

CHARCOAL AND WOOD VINEGAR FROM PYROLYSIS OF LEAD TREE WOOD AND ACTIVATED CARBON FROM PHYSICAL ACTIVATION

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Abstract

Wood of the Lead tree (*Leucaena Leucocephala*) is pyrolyzed in an Iwasaki kiln to produce charcoal with a graphitic-like structure with a surface area of 329 m²/g. The charcoal is ground into 3 different particle sizes (large, medium, and small) and activated with carbon dioxide to produce activated carbon. The structure, morphology, elemental composition, porosity, and functional groups of the activated carbon samples are compared with the charcoal precursor. The larger particle size of the charcoal gives activated carbon with a larger surface area, up to 609 m²/g. In addition, wood vinegar is collected during the pyrolysis at 3 temperature ranges and extracted by *n*-hexane, diethyl ether, and ethyl acetate. The compositions depend on the collecting temperature. The main components are ketones, organic acids, furan and pyran derivatives, esters, phenols and derivatives, alcohols, and alkanes.

Keywords: *Leucaena Leucocephala*, Lead tree, pyrolysis, carbonization, Iwasaki kiln, charcoal, activated carbon, wood vinegar

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Introduction

The Lead tree (*Leucaena Leucocephala*) is abundant in Thailand, including Nakhon Ratchasima province. It is a fast-growing tree which can be considered a problem because it can inhibit the growth of economic plants. From different origins, Lead tree wood is composed of cellulose (37-41%), hemicellulose (15-20%) and lignin (18-27%) (Antal *et al.*, 2000, Jiménez *et al.*, 2007, Feria *et al.*, 2011). In general, the wood can be converted to charcoal via a slow pyrolysis. For example, hemicellulose and cellulose from Moroccan wood decompose under a nitrogen atmosphere at 180- 240°C and 230- 310°C, respectively, whereas lignin decomposes slowly in a wide range between 150-750°C (Zerriouh and Belkbir, 1995).

As the charcoal from pyrolysis is rich in carbon, it can be modified into activated carbon to increase porosity, internal surface area, and mechanical strength. Activated carbon can be produced from various kinds of wood such as tamarind (Sahu *et al.*, 2010) and walnut and poplar (Heibati *et al.*, 2015).

Activated carbon can be produced by chemical and physical activation. The chemical activation employs chemicals which have to be

washed out and generate waste. On the other hand, physical activation by non-toxic gas such as carbon dioxide (CO₂) is more environmentally friendly. Although the activation may be limited by the size of the charcoal, the operation by CO₂ could be more complete when the charcoal of a small size is used. In this work, the Lead tree charcoal with different particle sizes is activated by CO₂.

Additionally, wood vinegar or pyrolygneous acid is obtained from the condensation of gaseous products during the wood pyrolysis. Wood vinegar is a reddish- brown liquid containing organic acids, phenols, ketones, aldehydes, alcohols, and esters. Alcohols are formed due to the decomposition of cellulose, and organic acids are formed by decomposition of hemicellulose. Moreover, phenols are formed due to decomposition of lignin (Wu *et al.*, 2015). The chemical contents in the liquid depend on the raw material types and the pyrolysis temperature (Wei *et al.*, 2010; Wu *et al.*, 2015). For example, wood vinegar is prepared from the walnut tree and waste from the cultivation of the walnut fruit at temperature ranges of 90-230°C, 230-370°C, and 370-450°C (Wei *et al.*, 2010). The wood

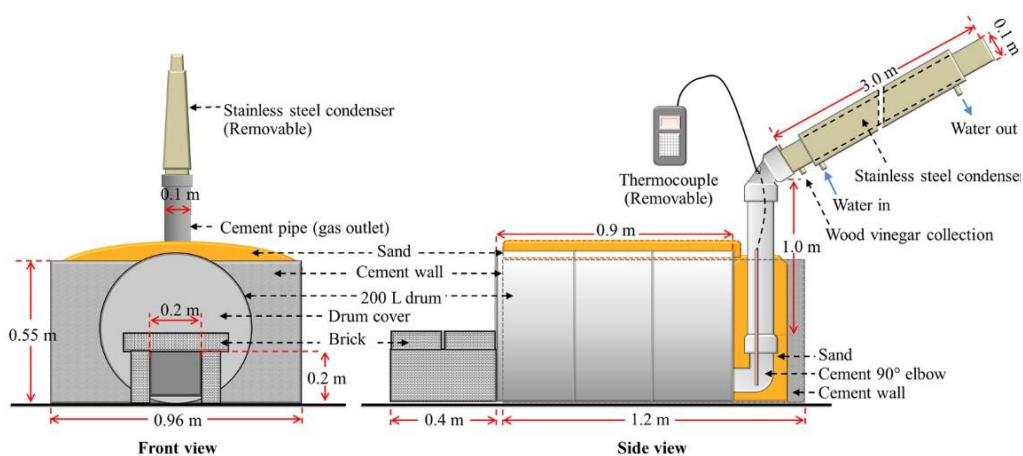


Figure 1. Iwasaki kiln from Energy Ashram: Appropriate Technology Association, Nakhon Ratchasima, Thailand

vinegar from 230-370°C has the highest chemical compositions such as phenols, organic acids, ketones, phenyl ethers, and furans and pyran derivatives. Wood vinegar is widely used to promote plant growth because of various effects against pathogens, microbial infections, and insects. Phenols and organic acids are the main organic compounds which have the strongest antimicrobial activity (Ma *et al.*, 2011).

