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Adsorption Capacity of Magnetic Activated Carbon Derived from Snake Fruit (*Salacca zalacca*) Seeds to Cd(II): Characteristics and Isotherm Model

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Abstract

Snake fruit seed is an agricultural waste that has the potential to be converted into magnetic activated carbon (MAC). The resulting MAC can be utilized for wastewater treatment, particularly for the adsorption of heavy metals from wastewater. This study developed a method for producing MAC employing chemical activation. The activated carbon was then modified with Fe_3O_4 composite to render it magnetic and reusable. The objectives of this study were to determine the optimal chemical activator concentration, characterize magnetic activated carbon, characterize the surface morphology and elemental composition of MAC, evaluate the adsorption capacity of MAC for Cd(II) in wastewater, and obtain the adsorption isotherm model of MAC for Cd(II) using the Langmuir and Freundlich models. Chemical activation was performed using an HCl-H_3PO_4 mixture with equal portions in a 1:1 volume ratio, with variable concentrations of 0.55, 1.05, 1.55, 2.05, and 2.55 M. The MAC's characteristics and adsorption capacity were analyzed using proximate analysis, BET, SEM-EDX, and AAS. The results showed that the optimal HCl-H_3PO_4 concentration was 2.05 M, MAC contained 1% moisture, 21.88% volatile matter, 38% ash, 39.13% fixed carbon, iodine number of 1218.24 mg/g, surface area of 175.604 m^2/g, and an average pore volume of 26.8093 cm^3/g, MAC adsorbed Cd(II) from wastewater with an adsorption efficiency of 80.12 – 87.75%, the Langmuir isotherm model yielded $R^2 = 0.9847$, $q_m = 35.0877$ mg/g, and b = 0.2714 L/mg, whereas the Freundlich model yielded $R^2 = 0.9729$, n = 1.5881, and $k_f = 7.6701$ mg/g, and MAC exhibited evenly distributed pores and contained dominant elements Fe (30.26%), C (29.08%), O (24.59%), Na (11.27%), with traces of Mg, Al, Mo, and Cl.

Keywords: *salak seeds; Cd(II); HCl; H_3PO_4; magnetic activated carbon*

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INTRODUCTION

Many people appreciate snake fruit (*Salacca zalacca*), locally known as salak as a delicious and nutritious fruit. Salak trees are extensively cultivated in various regions of Indonesia, including Yogyakarta, Bali, North Sumatra, Tasikmalaya, and Bogor. In addition to be consumed in the form of fresh fruit, this fruit is also utilized as a raw material in the preparation of various food products. The larger the harvest volume of salak fruit, will generate larger quantity of salak seeds. Typically, salak seeds are discarded after the fruit is consumed. However, salak seeds have significant potential for conversion into activated carbon. The utilization of salak seeds for activated carbon production addresses two critical environmental challenges: the valorization of salak seed waste and the application of activated carbon for the adsorption of heavy metals in wastewater. One of the hazardous heavy metals present in wastewater is Cd(II).

Several studies have been conducted to mitigate Cd(II) contamination in wastewater from coal mining industries (Chen *et al*., 2024), solid sludge waste (Chen *et al*., 2023), river sediments affected by the weathering of mining waste deposits (Rodríguez-Hernández *et al*., 2021), cement industry effluents (Anakhu *et al*., 2023), and electronic waste leachates (Parvez *et al*., 2024). Among various treatment alternatives, the adsorption process has been recognized as an efficient and effective method for Cd(II) removal (Budianto *et al*., 2021; Chen *et al*., 2024; Kusdarini *et al*., 2022a; Kusdarini *et al*., 2022b; Kusdarini *et al*., 2023; Kusdarini & Budianto, 2018; Kusdarini & Budianto, 2022). Activated carbon is one of the most commonly used adsorbents for industrial and wastewater treatment applications.

