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Comparative Analysis of Adsorption of Acetic Acid by Banana Pseudostem and Commercial Wood Charcoal

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Abstract: ***Clean drinking and sanitation water is an important social, economic and environmental issue. Due to the large scale of industrialization lot of chemical species, that is, dyes, heavy metals, and inorganic chemicals, are continuously discharged into water resources. There has been a great emphasis on developing inexpensive adsorbents and activated carbon for the treatment of inorganic impurities from wastewater due to the inability of developing countries to use available expensive treatment technologies on a mass scale. Bio-adsorbent characteristics of charcoals are promising for the removal of pollutants from residual waters. The use of biobased charcoals for decolorization processes has gained significant attention. Among these, banana pseudostem charcoal stands out as a promising alternative with its unique properties. This article reveals a comparative analysis of the adsorption capabilities of banana pseudostem charcoal (PSC) in contrast to commercial wood charcoal (WC), shedding light on their efficacy and potential applications. A higher value of n indicated that PSC has a good ability to adsorb acetic acid over its surface as compared to WC. In the SEM analysis of PSC, the pores observed were within two significant size ranges: a larger range from 1.6 to 3 µm and a smaller, nanoscale range between 720 to 810 nm. This dual-porosity structure suggests that PSC may possess the capacity to adsorb particles of varying sizes, enhancing its versatility as an adsorbent. The larger pores could facilitate the capture of larger molecules, while the nanoscale pores may allow the adsorption of smaller particles, broadening the material's applicability.***

Keywords: Banana pseudostem charcoal, commercial wood charcoal, adsorption isotherm, porosity

1. Introduction

PSC, derived from the agricultural waste of banana plants, has emerged as a sustainable alternative for decolorization purposes. Its porous structure and high carbon content make it an excellent adsorbent for removing impurities from various media.

The increased pollution of the aquatic environment by heavy metals and artificial coloring compounds has negatively impacted many aspects, especially in health terms. Previous studies have reported that effluent from several industries contains heavy metals like Cu, Cr, Pb, Fe, and Zn with concentrations far above the standards set by WHO [1]. Various activated carbons have been produced from biodegradable and non-biodegradable materials. Neolaka et al summarize the potential applications and properties of activated carbon, materials used to produce activated carbon, explore different techniques for creating active carbon for improved performance in specific applications, particularly low-cost adsorbents for heavy metal and synthetic dye removal derived from various sources [2]. Besides heavy metals, dyestuffs have also been reported to affect health and the environment adversely. Dyes can be categorized into three groups according to their chemical structure and solubility in water, such as cationic dyes, methylene blue, malachite green, and others [3]. Lead has been reported to cause diseases such as hypertension and cell degeneration. Long-term exposure to chromium has been reported to cause liver, kidney, blood circulation, and nervous tissue damage. Metals Arsenic and Cadmium are carcinogenic agents that can cause skin, lung, and liver cancer. Mercury at high concentrations is known to permanently damage nerve cells in the brain and kidneys [4].

The utilization of low-temperature PSC and acid post-treated banana pseudostem biochar (PT-PSC) for the removal of methylene blue from an aqueous solution was investigated. The maximum removal efficiency of methylene blue with PT-PSC and PSC was achieved at pH 7 and pH 6 at different adsorbent dosages [5]. The potential of banana pseudo-stem biochar prepared at 300ºC (BC300) was the highest removal percentage and amount of Crystal violet adsorbed. Biochar BC300 was then activated by chemical treatment with different acid and alkali solutions. The removal percentage of biochar treated with H_2SO_4, HCl, NaOH, and KOH was enhanced by various percentages, in comparison to untreated biochar [6]. Banana trunk was used as a low-cost activated carbon source material through the chemical activation method using phosphoric acid. The rotatable central composite design was used to maximize the surface area of the prepared banana trunk activated carbon under the optimal conditions of the variables [7]. Pyrolysis/gasification is a practical approach to use the waste and garbage in an environment-friendly technique to prepare the biochar for activated carbon. Improve

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and optimize the adsorption capacities of biochar towards the removal of organic and inorganic pollutants from water and gas pollutants from the air, an appropriate selection of precursors, carbonization process and optimum activation conditions are the most significant parameters. For dye removal, the performance of chemical and physicochemical activations is much better than physical activation for the higher functional groups. Whereas for the bigger size of the pollutants from metallic, phenolic and pesticides, the pore size and pore distribution have directed the efficiency [8].