In this work, we aim to characterize charcoal from pyrolysis of the Lead tree wood in an Iwasaki kiln. Then, it is modified to produce activated carbon. The effect of the charcoal particle size on the properties of the activated carbon is studied. Another goal is to analyze the components of the wood vinegar by-product.

Materials and Method

Configuration of Iwasaki Kiln

Pyrolysis of Lead tree wood is carried out in an Iwasaki kiln by courtesy of Energy Ashram: Appropriate Technology Association (Nakhon Ratchasima, Thailand). The components are illustrated in Figure 1. The kiln is built from a 200-L drum with dimensions of 0.58 m diameter and 0.9 m height. A removable drum cover has dimensions of 0.2 m width and 0.2 m height and is connected by 4 bricks to the entrance of the drum. The cement pipe outlet, equipped with a mobile thermocouple, pipelines the vaporized product into a 3-meter stainless steel condenser. The drum is surrounded by a cement wall which is filled with sand. The sand on top of the kiln is removed after the

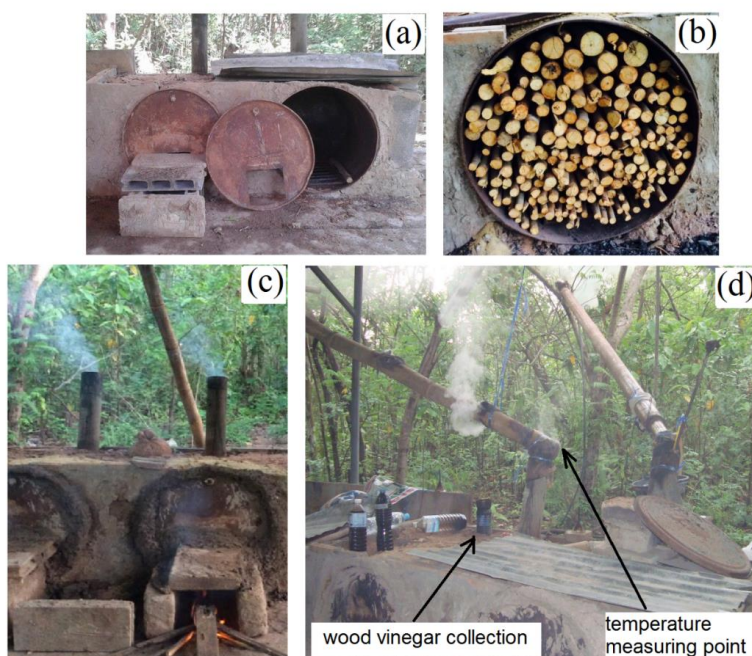


Figure 2. Iwasaki kiln and pyrolysis process: (a) front view before packing, (b) after packing with Lead tree wood, (c) after the fire ignition, and (d) showing long condenser tube, point of wood vinegar collection, and point of temperature measurement

pyrolysis is terminated to allow the kiln to cool down.

Pyrolysis Process and Collection of Wood Vinegar

Lead tree wood is obtained locally near the university. The fresh wood with a diameter around 2 to 5 cm is cut into lengths of approximately 80 cm, sundried in the open air for a month, and packed into the kiln (Figure 2(a) and 2(b)). After the kiln is loaded, the firewood at the front of the stove is ignited and completion of this step is indicated by the presence of opaque white smoke.

Then, the kiln front is closed and the 3-meter stainless steel condenser is connected to the outlet where the temperature is measured (Figure 2(c) and 2(d)). The carbonization temperature inside the kiln is around 300–400°C. The kiln is left overnight and the charcoal is collected the next day. At the beginning of the carbonization process, the gaseous products are condensed to wood vinegar under a continuous water flow and collected based on the temperature of the smokestack in three ranges: 80–85°C, 110–115°C, and 140–145°C. Their pH values are 3.0, 3.5, and 4.0, respectively. After collection, the wood vinegar is stored in a fridge at 5°C until extraction. From 70.3 kg of Lead tree wood, 17.1 L of wood vinegar are collected

from all temperature ranges and 13.8 kg of charcoal are obtained.

Preparation of Activated Carbon from Charcoal

Activated carbon is prepared by a procedure modified from the literature (Ngernyen *et al.*, 2006). The obtained charcoal is ground with a ball mill, sieved, and classified into 3 different sizes: large (L, between 2.36 mm and 1.70 mm), medium (M, between 1.70 mm and 250 μ m), and small (S, less than 250 μ m). The charcoal is dried at 100°C overnight in a hot-air oven. Then, the dried charcoal (4 g) is filled into a ceramic boat, placed at the middle of a horizontal tube furnace (Carbolite Gero Ltd., Hope Valley, UK) with a length of 122.2 cm and internal diameter of 3.8 cm, and purged with nitrogen gas for about 15 min. The setup of the activating equipment is shown in Figure 3. The temperature is increased from room temperature to 800°C at the heating rate of 10°C/min under the flow of nitrogen (100 mL/min, Lind Gas, 99.995%). Then, the nitrogen flow is stopped, and carbon dioxide (Lind Gas, 99.9%) is introduced into the furnace at the constant flow rate of 100 mL/min and held for 1 h. After that the power is switched off, and the furnace is cooled to ambient temperature under the flow of nitrogen. The obtained activated carbon is collected and stored in

