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The Characteristic of Pelleted Broiler Litter Biochar Derived from Pilot Scale Pyrolysis Reactor and 200-Liter-Oil-Drum Kiln

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Abstract
Biochar has been widely accepted as a soil fertilizer and soil conditioner. Pelleted broiler litter (PBL) can be converted to useful biochar which is produced by pyrolysis. In this study, PBL biochar was tested in two type of pyrolysis reactors including a pilot scale reactor (P kiln) and a 200-liter-oil- drum kiln (O kiln), respectively. PBL used in this study was selected from the Siriwan Co. Ltd.' s network broiler chicken (*Gallus gallus domesticus*) farm in Saraburi province, Thailand and controlled its parameters such as domesticated age, material litter, and production cycle. Slow pyrolysis method was conducted with the highest temperature of 500 ºC for 5 hours. The results showed that biochar derived from O kiln (PBLBO) had higher Brunauer-Emmett-Teller (BET) surface area, total pore volume than that of biochar from P kiln (PBLBP) while average pore diameter was not different. Not only PBLBO was enriched with phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) but also contained more organic matter (OM) and cation exchange capacity (CEC). However, PBLBP had higher nitrogen and moisture content. Besides, heavy metals; cadmium (Cd), mercury (Hg), and lead (Pb) were not detected in both biochars. In sum, PBLBO can be used as effective soil fertilizer and soil conditioner and the biochar producing procedure has proved to be simpliest way and lowest cost for socio-economic, self-sustainable, and low carbon agriculture.
Keywords: Biochar, cation exchange capacity, pelleted broiler litter, slow pyrolysis, surface area.

1. Introduction

Humans have recently been aware of harmful effects on environment of utilizing chemicals contained fertilizers. They are synthesized from inorganic substances which consider as sources of natural radionuclides for example, ^{238}U, ^{232}Th, and ^{210}Po (FAO, 2009). Savci (2012) mentions that most chemical fertilizers contain heavy metals such as As, Cd, Cu, Hg, Ni, and Pb. These chemicals are potential threats to water and soil because they can persist for a long period of time in the environment. Furthermore, when they enter the food chain, they can be very dangerous to humans as carcinogens. Therefore, the use of chemical fertilizers has been reduced and later replaced by natural based fertilizers.

Biochar, a solid material obtained from burnt biomass in anoxic condition, has drawn significant attention as a soil amendment and remediation. Being a fertilizer itself, biochar has ability to absorb water and nutrients and remains moist (Lehmann and Joseph, 2009). Biochar can be obtained from several natural wastes especially wastes from livestocks. From Chan et al. (2008) and Uchimiya et al. (2010a) study, broiler litter can be served as effective biochar since the biochar obtained from broiler litter (BLB) has more beneficial effects on improving soil quality and therefore, increasing crop yield than that produced from herbaceous, biomass material. Also, utilizing BLB reduces the waste and litter from livestock production process in the environment. Generally, biochar is studied in the pilot scale pyrolysis reactor, which is not suitable for the needs of rural and local people especially ones in the remoted areas. Consequently, this study was focused on the alternative means of adapting proposed biochar reactor with a 200-liter-oil-drum kiln which villagers are accustomed to using for charcoal production. The experiments were to determine and compare the physical and chemical properties of biochar obtained from both reactors. If the experiments are accorded to the plan, the 200-liter-oil-drum kiln can be a promising application which is cost-effective and easily self-produced by local people for their self reliance and sustainable agriculture.

2. Materials and methods

2.1 Preparation of feedstock

The broiler litter used in this experiment was taken from the Siriwan Company Limited's network broiler chicken (*Gallus gallus domesticas*) from Saraburi province, Thailand based on the recommendation of Suppadit (2009). The farm consisted of five 1,000 m^2 concrete-floored and closed houses with evaporative cooling system that measured 20.0 m wide × 50.0 m long with a stocking density of 17.5 chickens m^{-2}. The floor was covered with rice hull that widely used in chicken farms in Thailand. The production cycle was 50-day period and at the end of its production the broiler litter was removed for the next cycle. Then, the broiler litter was undergone the pelleting process according to the method of Suppadit and Panomsri (2010).

