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Effectiveness of Activated Carbon from Jackfruit Skin for The Heavy Metal Lead (Pb) Adsorption Using The Langmuir and Freundlich Equations

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ABSTRACT. Activated carbon is a commonly used medium for adsorption to combat environmental pollution in both water and air. It is produced from plant or plantation waste containing carbon. Jackfruit skin, often considered as plantation waste, contains lignocellulosic compounds and has the potential to be used as active carbon. Activated carbon from jackfruit skin has a good absorption capacity and can absorb heavy metal waste such as lead (Pb). A recent study aimed to evaluate the absorption effectiveness of active carbon from jackfruit skin. The process involved making activated carbon using the pyrolysis method, and then analyzing its lead absorption capacity in lead nitrate solution by varying the weight of the activated carbon (10g, 15g, 20g, 25g, 30g) and the adsorption time in minutes (40, 60, 80, 100, 120). The levels of absorbed lead on activated carbon were tested using Atomic Absorption Spectrophotometry (AAS) at a wavelength of 283.3 nm. The research findings indicate that the effectiveness of activated carbon absorption reaches 99%, and the appropriate equation model for the adsorption process is the Freundlich isotherm, indicating a multilayer adsorption process.

1. INTRODUCTION

A significant impact on Indonesia's economy is made by agriculture and plantations, given the country's abundant biodiversity. There is value in revitalizing unused natural resources. Biomass waste from agricultural, plantation, livestock, and forestry activities can be repurposed to recover their value. This biomass waste contains organic material formed from carbon dioxide, air, water, soil, and sunlight from plants and animals. If biomass waste is not handled properly, this can lead to the potential formation of dangerous greenhouse gases [1]. However, in processing, not all parts can be used. For example, with fruits like jackfruit, the skin, straw, and seeds are often discarded as waste [2]. The growth in jackfruit production each year is directly related to the output of jackfruit waste. Unfortunately, jackfruit waste has not been fully utilized to create a high-value product. The content found in jackfruit skin waste includes crude fiber and protein. Additionally, it contains glucose, fructose, sucrose, starch, fiber, pectin, carbon, and nitrogen. Jackfruit skin waste is rich in lignocellulose, typically consisting of cellulose (35%-50%), hemicellulose (20%-35%), and lignin (10%-25%) [3].

The high lignocellulose content in jackfruit skin waste allows it to produce activated carbon, which can then be used as an adsorbent. Activated carbon can adsorb gases and specific chemical compounds, and its adsorption properties are selective based on pore size, volume, and surface area [4]. The surface of non-activated carbon is covered by hydrocarbon deposits, which inhibit its adsorption action. The pore structure of activated carbon greatly influences its absorption capacity. The more pores on the surface of the activated carbon, the higher the adsorption power or capacity. Consequently, the adsorption speed will increase [5].

The carbonization process aims to decompose hydrocarbon compounds such as cellulose, hemicellulose, and lignin which are classified as lignocellulose into pure carbon and produce granules with high absorption capacity. [6]. Pyrolysis is a type of carbonization that breaks down the chemical structure of carbon-carbon bonds due to heat. This process occurs without the presence of an oxidizing medium from outside the system, meaning it happens with little or no oxygen. The goal of pyrolysis is to convert biomass into products that can be used as fuel. The products of pyrolysis include charcoal (biochar), which is a non-volatile residue rich in carbon, a gas consisting of low molecular mass gases such as CO and CO2, and tar, often referred to as pyrolysis oil (bio-oil), a product with a high molecular weight. Pyrolysis offers advantages over carbonization, such as the ability to produce syngas and high energy content tar [7]. The quality of activated carbon that approaches the quality requirements for activated carbon is activated carbon produced at a pyrolysis temperature of 275 ºC for 1 hour [8]. Slow pyrolysis is pyrolysis using low temperatures (<400°C), which can offer greater environmental benefits as it yields more biochar, which can be utilized to absorb pollutants in the environment [9]. The carbon chain in organic compounds can be broken down by using chemicals to produce carbon with a more porous surface area. Chemical activators like alkali metal hydroxides, carbonate salts, chlorides, sulfates, phosphates, or inorganic acids are utilized in this process[10]. NaCl has dehydrating properties that can reduce tar formation. Tar is a compound that results from the combustion residue of the carbonization process and can block the pores of activated carbon [11].