Research has been conducted to develop activated carbon from various organic waste sources, including grape pomace (Sabando-Fraile *et al*., 2025), grape shoots (Sabando-Fraile *et al*., 2024), cellulose-based materials and compost (Chen *et al*., 2025; Rahim *et al*., 2024), *vitex doniana* seeds (Anakhu et al., 2023), mangosteen peels (Ogata *et al*., 2023), agricultural residues such as *Catha edulis* stems (Gelaw *et al*., 2024), tea waste (Mariah *et al*., 2023), coconut shells (Baskaran & Abraham, 2022), corn cobs (Haryanto *et al*., 2025), and *Zanthoxylum armatum seeds* (Bhattarai *et al*., 2025). Several studies have been conducted to develop conventional activated carbon that can be used only once. This study develops magnetic activated carbon that can be used repeatedly.

Mostly, the conventional activated carbon is only capable of single-use applications. Activated carbon is a strong absorbent and is widely used in water and wastewater treatment. In order to improve its efficiency and durability, MAC can be modified using Fe_3O_4 composite solution permitting it multiple uses after regeneration. Previous researchers have developed MAC from date seeds. They employed the Fe_3O_4 co-precipitation method to convert date seeds activated carbon into MAC. They concluded that the MAC derived from date seeds demonstrated better capacity for lead removal than that of pristine activated carbon (Ali & Abdul-Hameed, 2025).

This study utilizes chemical activation to develop activated carbon from snake fruit seeds. It has been reported in earlier experiments that the chemical and physical activation of agricultural waste materials could improve both the surface area and adsorption capacity of the resulting activated carbon. This study, however, is limited to chemical activation since physical activation can be cost-prohibitive at the commercial-scale production of activated carbons.

Annual salak seed production in Indonesia reaches thousands of tons per year and can be expected to be successfully made into MAC. Salak seeds have been reported to have a higher fixed carbon content than that of date seeds. Therefore, production of MAC from salak seeds is therefore very promising. The novelty of this study is to produce activated carbon from snake fruit seeds through chemical activation and followed by modification using Fe_3O_4 composite to develop magnetic property for multiple use repetitions.

RESEARCH METHOD

This research was conducted experimentally in the ITATS process laboratory. Firstly, salak seeds were converted into char through a carbonization process. Furthermore, salak seeds char was converted into MAC. The resulting MAC was characterized and evaluated for adsorption of Cd(II) ions in waste. The adsorption study was carried out through laboratory-scale experiments.

Materials and Tools

The experiment requires the following materials: salak (snake fruit) pondoh seeds from Sleman, Yogyakarta, distilled water, $CdCl_2$ 99.99% (Merck), HCl 37-38% (Merck), H_3PO_4 85% (Merck), $FeSO_4 \cdot 7H_2O$ 99.5-102% (Merck), $FeCl_3 \cdot 6H_2O$ 99% (Merck), KOH 85% (Merck), NH_4OH 25-30% (Merck), starch, iodine p.a (Merck), and $Na_2S_2O_3 \cdot 5H_2O$ p.a. (Merck). The equipment used in this research include a grinder, analytical balance, pipette, volumetric flask, Erlenmeyer flask, filter paper, clamp, burette, furnace, beaker glass, aluminum foil, and funnel.

Activated Carbon Making

Activated carbon production begins with washing the snake fruit seeds, followed by drying and carbonization in a furnace at 345°C for 300 minutes. The resulting carbon is then ground and sieved using a 60-mesh sieve. The activated carbon is soaked in an HCl-H_3PO_4 mixture for 24 hours at equal concentrations with a volume ratio 1:1. The chemical activator concentrations studied were varied at 0.55, 1.05, 1.55, 2.05, and 2.55 M.

Subsequently, the activated carbon was washed with 0.1 M KOH solution and distilled water, separated using a filter paper, and dried in a furnace at 105°C for 3 hours. The next step involved converting the activated carbon into magnetic activated carbon (MAC) by treating it with a $FeCl_3 \cdot 6H_2O$ and $FeSO_4 \cdot 6H_2O$ mixture at a molarity ratio of 1:2 and a volume ratio of 1:1 to form a Fe_3O_4 composite. The carbon was soaked in this solution for 30 minutes. After washing, the MAC was reheated in a furnace at 100°C for 4 hours to complete the modification process.