The potential of banana pseudo stems as a natural adsorbent for the removal of copper ions from aqueous solution was achieved at optimized conditions of influential parameters. Therefore, banana pseudo stems have the potential to be utilized as a new biosorbent material in the removal of copper from water due to high adsorption efficiency and low cost [9]. Increasing the activation temperature efficiently increases the specific surface area (SBET) values of the activated carbon, and increasing the amount of the activating chemical agent drastically decreases the SBET values. Physically activated samples by steam showed significant performance for the removal of both phenol and methylene blue compared with either KOH or K_2CO_3 chemical activators [10]. The banana industry generates a large amount of biowaste that can be used in various recovery processes, such as the production of bioplastics, green nanoparticles, biofuels, and wastewater treatments focused on implementing a circular economy [11].

2. Materials and Methods

Banana pseudostem was collected from the field of Raver, Maharashtra, India. Banana pseudostem layers were washed and sun-dried for five days. Cut the dry layers into small pieces. The pyrolysis reaction is carried out in a novel biochar reactor (NBR). Initially, a few small pieces of banana pseudostem biomass were scattered at the bottom of the NBR. It heats up rapidly and begins to extinguish. Pyrolysis gases rise and are captured by the flame, where they react with the air entering the NBR from above. When the flame is extinguished, the next layer of biomass is added evenly from above to form an even layer. A fire curtain protects the charcoal under the upper layer from oxygen. As a result, a flame barrier is formed in the combustion area, preventing oxidation of the biochar base. Manual biomass layering is repeated until the 5 kg raw material amount is exhausted. We must be careful to spread each new biomass layer at the right time and at the right time by monitoring the flames, smoke and ash that are formed. When the flames subside and ash appears on the layer, extinguish the flames by spraying water from the top. When the system cools down, the charcoal is collected from the bottom cover. The product was dried in an oven at 110°C for one hour, cooled and weighed. Grind into a fine powder and store in an airtight container.

3. Adsorption of acetic acid on charcoal to compare Freundlich adsorption isotherm for WC and PSC

The Freundlich adsorption isotherm is a fundamental concept in the field of surface chemistry and adsorption. It provides a mathematical model to describe the relationship between the concentration of a solute in a solution and the amount of that solute adsorbed onto a solid adsorbent at a constant temperature.

The Freundlich equation is typically expressed as:
$Q = K \cdot C^{n}$

Where:
q is the amount of solute adsorbed per unit mass of the adsorbent.
C is the equilibrium concentration of the solute in the solution.
K is the Freundlich constant, which represents the adsorption capacity of the adsorbent.
n is the Freundlich exponent, indicating the intensity of adsorption.

PSC contains functional groups that facilitate interactions with contaminants, such as electronic attraction and hydrogen bonding, enhancing sorption efficiency. Charcoal produced at optimal temperatures exhibits a high surface area, which is crucial for effective adsorption. Utilizing agricultural waste like banana pseudostems for charcoal production not only addresses waste management but also provides an eco-friendly solution for water purification [12]. The Freundlich isotherm is commonly used to model adsorption on heterogeneous surfaces, where multiple layers of solute molecules can be adsorbed. Unlike the Langmuir isotherm, which assumes monolayer adsorption on a homogeneous surface, the Freundlich isotherm is more versatile and applicable to a wider range of experimental conditions.

