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Research Article

Adsorption Study of Rhodamine-B (RhB) on Activated Carbon derived from Coconut Leaves

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Abstract

In this study, the adsorption of Rhodamine B (RhB) on activated carbon obtained by processing coconut leaves was investigated. The effects of initial RhB concentration, temperature, and pH on the dye adsorption process were investigated. Initial RhB concentration and temperature were found to be important but pH did not affect RhB adsorption. Adsorption kinetic balance was examined. The adsorption kinetics of RhB were simulated using the pseudo-second-order kinetic model. The Langmuir isotherm model is effective in describing adsorption equilibrium data.

Keywords: Activated carbon, Adsorption, Rhodamine-B

INTRODUCTION

Water pollution is an environmental problem that affects everyone. Leakage of heavy metals into water is a serious problem that can cause water pollution. The inability to decompose and toxicity of metals, together with their concentration in water, cause serious diseases. It is well known that many metals such as Copper (Cu), Lead (Pb), Manganese (Mn), Mercury (Hg) are very toxic (Salleh MA, et al. 2011). Open burning of coconuts often results in the release of toxic chemicals. It makes the weather very bad. The use of regional agricultural products as adsorbents has attracted attention recently (Crini G, 2006; Gupta VK, et al. 2009). Agricultural wastes were converted into activated carbon for adsorption capacity of biomaterials. A chemical reaction is used to produce activated carbon at the laboratory level. At 400°C the stage 1 process was initiated (Demirbas A, 2009). It seems better to use the one-step method because a lower level of activation is needed, which reduces production costs and saves energy over time. This process produces activated carbon with high adsorption capacity (Amin NK, 2009). With the use of clean technology, waste can be recycled and the amount of waste thrown into landfills can be reduced. To enhance the detoxification effect, the second waste needs to be processed. The adsorption process is one of the most effective methods for recycling secondary waste.

MATERIALS AND METHODS

Experimental

Production of activated carbon: Place about 300 grams of coconut leaves in a 2.0 liter container. Orthophosphoric acid (H₃PO₄:biomass::3:1 w/w) was added slowly until the edge of the precursor was completely immersed in the acid. Soak the mixture in acid for 24 hours, stirring occasionally with a glass rod to increase the acid content of the biomass. Transfer the dry material from the beaker to a 30 cm x 9 cm x 9 cm Stainless Steel (SS) container. Place the SS container containing the acid-laden biomass into the muffle furnace with the lid half-open. A small amount of nitrogen is introduced into the furnace to maintain an oxygen-free environment. The oven was slowly heated to 400°C for 30 minutes and maintained at this temperature for 90 minutes. Heating was stopped immediately and the product was allowed to cool under a stream of nitrogen. The cooled sample was removed from the furnace the next day and acid-loaded activated carbon was obtained. The material was washed several times with distilled water to remove all phosphoric acid and then dried in an oven at 110°C for 6 hours. The dried sample is crushed and sieved to obtain coconut leaf activated carbon. Finished products pass

through 710, 500, 355 and 53 (pan) sieves, and the product qualities are CL-PA-710, CL-PA-500, CL-PA-355 and CL-PA-53 (pan).



Figure 1. Manufacturing of activated carbon from coconut leaves.

Methods of analysis: The Brunauer–Emmett–Teller (BET) surface area and the pore structure analysis were conducted on a micromeritics ASAP 2010 surface analyzer. The pore size distributions were calculated according to the Density Functional Theory (DFT) method. The absorbance of RhB was analyzed using a UV spectrophotometer (UV2400). The value of pH was measured by a pH meter (PHS-25).

