



SUSTAINABLE WASTEWATER TREATMENT USING SUGARCANE BAGASSE ACTIVATED CARBON: A LOW-COST SOLUTION FOR PHENOL REMOVAL

A. A. OLATUNJI^{1*}, A. A. AKANDE², M. O. ALAO¹, I. O. LAMIDI¹, S. T. OYEWO³, V. E. AKASI¹

¹Department of Civil Engineering, Federal Polytechnic Ede

²Department of Building Technology, Federal Polytechnic Ede

³Department of Civil Engineering, Redeemer's University Ede

***Corresponding Author: olatunjiaa@gmail.com, Tel: +2348068782879**

ABSTRACT

The increasing discharge of industrial effluents containing hazardous pollutants such as phenol poses a major environmental and public health concern. Phenol, widely present in paint wastewater, is toxic to humans, aquatic life, and ecosystems, necessitating effective removal prior to discharge. This study investigates the potential of sugarcane bagasse powdered activated carbon (SCBPAC), an agricultural waste-derived adsorbent, for the treatment of phenol-laden paint wastewater. Sugarcane bagasse was carbonized at 600 °C and thermally activated at 400 °C to produce powdered activated carbon, which was then applied at varying dosages (4 g, 6 g, and 8 g) in a jar test adsorption-coagulation process. X-ray fluorescence analysis revealed that SCBPAC contained high levels of silica (54.8%) and alumina (15.92%), compounds known to enhance adsorption efficiency. The initial phenol concentration of 1.11 mg/L exceeded the Federal Environmental Protection Agency (FEPA) permissible limit of 0.2 mg/L. Treatment with SCBPAC reduced phenol to 0.65 mg/L, 0.20 mg/L, and 0.15 mg/L at 4 g, 6 g, and 8 g dosages, corresponding to removal efficiencies of 41.44%, 81.98%, and 86.49%, respectively. Additional removal of chemical oxygen demand (COD), biological oxygen demand (BOD), nitrates, phosphates, and heavy metals was also achieved, though turbidity and total dissolved solids (TDS) increased due to lack of post-filtration. The highest overall efficiency (77.44%) was observed at 8 g dosage, making it the most effective treatment condition. These findings demonstrate that SCBPAC is a cost-effective, sustainable, and efficient adsorbent for phenol removal from industrial wastewater, with potential applications in large-scale wastewater treatment systems.

KEYWORDS: Sugarcane bagasse, Activated carbon, Phenol removal, Paint wastewater, Adsorption-coagulation

1. INTRODUCTION

Due to its possible detrimental effects on ecosystems and human health, the deteriorating quality of many freshwater supplies is a serious environmental issue that has attracted attention from all around the world (Hanna et al., 2019). It is crucial to remember that industrial operations generate a large amount of wastewater and frequently release effluents that contain a variety of dangerous contaminants, such as heavy metals, organic compounds, and nutrients. Public water supplies and aquatic habitats are seriously at risk from these pollutants if they are not appropriately treated (Hasan et al., 2025). Conventional treatment methods are essential to the removal of organic matter and nutrients from wastewater (Jafarinejad, 2020). However, because paint mostly comprises phenol, these systems are frequently inadequate in handling complicated industrial wastes and emerging contaminants (Wang et al., 2025), one example of such a waste is paint.



Water contamination can result from phenol, which is considered a significant environmental contaminant. There are two reasons it exists in water: either naturally or as a result of human activity. Phenol is found naturally in dead plants and animals that have decomposed in water. One of the main causes of the global shortage of drinkable water is the excessive levels of phenol in wastewater, rivers, and municipal drains. The term "anthropogenic activities" refers to the release of phenol from home, municipal, industrial, and agricultural sources. The breakdown of organic materials in the water itself and runoff water passing through decomposed material next to the water body were the natural causes of phenol in water. Water pollution would result from these industrial operations that either directly or indirectly release phenol-containing wastewater into bodies of water (Anku et al., 2017). Phenol discharge to the environment is strictly limited, even by international regulatory agencies (Sun et al., 2018). If phenol is released into the environment, it could endanger aquatic life as well as people, animals, plants, and other organisms. Through the National Pollutant Release Inventory (NPRI), the US Environmental Protection Agency (USEPA) and Canada have classified it as a priority pollutant (Villegas et al., 2016).

