

The Potential of Ironwood as an Activated Carbon Adsorbent for Heavy Metal Mercury (Hg) using the Pyrolysis Method

Potensi Kayu Ulin Sebagai Adsorben Karbon Aktif Untuk Logam Berat Merkuri (Hg) Menggunakan Metode Pirolisis

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ABSTRACT

This study focuses on the utilization of ironwood as an activated carbon adsorbent to remove heavy metal mercury (Hg). Mercury pollution from industrial sources poses significant risks to the environment and human health. The purpose of this study was to develop an effective method for adsorbing mercury using natural ironwood materials. Activated carbon was synthesized using pyrolysis and chemically activated, followed by adsorption tests under varying pH conditions, contact times, and acid concentrations. The optimum adsorption capacity was observed at a mercury concentration of approximately 500 ppm, with maximum efficiency at pH 1 and a contact time of 80 minutes. The results also showed that the adsorption kinetics followed a second-order model with a rate of 0.017119 g/mg.min. In conclusion, the mercury adsorption process using activated carbon from ironwood followed the Langmuir isotherm model, with an adsorption capacity of 63.036 mg/g, indicating that the adsorbent had been successfully synthesized and had an effective ability to remove mercury.

Keywords: Adsorption, Activated Carbon, Ironwood, Mercury, Pyrolysis.

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1. INTRODUCTION

Heavy metals are a distinct group of elements that exhibit properties similar to other metals but are typically characterized by a high atomic weight and density exceeding 4 g/cm³. These elements include transition metals with atomic numbers ranging from 22 to 34 and 40 to 50, as well as lanthanides and

actinides. Due to their specific physicochemical properties, heavy metals interact uniquely with biological systems, often exhibiting distinct biochemical responses in living organisms.

Heavy metal pollution has become more common and more reports since the mercury case in Minamata, Japan, in 1953. According

to Mursyidin, D. H. (2006), the United States Environmental Agency (EPA), thirteen heavy metals are known to have negative effects on the environment. There are some of them, such as arsenic (As), lead (Pb), mercury (Hg), and cadmium (Cd). While some heavy metals play essential roles in biological functions at trace levels, others become toxic when present in excessive concentrations.

Mercury (Hg) is a heavy metal characterized by its unique physical and chemical properties, including its liquid state at room temperature, high specific gravity, and excellent electrical conductivity. These attributes make mercury a critical component in various industrial and laboratory applications. Elemental mercury exhibits a silvery-white appearance, with a freezing point of 38.87 °C, a boiling point of 356.90 °C, a specific gravity of 13.55 g/cm³, and an atomic weight of 200.6. In nature, mercury is released from volcanic emissions and seawater evaporation, contributing to its presence in the environment (Hananingtyas, 2017).

Anthropogenic activities, particularly industrial processes, are significant contributors to mercury pollution. The chlor-alkali industry, gold mining, electrical equipment manufacturing, paint production, and the fabrication of thermometers and tensiometers all utilize mercury as a primary or auxiliary component. Additionally, mercury-containing amalgam used in dental treatments, as well as fossil fuel combustion, further exacerbate environmental mercury contamination (Sudarmaji & Prasasti, 2006). Given the persistence and toxicity of mercury, efficient removal techniques are essential to mitigate its impact on ecosystems and human health.

Adsorption using natural materials has been widely explored as a cost-effective and environmentally friendly approach for mercury removal. Various studies have demonstrated the effectiveness of agricultural waste-based adsorbents, such as rice husks and water hyacinth, in capturing mercury ions (Hg²⁺) from aqueous solutions. When treated with NaOH and activated for adsorption, water hyacinth has been shown to remove up to 94.26% of mercury within a short duration,

attributed to its highly porous surface and functional groups capable of binding heavy metals. The adsorption efficiency of these materials has been evaluated through Atomic Absorption Spectroscopy (AAS) (Miftahurrahmah et al., 2017).

In addition to adsorption, mercury remediation can also be achieved through coagulation and precipitation techniques. These methods involve the addition of chemical agents such as aluminum sulfate or iron salts, which promote the aggregation and sedimentation of mercury, facilitating its removal from wastewater (Harmono, 2020). Despite the effectiveness of these approaches, further research is required to develop sustainable and highly efficient adsorbents that can enhance mercury removal from contaminated water sources.