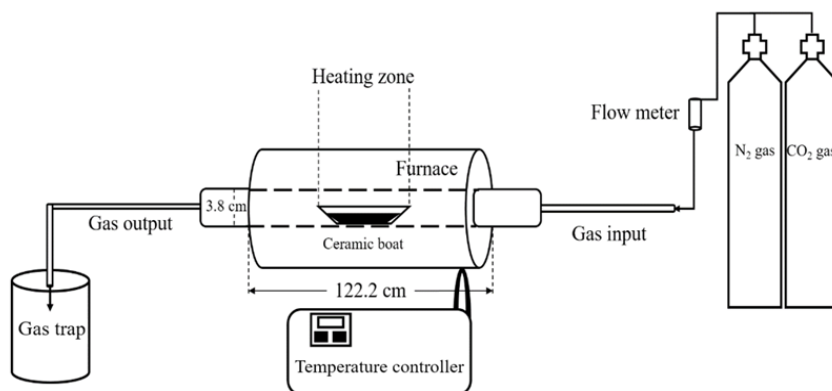


Figure 3. A horizontal tube furnace for preparation of activated carbon

a desiccator for further analysis. The samples from the large, medium, and small charcoal particles are named L-AC, M-AC, and S-AC, respectively.

Characterization of Charcoal and Activated Carbon

The morphologies of the charcoal and activated carbon are analyzed by scanning electron microscopy (SEM) with a JEOL model JSM-6400 (JEOL Ltd., Tokyo, Japan) running with an electron beam accelerating the voltage of 20 kV, the vacuum pressure of 10^{-4} Pa, and a tungsten filament. The thermal stability of the charcoal is studied by thermogravimetric analysis (TGA) on an SDT 2960, TGA-DTA (TA Instruments, New Castle, DE, USA). Approximately 10 mg of the sample is placed on an aluminum pan and heated from 30°C to 900°C with the heating rate of 20°C/min under N₂ gas with the flow rate of 100 mL/min.

The charcoal and activated carbon are also analyzed by X-ray diffraction (XRD) with an AXS D8 diffractometer (Bruker Corp., Billerica, MA, USA) using Cu K α radiation with Ni filtered at 40 kV and 40 mA with the step increment of 0.02 degree and step time of 0.5 s. The elemental composition is determined by elemental analysis (TruSpec Micro CHNO/S analyzer, LECO Corp., St. Joseph, MI, USA).

Nitrogen adsorption-desorption isotherms are obtained from a BELSORP-mini II (MicrotracBEL Corp., Osaka, Japan). Before analysis, about 0.15 g of each sample is purged with helium and then pretreated at 150°C under a vacuum system. The surface area and pore size distribution are obtained from the Brunauer-Emmett-Teller (BET) method and non-local density functional theory method, respectively.

The functional groups of the samples and the nature of the carbon are studied by Fourier-

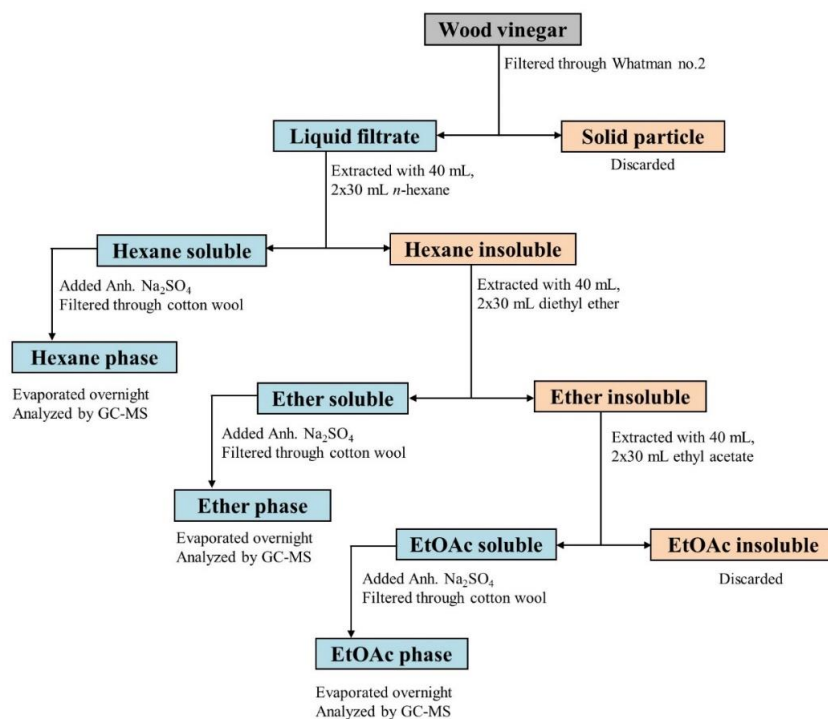


Figure 4. Scheme of extraction of Lead tree wood vinegar

transform infrared spectroscopy (FT-IR) and Raman spectroscopy using a Tensor 27 FTIR Spectrometer (Bruker Corp.). About 0.03 mg of the sample is mixed with a small amount of dried KBr, ground, and pressed with a hydraulic press. The sample is put on a sample holder and measured in the following conditions: resolution of 4 cm^{-1} , sample scans of 500 at 120 mW, and scan from $400\text{--}4000\text{ cm}^{-1}$ for the FT-IR mode and $900\text{--}3600\text{ cm}^{-1}$ for the Raman mode.