2.2 Preparation of biochar

The combustion of pelleted broiler litter (PBL) was conducted under two conditions which were in pilot scale pyrolysis reactor and 200-liter-oil-drum kiln in order to compare the chemical and physical characteristics of biochar. First, the 200-liter-oil-drum kiln was introduced under the support by the Wihandang Small and Medium Enterprises, Wihandang district, Saraburi province, Thailand. In fact, the oil drum kiln was originally designed for low-cost charcoal burning tank which is a tight seal tank, cut on the top. Placed in horizontal direction, the kiln allows only hot dry air to access and has little fume emitting to the environment. This folk wisdom can ultimately reduce pollution in the atmosphere. The burning process consisted of composition and installation, PBL loading, front kiln composition, and burning (ATA, 2003). After composition and installation, 10 kilograms of PBL was loaded in the kiln and was pre-heated to drive the cool air in the tank and dehydrate the sample at 55 – 60 ºC and 150 ºC, respectively, until the smoke turned white. Then, the wood fuel was continued to burn until the temperature increase up to 500 ºC. The fuel loading was reduced to pertain the heat at 500 ºC. With continuous burning, PBL was heated at 500 ºC for 5 hours. Second, the pilot scale pyrolysis used in this study was tested at Land Development 1st Region, Prathumthani province, Thailand. 10 kilograms of PBL was produced at a 500 ºC pyrolysis temperature based on the recommendation of Lehmann (2007), for 5 hours to generate biochar according to Uzoma et al. (2011). After the pyrolysis process, the reactor was cooled off at room temperature and biochar was collected.

PBL was run 4 times in each reactor to generate PBLBP and PBLBO. PBLBP and PBLBO were randomly sampled for physical and chemical analysis. The biochar production process from both reactors was presented in figure 1.

