Preparation of Activated Carbon from Various Biomasses by Single-Stage Pyrolysis

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Abstract. Nowadays, activated carbon were successfully synthesized from biomass. Activated nanoporous carbon have been widely for several applications such as solution to air pollution, solution to water pollution. In this work, study the effects of pyrolysis temperature of activated carbon synthesized from coconut shell, coconut leaves, coconut bracts, cattail flower, cattail leaves, mangosteen bracts, durian bracts, corn leaves, eucalyptus bracts, sugarcane leaves and toddy palm bracts. The pyrolysis of various biomass was studied at the temperature of 700-900 °C for 2 h under N₂ flow of 100 ml/min. The results showed that biomass types and pyrolysis temperature affects the structural and physicochemical properties of activated carbon such as pore structures, surface functional groups and elemental compositions. Activated carbon obtained at 800 °C for 2 h had the highest composed of amorphous phase, porosity and surface area.

1. Introduction

Biomass is an abundant renewable energy resource that can be converted to fuel and chemicals via thermochemical processes (pyrolysis processes, gasification processes, hydrothermal process). Pyrolysis has been considerably applied as an encouraging platform valorize various types of biomass and this process is very dependent on the moisture content of the feedstock, which should be around 10%. At higher moisture contents, high levels of water are produced and at lower levels there is a risk that the process only produces dust instead of oil. High-moisture waste streams require drying before subjecting to pyrolysis. The biomass pyrolysis process consists of both simultaneous and successive reactions when organic material is heated in a non-reactive atmosphere. Thermal decomposition of organic components in biomass starts at 350 °C–550 °C and goes up to 700 °C–900 °C in the absence of air. The chains of carbon, hydrogen and oxygen compounds in biomass break down into smaller molecules in the form of gases, biochar, bio-oil and biochar under pyrolysis conditions. Rate of decomposition of each of these components depends on the process parameters of the reactor temperature, biomass heating rate, pressure, reactor configuration and type of biomass. Moreover, the
biochar can be fabricated to activated carbon have been widely for several applications such as solution to air pollution, solution to water pollution, use as adsorbents and catalyst supports.

The agricultural bio-waste such as coconut shell, coconut leaves, cattail leaves, mangosteen bracts, durian bracts, corn leaves, eucalyptus bracts, sugarcane leaves and toddy palm bracts with low combustion value and potential damage to the environment. However, the various biomass can be converted into biochar through the pyrolysis at high temperatures. Therefore, pyrolysis of the lignin-rich biomass in an inert atmosphere yield highly porous carbon and larger surface areas. This work comparatively studied preparation of activated porous carbon from various biomasses by single-stage. Biomass types and pyrolysis temperature affect the structural and physicochemical properties of activated porous carbon such as pore structures, surface functional groups and elemental compositions.

2. Experimental

2.1. Material
Coconut shell, coconut leaves, cattail leaves, mangosteen bracts, durian bracts, corn leaves, eucalyptus bracts, sugarcane leaves and toddy palm bracts used for preparation of activated carbon were obtained locally. The precursor was first wash with distilled water, dried, crushed. Then precursor was dried in oven at 100 °C for 10 h and allowed to carbonized in 700-900 °C for 2 h under N₂ flow of 100 ml/min.

2.2. Synthesis of activated porous carbon
The pyrolysis experimental were conducted in a stainless steel vertical tubular reactor placed in a tube furnace at 700 °C, 800 °C and 900 °C for 2 h under N₂ flow of 100 ml/min.

![Figure 1. Schematic of biomass pyrolysis](image)

2.3. Characterization
The surface functional groups of biochar were characterized using the crystalline structures of char were analyzed using the X-ray diffraction (XRD, Rigaku). The Fourier Transform Infrared Spectrometer (FTIR, PerkinElmer Scientific) was recorded between wave number of 400 cm⁻¹ and 4000 cm⁻¹. The information about the structure of char were analyzed using the Raman spectrometer (Thermo Fisher Scientific). The surface microstructures of activated carbon were analyzed using the scanning electron microscope (SEM)

3. Results and discussion

3.1. XRD Analysis
The crystallinity of the activated porous carbon were characterized by the XRD analysis. The broad peaks the broad peaks at around 2θ = 20–30° due to the aliphatic chain were observed for the alkali
lignin and its carbon. Pyrolysis of the alkali lignin represented the graphitization process and the alkali lignin carbons had the amorphous carbon structures. As shown in Figure 2, there were an obvious diffraction peak at 29° and 49° represented the formation of carbon. Furthermore, the broad peak at around 42° represented the formation of graphite.