Extraction and Analysis of Wood Vinegar

The refrigerated wood vinegar is allowed to warm to room temperature (in about 2 h) and filtered through Whatman paper no. 2. The filtrate volume of 100 mL is extracted 3 times with *n*-hexane with volumes of 40, 30, and 30 mL, respectively. After extraction, the *n*-hexane layer is collected in an Erlenmeyer flask, added with anhydrous sodium sulfate (Na_2SO_4) to remove the water, and filtered through cotton wool. The aqueous layer is separated again with the same ratio of the extracting solvents of diethyl ether and ethyl acetate, as shown in Figure 4, respectively.

The 3 collected fractions are evaporated overnight at room temperature and filtered through nylon syringe filters to be analyzed by gas chromatography-mass spectrometry (Gas Chromatograph 450-GC with Mass Spectrometer 320-MS, Bruker Corp.) with a splitless mode, fused silica capillary column stabilwax, and helium as a carrier gas with the flow rate of 1 mL/min. The column is heated from 35°C to 100°C with the rate $3^\circ\text{C}/\text{min}$ and to 240°C with the rate $5^\circ\text{C}/\text{min}$, and then held for 10 min. The injection port temperature is 250°C . Detection is carried out by electron ionization mass with ionization energy of 70 eV and the mass acquisition range of 30–400 amu (Chinnici *et al.*, 2009). Organic components are identified by matching the retention time and mass spectra with library data of the mass spectra (NIST). Although the quantitative analysis is not conducted, the peak areas imply the quantity. The relative peak area (%) is calculated as the following equation:

$$\text{Relative peak area (\%)} = \frac{\text{Peak area of interested compound} \times 100}{\text{Total intergrated peak area}} \quad (1)$$

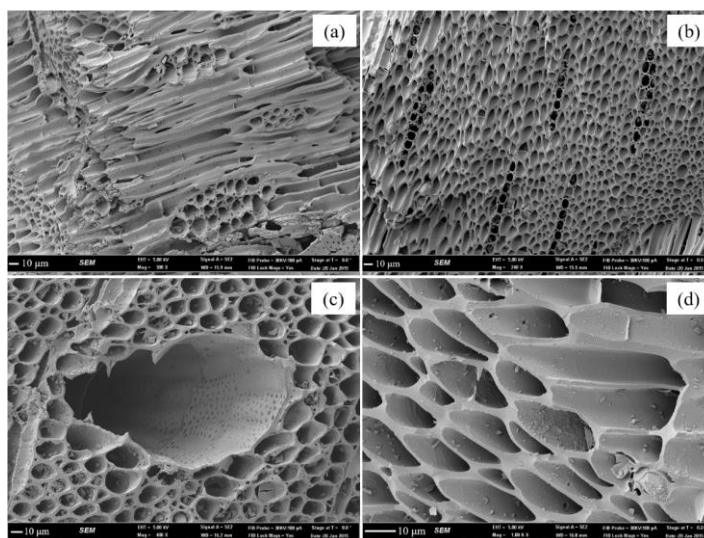


Figure 5. SEM images (a-d) of charcoal from Lead tree wood showing rough external surfaces and various pore sizes

Results and Discussion

Composition, Morphology and Thermal Stability of Lead Tree Charcoal

SEM images of the charcoal at different points on the charcoal's surface are shown in Figure 5(a-d) displaying a rough external surface and various pore sizes. Figure 5(b) shows a pore size of approximately 10 μm and a wall thickness of approximately 3 μm . Figure 5(c) also shows pores with diameters of approximately 10-40 μm . Some pores partially contain non-uniform particles. In addition, Figure 5(c) shows a macropore which contains small pores on its wall. Figure 5(d) shows particles on the pore wall.

A thermogram of the Lead tree charcoal under inert gas is shown in Figure 6. The decrease between 50-150°C corresponds to the removal of the moisture. Then, the weight loss occurs slightly until approximately 350°C when the decrease occurs gradually until the final temperature. Although the charcoal is obtained from pyrolysis in the Iwasaki kiln, the weight loss indicates that the pyrolysis is not complete. This is consistent with the elemental analysis indicating that the charcoal still contains oxygen (Table 1). Thus, further decomposition of the carbon fiber, cellulose, hemicellulose, and lignin can take place. The degradation of the hemicellulose and cellulose takes place around 300°C and 350°C, respectively (Poletto

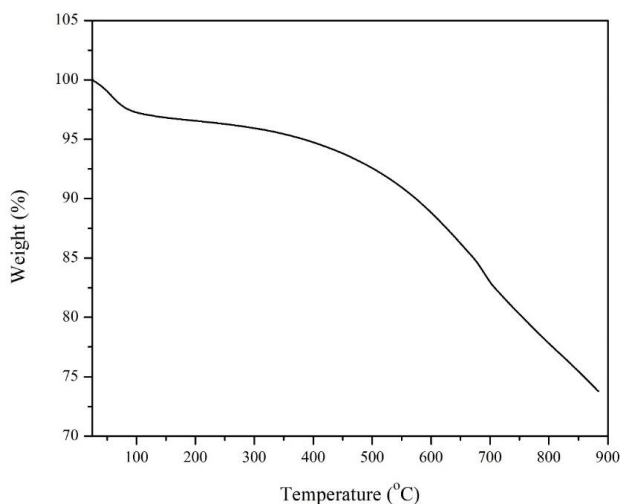


Figure 6. TGA thermogram of charcoal from Lead tree wood

Table 1. Elemental analysis of Lead tree charcoal and activated carbon

Sample	Elemental composition (%)					C/H
	C	H	N	S	O	
M-Charcoal	80.99	3.123	0.941	0.032	9.592	25.93
L-AC	80.09	1.710	1.049	0.008	8.353	46.84
M-AC	81.87	1.151	1.118	0.029	8.209	71.13
S-AC	86.94	1.518	0.961	0.016	6.122	57.27

et al., 2012). The degradation of lignin occurs between 250°C and 500°C.