4. Experimental Procedure

Materials: Charcoal (adsorbent), 0.5 N Acetic acid solution, 0.1N NaOH solution, stirring rod or magnetic stirrer, filter paper, funnel, graduated cylinders or pipettes, five stopper reagent bottles.

The reagent bottles were cleaned, dried and filled from one to five. Using a burette, 50, 40, 30, 20, and 10 ml of 0.5 N acetic acid or oxalic acid and 0, 10, 20, 30, and 40 ml of distilled water were added to bottles 1, 2, 3, 4, and 5, respectively. 1 gm of activated carbon was accurately weighed and added to each bottle. The bottles were shaken for 30 minutes. At the same time, the initial concentration of acetic acid (Ci) was determined using the formula V x 0.5/50 in the analysis table, where V was the volume of acetic acid added to the bottle. The solution in each bottle was filtered using filter paper, and 10 ml of the solution was taken from the bottle. The solution was titrated with 0.1 N NaOH solution from the burette in the presence of phenolphthalein, and the formula (Ce) / V × 0.5

was used in the laboratory calculation, where V was the volume of NaOH required to reach the endpoint. The amount of adsorbed acetic acid (X) was calculated by using the data in the examination table. Freundlich's exponent and Freundlich's constant for wood and PSC are shown in Tables 3 and 6, and the experimental results are shown in Tables 1, 2, 4 and 5. The adsorption of acetic acid on wood and PSC surfaces is shown by graphs in Fig. 1 and 2.

5. Results and Discussion

To conduct a Freundlich adsorption isotherm experiment, researchers typically vary the concentration of the solute in the solution and measure the corresponding amount of adsorption onto the solid adsorbent. The experimental data is then analyzed using the Freundlich equation to determine the values of K and n, providing insights into the adsorption behavior and characteristics of the system under investigation. Langmuir adsorption model and pseudo-second-order kinetics were suitable for modelling the biosorption of Cr (VI) [13]. Banana and WC follow the Freundlich and Langmuir adsorption isotherm models, indicating multilayer adsorption on heterogeneous surfaces. The kinetics of acetic acid adsorption aligns with second-order models for banana pseudostem biochar and first-order for wood biochar [14].

Table 1: Amount of acetic acid adsorbed on WC surface at different concentrations

Flask No.	Acetic Acid (ml)	Water (ml)	The initial concentration of Acetic Acid (Ci) = V x 0.5/50	Concentration of Acetic Acid After Adsorption. (Ce) = V' x 0.5/50	(Ci) - (Ce)	Amount of acetic acid adsorbed *x* *x* = [(Ci - Ce) x 50 x 60] / 1000
1	10	40	(Ci) = 10 x 0.5/50 = 0.1	(Ce) = 6 x 0.5/50 = 0.06	0.04	0.12
2	20	30	(Ci) = 20 x 0.5/50 = 0.2	(Ce) = 13 x 0.5/50 = 0.13	0.07	0.21
3	30	20	(Ci) = 30 x 0.5/50 = 0.3	(Ce) = 18 x 0.5/50 = 0.18	0.12	0.36
4	40	10	(Ci) = 40 x 0.5/50 = 0.4	(Ce) = 24 x 0.5/50 = 0.24	0.16	0.48
5	50	00	(Ci) = 50 x 0.5/50 = 0.5	(Ce) =w 31 x 0.5/50 = 0.31	0.19	0.06

Table 2: Freundlich sorption parameters for WC

Flask No.	*m* = weight of charcoal gm	*x*/ m	log (*x*/ m)	log Ce
1	1	0.12	-0.920818754	-1.22185
2	1	0.21	-0.677780705	-0.88606
3	1	0.36	-0.443697499	-0.74473
4	1	0.48	-0.318758763	-0.61979
5	1	0.06	-1.22184875	-0.31876