RESULTS AND DISCUSSION

Surface area analysis

Brunauer-Emmett-Teller nitrogen adsorption technology is used to calculate the surface area of activated carbon (Preethi S, et al. 2006) Scanning electron microscope data show that H_3PO_4 is the best activator in terms of physical and chemical properties of activated carbon. According to Table 1, carbon CL-PA-355 has a larger area than carbon CL-PA-710 and carbon CL-PA-500. Model NO: CL-PA-53. In addition, the adsorption capacity of CL also increases due to its type IV isotherm pattern. The increased surface area of CL-PA-355, as shown in Table 1, may be due to the presence of micropores. CL-PA-355 was modified for further studies as it has a larger area.

flexible SEM analysis was conducted; fiber and sheet-like

particles may be seen in Figure 2.

 Table 1. Adsorbents used, their surface areas (found by Autosorb-1).

Sr. No.	Adsorbents	Surface area (m ² /g)
1	Coconut leaves (CL-PA-710)-1:1	760.54
2	Coconut leaves (CL-PA-500)-2:1	1003.9
3	Coconut leaves (CL-PA-355)-3:1	1060.57
4	Coconut leaves (CL-PA-53)-4:1	875.87

SEM Analysis

To obtain the coconut leaves' carbon display morphology, a



Figure 2. SEM images A, B, C at 5000x magnification, of synthesized adsorbents with phosphoric acid, for varying {Acid: Adsorbent} ratio.

Figure 3 shows fiber like sand sheet like structure, which indicates the adsorption capacity of active carbon in turn will

help to describe the adsorption kinetics.



Figure 3. SEM 3D surface plot of coconut leaves active carbon.

Texture properties of activated carbons

Table 1 provides a summary of the properties of various activated carbons. Small volume (0.00148 m³/g) and low BET area (760.54 m²/g) belong to CL-PA-710. Treatment of CL-PA-355 with hot water resulted in an increase in BET surface area and pore volume. CL-PA-355 has a large pore volume and BET surface area. Most have mesopores (Figure 2 and Table 1). For CL-PA-355, the micropore surface area can reach 1060.57 m²/g, which is larger than the mesopore surface area of 1193 m²/g. Briefly, the BET area of the four materials increases in the following order: CL-PA-355, CL-PA-53, CL-PA-500, and CL-PA-710.

Effect of different activated carbons on adsorption

RhB was adsorbed onto four carbons in the following order: CL-PA-355, CL-PA-53, CL-PA-500, and CL-PA-710 (Figure 4a). This is based on BET surface area change. Considering the value of activated carbon, the CL-PA-355 study is the main focus of this study. In particular, most of the pores in CL-PA-355 are larger than 2 nm (Figure 4b), making them suitable for adsorbing RhB. The length and width of RhB molecules are 1.8 and 0.7 nm, respectively (Gad HM, et al. 2009; Guo Y, et al. 2005).



Figure 4. (a): N₂ adsorption and desorption isotherms; (b): DFT pore size distribution curves of different activated carbons.

Effect of contact time and initial RhB concentration

As contact time increased, CL-PA-355 absorbed more RhB. The change in absorbance was very small when the exposure time was more than 5 h, indicating an equilibrium time of approximately 5 h. The amount of RhB adsorbed by activated carbon at equilibrium serves as a measure of RhB adsorption capacity. At the beginning of adsorption, many active sites (including pores) of activated carbon are empty. Therefore, immediate adsorption occurs in 0-0.5 hours. After this, the adsorption rate slows down (0.5-6 hours) as the number of available adsorption sites decreases, forcing the RhB molecules to pass through deep holes in the activated carbon.



Figure 5. Effect of contact time on adsorption of RhB on different activated carbons (C₀: 300 mg L⁻¹; Temperature: 400°C). (a): Effect of contact time on RhB adsorption on CL-PA-355 at different initial RhB concentration (Temperature: 293 K); (b): pH (C₀: 300 mg L⁻¹; Temperature: 293 K), the inset is the effect of pH on the uptake at equilibration time (5 h).