Elemental compositions of the charcoal with medium-sized particles (M-charcoal) and activated carbon samples from charcoal particles with different sizes are shown in Table 1. The main component of M-charcoal is C followed by O with a trace of H, N, and S. The high C content or C/H ratio indicates that pyrolysis in the Iwasaki kiln converts hydrocarbon compounds to carbon via graphitization (Hou *et al.*, 2015). After the M-charcoal is activated by CO₂, the corresponding activated carbon (M-AC) has a slight increase of carbon content due to the removal of other elements. Among the activated carbon samples, the higher C content is

obtained from the charcoal with a smaller size. The range of C, O, N, and H from this work is in line with activated carbon samples from the Lead tree wood which are produced by combined chemical and physical activation (Hou *et al.*, 2015).

Figure 7 displays SEM images of activated carbons prepared by physical activation with the sample sizes of large (Figure 7(a) and 7(b)), medium (Figure 7(c) and 7(d)), and small (Figure 7(e) and 7(f)). The morphology of the activated carbon is similar to that of the charcoal precursor, containing pores with various diameters. After activation, some particles on the surface and in the pores are removed. This could lead to a larger surface area.

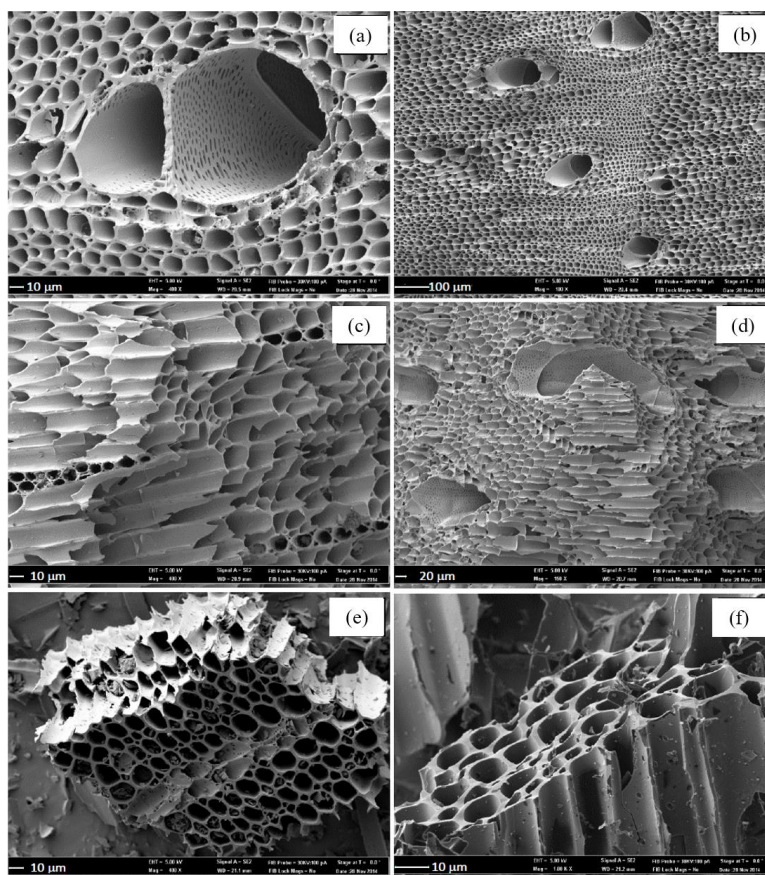


Figure 7. SEM images of activated carbons from various charcoal sizes of (a, b) large, (c, d) medium, and (e, f) small

XRD patterns of the Lead tree charcoal and activated carbon from various charcoal particle sizes are shown in Figure 8. Two broad diffraction peaks are observed at 24° and 43°

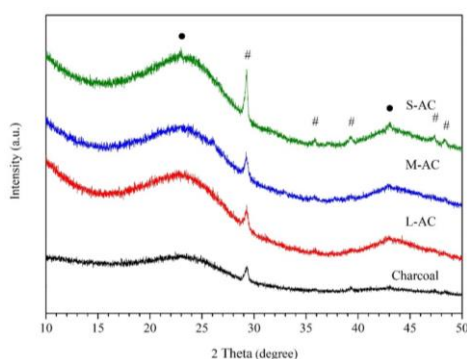


Figure 8. XRD patterns of charcoal and its derived activated carbon of charcoal from Lead tree wood

corresponding to (002) and (100) reflection planes of a graphitic-type lattice in graphitic carbon. This (100) reflection indicates a limited degree of graphitization (Xu *et al.*, 2014). The diffraction peaks (#) at 29.3° , 36.7° , 39.3° , 47.2° , and 48.2° corresponding to calcium carbonate, also called calcite, are observed (Xu and Poduka, 2014). When lignocellulosic materials are burnt, calcium oxalate crystals (monoclinic whewellite, $\text{CaC}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$, or quadratic weddellite, $\text{CaC}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$) are converted into calcium carbonate with the temperature range of $430\text{--}510^\circ\text{C}$ (Brochier and Thimon, 2003). This calcium species is commonly found in the ash of biomass (Raveendran *et al.*, 1995). The peaks of calcium carbonate increase when the particle of charcoal is smaller. To confirm the existence of calcium carbonate, the particle in the pore is analyzed by EDX. Figure 9(a) shows the SEM image and EDX spectrum of activated carbon containing particles which are calcium carbonate (see Figure 9(b) and 9(c)).