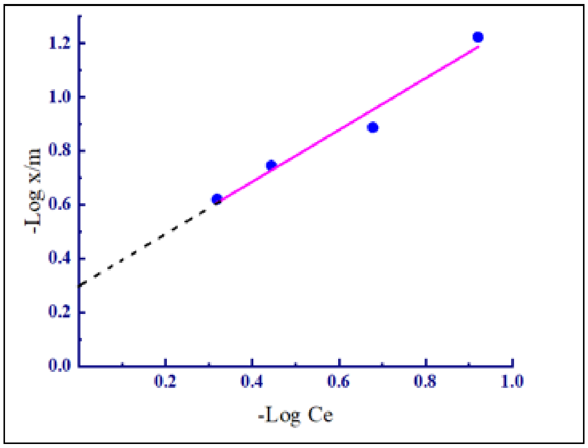


Figure 1: Plot of -Log x/m Vs -Log Ce of WC

Intercept = c = Log K = 0.337
Hence K = 2.17
Slope = Log n = 0.96
Hence n = 9.12

Table 3: Freundlich's constant and Freundlich's exponent of WC

Term	Values
n Freundlich's exponent for acetic acid for activated Charcoal	9.12
K Freundlich's constant for acetic acid for activated Charcoal	2.17

After repeating the same procedure for PSC, we got results with an enhancement in adsorption ability.

Table 4: Amount of acetic acid adsorbed on the PSC surface at different concentrations

Flask No.	Acetic Acid (ml)	Water (ml)	Initial concentration of Acetic Acid (Ci) = V x 0.5/50	Concentration of Acetic Acid After Adsorption. (Ce) = V' x 0.5/50	(Ci) - (Ce)	Amount of acetic acid adsorbed *x* *x* = [(*Ci - Ce)* x 50 x 60] / 1000
1	10	40	(Ci) = 10 x 0.5/50 = 0.1	(Ce) = 8.2 x 0.5/50 = 0.082	0.018	0.06
2	20	30	(Ci) = 20 x 0.5/50 = 0.2	(Ce) = 18 x 0.5/50 = 0.18	0.020	0.12
3	30	20	(Ci) = 30 x 0.5/50 = 0.3	(Ce) = 27 x 0.5/50 = 0.27	0.030	0.15
4	40	10	(Ci) = 40 x 0.5/50 = 0.4	(Ce) = 38 x 0.5/50 = 0.38	0.020	0.24
5	50	00	(Ci) = 50 x 0.5/50 = 0.5	(Ce) = 48 x 0.5/50 = 0.48	0.020	0.27

Table 5: Freundlich sorption parameters for PSC

Flask No.	*m* = weight of charcoal gm	*x*/ m	log (*x*/ m)	log Ce
1	1	0.06	-1.22184875	-1.096910013
2	1	0.12	-0.920818754	-0.795880017
3	1	0.15	-0.823908741	-0.602059991
4	1	0.24	-0.619788758	-0.494850022
5	1	0.27	-0.568636236	-0.387216143