Ironwood (*Eusideroxylon zwageri*), commonly known as Ulin wood, is a tropical hardwood species endemic to Kalimantan. It is recognized for its exceptional durability and mechanical strength, making it a valuable resource in various construction applications, including residential structures, bridges, railroad sleepers, electric poles, and maritime vessels (Sidiyasa & Juliaty, 2003; Baroya et al., 2023). Due to its Class I durability rating, ironwood is often referred to as "Iron Wood," and its properties are considered superior compared to most other timber species.

Ironwood trees can attain heights exceeding 30 meters, with trunk diameters surpassing 90 cm. The species thrives under tropical rainforest conditions, preferring temperatures between 25–35 °C and annual precipitation ranging from 2500 to 3900 mm. It is commonly found at elevations of 100–600 meters above sea level, with a natural density of approximately 4–8 trees per hectare. The reproductive cycle of ironwood varies by region; in Palembang, flowering occurs between August and September, whereas in South Kalimantan, it occurs from October to November. The maturation period from flower to seed completion is approximately three months. Additionally, ironwood is frequently found growing in association with more than 100 other tree species, including *Palaquium hasseltii*, *Ochanostachys amentaceae*, and

Shorea spp. in Jambi (Hendalastuti & Siregar, 2007).

The geographical distribution of *Eusideroxylon zwageri* spans the tropical rainforests of Kalimantan, Sumatra, and parts of Malaysia. However, due to extensive deforestation and commercial exploitation, the population of this species has experienced a significant decline. In South Kalimantan, the estimated availability of ironwood in natural forests has been reduced to approximately 1.35 m³/ha for poles and 6.82 m³/ha for mature trees. Furthermore, inter-provincial trade contributes to its distribution, with supply chains extending from East Kalimantan and Tanjung (Yudi & Itta, 2014).

Beyond its structural applications, ironwood has demonstrated potential in environmental remediation, particularly in water treatment. It serves as a promising precursor for activated carbon production, a material known for its high surface area and effective adsorption properties. Activated carbon derived from ironwood has been utilized to remove natural organic matter (Bahan Organik Alami, BOA) from peat water. The activation process, which involves carbonization followed by chemical treatment, enhances the porosity and adsorption efficiency of the material. Consequently, ironwood-based activated carbon offers a dual benefit, functioning as both a high-value construction material and an effective adsorbent for wastewater treatment applications (Nafilah & Noor, 2021).

Activated carbon is a material that is widely used as an adsorbent because it has a high surface area and pores that are effective in capturing small molecules from liquids or gases. One potential source of activated carbon is ironwood (*Eusideroxylon zwageri*), a hardwood originating from Kalimantan and Sumatra. In addition to its strength and resistance to the environment, ironwood also has the potential to be processed into high-quality activated carbon (Nafilah, S., & Noor, R. 2021). Ironwood as a basic material for activated carbon offers several benefits and wide applications in various industries, including: (1.) Water Filtration: Activated carbon from ironwood can be used to filter

water, especially in removing natural organic materials, such as in research on peat water. The adsorbent properties of activated carbon are able to bind hazardous compounds contained in water, resulting in water that is cleaner and safer for consumption. (2.) Liquid Waste Treatment: Liquid waste from industry often contains hazardous chemicals and organic compounds that are difficult to decompose. Ironwood activated carbon can be used in the liquid waste purification process to reduce contaminant levels, including organic materials and heavy metals, so that the waste produced is more environmentally friendly. (3.) Air Treatment: In air treatment, activated carbon can absorb volatile organic compounds (VOCs) and unpleasant odors. Ironwood processed into activated carbon with certain techniques has the potential to be used in air purifiers. (4.) Refining Used Cooking Oil: The use of activated carbon from ironwood has also been proven effective in refining used cooking oil through the adsorption process. This activated carbon is able to bind free fatty acids, reduce peroxide content, and improve the quality of the oil that has been used.

The process of making activated carbon from ironwood goes through several main stages, including: 1) Carbonization; The process of heating ironwood at high temperatures without oxygen to form carbon. 2) Activation; The further process of providing chemicals or water vapor to open the pores of the carbon formed, resulting in activated carbon with a high surface area. Activated carbon produced from ironwood has physical and chemical properties that are ideal for use in various filtration and adsorption applications (Oko, Syarifuddin, et al 2020).

Activated carbon is widely recognized as an effective adsorbent due to its high surface area and well-developed porosity, which facilitate the capture of small molecules from liquid and gaseous phases. This material plays a crucial role in various environmental applications, particularly in water purification, air filtration, and industrial waste treatment. One promising precursor for activated carbon production is ironwood (*Eusideroxylon zwageri*), a dense hardwood native to Kalimantan and Sumatra, known for its

exceptional strength and environmental resistance (Nafilah & Noor, 2021). Given its structural properties, ironwood presents a viable alternative for the synthesis of high-quality activated carbon with significant adsorption capabilities.

