

Adsorption of Mercury (Hg) Using Activated Carbon Derived from Meranti Wood

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ABSTRACT

This study aims to evaluate the adsorption capability of activated carbon synthesized from Meranti wood (*Shorea* spp.) for the removal of mercury (Hg^{2+}) ions from aqueous waste. The activated carbon was produced through a pyrolysis process followed by chemical activation using HCl with a ratio of 1:10 (w/v). Characterization using X-ray Diffraction (XRD) confirmed the amorphous structure of the activated carbon, while Fourier Transform Infrared Spectroscopy (FTIR) identified the presence of functional groups such as hydroxyl ($-\text{OH}$), carboxyl ($-\text{COOH}$), and carbonyl ($\text{C}=\text{O}$), which play a crucial role in mercury adsorption. The effects of pH, contact time, and mercury concentration on adsorption efficiency were systematically investigated. The highest adsorption efficiency of 97.610% was achieved at pH 3, with an optimal contact time of 80 minutes and an adsorption rate of 94.30%. These findings indicate that Meranti wood-based activated carbon exhibits excellent potential as an effective and sustainable adsorbent for mercury removal from wastewater. Furthermore, the utilization of Meranti wood waste contributes to environmentally friendly approaches in water purification and heavy metal remediation.

ABSTRAK

Penelitian ini bertujuan untuk menilai kemampuan karbon aktif yang disintesis dari kayu meranti (*Shorea* spp.) dalam mengadsorpsi logam berat merkuri (Hg^{2+}) dari limbah cair. Proses pembuatan karbon aktif dilakukan melalui tahapan pirolisis dan aktivasi kimia menggunakan HCl dengan perbandingan 1:10 (b/v). Karakterisasi menggunakan XRD menunjukkan bahwa karbon aktif memiliki struktur amorf, sedangkan hasil FTIR mengidentifikasi adanya gugus fungsi $-\text{OH}$, $-\text{COOH}$, dan $\text{C}=\text{O}$ yang berperan penting dalam proses adsorpsi merkuri. Pengujian parameter pH, waktu kontak, dan konsentrasi menunjukkan bahwa efisiensi adsorpsi tertinggi dicapai pada pH 3 dengan nilai efisiensi 97,610%, serta waktu optimum sebesar 80 menit dengan tingkat adsorpsi 94,30%. Hasil ini menunjukkan bahwa karbon aktif dari kayu meranti memiliki kemampuan tinggi dalam menghilangkan merkuri dari air limbah. Pemanfaatan limbah kayu meranti sebagai bahan dasar adsorben juga mendukung konsep pengelolaan sumber daya alam yang berkelanjutan serta memberikan alternatif ramah lingkungan untuk penanganan pencemaran logam berat dalam air.

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Introduction

Water pollution can originate from various sources. In everyday life, humans and other

organisms produce waste, which then enters rivers, lakes, seas, and other water bodies. This is especially true in the industrial sector, which

produces waste that ultimately enters water bodies and can cause water pollution [1]. This waste causes bacteriological contamination and excessive nutrient loads at high concentrations. Inorganic waste, in particular, is more difficult to clean and has a greater potential for harm [2]. The hazardous chemical industry produces hazardous waste consisting of toxic compounds, also known as hazardous materials, and heavy metals, such as mercury (Hg), which are dangerous. With the increasing industrialization in Indonesia, mining processes and industrial waste can contain heavy metals, such as lead and copper, which then flow into rivers [3][4]. These heavy metals can cause health problems and damage the environment [5].

One of the heavy metals that is produced as waste is mercury. Mercury is a chemical element that is highly hazardous to the environment and human health, and is often found in everyday equipment, beauty products, and even food [6][7]. Wastewater containing heavy metals such as mercury is extremely dangerous to life. Most heavy metals enter aquatic organisms through the food chain, and only a small amount is removed from the water, making them hazardous due to bioaccumulation [8][9].

Central nervous system (CNS) symptoms such as personality disorders, tremors, convulsions, dementia, insomnia, loss of self-confidence, irritation, depression, and fear are the result of Hg poisoning. Gastrointestinal (GI) symptoms include stomatitis, hypersalivation, colitis, painful chewing, gingivitis, lead lines, and loose teeth [9][10]. Dermatitis and sores can occur on the skin. Several mercury purification processes include: 1. Sulfide precipitation to reduce mercury; 2. Coagulation or co-precipitation to reduce mercury; and 3. Activated carbon adsorption to reduce mercury. However, the most effective method is adsorption using activated carbon [11].