Physical and Chemical Characterization of MAC

MAC of salak seeds was characterized for its water content, carbon content, volatile matter and fixed carbon. Additionally, the MAC was also analyzed for its specific surface area and pore volume using BET equipment. MAC was also tested using SEM-EDX equipment to determine changes in surface morphology.

MAC Adsorption Power Test for Cd(II) Ions

MAC from salak seeds was tested for adsorption of Cd(II) ions from artificial heavy metal containing waste. Two hundred milliliters of cadmium salt solution with Cd(II) ions concentration in the waste was varied at 25, 21, 15, 12, and 8 mg/L. The MAC particle was added to each waste at a dose of 1 g/L. The adsorption was carried out for 24 hours. After the accomplishment of the adsorption study, MAC was separated from the waste using a filter paper. The resulting filtrate was analyzed for its Cd(II) ion content using an atomic absorption spectrophotometer (AAS). The data from measuring the concentration of Cd(II) are processed using the Freundlich and Langmuir isothermal adsorption model equations. The Freundlich isothermal adsorption equation is presented in Equation (1).

$$\log q_e = \log k_f + \log Ce.\frac{1}{n} \tag{1}$$

where q_e is the mass of Cd(II) ions adsorbed per unit mass of MAC (mg/g), while kf is the Freundlich constant, and n is an empirical parameter, and C_e is the equilibrium concentration of dissolved Cd(II) ions in mg/L. The development of Equation (1) is done by plotting as a straight-line equation which will produce the constants k_f and n.

By obtaining the equation, the equilibrium adsorption capacity can be determined. The adsorption capacity, q_e is the amount of Cd(II) ions adsorbed per unit mass of activated carbon (mg/g). The symbol C_e (mg/L) is the equilibrium concentration of Cd(II) ions in the waste solution after MAC adsorption. K_f and n are empirical constants derived from experimental data. Meanwhile, the Langmuir isotherm adsorption equation is presented in Equation (2).

$$\frac{Ce}{qe} = \frac{Ce}{qm} + \frac{1}{b\ qm} \tag{2}$$

where C_e is the concentration of Cd(II) ions in wastewater at equilibrium conditions (mg/L), and q_e is the mass of Cd(II) ions adsorbed per unit mass of magnetic bioadsorbent (mg/g). From Equation (2) and the measurement results obtained using an AAS equipment, the constants b and qm can be determined.

RESULTS AND DISCUSSION

This study obtained findings on the characteristics of MAC derived from snake fruit seeds and its adsorption capacity for Cd(II).

Characteristics of Activated Carbon

Activated carbon, after undergoing chemical activation using five different concentrations of mixed HCl and H_3PO_4 solutions, was tested for its iodine number. The results are presented in Figure 1. Figure 1 indicates that the activator concentration of 2.05 mol/L resulted in the highest iodine number (1243.6 mg/g).

Figure 1 presents the iodine numbers of activated carbon derived from salak seeds at various concentrations of chemical activators. The results indicate that the iodine number of activated carbon with chemical activation ranges from 1190 to 1243 mg/g, which exceeds 65% of the SNI Standard. An increase in activator concentration initially decreases the iodine number within the concentration range of 0.55-1.55 M. However, beyond this range, the iodine number increases and peaks at an activator concentration of 2.05 M. This trend is attributed to the dehydration process occurring at 0.55-1.55 M hydrochloric and phosphoric acid concentrations, reducing water content and volatile matter. At this stage, the acid effectively opens carbon pores but does not fully develop deep and extensive pore structures. Additionally, within this concentration range, intermediate products form, causing pore blockages and reducing pore volume.

At an acid concentration of 2.05 M, an optimal condition was achieved, marked by increased pore volume and the highest recorded iodine number.