The utilization of ironwood-derived activated carbon extends across multiple industrial sectors. In water treatment, it has been shown to effectively remove natural organic matter, such as humic substances in peat water, thereby improving water quality for consumption. In industrial wastewater treatment, activated carbon plays a critical role in the adsorption of hazardous chemicals, organic pollutants, and heavy metals, reducing their environmental impact. Additionally, its application in air purification enables the removal of volatile organic compounds (VOCs) and odor control, while in the food industry, it is employed in refining used cooking oil by adsorbing free fatty acids and reducing peroxide content, thereby enhancing oil quality. These broad applications highlight the versatility and efficacy of ironwood-based activated carbon in addressing environmental challenges.

The production of activated carbon from ironwood involves two fundamental processes: carbonization and activation. Carbonization entails the thermal decomposition of ironwood in an oxygen-deficient environment to produce a carbon-rich residue. This step is followed by activation, which enhances porosity through chemical or physical means, such as treatment with activating agents (e.g., phosphoric acid or steam), ultimately increasing the surface area and adsorption capacity of the final product (Okon et al., 2020). The resulting activated carbon exhibits properties that make it highly effective for adsorption-based applications, including heavy metal removal.

Heavy metal contamination, particularly from elements such as lead (Pb), mercury (Hg), cadmium (Cd), and nickel (Ni), poses significant environmental and health risks. These metals, frequently found in industrial effluents, are persistent pollutants that accumulate in ecosystems and exhibit toxic effects even at low concentrations. The

application of activated carbon in wastewater treatment has been extensively studied for its ability to sequester heavy metals through both physical and chemical adsorption mechanisms. Physical adsorption relies on Van der Waals interactions to trap metal ions within the porous matrix, while chemical adsorption involves the formation of coordination bonds between metal ions and oxygen-containing functional groups, such as carbonyl and hydroxyl groups, on the surface of activated carbon.

The reusability of activated carbon further enhances its practicality as an adsorbent, making it an economically and environmentally sustainable solution for industrial waste treatment. Several studies have demonstrated its effectiveness in heavy metal adsorption. For instance, activated carbon derived from coconut shells was reported to remove up to 85% of lead (Pb) ions from electroplating wastewater (Hidayat & Nasution, 2018). Similarly, sawdust-based activated carbon exhibited a mercury (Hg) removal efficiency of approximately 75% in mining effluent (Ramanda & Sukadana, 2020). These findings underscore the potential of ironwood-derived activated carbon as a highly efficient adsorbent for heavy metal remediation in wastewater treatment systems.

Given its high adsorption capacity, structural durability, and regeneration potential, ironwood-based activated carbon presents a promising solution for mitigating environmental pollution. This study aims to evaluate the adsorption performance of ironwood-derived activated carbon in the removal of mercury (Hg) from aqueous solutions, with a focus on optimizing adsorption conditions and understanding the underlying kinetic and isotherm models governing the process.

2. MATERIALS AND METHODS

2.1. Materials

Materials used in this study consisted of liquid waste from Jl. Mahir Mahar River (Palangka Raya, Central Kalimantan), ironwood, HCl p.a., NaOH p.a., H₃PO₄ p.a., HgCl₂. Additional laboratory consumables included glass wool, filter paper,

demineralized water, and ice cubes. The equipment used in this study included analytical balance, magnetic stirrer, pyrolysis reactor, condenser, hose, pipe, blender, stopwatch, burette or glass box, clamp and static, water pump, knife, 100 mesh sieve, pH meter, aluminum foil, and various glassware. For material characterization and adsorption analysis, the study employed X-ray Diffraction (XRD) for phase identification, Fourier Transform Infrared Spectroscopy (FTIR) to determine functional groups, and Atomic Absorption Spectrometry (AAS) for quantifying mercury concentrations in liquid waste before and after adsorption.

2.2. Ironwood preservation

Ironwood utilized in this study was sourced from wood processing waste at CV. Banggaris Sejahtera, Palangka Raya City, Central Kalimantan Province. The raw material was thoroughly washed with deionized water to remove impurities, followed by drying in a laboratory oven at 105 °C for 24 hours to eliminate residual moisture. The dried samples were subsequently ground using a high-speed blender and sieved through a 100-mesh sieve to obtain a uniform particle size suitable for further processing.