One type of wood that has potential as an activated carbon is meranti. Meranti (*Shorea* spp.) is one of Indonesia's main timber-producing forest trees [12][13]. Meranti trees reach a height of 60 m, a branchless tree of 35 m, and a diameter of 1 m. Utilizing them as activated charcoal powder is one way to address this waste problem [14]. Activated charcoal is a highly adsorbent substance that has numerous applications for absorbing undesirable substances from gases and solutions. Any material containing a sufficiently high amount of carbon can be converted into activated charcoal, but the final result depends on the raw material, the activating agent, and the activation conditions [15][16]. Wood texture

is influenced by the uniformity of the wood's cell size. In general, meranti wood is characterized by a circular pore vessel, single and double radial distribution, indistinct ring boundaries, and a flat texture due to the lack of annual rings [17]. Biomass modification processes such as pyrolysis allow this wood to be converted into activated carbon through an incomplete combustion process, also known as oxygen-limited combustion, using thermal/heat treatment [18].

Meranti wood can be used as a source of activated carbon, also known as activated charcoal. Activated carbon is a form of carbon with a very large surface area, reaching approximately 500 square meters per gram, based on nitrogen gas adsorption measurements. This unique property makes activated carbon highly effective in adsorbing various hazardous substances, including heavy metals, in water. Many researchers have investigated adsorption methods as a way to purify water from contaminants [19]. This process works by adsorbing metal particles onto the surface of the adsorbent. Therefore, biomass materials with high carbon content, such as meranti wood, are highly suitable as a base material for producing efficient adsorbents [12][20].

Activated carbon from meranti wood not only offers a solution to water pollution problems but also utilizes natural resources sustainably. With further development, the use of meranti wood as activated carbon could be a significant step in addressing pollution problems and improving water quality, thus benefiting the environment and public health [21].

Materials and Methods

In this study, several tools were used, including an analytical balance, magnetic stirrer, condenser, pyrolysis reactor, hose, pipe, blender, stopwatch, glass box or burette, clamps and static, water pump, knife, 100-mesh sieve, pH meter, aluminum foil, and glassware. Atomic absorption spectrometry (AAS), X-ray diffraction (XRD), and Fourier Transform Infrared (FTIR) were used as instruments. Meanwhile, the materials used were liquid waste from the river on Jl. Mahir Mahar in Palangka Raya City, Central Kalimantan Province; Meranti wood; HCl p.a.; NaOH p.a.; H₃PO₄ p.a.; HgCl₂; filter paper; ice cubes; and demineralized water.

1. Preparation of Meranti Wood:

The Meranti wood used was wood waste processed at CV. Bangaris Sejahtera, located in Palangka Raya, Central Kalimantan Province. Meranti wood waste was washed several times and dried for one day in an oven at 105°C. Afterward, the sample was ground with a blender and sieved.

2. Hydrochar Synthesis through Pyrolysis:

A pyrolysis reactor was used in this process, which was carried out using the following method: (a) Eight grams of Meranti wood waste was added to 70 milliliters of deionized water and the mixture was adjusted to pH 1 with H_3PO_4 . It was then placed in the pyrolysis reactor for six hours at 260°C. Afterward, the liquid phase and the solid phase (residue) were separated through vacuum filtration. The solid phase (residue) produced from pyrolysis is called hydrochar. For two to three hours, the hydrochar was dried in an oven at 105°C.



Figure 1. Hydrochar

3. Hydrochar Activation (Activated Carbon Production):

HCl activates the hydrochar. The ratio with the activator is 1:10 (w/v). Ten grams of hydrochar was ground, weighed, and soaked for 24 hours in 100 milliliters of 1M HCl solution. The sample was then filtered and washed to ensure a neutral pH. The residue was then dried for three hours in an oven at 110°C. This residue is the activated carbon produced during the reaction.



Figure 2. Hydrochar Activation

4. Liquid Waste Preparation Process:

The liquid waste used as the test sample was taken from a river on Jl. Mahir Mahar, located in Palangka Raya City, Central Kalimantan Province. The water sampling method used was filtering the water sample to remove impurities or analytes. Prior to adsorption, the liquid waste sample was tested for Hg(II) concentration using AAS and its acidity (pH).

5. Optimum Conditions for Batch Adsorption:

In this study, three parameters for the optimum conditions for the batch adsorption process will be discussed, and the spike technique will be used to determine how the matrix affects the adsorption of liquid waste samples with conventional analytes. To obtain a $HgCl_2$ solution as a source of Hg(II) to be added to the liquid waste, one gram of adsorbent was added to 100 milliliters of liquid waste. The pH of the liquid waste varied from 3, 5, 7, and 9 according to the concentrations of NaOH and HCl. The mixture was stirred using a shaker for 60 minutes at 150 rpm. It was then filtered and allowed to stand for 15 minutes. The filtrate was tested using AAS, and the adsorption efficiency was calculated.