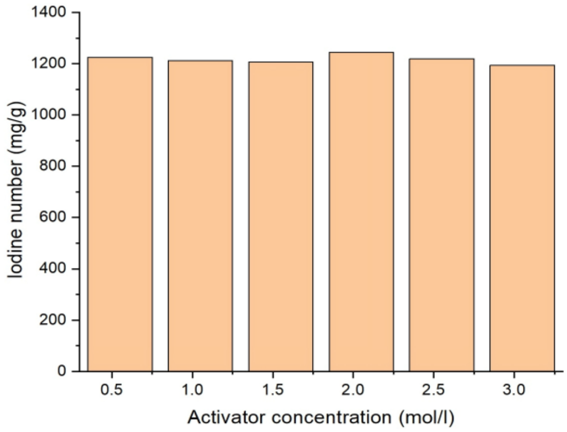

Figure 1. The correlation between the chemical activator concentration and the iodine number of activated carbon derived from salak seeds.

Table 1. Characteristics of magnetic activated carbon powder

Parameter	MAC	Standart*
Water content (%)	1	Max 15
Volatile matter (%)	21.875	Max 25
Ash content (%)	37.624	Max 10
Fixed Carbon (%)	39.501	Min 65
Iodine number (mg/g)	1218.24	Min 750
Surface area (m^2/g)	175.604	-
Average pore volume (cm^3/g)	26.8093	-

* SNI 06-3730-1995

However, at higher concentrations up to 2.55 M, excess acid leads to overexpansion of pore volume beyond the structural limit, resulting in partial pore collapse. This is reflected by a decline in the iodine number at this concentration range.

The proximate test based on SNI 06-3730-1995 was conducted to determine MAC's characteristics, as summarized in Table 1. Additionally, Table 1 presents the MAC's iodine number, pore surface area, and pore volume measurements.

Table 1 indicates that all MAC parameters, including water content and fixed carbon, comply with the technical specifications for powdered activated carbon as outlined in SNI 06-3730-1995. Additionally, the BET analysis of magnetic activated carbon provides data on the average surface area and pore volume. Meanwhile, the SEM-EDX analysis reveals the surface morphology of activated carbon at different stages: after carbonization, chemical activation, and transformation into magnetic activated carbon. These morphological observations are presented in Figure 2, 3, and 4.

Figure 2 illustrates that the activated carbon surface, after carbonization, exhibits evenly distributed pores with varying pore volumes and shallow depths. Figure 3 depicts a carbon surface with deeper pores compared to the carbonized sample; however, some material appears to partially obstruct specific pores, resulting in a more uniform pore volume than after carbonization. Meanwhile, Figure 4 indicates that magnetic activated carbon features more diminutive and uniformly distributed pores than activated carbon after carbonization and chemical activation.

Additionally, the SEM-EDX analysis provides insights into activated carbon's elemental composition and content, as presented in Table 2. Table 2 indicates that following the activation of salak seed-derived activated carbon with a magnetic solution, the carbon (C) content decreased due to the incorporation of additional iron (Fe) and oxygen (O) elements from the Fe_3O_4 composite.

The study results demonstrated a Cd(II) removal efficiency of 80.12–87.75% using magnetic biosorbent. The removal percentage achieved in this study was higher than that of adsorbents derived from compost and Vitex doniana seeds (Anakhu *et al*., 2023; Rahim *et al*., 2024).

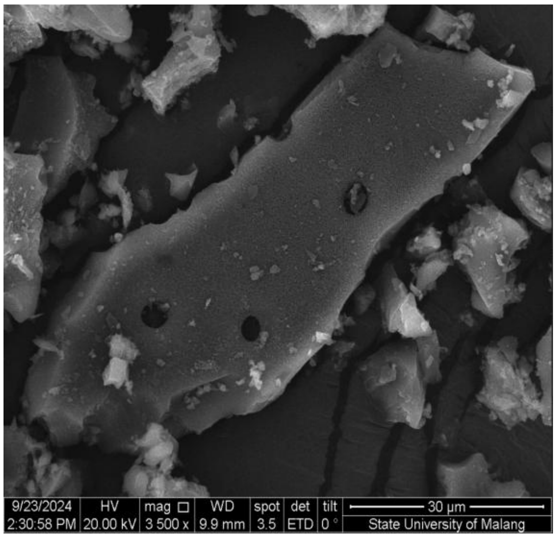

Figure 2. Surface morphology of activated carbon after carbonization (3500x magnification)