2.3. Hydrochar synthesis through pyrolysis

The pyrolysis process was conducted using a reactor following this method. A total of 8 grams of ironwood waste sample is mixed with 70 mL of deionized water, then the pH of the mixture is adjusted to 1 using H_3PO_4 . This mixture is put into a pyrolysis reactor at a temperature of 260 °C for 6 hours. After that, the liquid and solid phases (residue) are separated by vacuum filtration. The solids from pyrolysis, called hydrochar, are then dried in an oven at 105 °C for 2-3 hours.

2.4. Hydrochar activation

Hydrochar was activated using HCl, with a ratio of Hydrochar and activator of 1:10 (w/v). A total of 10 grams of Hydrochar was ground and weighed, then soaked in 100 mL of 1M HCl solution for 24 hours. After that, the sample was filtered and washed until it reached a neutral pH. The residue obtained

was then dried in an oven at 110 °C for 3 hours. This residue is activated carbon produced from the activation process.

2.5. Determination of liquid waste preparation

The liquid waste sample utilized in this study was collected from the Jl. Mahir Mahar River, Palangka Raya City, Central Kalimantan Province, employing the grab sampling method. To eliminate particulate matter and potential interfering analytes, the sample was filtered immediately upon collection. Prior to the adsorption experiments, an initial characterization of the wastewater was conducted, which included the determination of Hg(II) concentration via AAS and pH measurement to assess its acidity level.

2.6. Optimum batch adsorption conditions

To determine the optimal conditions for the batch adsorption process, three key parameters were evaluated: pH variation, contact time, and adsorption isotherm analysis. The effect of the matrix on liquid waste samples was also examined using the spike technique, with $HgCl_2$ solution serving as the Hg(II) source.

The effect of pH on adsorption efficiency was assessed by adding 1 g of activated carbon adsorbent to 100 mL of liquid waste with pH values adjusted to 3, 5, 7, and 9 using 0.1 M NaOH and HCl solutions. The suspensions were agitated at 150 rpm for 60 minutes using a mechanical shaker and subsequently allowed to settle for 15 minutes before filtration. The resulting filtrates were analyzed via AAS to determine the adsorption efficiency (%).

To evaluate the effect of contact time on mercury adsorption, 1 g of the adsorbent was added to 100 mL of liquid waste at the previously determined optimum pH. The mixture was stirred at 150 rpm, with contact times varied at 30, 60, 90, and 120 minutes. After each interval, the suspensions were left to settle for 15 minutes before filtration. The filtrates were analyzed using AAS, and the adsorption efficiency (%) and adsorption kinetics were calculated.

To investigate the adsorption isotherm, the adsorbent mass was varied at 1, 1.5, 2, 2.5, and 3 g, each added to 100 mL of liquid waste at the optimum pH and contact time. The samples were stirred under identical conditions, left to stand for 15 minutes, and then filtered. The final filtrates were analyzed via AAS, and the adsorption efficiency (%), adsorption capacity, and adsorption isotherm models were evaluated.

2.7. *Dynamic adsorption process (fixed-bed column)*

A glass tube with 1.5 cm in diameter and 20 cm in height was used to construct the column reactor. Activated carbon adsorbent was inserted into the column and compacted using a spatula. Glass wool will be added to the top and bottom of the adsorbent in the column. The liquid waste sample will use the optimum pH that has been tested in the batch adsorption process. The adsorption process lasts for 24 hours, with effluent sampling every 60 minutes. The effluent will be tested using AAS. Dynamic adsorption system (fixed bed column) will be used, and the removal percentage (%) and adsorption kinetics are calculated using Thomas and Bohart-Adam models.

3. RESULTS AND DISCUSSION

3.1. *Pyrolysis and acid activation of ironwood-based activated carbon*

The synthesis of activated carbon involves pyrolysis as an initial step, wherein organic precursors are subjected to high temperatures (400–800 °C) under anoxic conditions. This thermal decomposition process volatilizes organic compounds, yielding a porous carbonaceous solid with a well-defined microstructure. The resulting carbon material, typically characterized by macro and mesopores, possesses a relatively low surface area, necessitating further activation to enhance its adsorption properties (Ioannidou & Zabaniotou, 2007).

To improve porosity and surface functionality, acid activation was employed using phosphoric acid (H_3PO_4) and sulfuric acid (H_2SO_4). Acid treatment promotes pore expansion and the formation of new

adsorption sites, thereby augmenting the adsorption capacity of the carbon matrix. Additionally, acid activation enhances the hydrophobic nature of the material, improving its efficiency in sequestering non-polar organic compounds and metal contaminants from aqueous media (Tseng, 2006). This modification is critical for optimizing the carbon's performance in heavy metal removal applications.