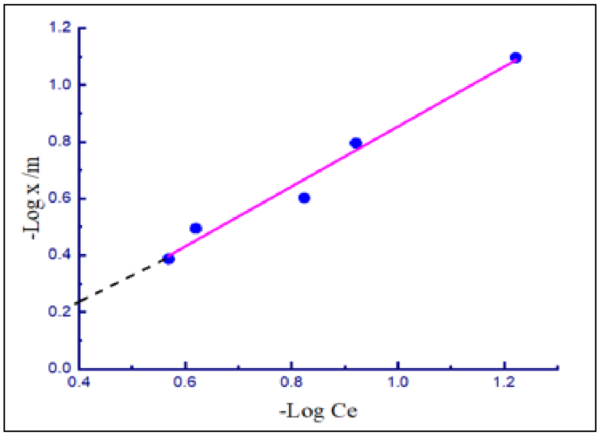


Figure 2: Plot of -Log x/m Vs -Log Ce of PSC

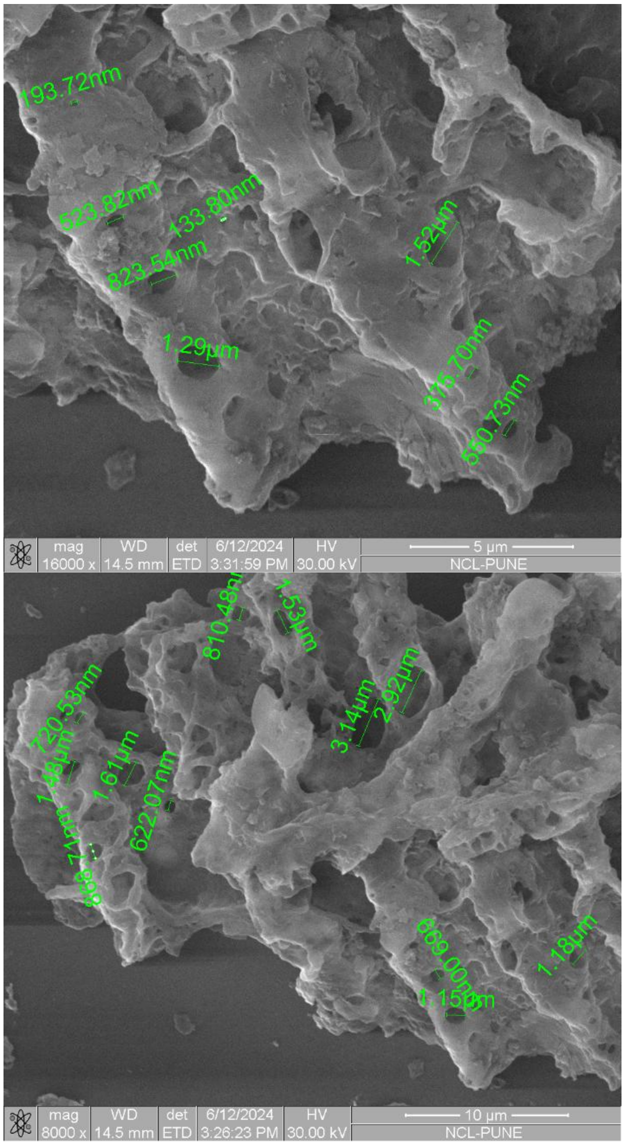
Intercept = c = Log K = 0.21
Hence K = 1.62
Slope = Log n= 1.05
Hence n = 11.22

Table 6: Freundlich's constant and Freundlich's exponent of PSC

Term	Values
n Freundlich's exponent for acetic acid for PSC	11.22
K Freundlich's constant for acetic acid for PSC	1.62

6. SEM Analysis

SEM analysis revealed the surface morphology of the PSC, showing a porous, three-dimensional framework with interconnected nano sheets. The external surface exhibited a rough texture, indicating significant porosity, which is crucial for efficient mass and charge transfer [15]. In the present study, we investigated PSC as a potential adsorbent, examining its surface characteristics to evaluate its effectiveness. To gain insights into the microstructural features, we conducted a Scanning Electron Microscopy (SEM) analysis. This SEM analysis revealed diverse pore sizes within the charcoal sample, indicating a potentially favorable structure for adsorption applications. Notably, the pores observed were within two significant size ranges: a larger range from 1.6 to 3 µm and a smaller nanoscale range between 720 to 810 nm shown in Fig. 3. This dual-porosity structure suggests that PSC may possess the capacity to adsorb particles of varying sizes, enhancing its versatility as an adsorbent. The larger pores, measuring between 1.6 and 3 µm, could facilitate the capture of larger molecules, while the nanoscale pores, 720 to 810 nm, may allow for the adsorption of smaller particles, broadening the material's applicability. This bimodal pore distribution potentially increases the surface area, enabling more active sites for adsorption. These structural characteristics, evident through SEM, suggest that PSC holds promise as an efficient and versatile adsorbent material, capable of capturing contaminants across a range of particle sizes. Further exploration of its adsorption efficiency could solidify its role in environmental or industrial applications.