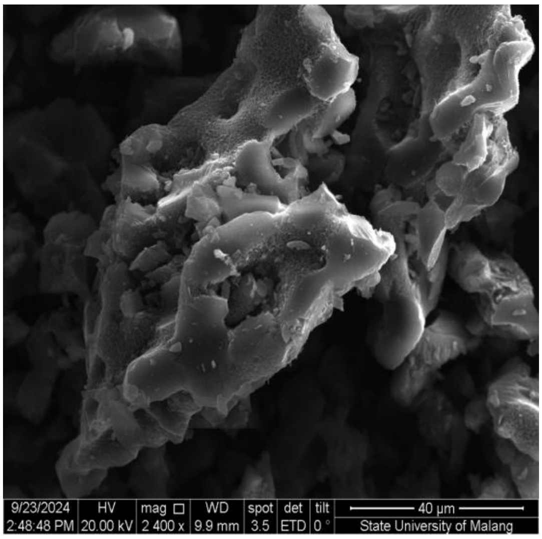

Figure 3. Surface morphology of activated carbon after chemical activation (2400× magnification)

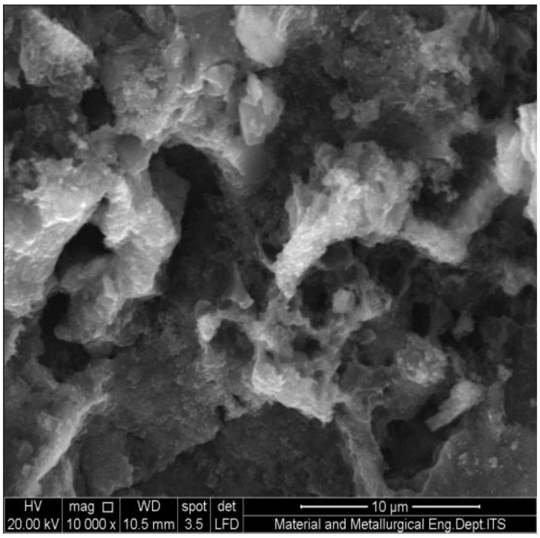

Figure 4. Surface morphology of activated carbon after becoming MAC (10000x magnification)

Table 2. Activated carbon content

Element	Elemental composition (%)		
	After carbonization	After chemical activation	After becoming MAC
C	83.7	84.2	29.08
O	18.0	15.1	24.59
Mg	0.1	-	00.50
P	0.2	0.2	-
Cl	0.7	0.1	02.52
K	1.3	0.1	-
Al	-	0.3	00.44
Na	-	-	11.27
Si	-	-	00.31
Mo	-	-	01.02
Fe	-	-	30.26

However, the Cd(II) removal efficiency was lower compared to biosorbents derived from grape pulp and cellulose-based materials (Chen *et al.*, 2025; Sabando-Fraile *et al.*, 2025), as well as grape shoots, mangosteen peels, catha edulis stems, and tea dregs (Gelaw *et al.*, 2024; Mariah *et al.*, 2023; Ogata *et al.*, 2023; Sabando-Fraile et al., 2024).

MAC Adsorption Power Test of Cd(II)

The results of the MAC adsorption capacity test for Cd(II) ions in industrial wastewater are presented in Table 3.

Table 3. MAC adsorption power towards Cd(II)

	Cd(II) (mg/L)				
	C1	C2	C3	C4	C5
C_o	25	21	15	12	8
Ce	4.97	3.66	1.98	1.56	0.98
q_e	20.03	17.34	13.02	10.44	7.02
$\frac{Ce}{qe}$	0.2481	0.2111	0.1521	0.1494	0.1396
% R	80.12	82.57	86.80	87	87.75

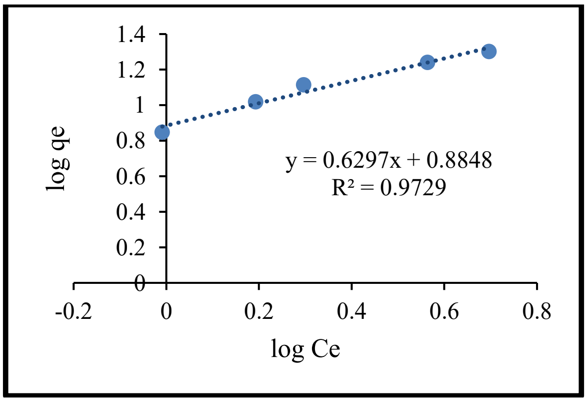

Figure 5. Freundlich isotherm adsorption test obtained from plotting of log C_e vs q_e