3.2. *Adsorption performance and mercury removal efficiency*

The adsorption capability of ironwood-derived activated carbon for mercury removal was evaluated under varying experimental conditions. Batch adsorption studies demonstrated a direct correlation between the mass of activated carbon and the reduction in mercury concentration. The results indicated that increasing the adsorbent dosage led to enhanced mercury sequestration, reflecting the material's high adsorption efficiency.

At an initial adsorbent dose of 0.1 g, the residual mercury concentration in solution was measured at 5.157 ppm, corresponding to an adsorption efficiency of 86.23%. As the adsorbent mass was progressively increased to 0.7 g, the mercury concentration decreased significantly to 1.306 ppm, achieving a maximum adsorption efficiency of 96.53%. The highest recorded adsorption capacity was 36.163 mg/g, underscoring the strong affinity of ironwood-based activated carbon for mercury uptake. These findings highlight the potential of acid-activated ironwood as a viable adsorbent for heavy metal remediation, demonstrating its effectiveness in aqueous mercury removal applications.

3.3. *Effect of pH on mercury adsorption efficiency*

The impact of pH on mercury adsorption efficiency was investigated by varying the pH from 1 to 4. The experimental results indicate that pH plays a critical role in the adsorption process, influencing the interaction between mercury ions and the activated carbon surface. At pH 1, the highest adsorption was observed, with an adsorbed mercury concentration of 38.19 ppm. As the pH increased to 2, the

adsorbed mercury concentration slightly decreased to 35.31 ppm, suggesting a decline in adsorption efficiency. A further reduction was recorded at pH 3, where the adsorbed mercury concentration was 35.05 ppm, followed by a slight increase to 36.15 ppm at pH 4.

The adsorption behavior across different pH levels is depicted in **Figure 2**, which demonstrates fluctuations in adsorption

efficiency as a function of pH. These variations highlight the importance of maintaining an optimal pH level for effective mercury removal. The maximum adsorption was achieved at pH 1, indicating that lower pH conditions facilitate stronger interactions between mercury ions and the activated carbon surface.