One gram of adsorbent was added to 100 milliliters of liquid waste with an optimal pH to determine the optimal time. Using a shaker at 150 rpm, the mixture was stirred with varying contact times of 30, 60, and 100 minutes. The mixture was allowed to stand for 15 minutes before being filtered. The filtrate was then tested using AAS. The adsorption efficiency (%) and adsorption kinetics were then calculated.

To determine the adsorption isotherm, various adsorbent masses were used. The mass variations used were 1, 1.5, 2, 2.5, and 3 grams. The adsorbent was added to 100 milliliters of liquid waste at the ideal time and pH. The mixture was filtered and left for fifteen minutes. Afterward, the filtrate was tested using AAS. The adsorption efficiency (%), adsorption capacity, and adsorption isotherm were then calculated.

6. Dynamic Adsorption Process (Fixed Bed Column):

The adsorption column was constructed using a glass tube with a diameter of 1.5 cm and a height of 20 cm. Activated carbon adsorbent was inserted into the column and compacted with a spatula. Glass wool was added to the top and bottom of the adsorbent in the column. The ideal pH tested in the batch adsorption process was used to collect the liquid waste. The adsorption process lasted for 24 hours, and the effluent solution was collected every 60 minutes. The effluent will be tested using AAS, a series of dynamic system adsorption apparatus models known as bed columns established using the Thomas and Bohart-Adam models, calculate the adsorption kinetics (%) and the amount of removal (%).

Results and Discussion

The adsorption of the heavy metal mercury (Hg^{2+}) by the surface of activated carbon occurs through physical and chemical interactions between mercury ions and functional groups present on the surface of the activated carbon. Activated carbon has a very large surface area and contains various active groups such as hydroxyl (-OH), carboxyl (-COOH), and carbonyl (C=O), which can act as active sites for binding mercury ions. Adsorption can occur physically through van der Waals forces or chemically through the formation of coordinate bonds between Hg^{2+} ions and oxygen groups on the surface of the activated carbon. Furthermore, microscopic pores in activated carbon help trap mercury ions, thereby increasing the adsorption capacity.

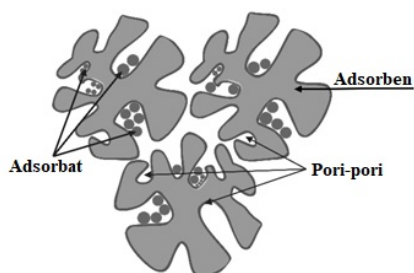


Figure 3. Activated carbon adsorption process

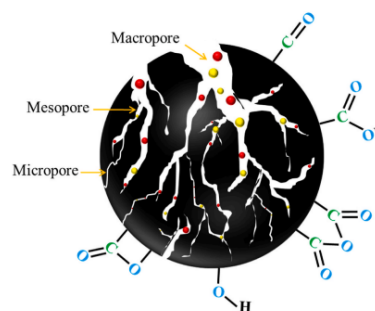


Figure 4. Illustration of pore structure and active groups

Activated Carbon that has been characterized using XRD to determine the crystallinity or amorphous nature of activated carbon, as shown in the Figure below. In the three spectra, it shows the amorphous nature of activated carbon and an illustration of the amorphous structure of activated carbon is presented in Figure 4.5. In the black spectrum showing the diffraction pattern of OPEFB at $2\theta = 21.18^\circ$; 26.57° and 50.03° , for $2\theta = 21.1831^\circ$ indicates the presence of cellulose (JCPDS No. 00-003-0192) while for $2\theta = 26.57^\circ$ and 50.03° indicates the presence of SiO_2 with intensity (JCPDS No. 00-001-0649). In the OPEFB diffraction pattern, it shows a decrease in diffraction intensity from $2\theta = 26.57^\circ$ and 50.03° . The presence of SiO_2 in this case is considered an impurity.

The red spectrum shows a shift in the hydrochar diffraction pattern at $2\theta = 21.3377^\circ$, indicating the presence of cellulose. This indicates that, at the HTC stage, the cellulose decomposition process has not yet fully occurred, so the diffraction pattern still contains a peak at $2\theta = 21.3377^\circ$. Furthermore, a peak at $2\theta = 26.5677^\circ$ indicates the presence of SiO_2 . During the activation process, the activated carbon diffraction pattern reduces, with only one peak at $2\theta = 26.5373^\circ$, indicating the presence of SiO_2 . The activation process indicates cellulose decomposition when comparing the diffraction patterns of hydrochar and activated carbon, which also aligns with Tu's research.