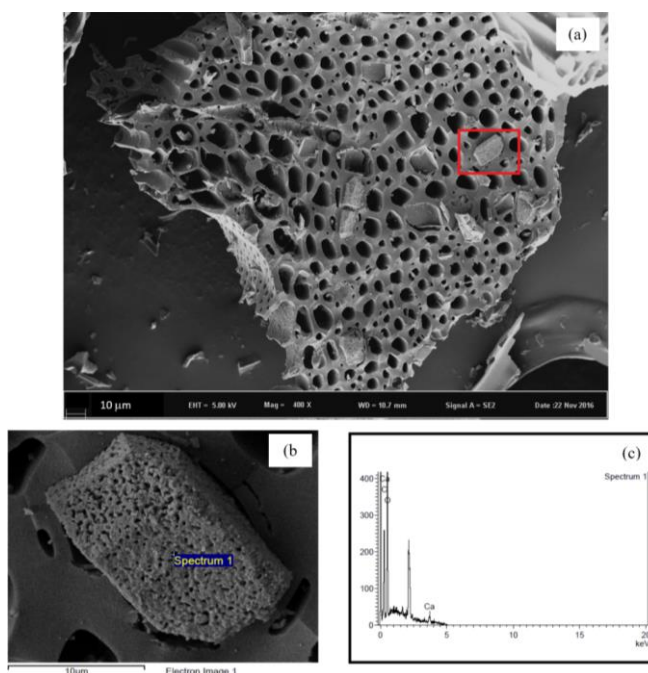


Figure 9. SEM image of (a) representative activated carbon, (b) EDX measurement area, and (c) its EDX spectra

Porosity of the charcoal is confirmed by nitrogen adsorption-desorption analysis as shown in Figure 10 and Table 2. The isotherm is type I according to the IUPAC classification

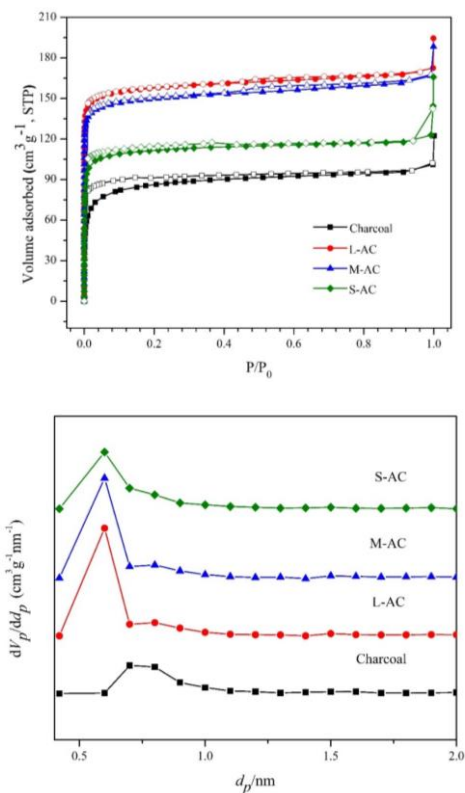


Figure 10. (a) N₂ adsorption isotherms and (b) pore size distributions of activated carbon; filled: adsorption, and empty: desorption

(Thommes *et al.*, 2015). This indicates that the microporous topology of the produced carbon material is generated during the pyrolysis (Moreno-Piraján *et al.*, 2010). The specific surface area (S_{BET}) is 329 m²/g. The long-time carbonization transforms micropore to mesopore resulting in obtaining both microporous and mesoporous volumes. These properties are suitable for further use as an absorbent and support material.

N₂ adsorption-desorption isotherms of the Lead tree charcoal and activated carbon samples are shown in Figure 10. The surface areas and pore volumes are reported in Table 2. All samples also have a type I isotherm according to the IUPAC classification indicating that the micropores are dominant (Thommes *et al.*, 2015). All activated carbon samples have higher surface areas than the charcoal precursor attributed to an increase of pore volumes after the removal of particles in the pores. The particle size of the charcoal has an influence on the surface area of the corresponding activated carbon, so that the larger charcoal size gives activated carbon with a larger surface area.

Figure 11 shows the FT-IR spectra of the charcoal and activated carbon samples. All samples have band positions similar to the literature (Ozdemir *et al.*, 2014). The broad band around 3400 cm⁻¹ corresponds to -OH stretching vibration of alcohol, and phenol or carboxylic acid.