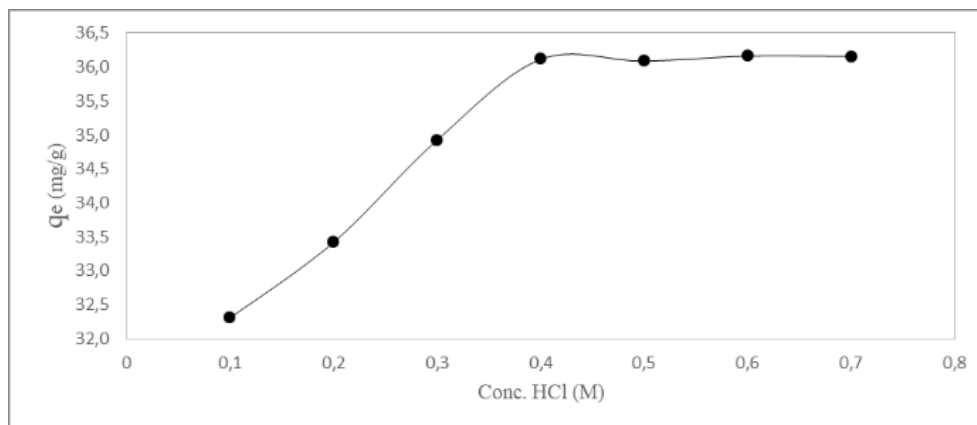


Figure 1. Effect of HCl concentration on Ironwood activated carbon

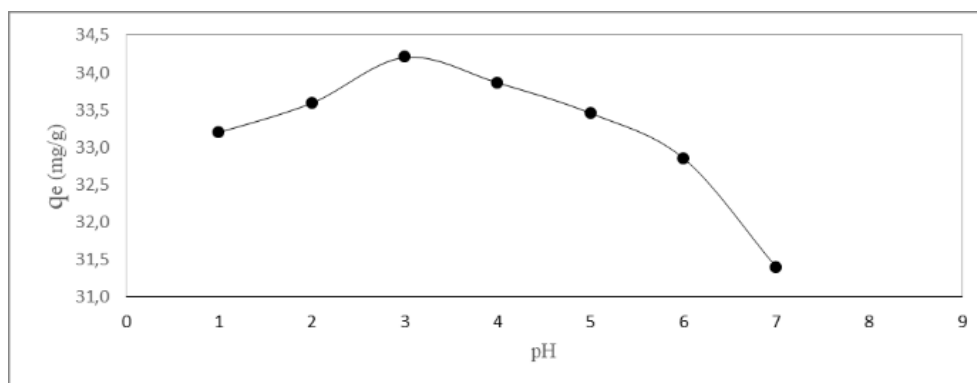


Figure 2. Impact of pH on the adsorption capacity of Ironwood activated carbon

3.4. Effect of contact time on mercury adsorption

To evaluate the influence of contact time on adsorption efficiency, experiments were conducted with varying contact durations ranging from 20 to 100 minutes. The results revealed that adsorption efficiency increased with contact time until equilibrium was reached. At 20 minutes, the remaining mercury concentration was 4.99 ppm,

corresponding to an adsorption efficiency of 86.97%. As contact time increased to 40 minutes, the remaining mercury concentration decreased to 2.77 ppm, with an adsorption efficiency of 92.75%. The trend continued, reaching 94.31% adsorption efficiency at 80 minutes (2.18 ppm mercury concentration). However, after 100 minutes, the efficiency plateaued at 94.59%, with a final mercury

concentration of 2.07 ppm, indicating equilibrium had been established.

The adsorption capacity also increased with contact time, reaching a maximum of 36.26 mg/g at 100 minutes (**Figure 3**). These

results suggest that activated carbon exhibits high mercury-binding efficiency, particularly during the initial adsorption phase, before approaching saturation.

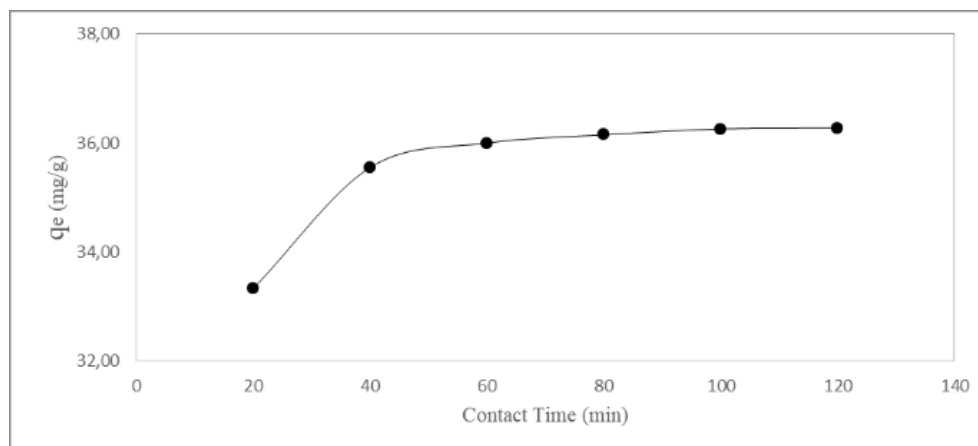


Figure 3. Impact of contact duration on the adsorption capacity of Ironwood activated carbon

3.5. Adsorption kinetics analysis

The adsorption kinetics were analyzed using both first-order and pseudo-second-order models to determine the mechanism governing mercury uptake. The experimental data exhibited a stronger correlation with the pseudo-second-order kinetic model, as demonstrated by the linear relationship in **Figure 4**. The correlation coefficient (R^2) for

the pseudo-second-order model exceeded 0.9998, while the first-order model exhibited a significantly lower fit ($R^2 = 0.1104$). This suggests that the adsorption process is predominantly controlled by chemisorption, where chemical interactions between mercury ions and functional groups on the activated carbon surface dictate the adsorption rate.

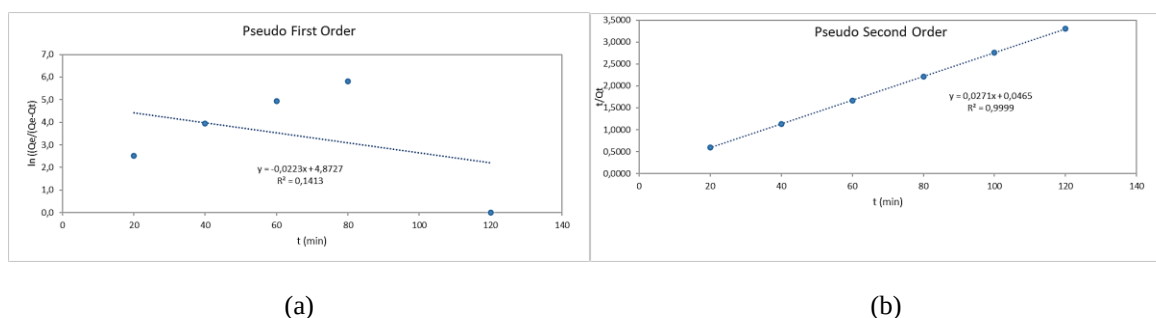


Figure 4. Linear fitting representing (a) pseudo-first-order and (b) second-order kinetics of mercury adsorption