This discrepancy is likely due to suboptimal operating conditions, such as pH, adsorbent dosage, and stirring time. Furthermore, the adsorption capacity of activated carbon was analyzed using isotherm models based on the Freundlich and Langmuir equations. According to Table 4, a plot of log C_e vs. log q_e was generated to produce the Freundlich isotherm graph, as presented in Figure 5. Meanwhile, the isothermal parameters of Cd(II) ion adsorption by MAC are presented in Table 4.

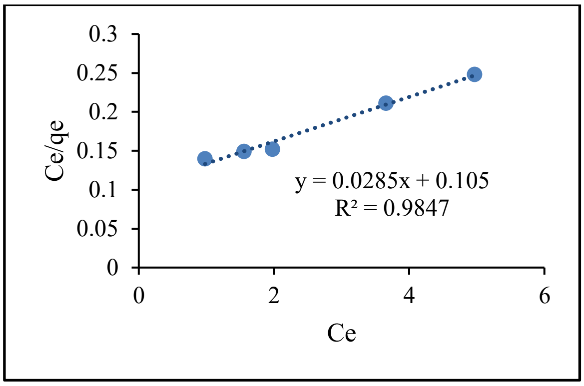

Figure 6. Langmuir isotherm adsorption test obtained from plotting C_e vs. $\frac{Ce}{qe}$

Table 4. Isothermal parameters against Cd(II) adsorption by MAC

Adsorption System		MAC
Freundlich isotherm	R^2	0.9729
	n	1.5881
	k_f (mg/g)	7.6701
Langmuir isotherm	R^2	0.9847
	b (L/mg)	0.2714
	q_m (mg/g)	35.0877

Figure 5 presents the Freundlich isotherm adsorption test results. The Freundlich adsorption equation for activated carbon against Cd(II) can be represented by a linear equation as: y = 0.6297. x + 0.8848, with R^2 = 0.9729, yielding the constants are presented in Table 4. The value of consntans n = 1.5881 indicates that the adsorption behavior follows a linear trend.

Figure 6 presents the results of the Langmuir isotherm adsorption test, with a Ce vs $\frac{Ce}{qe}$ plot yielding a straight-line equation: y = 0.0285. x + 0.105, with R^2 = 0.9847, yielding the constants are presented in Table 4. Based on the data from Figures 5 and 6, it was determined that the adsorption isotherm equation for MAC derived from salak seeds for Cd(II) ions aligns more closely with the Langmuir isotherm adsorption model compared to the Freundlich isotherm adsorption model.

CONCLUSION

The study found that the optimal operating conditions in the manufacture of MAC were at a concentration of HCl-H_3PO_4 of 2.05 M. Under these operating conditions, the MAC produced contained 1% water, 21.88% volatile matter, 38% ash, 39.13%

bound carbon, an iodine number of 1218.24 mg/g, a surface area of 175.604 m^2/g, and an average pore volume of 26.8093 cc/g. MAC was also able to adsorb Cd(II) from wastewater with an efficiency of 80.12 – 87.75%. The study also produced a Langmuir isotherm model with $R^2 = 0.9847$, $q_m = 35.0877$ mg/g, and $b = 0.2714$ L/mg, while the Freundlich isotherm model with $R^2 = 0.9729$, $n = 1.5881$, and $k_f = 7.6701$ mg/g. Furthermore, the surface morphology of magnetic activated carbon from salak seeds exhibits more pores, uniform distribution, and increased depth than activated carbon after carbonization and chemical activation. The elemental composition of activated carbon is predominantly Fe (30.26%), C (29.08%), O (24.59%), and Na (11.27%), with trace amounts of Mg, Al, Mo, and Cl.

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