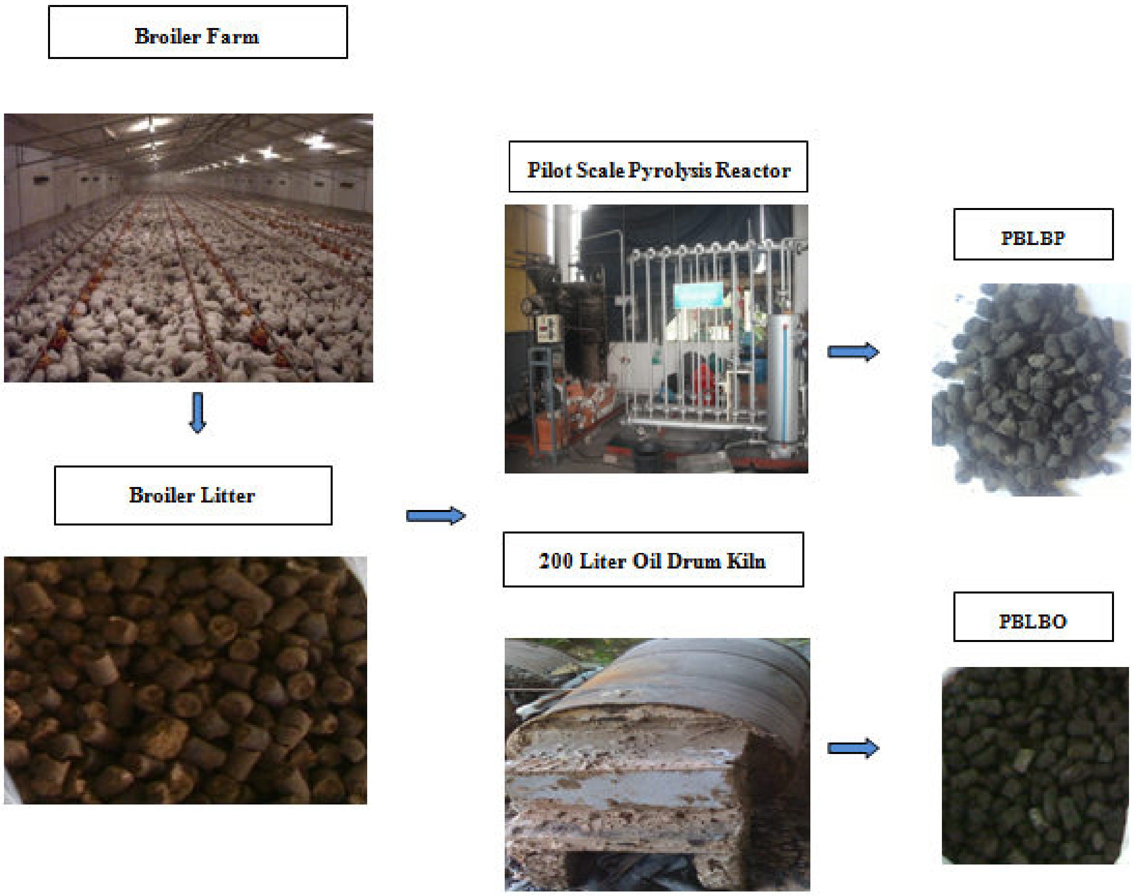

Figure 1. Biochar production process from broiler litter

2.3 Chemical analysis

Both biochars were send to determine the physical and chemical properties at Land Development 1st Region, Prathumtani province, Thailand. Heavy metals composition were measured using the atomic-direct aspiration method for Cd, Hg, and Pb and atomic absorption spectrophotometer (AAS) according to procedures of Tessier et al. (1979). Macronutrients were measured using the inductively coupled plasma atomic emission spectrophotometer according to procedures of AOAC (1970; 1980). The chemical characteristics in terms of EC and pH before and after the experiment were determined in a 1:10 ratio (solid : water extracts) using a conductivity meter (electrical conductivity method) and a pH meter, respectively, according to procedures of Peverill et al. (1999). Cation exchange capacity (CEC) was estimated using an NH_4^+ replacement method according to procedures of Schollenburger and Simon (1945), and the leachates were analyzed for exchangeable cations, including K, Ca, and Mg, according to procedures of Uzoma et al. (2011). Moisture content was determined according to gravimetric method by diluting the biochar with de-ionized water. Then the suspension was heated to about 90 ºC and stirred for 20 minutes to allow the dissolution of the soluble biochar components. The loss-on-ignition (LOI) method used for determination of organic matter (OM) in biochar according to procedures of ASTM (2000).

2.4 Pore size analysis of biochar

Surface area, pore size, and pore volume were determined using N_2 sorption isotherms run on Beckman Coulter SA (TM) 3100 Surface Area and Pore Size Analyzer. The Brunauer-Emmett-Teller (BET) method was used to determine mesopore-enclosed surfaces. Scanning Electron Microscope (SEM) analysis was carried out for both samples using a Joel 6360 OLA, according to procedures of Saleh et al. (2012).

2.5 Statistical analyses

Data were analyzed using t-test analysis of the Statistical Analysis System (SAS version 6.12) to test the differences among the physio-chemical of PBLBP and PBLBO, means at a significance level of $P < 0.05$ (SAS Institute, 1996).

3. Results and Discussion

3.1 Pore analysis

There were significantly different ($p < 0.05$) of the BET surface area, average pore diameter, and total pore volume between PBLBO and PBLBP which PBLBO values showed higher than in PBLBP. The BET surface area, average pore diameter, and total pore volume in PBLBP were 5.20 $m^2\ g^{-1}$, 1.95 nm and 0.00253 $cm^3\ g^{-1}$ while those of PBLBO were 6.41 $m^2\ g^{-1}$, 1.96 nm, and 0.00315 $cm^3\ g^{-1}$. The SEM of surface area of PBLBP and PBLBO were presented in figure 2. The results were also shown in table 1. From the results, BET surface area and total pore volume in PBLBO were higher than in PBLBP but average pore diameter was not much different. Although controlled at 500 ºC, BET and total pore volume yielded higher in PBLBO because the peak temperature produced in PBLBO burning fluctuated higher than 500 ºC as manually experimenting. The peak temperature controls a wide range of properties in biochar production such as volatile matter content, pore structure, surface area and absorption capacity (Antal and Gronli, 2003). Chun et al. (2004) and Chen et al. (2008) explained that biochar produced at low pyrolysis temperatures were more organic in nature and their surfaces had much higher functional polar groups such as –OH, C=C, C-O. With increasing pyrolysis temperature, these polar groups largely diminish, which results in the surface of biochar becoming more hydrophobic. The surface properties of biochar may thereby affect their sorption capacity for nutrient and water (Zheng et al., 2010). Thus, controlling the optimum parameters including the feedstock type, the particle size, and temperature in burning process is vital to determine pore size distribution and its total surface area (Babu and Chaurasia, 2003). The pore analysis showed that the PBLBO was higher resulting in more capability to retain nutrients and moisture.