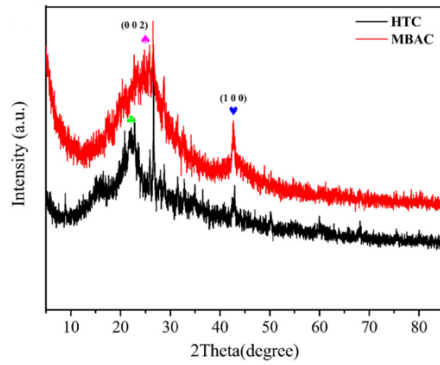


Figure 5. XRD Diffractograms of Hydrochar and Activated Carbon

The adsorbent was characterized using Fourier Transform Infrared Spectroscopy (FTIR) to determine the functional groups present in activated carbon. The FTIR pattern in the image shows OH vibrations at a wave number of 3301.68 cm^{-1} from the molecules that make up OPEFB. The molecules that make up OPEFB include cellulose, lignin, and hemicellulose. C=C bonds were also identified at wave numbers of 1695.77; 1600.21; 1510.36, and 1454.74 cm^{-1} , which indicates the increasing purity of the Carbon element in activated carbon. There are also C-H bonds at wave numbers of 2920.88 - 2851.00 cm^{-1} and C-O groups at wave numbers of 1266.48; 112.45, and 1032.50 cm^{-1} . In the study, there were also Si-O stretching vibrations at wave numbers of 818.65 cm^{-1} . The presence of Si-O vibrations indicates microcrystalline SiO_2 , an impurity also detected in XRD characterization.

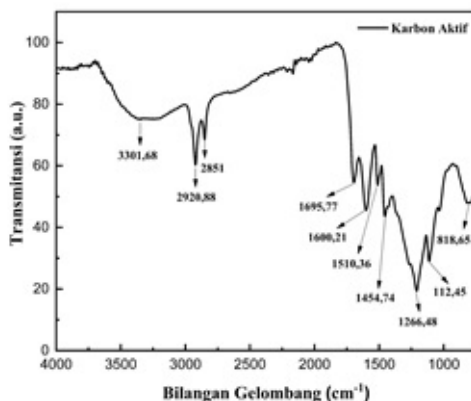


Figure 6. FTIR of activated carbon

Calibrating mercury concentration using a calibration curve is an effective method for determining mercury levels in samples. The data obtained show a clear relationship between concentration and absorbance, which can be used for further analysis:

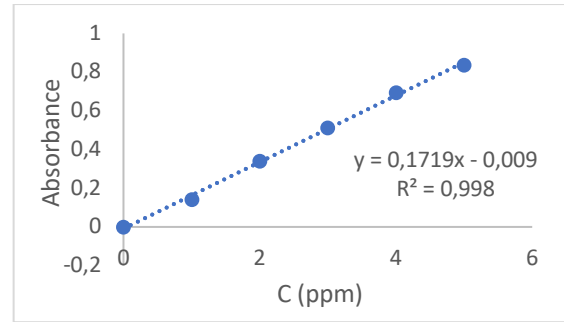


Figure 7. Diagram of the relationship between absorbance and concentration

In this study, the acid concentration associated with mercury (Hg) adsorption was HCl at a concentration of 36.0 M, where mercury (Hg) began to adsorb stably at a concentration of 0.4 M:

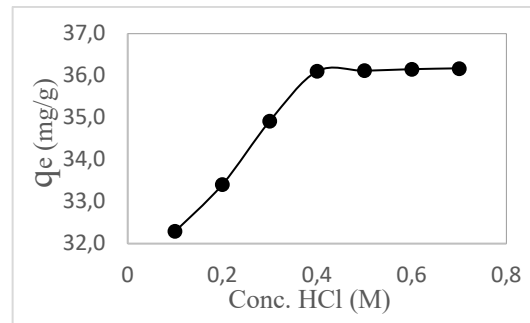


Figure 8. Relationship between acid pH and Hg absorption

Furthermore, the adsorption capacity of activated carbon increased significantly from pH 1 to pH 3, with an adsorption percentage of 97.610%. This indicates that activated carbon adsorbs the tested substances better under higher acid conditions.