The adsorption mechanism follows a chemisorption model, further supported by the kinetic rate dependency on the square of mercury concentration, expressed as $(q-q_e)t^2$. The kinetic parameters obtained for the adsorption process are presented in **Table 1**. These findings reinforce the hypothesis that

activated carbon adsorption of mercury is a chemically driven process rather than purely physical interaction.

3.6. Effect of mercury concentration on adsorption capacity

The adsorption behavior of mercury onto ironwood-derived activated carbon was evaluated by varying the initial mercury concentration. As depicted in **Figure 5**, the adsorption capacity exhibited a distinct trend as a function of mercury concentration. At lower concentrations (<500 ppm), the adsorption process proceeded at a relatively slow rate, likely due to the availability of a substantial number of unoccupied active sites on the adsorbent surface. This condition allowed nearly complete adsorption of the available mercury ions, resulting in a lower overall adsorption rate.

Conversely, at higher mercury concentrations (>500 ppm), the adsorption process reached a plateau, indicating

saturation of the available active sites on the adsorbent. As the adsorption sites became fully occupied, no additional mercury ions could be effectively adsorbed, thereby leading to an equilibrium state. The findings suggest that mercury adsorption onto ironwood-activated carbon achieved a maximum capacity at approximately 500 ppm before gradually declining as the concentration increased further. This decline may be attributed to the limited availability of additional adsorption sites or potential repulsive interactions between the adsorbed mercury ions and those remaining in the solution.

Table 1. Adsorption kinetic model for mercury

Material	Pseudo 1 st Order		Pseudo 2 nd Order	
	β (menit-1)	R ²	K ₂ (g/mg.menit)	R ²
Ironwood activated carbon	0,0204	0,9998	0,01712	0,1104

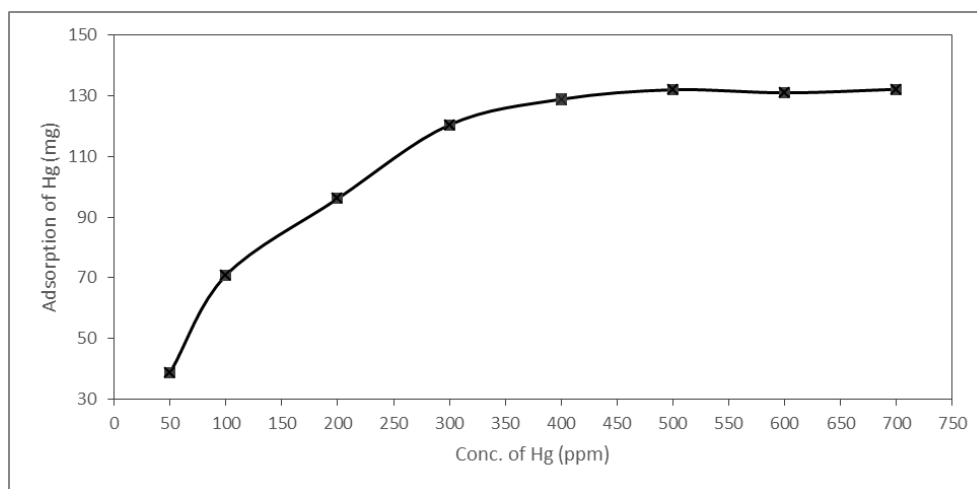


Figure 5. Effect of mercury concentration on the adsorption capacity of Ironwood activated carbon

3.7. Adsorption isotherm modeling

To gain deeper insights into the adsorption mechanism, the equilibrium adsorption data were analyzed using the Langmuir and Freundlich isotherm models. Adsorption equilibrium, which governs adsorption energy

and capacity, is described by these isotherm models, illustrating the relationship between the amount of mercury adsorbed and its residual concentration in solution. The results of the model fitting are presented in **Figure 6**.