This band is more intense in the activated carbon suggesting that the activation by CO₂ could increase the hydroxyl groups. The small peaks at 2910 and 2820 cm⁻¹ in the spectra of

Table 2. Results from N₂ adsorption-desorption analysis of charcoal and activated carbon by physical activation (with CO₂ at 800°C, 1 h) including BET surface area (S_{BET}), micropore volume (V_{micro}), mesopore volume (V_{meso}), total pore volume (V_{total}), and mean pore diameter (D_n)

Sample	S_{BET} (m ² /g)	V_{micro} (cm ³ /g)	V_{meso} (cm ³ /g)	V_{total} (cm ³ /g)	D_n (nm)
Charcoal	329	0.143	0.036	0.156	1.89
L-AC	609	0.267	0.034	0.266	1.75
M-AC	593	0.253	0.038	0.258	1.74
S-AC	431	0.189	0.026	0.190	1.76

L-AC represent C-H stretching vibration of aliphatic C-H bonds (Ozdemir *et al.*, 2014). The results are consistent with the elemental analysis indicating that small quantities of H and O are detected from all samples. The bands around 1600 and 1500 cm^{-1} are assigned to C=C aromatic ring stretching vibration (Ozdemir *et al.*, 2014). The broad band in the region of 1300 to 1000 cm^{-1} may be ascribed to the combination of C-O bonds in acids, alcohols, phenols, ethers, or ester groups in the precursor fiber (Liu *et al.*, 2016). The peaks between 900 and 650 cm^{-1} are observed from the charcoal precursor corresponding to C-H out-of-plane bending vibration of the aromatic rings. Those peaks are barely observed from the activated carbon samples as a result of the decrease of H. The peak at 878 cm^{-1} can be assigned to isolated H in the aromatic rings (Liu *et al.*, 2016). The IR results agree with the elemental analysis that the charcoal and

activated samples still contain hydrogen and oxygen.

The nature of carbon in activated carbons, especially the distribution and state of sp^2 bonded carbon, is analyzed by Raman spectroscopy. Figure 12 shows the Raman spectra of the activated carbon samples. The spectra have 3 main characteristic bands being the disorder, D-band at 1350 cm^{-1} , the graphite, G-band at 1585 cm^{-1} , and 2D-bands at around 2700 cm^{-1} . The G peak is contributed to the C-C bond stretching of all pairs of sp^2 atoms in both rings and chains. Thus, the G peak is the main Raman signature for sp^2 carbon. The D band is attributed to in-plane vibrations of sp^2 bonded carbon within structural defects (Rhim *et al.*, 2010). All of the samples show band shifts of D, G, and 2D confirming that they contain graphitic carbon. The weak intensities indicate poor crystallinity, consistent with the XRD results.

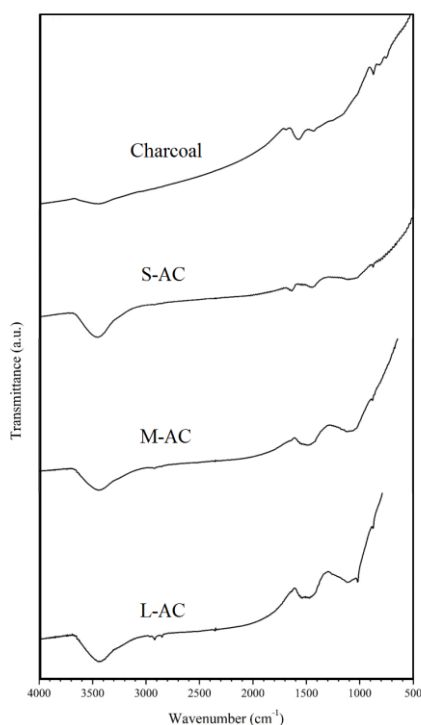


Figure 11. FTIR spectra of charcoal and activated carbons

Chemicals in Lead Tree Wood Vinegar

The appearance of the wood vinegar collected at various temperatures is displayed in Figure 13(a). As the temperature increases, the color of the vinegar becomes darker. Table 3 displays the chemicals in the Lead tree wood vinegar and relative amounts based on the peak area. Due to the complicated composition and changes that may happen during the storage period, the fraction collected at a higher temperature is darker in color with some black

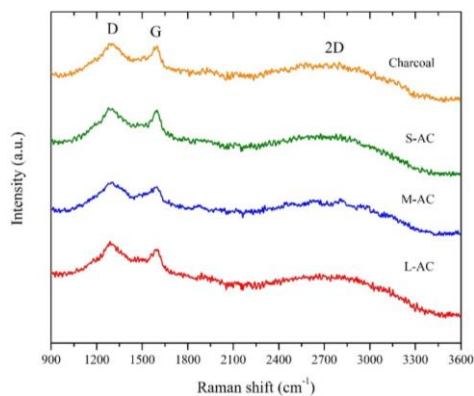


Figure 12. Raman spectra of charcoal and activated carbons

residue on the top. During the storage, the wood vinegar has 2 separate layers. The bottom layer has a darker color. Consequently, we believe that it is neither worthwhile nor reliable to determine the actual quantity of each compound. The main compounds are ketones, organic acids, furan and pyran derivatives, esters, phenols and derivatives, alcohols, and alkanes. Distribution of the main organic compounds from extraction by each solvent is shown in Figure 13(b). Acids are the major components from the extraction by ethyl acetate and diethyl ether, whereas alkanes are extracted well by *n*-hexane. In general, the composition and distribution of the compounds in wood vinegar vary with the types of wood (Wu *et al.*, 2015). The difference between wood vinegar from the Lead tree and other plant material, for example from walnut tree branches (Wei *et al.*, 2010) and fir sawdust

(Wu *et al.*, 2015), is that the vinegar from this work contains alkanes.