Adsorption is a physical phenomenon that happens when gas or liquid molecules come into contact with a solid surface and some of the molecules stick to the solid surface [12]. When a fluid containing the adsorbate is in contact with a solid adsorbent, the adsorbate molecules move from the fluid to the solid until the adsorbate concentration in the fluid flow reaches equilibrium with the adsorbate adsorbed in the solid adsorbent [13]. This research examines the efficacy of utilizing active carbon derived from jackfruit skin to absorb pollutants, specifically lead metal ions (Pb). The purpose of this study is to assess how well jackfruit peel-activated carbon absorbs lead (Pb) from lead nitrate solutions. This will involve subjecting biochar to a pyrolysis process, followed by an activation process while varying the contact time and weight of the activated carbon. The goal is to determine the most suitable isotherm equation for this process.

2. MATERIALS AND METHODS

This study utilized jackfruit skin waste as the primary ingredient for producing activated carbon. Distilled water (H_2O) was used as a solvent, Sodium Chloride (NaCl) as a carbon activator, and Lead Nitrate ($Pb(NO_3)_2$) as an adsorbate solution in the adsorption process. The research involved several stages, including the pretreatment of raw material, the pyrolysis process, the activation of carbon, and the adsorption process.

2.1 Pretreatment of Raw Material

The first treatment of the raw material is by washing and cutting the skin of the jackfruit into 6-8 cm pieces to aid the drying process, followed by sun-drying. A sample of jackfruit skin weighing several grams was used for content analysis.

2.2 Pyrolysis Process

The dried jackfruit skin is placed in a holding tank (reactor). Carry out combustion using the pyrolysis method for carbonization with a temperature of 275ºC and a time of 45 minutes. In these operating conditions, the jackfruit skin decomposes very effectively.

2.3 Activation of Carbon

The jackfruit skin is carbonized into biochar and then reduced to 100 mesh size. To clean the closed carbon pores, the biochar is activated by immersing it in a 35% NaCl solution with a ratio of 10 grams in 100 ml. The mixture is stirred using a hot plate magnetic stirrer at a temperature of 80ºC and a speed of 100 rpm for 60 minutes to ensure optimal contact. After that, it is left for 8 hours before being separated. The precipitate is neutralized with distilled water and then dried in an oven at 105ºC for one hour to remove water content.

2.4 Adsorption Process

Activated carbon with varying masses of 10, 15, 20, 25, and 30 grams was added to the Pb(NO3)2 solution and then stirred at a speed of 100 rpm with varying times of 40, 60, 80, 100, and 120 minutes. Allow to settle for 30 minutes then separate. The filtrate was analyzed using Atomic Absorption Spectrophotometry (SSA).

3. RESULTS AND DISCUSSION

The composition of the jackfruit skin needs to be tested to determine if the material is suitable for research. The analysis data results are presented in Table 1.

Table 1. Jackfruit Skin Composition

Material	Parameter	Result (%)	Method
Jackfruit Skin	Cellulose	52,739	Chesson
	Lignin	10,599	Chesson
	Hemicellulose	16,913	Chesson

Based on the analysis data in Table 1, it has been found that jackfruit skin can be used as active carbon, as shown in Figure 1. This activated carbon has the necessary composition and high cellulose content, which are crucial components in the carbon atomic framework structure after being heated at high temperatures. This process makes the activated carbon effective in absorbing liquid waste. Moreover, the carbon can be activated with chemicals to reduce the water content and increase its absorption capacity

Figure 1. Adsorbent Before and After Pyrolisis

Adsorption of Pb onto activated carbon from jackfruit skin was conducted using a 163.2 mg/L solution of Pb(NO3)2 as the test material. The analysis of Pb content (mg/L) in several solutions with different adsorbent weights and contact times is presented in Table 2.