The correlation coefficient (R^2) was employed to assess the suitability of each model in describing the experimental data. The Freundlich isotherm model exhibited a correlation coefficient of $R^2 = 0.9519$, indicating moderate agreement with the data. However, the Langmuir model provided a significantly better fit, with $R^2 = 0.999$, suggesting a high degree of consistency with the experimental results. The superior fit of the Langmuir model implies that mercury adsorption onto ironwood-activated carbon occurs predominantly as a monolayer on a homogenous surface, with uniform adsorption energy across all sites.

Based on these findings, the adsorption process is likely governed by chemisorption or strong electrostatic interactions between the mercury ions and the functional groups present on the adsorbent surface. The equilibrium adsorption parameters derived from both isotherm models are summarized in **Table 2**, further confirming that the Langmuir model provides a more accurate description of the adsorption behavior. These results showed the effectiveness of ironwood-activated carbon as a potential adsorbent for mercury removal,

with adsorption characteristics that align well with monolayer adsorption principles. Future studies could explore the influence of additional factors, such as temperature and competing ions, to further optimize the adsorption process for practical applications in wastewater treatment.

The adsorption capacity (B) of mercury on the Ironwood activated carbon composite can be calculated using the Langmuir isotherm model, as shown in Table 2. The adsorption capacity (B) of the Ironwood activated carbon composite is 4.372×10^{-4} mol/g for mercury. The adsorption energy is calculated using the Langmuir isotherm model with the formula $E = RT \ln K$. The calculation results show that an energy of 26.64 kJ/mol is required for the adsorption of mercury on the Ironwood activated carbon composite. This indicates the presence of electrostatic interactions between the adsorbent and mercury. Since mercury is positively charged and the active sites of the Ironwood activated carbon composite are also positively charged, an electrostatic bond is formed between the two.

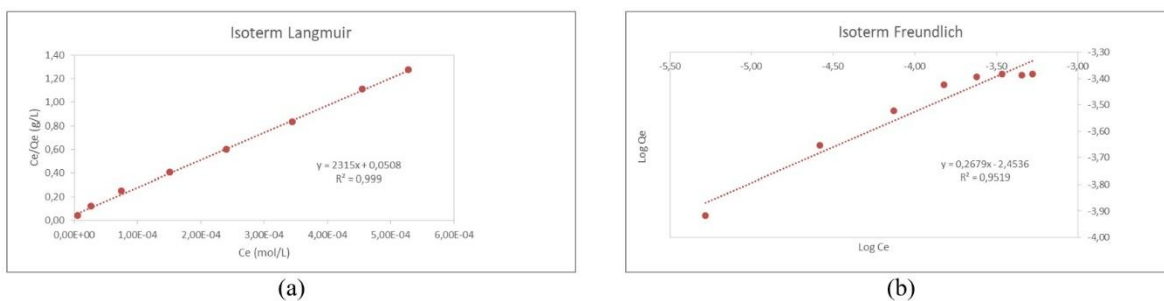


Figure 6. Linearized adsorption isotherm curve for mercury adsorption adsorbent. (a) Langmuir model and (b) Freundlich model

Tabel 2. Equilibrium kinetic model for mercury

Material	Adropsi Langmuir				Adsorpsi Freundlich		
	B (mg/g)	K (L/mol)	E (kJ/mol)	R^2	B (mg/g)	N	R^2
Ironwood activated carbon	$4,372 \times 10^{-4}$	48558,39	26,64	0,9992	$3,574 \times 10^{-3}$	3,743	0,9456

4. CONCLUSIONS

The study confirmed the successful synthesis of ironwood-based activated carbon, which demonstrated high efficiency in mercury adsorption. Activation of the adsorbent using HCl acid was proven to significantly increase the mercury adsorption efficiency. The optimum pH value found was pH 1, where high hydrogen ions (H^+) increased the interaction between mercury and active sites on the adsorbent surface, resulting in maximum adsorption efficiency. In addition, the optimum contact time for mercury adsorption was achieved at 80 minutes, after which the adsorption process reached equilibrium and did not show a significant increase in mercury absorption. The adsorption kinetics data showed that this process followed a second-order kinetic model, with an adsorption rate of 0.017119 g/mg.min, which was more in accordance with the experimental results compared to the first-order model. The optimum mercury concentration for adsorption was around 500 ppm, where the maximum adsorption capacity was achieved before the process reached equilibrium. The Langmuir isotherm model best fit the data, with an adsorption capacity of 63.036 mg/g, suggesting strong electrostatic interactions between mercury and the adsorbent.

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