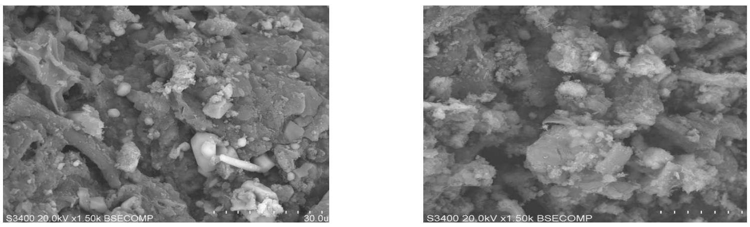

Figure 2. SEM images of PBLBP (left) and PBLBO (right) at 200X Magnification

Table 1. Pore size analysis of broiler litter biochar from PBLBP and PBLBO

Parameter	PBLBP	PBLBO
BET surface area (m^2g^{-1})	5.20[b]	6.41[a]
Average pore diameter (nm)	1.95[b]	1.96[ab]
Total pore volume (cm^3g^{-1})	0.00253[b]	0.00315[a]

Means in the same row with different letters are significantly different at $P < 0.05$.

3.2 Biochar characteristics

The physical and chemical analyses were conducted. The results showed pre and post pyrolysis process and were presented in table 2. Moisture content was higher in PBLBP due to the increasing of the peak temperature in burning process of PBLBO and was significant ($p < 0.05$). Biochar was basic with higher pH in PBLBO as its pH increased. In fact, biochar is alkaline in nature (Suppadit, 2009). The electrical conductivity increased after pyrolysis process and therefore its high salt content. The pH and EC were not differently significant ($p > 0.05$).

Organic matter content decreased due to the evaporation of volatile organic matter with a higher in PBLBO. The measurements of macronutrients were determined. Phosphorus, potassium, calcium, and magnesium contents in PBL were higher after burning. Phosphorus were 4.25 % and 5.33 %; potassium were 5.07 % and 5.26 %, calcium were 5.27 % and 7.38 %; magnesium were 2.17 % and 2.27 % in PBLBP and PBLBO, respectively. These elements were much presented in PBLBO and were significant ($p < 0.05$). However, only nitrogen in the samples relatively lowered from 3.25 % in PBL to 2.97 % in PBLBP and 2.86 % in PBLBO, respectively. The nitrogen measurement was not differently significant but a higher in PBLBP. Bruun (2011) suggests that during pyrolysis the mineral content of the feedstock in concentrated in the biochar product, which ends up containing a considerably higher proportion of ash that may supply important macro- and micronutrients beneficial for the plant and soil microbial community (Bruun, 2011). The cation exchange capacity gained after pyrolysis process and was significant ($p < 0.05$). CEC represents the fertility of biochar. Heavy metals (Cd, Hg, and Pb) were not detected in all samples.

Table 2. Physico-chemical properties of broiler litter biochar from PBLBP and PBLBO

Parameter	PBL	PBLBP	PBLBO
Moisture content	5.99	5.80^{a}	5.25^{b}
pH	6.00	9.40^{a}	9.90^{a}
EC (dS/m)	7.87	10.2^{a}	10.9^{a}
OM (%)	3.97	3.30^{b}	3.37^{a}
N (%)	3.52	2.97^{a}	2.86^{a}
P (%)	2.53	4.25^{b}	5.33^{a}
K (%)	2.71	5.07^{b}	5.26^{a}
Ca(%)	2.37	5.27^{b}	7.38^{a}
Mg (%)	1.22	2.17^{b}	2.27^{a}
CEC (me/100 g)	10.3	17.6^{b}	18.2^{a}
Heavy metal			
Cadmium(mg kg^{-1})	nd	nd	nd
Mercury (mg kg^{-1})	nd	nd	nd
Lead (mg kg^{-1})	nd	nd	nd

nd = not detected (< 0.0001 ppm)

Means in the same row with different letters are significantly different at $P < 0.05$

4. Conclusion

PBLBO provided material for good environmental conditions. PBL undergone in 200-liter-oil-drum kiln has proved in better results from those of pyrolysis. The physical and chemical properties were relatively corresponded with slight differences. The 200-liter-oil-drum kiln can ultimately be alternative application for socio-economic, self-sustainable and low carbon agriculture. Additional field studies on the biochar production procedure with accurate controlled measurements are needed to understand. Additional field studies on the biochar production procedure with accurate controlled measurements are needed to understand.

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