Figure 2. XRD peak of activated carbon of A) coconut shell B) coconut leaves C) coconut bracts. D) cattail flower E) cattail leaves and F) mangosteen bracts.
**Figure 3.** XRD peak of activated carbon of A) durian bracts B) corn leaves C) eucalyptus leaves. D) sugarcane leaves and E) toddy palm bracts.
3.2. FTIR Analysis

The FTIR spectra indicate that activated carbon is dominated by functional groups typical of oxygenated hydrocarbons, reflecting the structure of cellulose hemicelluloses and lignin. The pyrolysis process can cause the disappearance of absorption bands characteristic of raw material and the appearance of new bands typical of activated carbon samples. In Figure 13-18, The band at around 650-690 cm$^{-1}$ were attributed to the presence of bending vibration of C–H bond. The band occurring at 1033 cm$^{-1}$, 1114 cm$^{-1}$ were attributed to aromatic C–O stretching of ester groups in cellulose and hemicelluloses and the band occurring at 1061 cm$^{-1}$ was attributed to C=O stretching of ketones, aldehydes and esters. The band centered at 1278 cm$^{-1}$ was attributed to the presence of C–O–C groups and ethers, phenolic associated with lignin. The band occurring at 1735 cm$^{-1}$ was attributed to C=O stretching of ketones, aldehydes and esters.

The effect of temperature on activated carbon structure and functional groups, The activated carbon produced at high temperatures exhibits a highly hydrophobic nature with well-organized C layers. However, it is characterized by lower contents of H- and O-containing functional groups due to dehydration and deoxygenation of the biomass. As a result, the structure of activated carbon appears to have more organized C layers and less content of surface functional groups when pyrolysis temperature increases.

**Figure 4.** FTIR peak of activated carbon of A) sugarcane and coconut shell B) coconut leaves and coconut bracts C) toddy palm bracts and Durian peel and D) cattail flower and mangosteen bracts
3.3. Raman Analysis

Raman spectroscopy is a technique widely used for analyzing carbon based materials due to its sensitivity to different carbon structures. It can be used to obtain quality of activated carbon by means of G-band and D-band. While G-peak observed in approximately 1550-1600 cm\(^{-1}\) indicates the degrees of the graphitization of carbon, D-band is a measurement of the structural defects. Therefore, D/G ratio is the ratio of intensity at D (defect) and G (graphite) band. \(I_D/I_G\) ratio of carbon have been reported to be around 0.86 to 1.20. From table 1 shown, Activated carbon obtained at 800 °C had the highest \(I_D/I_G\) ratio.
Figure 7. FTIR peak of activated carbon of A) toddy palm bracts and durian peel B) cattail flower and mangosteen bracts and C) cattail leaves and corn.
Table 1. $I_D/I_G$ ratio of activated porous carbon from various biomasses

| Biomasses      | $700 \degree C$ | $800 \degree C$ | $900 \degree C$ |
|----------------|------------------|------------------|------------------|
| Corn leaves    | 1.017            | 1.179            | 1.048            |
| Sugarcane leaves | 0.992           | 1.206            | 1.052            |
| Cattail leaves | 1.022            | 1.181            | 1.123            |
| Cattail flower | 0.956            | 1.154            | 1.149            |
| Coconut leaves | 0.931            | 1.327            | 1.064            |
| Coconut bracts | 1.118            | 1.171            | 1.112            |
| Coconut shell  | 0.986            | 1.087            | 1.027            |
| Mangosteen bracts | 0.986       | 1.221            | 1.087            |
| Eucalyptus peels | 1.086           | 1.085            | 1.098            |
| Toddy palm bracts | 1.012         | 1.069            | 1.048            |
| Durian peels   | 1.040            | 1.104            | 1.072            |

3.4. SEM analysis
The morphology of activated carbon from various biomasses after the single-stage pyrolysis is presented in Figure 8. Woody biomass primarily comprises residues from forestry and trees. The characteristics of woody biomass are low moisture, low ash, high calorific value and high bulk density. Non-woody biomass consists of agricultural crops and residues, animal waste, urban and industrial solid waste. It is considered to have high moisture and high ash content, lower calorific value, low bulk density and higher voidage. The effect of pyrolysis were procedures caused generation of cracks, crevices, defects, vacancies and new pores in the carbon matrix. The sample after the single-stage pyrolysis were more homogenous and well structured.
4. Conclusions

The activated porous carbon from various biomasses were synthesized by single-stage pyrolysis. The moisture of lignin and cellulose content in biomass have considerable influence on activated carbon formation. These can be attributed to the presence of different organic constituents in feedstock. The FTIR analysis confirmed the effect of temperature on activated porous carbon structure and functional groups. The activated porous carbon produced at high temperatures have the structure of activated porous carbon appears to have more organized C layers and less content of surface functional groups when pyrolysis temperature increases. The raman analysis showed activated porous carbon obtained at 800 °C were highly composed of amorphous phase more than activated porous carbon prepared at 700 °C and 900 °C.

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