Conclusions

Charcoal from Lead tree wood is obtained from pyrolysis in an Iwasaki kiln, crushed to different particle sizes, and further modified to activated carbon by physical activation with carbon dioxide. The activated carbon samples have a similar morphology to the charcoal precursor but with more open pores and higher surface areas. All samples have a graphitic structure with low crystallinity. They show adsorption isotherm type I.

The activated carbon from the larger charcoal particle size has a larger surface area. Functional groups of the charcoal and activated carbon include -OH, C-O, aliphatic and aromatic C-H, and graphitic C=C bonds in good agreement with elemental analysis. Moreover, wood vinegar is collected at various temperatures during the pyrolysis of the Lead tree wood. After extraction with *n*-hexane, diethyl ether, and ethyl acetate, the compounds are analyzed by GC-MS. The main compounds are ketones, organic acids, furan and pyran derivatives, esters, phenols and derivatives, alcohols, and alkanes.

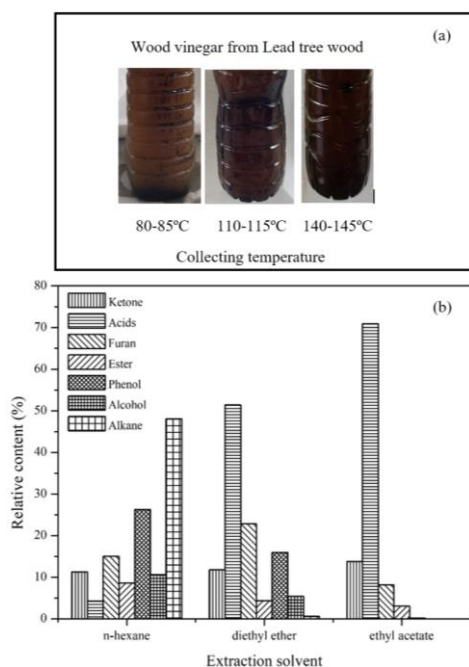


Figure 13. (a) Appearance of wood vinegar at various collecting temperatures and (b) extraction ability of different extraction solvents on the main components in wood vinegar

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Table 3. Chemicals in wood vinegar collected with varied outlet temperatures

No.	Compounds	Relative peak areas (%)		
		80-85°C	110-115°C	140-145°C
<i>Ketones</i>				
1	Propan-2-one (C ₃ H ₆ O)	1.13	0.51	1.06
2	1-Hydroxy-2-propanone (C ₃ H ₆ O ₂)	1.52	1.80	1.94
3	2-Methyl-2-cyclohexen-1-one (C ₇ H ₁₀ O)	1.23	1.03	0.99
4	2-Methyl-2-cyclopenten-1-one (C ₆ H ₈ O)	0.81	1.17	1.13
5	1-Hydroxy-2-butanone (C ₄ H ₈ O ₂)	1.08	0.66	0.66
6	1-(Acetyloxy)-2-propanone (C ₅ H ₈ O ₃)	1.07	0.99	1.21
7	3-Methyl-2-cyclopenten-1-one (C ₆ H ₈ O)	0.53	0.50	0.68
8	Methyl cyclopentenolone (C ₆ H ₈ O ₂)	1.02	0.96	1.18
<i>Organic acids</i>				
9	Acetic acid (C ₂ H ₄ O ₂)	31.76	36.15	36.40
10	Propanoic acid (C ₃ H ₆ O ₂)	2.22	2.06	2.11
11	Butanoic acid (C ₄ H ₈ O ₂)	1.50	1.24	1.45
<i>Furans and pyran derivatives</i>				
12	Furfural (C ₅ H ₄ O ₂)	1.73	1.92	1.14
13	1-(Furan-2-yl)ethan-1-one (C ₆ H ₆ O ₂)	0.77	1.14	1.04
14	Tetrahydro-2-furanmethanol (C ₅ H ₁₀ O ₂)	3.43	3.72	4.33
15	2-Furanmethanol (C ₅ H ₆ O ₂)	5.34	4.65	5.02
<i>Ester</i>				
16	Ethyl acetate (C ₄ H ₈ O ₂)	4.25	1.76	1.28
<i>Phenol and derivatives</i>				
17	2-Methoxyphenol (C ₇ H ₈ O ₂)	4.28	1.49	6.47
18	2-Methoxy-4-methylphenol (C ₈ H ₁₀ O ₂)	1.59	2.45	2.35
19	2-Methylphenol (C ₇ H ₈ O)	0.51	0.72	0.95
20	Phenol (C ₆ H ₆ O)	2.21	1.48	2.10
21	4-Ethyl-2-methoxyphenol (C ₉ H ₁₂ O ₂)	0.85	1.43	1.34
22	3-Methylphenol (C ₇ H ₈ O)	0.65	0.51	0.74
23	2,6-Dimethoxyphenol (C ₈ H ₁₀ O ₃)	1.54	1.39	1.31
24	3-Methyl-1,2-benzenediol	0.67	0.70	0.68
25	Benzene-1,2-diol	1.11	1.06	1.24
<i>Alcohol</i>				
26	Methanol (CH ₃ OH)	4.40	2.90	1.48
<i>Alkanes</i>				
27	2-Methylpentane (C ₆ H ₁₄)	1.40	1.07	0.73
28	Methylcyclopentane (C ₆ H ₁₂)	21.39	24.54	18.97
	Total (%)	100.00	100.00	100.00

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