The adsorption capacity increased from 223.8 to 233.9 mg g^{-1} , and the pH increased from 1.3 to 3.20, as shown in Figure 3b. In the pH range between 3.20 and 10.1, the adsorption capacity does not change much. When the pH value increased from 10.1 to 13.5, the adsorption capacity decreased from 232.5 to 217.8 mg g⁻¹. The mechanism by which initial pH affects RhB adsorption is complex. According to Lagura, et al. the electrostatic interaction between the negative charge of RhB and the negative charge of the adsorbent causes the adsorption of RhB to increase with increasing pH (Largura MC, et al. 2010). Different results were presented by Jain, et al. who found that RhB adsorption decreased with increasing pH. The explanation for this phenomenon is that low pH causes protonation of the adsorbent, thereby causing RhB diffusion and creating a large number of active sites on the adsorbent surface (Jain R, et al.). Wang and Zhu found that RhB adsorption was less affected by pH; this phenomenon is due to the presence of many functional groups of RhB (Wang S, et al. 2007). Additionally, RhB can exhibit different molecular structures depending on the pH of the solution; below pH = 3.5 it is a monomer and a zwitterion. pH = 3.5 (Anandkumar J, 2011). In RhB solution, H⁺ ions and OH can compete with cations and anions, respectively. In addition to the RhB molecular form, pH also affects the surface of activated carbon. Considering the above reasons, it is not surprising that the change in adsorption capacity is not stable. The adsorption capacity changes as pH changes, but only slightly. The zero charge pH point of CL-PA-355 is 6.48 (Figure 5b), which is close to the middle, indicating that the number of acidic and simple functional groups on the CL surface of PA-355 will be approximately equal.

Point zero charge

CL-PA-355 has a zero charge pH point of 6.48, which is close to the middle. This indicates that the number of basic and acidic functional groups on the PK surface AC will be approximately equal. RhB was adsorbed to CL-PA-355 only at low pH values. Even in alkaline or acidic liquids, CL-PA-355 shows strong adsorption capacity. This result shows that CL-PA-355 has good performance as an adsorbent. Therefore, iodine and methylene blue numbers were used to confirm the results. When the balance of positive charges and negative charges is equal, the pH point of the charge is zero and is the pH value of the liquid around the adsorbent (Gezici O, et al. 2006). According to published data, the addition method was used to obtain the null value of CL-PA-355.



Figure 6. Point zero charge of CL-PA-355.

Mesh size	710	500	355	53 (Pan)	
Burette reading (ml)	31.7	22.9	17.6	15.2	
Filtrate normality	0.0634	0.0458	0.0352	0.0304	
Factor	0.82	0.84	0.92	0.94	
lodine number	315.37	529.76	716.55	710.21	
Note: lodine number for CL-PA-355 gives higher value of iodine number.					

Table 2. lodine number value for different mesh size.

Table 3. Methylene blue number.							
Sample	Wt. of sample (gm.)	Burette reading	Decolorizing power				
CL-PA-53	0.1	59	700.5				
CL-PA-355	0.1	47	705				
CL-PA-500	0.1	39	585				
CL-PA-710	0.1	23	345				

Methylene blue value for CL-PA-355 gives higher value which indicates that coconut based activated carbon is feasible to remove the dye.

Adsorption kinetics

Adsorption kinetics of RhB, including the adsorption mechanism and rate controlling steps, were examined by pseudo-first order, pseudo-second order and intra-particle diffusion model.

Pseudo-first order model: The pseudo-first order model is depicted as (Demirbas E, et al. 2009):

$$Log(q_e - q_t) = log q_e - k_1 t/2.303$$

Where $q_e (mg g^{-1})$ and $qt (mg g^{-1})$ are the adsorption capacity

of RhB onto CL-PA-355 at equilibrium and at time t, respectively. k_1 (min⁻¹) is the pseudo-first order rate constant. The values of k1 and ge, obtained from the slop and the intercept of plots of $log(q_e-q_t)$ versus t, are displayed in Table 4.