Table 2. Effect of Contact Time (minutes) and Mass (grams) on the Final Concentration of Pb (ppm)

Time (Minute) \ Mass of activated carbon(gram)	10	15	20	25	30
40	3,01	3,23	2,57	2,64	2,72
60	2,45	2,24	2,14	2,04	1,99
80	1,90	1,86	1,83	1,69	1,55
100	1,86	1,78	1,67	1,56	1,36
120	1,82	1,67	1,53	1,35	1,18

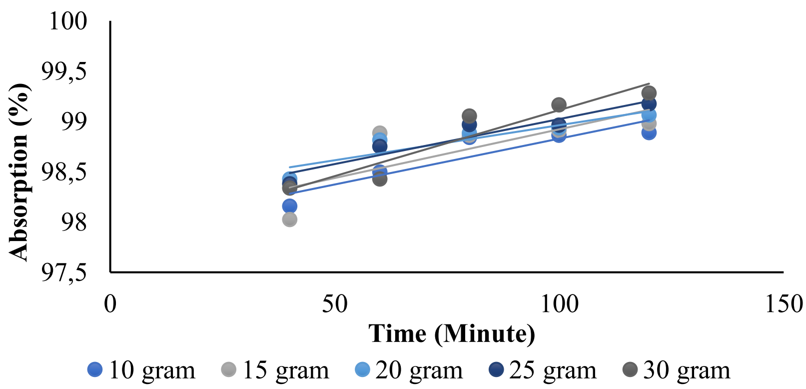

Figure 2. Correlation between Adsorption Time and Activated Carbon Absorption Capacity

Based on Table 2, there is a decrease in Pb levels after the adsorption process using Jackfruit Skin Activated Carbon. This can be observed in the relationship between contact time and absorbed Pb levels, indicating that the longer the contact time, the lower the Pb content in the solution.

Figure 2 shows that using more activated carbon mass can increase its absorption capacity. Figure 2 demonstrates that the contact time affects the ability of activated carbon to absorb lead (Pb) metal; the percentage of absorption increases with longer contact times. The best absorption maximum capacity of active carbon from jackfruit skin was 99.277% at a contact time of 120 minutes with an adsorbent weight of 30 grams. The best time adsorption to determine the isotherm equation is in Table 4.

Table 4. Langmuir Adsorption Isotherm Calculation.

Mass (gram)	Time (minute)	Initial Concentration (C_0)(mg/l)	Final Concentration(Ce) (mg/l)	Adsorption effectiveness (W) (mg/g)	Ce/W (g/l)
10	120	163,2	1,82	4,0345	0,45111
15	120	163,2	1,67	2,69208	0,62219
20	120	163,2	1,53	2,02088	0,7571
25	120	163,2	1,35	1,61845	0,83722
30	120	163,2	1,18	1,35017	0,87397

Final concentration (Ce) and adsorption effectiveness (W) can be used to determine the Langmuir adsorption isotherm equation for each adsorbent mass by graphing the relationship between Ce and $\frac{Ce}{W}$ As shown in Figure 2.

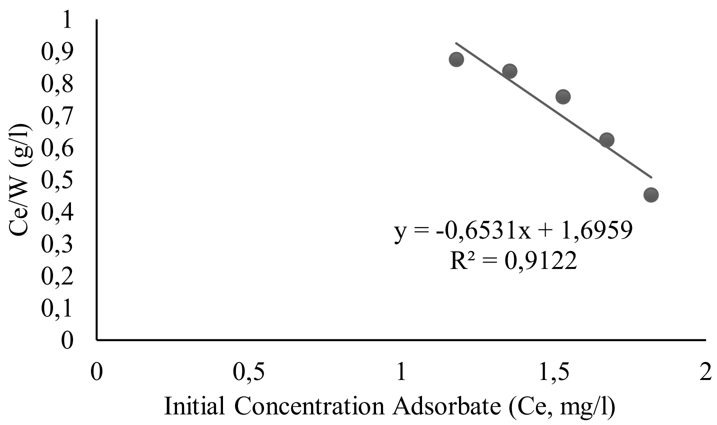

Figure 3. Langmuir Isotherm

Figure 3 shows the Langmuir adsorption isotherm equation for the adsorbent mass y = -0.6531x + 1.6959 with a value of $R^2 = 0.9122$. The best isotherm if the R^2 value obtained is $0 < R^2 < 1$. In addition, the equation from Figure 3 is used to determine the maximum adsorption capacity value (a) and the Langmuir constant value (b), which are shown in Table 4. using the Langmuir adsorption isotherm equation as follows :

