| Longan peel      | 3.18                   | 49.65| 31.58| 17.66| 0.02 | 0.13 |
|                  | 4.76                   | 64.60| 3.97 | 27.47| 0.79 | 0.51 |
|                  | 6.35                   | 79.06| 0.45 | 17.27| 0.96 | 0.12 |

4. Conclusions
The result of testing the design of different core puncture diameters and agricultural residue shows that 3.18 mm diameter had the highest temperature of biochar from rice husk, corncob, and longan peel in the ranges of 583°C, 512°C, and 503°C respectively.

The temperature distributions in biochar kiln with different agricultural residues the order that rice husk > corncobs > longan peel giving biochar yields were of 45.7, 34.3 and 31.4 wt.% respectively and The amount of gas yield from the biochar production gave the order that longan peel > corncobs > rice husk giving gas yields of 68.6, 68.6, and 48.6 wt.% respectively.

References
[1] Collison, M., et al., 2009. Biochar and carbon sequestration: a regional perspective. Low Carbon Innovation Centre, UEA: Norwich, UK.
[2] Qiu, Q., et al., 2019. A comparative investigation on direct carbon solid oxide fuel cells operated with fuels of biochar derived from wheat straw, corncob, and bagasse. Biomass and bioenergy. 121: p. 56-63.
[3] Ścisłowska, M., et al., 2015. Biochar to improve the quality and productivity of soils. Journal of Ecological Engineering. 16(3).
[4] Peng, X., et al., 2011. Temperature-and duration-dependent rice straw-derived biochar: Characteristics and its effects on soil properties of an Ultisol in southern China. Soil and Tillage Research. 112(2): p. 159-166.
[5] Deal, C., et al., 2012.Comparison of kiln-derived and gasifier-derived biochars as soil amendments in the humid tropics. Biomass and Bioenergy. 37: p. 161-168.
[6] Özçimen, D. and A. Ersoy-Meriçboyu, 2010. Characterization of biochar and bio-oil samples obtained from carbonization of various biowaste materials. Renewable Energy. 35(6): p. 1319-1324.
[7] Novak, J.M., et al., 2009. Characterization of designer biochar produced at different temperatures and their effects on a loamy sand. Annals of Environmental Science.
[8] Gaskin, J.W., et al., 2008. Effect of low-temperature pyrolysis conditions on biochar for agricultural use. Transactions of the ASABE. 51(6): p. 2061-2069.
[9] Mengesha, T.T. and A.V. Ramayya, Heat Transfer Validation and Comparative Evaluation of Biochar Yield from Pyrolysis Cook Stove.
[10] Manyà , J.J., 2012. Pyrolysis for biochar purposes: a review to establish current knowledge gaps and research needs. Environmental science & technology. 46(15): p. 7939-7954.
[11] Lee, Y., et al., 2013. Comparison of biochar properties from biomass residues produced by slow pyrolysis at 500 C. Bioresource technology. 148: p. 196-201.
[12] Mullen, C.A., et al., 2010. Bio-oil and bio-char production from corn cobs and stover by fast pyrolysis. Biomass and bioenergy. 34(1): p. 67-74.
[13] Sukiran, M.A., et al., 2011. Production and characterization of bio-char from the pyrolysis of empty fruit bunches. *American Journal of Applied Sciences*. 8(10): p. 984.

[14] Wu, W., et al., 2012. Chemical characterization of rice straw-derived biochar for soil amendment. *Biomass and bioenergy*. 47: p. 268-276.

[15] Claoston, N., et al., 2014. Effects of pyrolysis temperature on the physicochemical properties of empty fruit bunch and rice husk biochars. *Waste Management & Research*. 32(4): p. 331-339.

[16] Zarzycki, R., M. Imbierowicz, and M. Stelmachowski, 2007. Wprowadzenie do inżynierii i ochrony środowiska: Fizykochemiczne podstawy inżynierii środowiska. *Wydawnictwa Naukowo-Techniczne*.

[17] Kacprzak, M., 2007. Wspomaganie procesów remediacji gleb zdegradowanych. *Wydawnictwo Politechniki Częstochowskiej*.

[18] Yihunu, E.W., et al., 2019. Preparation, characterization and cost analysis of activated biochar and hydrochar derived from agricultural waste: a comparative study. *SN Applied Sciences*. 1(8): p. 873.

[19] Wang, H., et al., Effects of atmospheric ageing under different temperatures on surface properties of sludge-derived biochar and metal/metalloid stabilization. *Chemosphere*, 2017. 184: p. 176-184.

[20] Czekała, W., A. Jeżowska, and D. Chelkowski, 2019. The use of biochar for the production of organic fertilizers. *Journal of Ecological Engineering*. 20(1): p. 1-8.

[21] Enders, A. and J. Lehmann, 2012. Comparison of wet-digestion and dry-ashing methods for total elemental analysis of biochar. *Communications in soil science and plant analysis*. 43(7): p. 1042-1052.

[22] Arami-Niya, A., et al., 2012. Optimization of synthesis and characterization of palm shell-based bio-char as a by-product of bio-oil production process. *BioResources*. 7(1): p. 0246-0264.

[23] Enders, A., et al., 2012. Characterization of biochars to evaluate recalcitrance and agronomic performance. *Bioresource technology*. 114: p. 644-653.

[24] Al-Wabel, M.I., et al., 2013. Pyrolysis temperature induced changes in characteristics and chemical composition of biochar produced from conocarpus wastes. *Bioresource technology*. 131: p. 374-379.

[25] Sun, Y., et al., 2014. Effects of feedstock type, production method, and pyrolysis temperature on biochar and hydrochar properties. *Chemical Engineering Journal*. 240: p. 574-578.

[26] Chen, D., et al., 2015. Bamboo pyrolysis using TG–FTIR and a lab-scale reactor: Analysis of pyrolysis behavior, product properties, and carbon and energy yields. *Fuel*. 148: p. 79-86.

[27] Yuan, J.-H., R.-K. Xu, and H. Zhang, 2011. The forms of alkalis in the biochar produced from crop residues at different temperatures. *Bioresource technology*. 102(3): p. 3488-3497.

[28] Jung, K.-W., et al., 2016. Influence of pyrolysis temperature on characteristics and phosphate adsorption capability of biochar derived from waste-marine macroalgae (Undaria pinnatifida roots). *Bioresource technology*. 200: p. 1024-1028.

[29] Ahiduzzaman, M. and A.S. Islam, 2016. Preparation of porous bio-char and activated carbon from rice husk by leaching ash and chemical activation. *SpringerPlus*. 5(1): p. 1248.

[30] Rajkovich, S., et al., 2012. Corn growth and nitrogen nutrition after additions of biochars with varying properties to a temperate soil. *Biology and Fertility of Soils*. 48(3): p. 271-284.

**Acknowledgements**

This research was supported by Meajo University’s Graduate school Scholarship and Faculty of Engineering and Agro-industry Maejo University and Research and Researcher for Industries (IRR Contract no. MSD62I0058)