Pseudo-second order model: The pseudo-second order model is expressed as (Al-Othman ZA, et al. 2012):

$$\frac{\mathrm{t}}{\mathrm{q}_{\mathrm{t}}} = \frac{1}{\mathrm{k}_2 \mathrm{q}_{\mathrm{e}^2}} + \frac{\mathrm{t}}{\mathrm{q}_{\mathrm{e}}}$$

Where k_2 (g mg⁻¹ min⁻¹) denotes the pseudo-second order rate constant. The values of k_2 and q_e were calculated from the slope and intercept of plots of t/q_t versus t. The initial adsorption rate is denoted as h (mg g^{-1} min⁻¹).

	q _{e,exp} (mg g ⁻¹)	Pseudo-first order model		Pseudo-seco	nd order mode	el	
		k₁ (min ⁻¹)	q _e (mg g ⁻¹)	R ²	k ₂ (g mg ⁻¹ min ⁻¹)	q _e (mg g ⁻¹)	R ²
C₀ (mg L ⁻¹)							
100	100.1	0.0056	10.8	0.945	0.00168	98.2	0.999
200	181.2	0.0112	77.6	0.810	0.00029	185.9	0.997
300	241.5	0.0085	62.0	0.871	0.00030	245.7	0.999
400	288.1	0.0064	114.6	0.978	0.00013	315.5	0.996

Table 4. Kinetic parameters for RhB adsorption onto CL-PA-355 at different initial RhB concentration, temperature and Ph.

500	350.0	0.0071	145.4	0.901	0.00010	370.4	0.996
600	413.9	0.0187	491.2	0.672	0.00008	409.8	0.994
т (К)							
573	241.5	0.0085	62.0	0.871	0.00030	245.7	0.999
623	275.2	0.0091	90.8	0.981	0.00020	286.5	0.999
673	279.3	0.0085	84.4	0.982	0.00023	295.0	0.999
723	286.1	0.0141	99.2	0.986	0.00030	295.9	0.999
рН							
1.3	223.8	0.0114	95.6	0.997	0.00023	237.0	0.999
3.2	233.9	0.0057	93.3	0.988	0.00015	257.7	0.994
6.8	234.0	0.0063	95.0	0.979	0.00015	257.1	0.995
10.1	232.4	0.0078	86.7	0.978	0.00020	248.8	0.998
13.5	217.7	0.0055	85.2	0.971	0.00016	243.3	0.994

Table 4 contains a list of the k_2 , q_e , and h. The correlation coefficients R^2 of the pseudo-second order model were greater than the pseudo-first order model, being near to 1 (>0.99). The q_e estimated from the pseudo-second order model was substantially closer to the $(q_{e,exp})$ obtained from the experiment compared to the pseudo-first order model (Table 5). As a result, the pseudo-second order model was well obeyed by this adsorption system. Physisorption and chemisorption processes were assumed to provide the basis for the pseudo-first order model and pseudo-second order model, respectively (Singha B, et al. 2013). Therefore, RhB may have been adsorbed onto CL-PA-355 through a chemisorption process.

equation described in previous work forms the basis of the intra-particle diffusion model (Safa Y, et al. 2011). In this document, the intra-article diffusion rate constant is expressed as K_{pi} (mg g⁻¹ min 0.5). Table 5 shows K_{pi} and C_i determined from the slope and intercept of the plot of q_t versus t 0.5. The adsorption process and rate control step were determined using this model. The sorbate adsorption on the interior of the adsorbent is mainly controlled by the steps of the adsorption process, which include (1) Film diffusion, (2) Intra-particle diffusion, (3) and the combination of the above steps (Wu J, et al. 2021). In this case, the graph of q_t versus t 0.5 is a straight line that does not pass through the origin. According to this finding, intra-particle diffusion is not the only problem.