$$\frac{Ce}{W} = \frac{1}{a}Ce + \frac{1}{a.b} \quad (1)$$

From the equation y = -0.6531x + 1.6959 with 1/a -0.6531x and 1/a.b = 1.6959, it can be used to calculate the Langmuir adsorption isotherm capacity with the values b = -0.3851 and a = -1,5311.

Table 5. Freundlich Adsorption Isotherm Calculation

Mass (gram)	Time (minute)	Initial Concentration (C_0) (mg/l)	Final Concentration (Ce) (mg/l)	Adsorption effectiveness (W) (mg/g)	log w	log Ce
10	120	163,2	1,82	4,0345	0,60579	0,26007
15	120	163,2	1,67	2,69208	0,43009	0,22401
20	120	163,2	1,53	2,02088	0,30554	0,18469
25	120	163,2	1,35	1,61845	0,2091	0,13194
30	120	163,2	1,18	1,35017	0,13039	0,07188

Table 5. shows data on adsorption effectiveness (W) and final concentration (Ce) to determine the Freundlich adsorption isotherm equation by making a relationship between log Ce and log W, as in the following Figure 3.

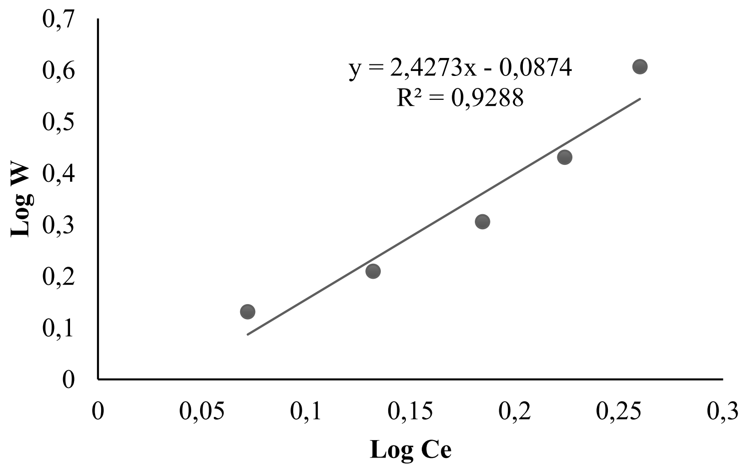

Figure 4. Freundlich Adsorption Isotherm

Figure 4. shows the Freundlich equation with y = 2.4273x + 0.0874 with a value of R^2 = 0.9288. This equation is used to determine the intensity factor (n) and the value of the adsorption capacity factor (K) which are shown in Table 5. using the Freundlich adsorption isotherm equation as follows :

$$\log W = \log K + \frac{1}{n}\log Ce. \quad (2)$$

The equation y = 2.4273x + 0.0874 and the values log K = -0.0874 and 1/n = 2.2473 are used to calculate the Freundlich adsorption isotherm capacity. The calculated capacity values K = 0.8177 and n = 0.4119 provide insights into the non-linearity between solution concentration and adsorption. The value 1/n represents the heterogeneity factor, while n measures the deviation from adsorption linearity [14].

4. CONCLUSION

The skin of the jackfruit is highly effective as activated carbon due to its ability to adsorb high-concentration solutions. The suitability of the adsorption model is determined by comparing the correlation coefficient (R^2) value of each graph, which is calculated to predict overall adsorption. In this research, data on the adsorption of Pb metal with activated carbon from jackfruit skin followed the Freundlich isotherm model, with a correlation coefficient (R^2) value of 0.9288. The Freundlich model suggests that the adsorbate adheres to the surface of the adsorbent physically (physisorption), there are multiple surface layers (multilayer), and the surfaces are heterogeneous [14].

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