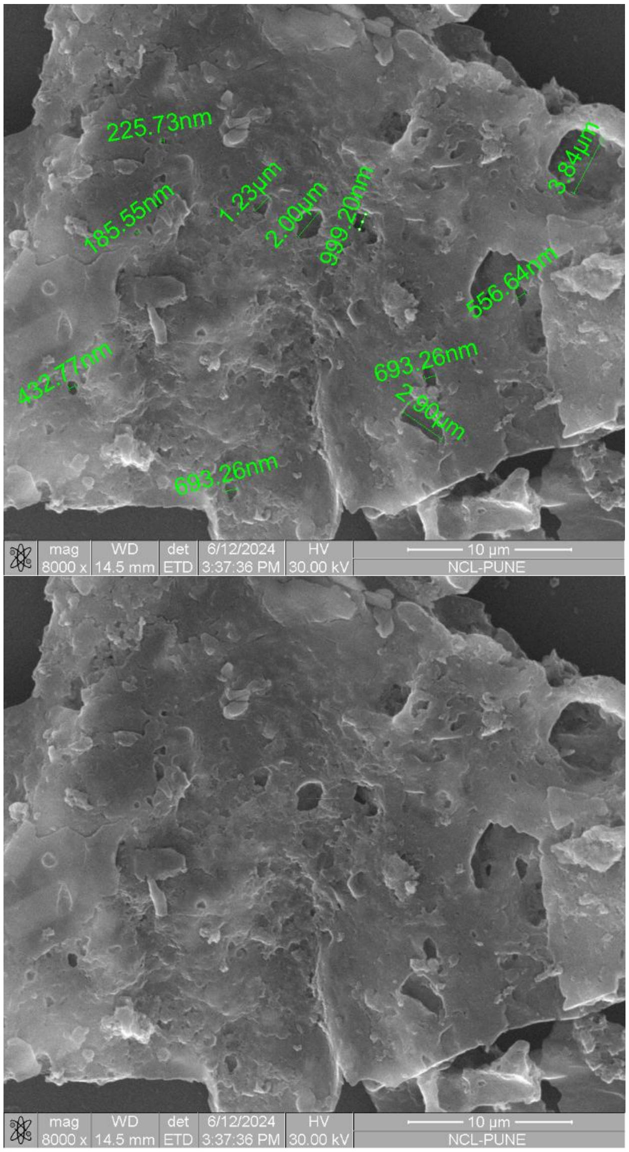


Figure 3: SEM Analysis of PSC

7. Conclusion

PSC emerges as a standout performer with its superior adsorption capacity, sustainable sourcing and cost-effective production. By comparing its properties with other biobased charcoals, we can appreciate the unique advantages it offers for decolorization applications. Embracing the potential of banana pseudostem charcoal can pave the way for more sustainable and efficient decolorization processes in diverse industries. The higher value of n indicated that PSC has a good ability to adsorb acetic acid over its surface as compared to WC. The importance of these findings lies in the potential applications of PSC as a sustainable and cost-effective adsorbent. Given its dual pore structure, PSC could serve effectively in environmental cleanup processes, such as wastewater treatment or air purification, where removing pollutants of varying sizes is essential. Additionally, the presence of both micro- and nano-sized pores suggests a higher adsorption capacity, which could improve the efficiency of pollutant capture compared to single-porosity adsorbents. This characteristic makes PSC not only an economically viable alternative to synthetic adsorbents but also an eco-friendlier option, utilizing agricultural waste to address environmental challenges. The discovery of these structural properties underscores the material's promise for real-world applications in pollution control and resource recovery, aligning with sustainable development goals.

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