Weber and Morris intraparticle diffusion model: The

Intra-particle diffusion model							
K _{pi} (mg g ⁻¹ min 0.5) C _i R ²							
C ₀ (mg L ⁻¹)							
100	0.69	84.4	0.968				
200	3.13	120.9	0.980				
300	4.25	163.9	0.893				
400	7.01	171.0	0.979				
500	9.25	182.6	0.940				
600	10.13	196.6	0.989				
т (к)							
573	4.25	163.9	0.893				
623	5.51	177.8	0.950				
673	4.89	197.9	0.965				
723	4.52	210.2	0.896				
рН							
1.31	4.82	142.3	0.948				
3.20	5.54	141.1	0.989				
6.84	5.60	140.0	0.985				

10.19	4.86	149.5	0.982
13.56	5.22	134.1	0.982

Adsorption isotherms

Adsorption isotherms provide important information that is useful for deducing adsorption mechanism and designing adsorption systems. The equilibrium data obtained at different initial RhB concentration, temperature and pH were analyzed by Langmuir and Freundlich model.

Langmuir isotherm: The Langmuir equation (Invinbor AA, et al. 2015; Al-Saidi HM, et al. 2021) is given as:

$$\frac{C_e}{q_e} = \frac{1}{q_m k_L} + \frac{C_e}{q_m}$$

Where $C_e (mg L^{-1})$ denotes the equilibrium concentration of RhB in solution, $q_m (mg g^{-1})$ is the maximum adsorption capacity, $k_L (L mg^{-1})$ represents the Langmuir constant related to energy of adsorption. k_L and q_m are calculated from slop and intercept of the plot of C_e/q_e versus C_e . The feasibility of adsorption process can be determined by separation factor R_L , which is defined by:

$$R_{L} = \frac{1}{1 + K_{L}C_{0}}$$

Where C_0 (mg L⁻¹) is the initial RhB concentration, k_L denotes the Langmuir constant mentioned above.

Freundlich isotherm: Freundlich is described as:

$$\ln q_{e} = \ln k_{f} + \frac{1}{n} \ln C_{e}$$

Table 6 provides a summary of the Langmuir and Freundlich isotherm adsorption characteristics. The Langmuir isotherm model produced a higher correlation coefficient of 0.988 when compared to the Freundlich isotherm model. The Langmuir isotherm therefore provided a good fit for the experimental data, illuminating the fact that the RhB adsorption process comprised chemisorption and that the distribution of the adsorbent's surface adsorption sites and sorption energies was homogeneous. Additionally, the RL values obtained at various temperatures ranged from 0 to 1, indicating that RhB was successfully adsorbed on CL-PA-355.

Table 6. Langmuir and Freun	dlich isotherm constants.
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Langmuir isotherm model			Fre	undlich isoth	erm mode	el	
т (к)	q _m (mg g ⁻¹)	kL (L mg ⁻¹)	R ²	RL	k _f (L mg ^{−1})	1/n	R ²
573	478.5	0.0259	0.988	0.11410	78.006	0.2909	0.941
623	478.5	0.0777	0.993	0.04115	135.263	0.2151	0.970
673	518.1	0.0669	0.997	0.04749	150.181	0.2097	0.968
723	518.1	0.0867	0.998	0.03701	174.300	0.1857	0.978

CONCLUSIONS

This study had demonstrated that CL-PA-355 was an effective adsorbent for removal of RhB from aqueous solution. Both a low initial RhB concentration and a high temperature were benefit to RhB adsorption. pH value of solution only had a little effect on adsorption. Kinetics studies suggested that the adsorption mechanism of RhB followed the pseudo-second model well. Intra-particle diffusion was not the only rate controlling step. The equilibrium analysis reflected that the Langmuir model fitted isotherm date well. Therefore, it can be concluded that the CL-PA-355 based activated carbon is a promising adsorbent.

REFERENCES

1. Salleh MA, Mahmoud DK, Karim WA, Idris A (2011). Cationic and anionic dye adsorption by agricultural solid wastes: A

comprehensive review. Desalination. 280: 1-13.