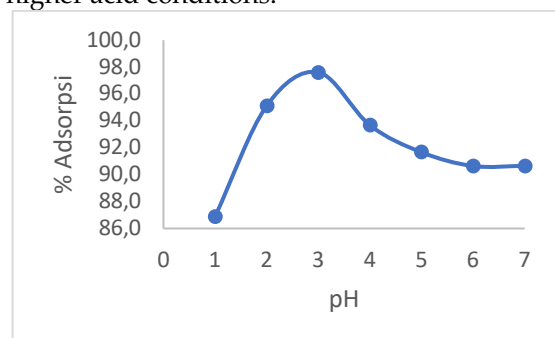


Figure 9. Diagram of the relationship between adsorption percentage and pH

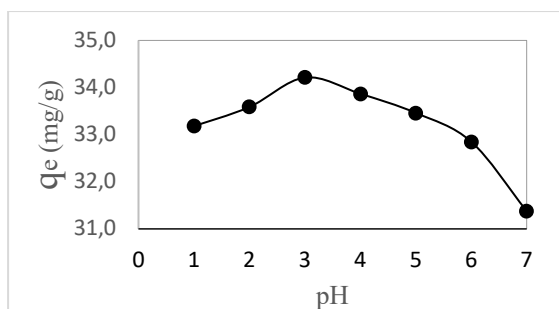


Figure 10. Relationship between pH and absorption

However, after pH 3, there was a decrease in adsorption at pH 4, followed by a further decrease at pH 5, 6, and 7. Nevertheless, the adsorption value remained above 90% from pH 5 to pH 7, indicating that activated carbon still has good adsorption capacity under slightly acidic to neutral conditions.

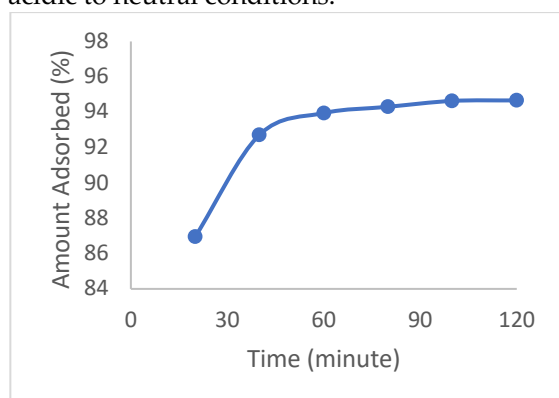


Figure 11. Diagram of the effect of time variations

Next, the effect of time variations on adsorption was also analyzed. At 80 minutes, the adsorption rate reached 94.30%, with 36.156 mg of mercury adsorbed. This indicates that sufficient exposure time can increase adsorption efficiency. Finally, the effect of concentration variations on absorption can be seen:

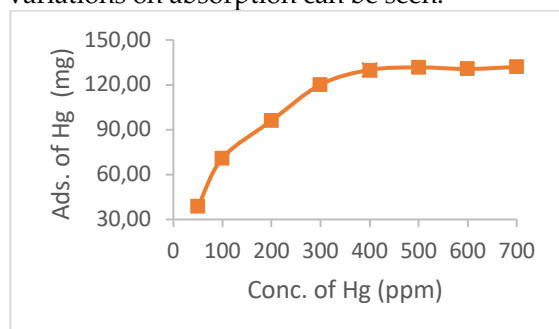


Figure 12. Relationship between concentration and absorption

The analysis diagram of the effect of concentration variations on absorption shows that changes in mercury concentration directly affect the ability of activated carbon to adsorb

the substance. By understanding the relationship between pH, time, and concentration, we can optimize conditions to increase the efficiency of the mercury adsorption process by activated carbon.

Conclusion

The study demonstrated that activated carbon derived from Meranti wood (*Shorea* spp.) possesses a strong capability to adsorb mercury (Hg^{2+}) ions from aqueous waste. The adsorption process was highly influenced by pH, contact time, and mercury concentration. The optimal adsorption occurred at pH 3, achieving an efficiency of 97.610%, while adsorption stability was reached within 80 minutes with a rate of 94.30%. Characterization using XRD and FTIR confirmed that the activated carbon produced exhibited an amorphous structure and contained functional groups such as hydroxyl ($-\text{OH}$), carbonyl ($\text{C}=\text{O}$), and carboxyl ($-\text{COOH}$) that facilitated mercury binding.

Furthermore, the pyrolysis and acid activation process successfully enhanced the surface area and porosity of the adsorbent, making Meranti wood-based activated carbon an effective and sustainable material for heavy metal removal. This research not only supports the utilization of biomass waste but also contributes to environmentally friendly water purification technology. Overall, activated carbon from Meranti wood provides a promising and eco-efficient alternative for mitigating mercury contamination in wastewater.

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