- 2. Crini G (2006). Non-conventional low-cost adsorbents for dye removal: A review. Bioresour Technol. 97: 1061-1085.
- 3. Gupta VK, Suhas (2009). Application of low-cost adsorbents for dye removal A review. J Environ Manage. 90: 2313-2342.
- Demirbas A (2009). Agricultural based activated carbons for the removal of dyes from aqueous solutions: A review. J Hazard Mater. 167: 1-9.
- Amin NK (2009). Removal of direct blue-106 dye from aqueous solution using new activated carbons developed from pomegranate peel: Adsorption equilibrium and kinetics. J Hazard Mater. 165: 52-62.
- 6. Preethi S, Sivasamy A, Sivanesan S, Ramamurthi V, Swaminathan G (2006). Removal of safranin basic dye from aqueous solutions by adsorption onto corncob activated carbon. Ind Eng Chem Res. 45: 7627-7632.
- Gad HM, El-Sayed AA (2009). Activated carbon from agricultural by-products for the removal of Rhodamine-B from aqueous solution. J Hazard Mater. 168: 1070-1081.

- Guo Y, Zhao J, Zhang H, Yang S, Qi J, Wang Z, Xu H (2005). Use of rice husk-based porous carbon for adsorption of Rhodamine B from aqueous solutions. Dyes Pigm. 66: 123-128.
- Largura MC, Debrassi A, Santos HH, Marques AT, Rodrigues CA (2010). Adsorption of Rhodamine B onto Ocarboxymethylchitosan-N-lauryl. Sep Sci Technol. 45: 1490-1498.
- 10. Jain R, Mathur M, Sikarwar S, Mittal A (2007). Removal of the hazardous dye rhodamine B through photocatalytic and adsorption treatments. J Environ Manage. 85: 956-964.
- 11. Wang S, Zhu ZH (2007). Effects of acidic treatment of activated carbons on dye adsorption. Dyes Pigm. 75: 306-314.
- 12. Anandkumar J, Mandal B (2011). Adsorption of chromium (VI) and Rhodamine B by surface modified tannery waste: Kinetic, mechanistic and thermodynamic studies. J Hazard Mater. 186: 1088-1096.
- Gezici O, Küçükosmanoğlu M, Ayar A (2006). The adsorption behavior of crystal violet in functionalized sporopolleninmediated column arrangements. J Colloid Interface Sci. 304: 307-316.
- 14. Demirbas E, Dizge N, Sulak MT, Kobya M (2009). Adsorption kinetics and equilibrium of copper from aqueous solutions using hazelnut shell activated carbon. Chem Eng J. 148: 480-487.
- 15. Al-Othman ZA, Ali R, Naushad M (2012). Hexavalent

chromium removal from aqueous medium by activated carbon prepared from peanut shell: Adsorption kinetics, equilibrium and thermodynamic studies. Chem Eng J. 184: 238-247.

- Singha B, Das SK (2013). Adsorptive removal of Cu (II) from aqueous solution and industrial effluent using natural/agricultural wastes. Colloids Surf. B Biointerfaces. 107: 97-106.
- Safa Y, Bhatti HN (2011). Kinetic and thermodynamic modeling for the removal of direct red-31 and direct orange-26 dyes from aqueous solutions by rice husk. Desalination. 272: 313-322.
- Wu J, Yan X, Li L, Gu J, Zhang T, Tian L, Su X, Lin Z (2021). Highefficiency adsorption of Cr (VI) and RhB by hierarchical porous carbon prepared from coal gangue. Chemosphere. 275: 130008.
- Inyinbor AA, Adekola FA, Olatunji GA (2015). Adsorption of Rhodamine B dye from aqueous solution on Irvingia gabonensis biomass: Kinetics and thermodynamics studies. S Afr J Chem. 68: 115-125.
- Al-Saidi HM, Abdel-Fadeel MA, Alharthi SS (2021). Preconcentration and ultrasensitive spectrophotometric estimation of tungsten in soils using polyurethane foam in the presence of rhodamine B: Kinetic and thermodynamic studies, and designing a simple automated preconcentration system. J Saudi Chem Soc. 25: 101301.