Untreated paint wastewater contains phenol, which has multiple negative effects on humans, animals, and plants. To prevent these effects on our daily lives, wastewater must be treated before being released into the environment. The regulatory body has set a limit of 0.2 mg/l of phenol that can be consumed (Sun et al., 2018). One of the main crops grown in tropical and sub-tropical nations worldwide is sugarcane. Its botanical name is *Saccharum officinarum*, and it is a member of the Gramineae family (Silertruksa and Gheewala, 2019). One of the most common agroindustry processing wastes is sugarcane bagasse, which is the portion of biomass left over after sugarcane is cleaned, prepared, and extracted. Cellulose (32–45%), hemicelluloses (20–32%), lignin (17–32%), ash (1.0–9.0%), and a few extractives make up the fibrous residue of sugarcane bagasse (Arni, 2018).

In the coagulation-flocculation process, the addition of powdered activated carbon (PAC) may impact the floc formation process and effluent turbidity, even if it may increase the removal efficacy of dissolved organic pollutants (Huang et al., 2020). The process of turning industrial waste and agricultural byproducts into activated carbon has gained popularity. Sugarcane bagasse, cocoa pod husks, walnut shells, coconut shells, palm kernel shells, and bamboo stem wastes are among the agricultural wastes that have been recycled and given value through the manufacturing of activated carbon. Activated carbon is a porous carbonaceous substance with rapidly developing applications in water treatment and desalination, wastewater treatment and air purification due to its unique features. A range of carbonaceous rich materials, including sugarcane bagasse and coconut shell, are used to make activated carbon. The carbon structures contain the primary functional groups that are in charge of adsorbing contaminants, such as carboxyl, carbonyl, phenol, lactone, and quinine. These groups have a variety of uses in water purification, residential and commercial wastewater treatment, odor and pollutant removal, and medical applications (Kosheleva et al., 2019; Yousefi et al., 2019).

These days, getting and using clean drinking water has become very difficult. Wastewater recycling thus successfully addresses these important issues. Adsorbents are the most frequent issue encountered throughout the water treatment process. In the water treatment process, adsorbents are expensive and scarce. As a result, the entire procedure becomes costly and unprofitable. As an adsorbent, activated carbon made from agricultural biowaste can be employed. Because of its high performance and low cost, it has a significant potential to replace commercial activated carbon in wastewater treatment operations. Water scarcity issues can be resolved by improving the adsorption process with biomass. It will undoubtedly result in the wastewater treatment industry using activated carbons from renewable sources on a significant



scale (Rajan and Anish, 2022). The study investigated the removal of phenol from paint effluent using powdered activated carbon made from sugarcane bagasse (SCBPAC).

2. MATERIALS AND METHODS

2.1 Materials

In Oshogbo, Osun State, Nigeria, a paint production company's point of discharge channel was where the paint wastewater sample was taken. Sugarcane bagasse was the source of the PAC employed in this investigation. As shown in Plate 1(a), sugarcane bagasse (SCB) was gathered from a number of sugarcane vendors in Oje market, Ede, Osun State, Nigeria.

2.2 Methods

Preparation of SCBPAC

The adsorbent/coagulant was made according to the procedure described by Zurina et al. (2014). Distilled water was used to completely wash the sugarcane bagasse in order to get rid of any contaminants, dirt, and sugar content. After six days of sun drying, the bagasse was burned for four hours at 600°C in the furnace to carbonate it, as indicated in Plate 1(b). It was then thermally activated for approximately an hour at 400°C. A 212 µm sieve was then used for sieving the finely powdered activated carbon.

X-ray fluorescence

Using Phillips PW-1800 equipment, an X-ray fluorescence (XRF) examination was performed to identify main and trace elements and ascertain the chemical composition of the SCBPAC. The way XRF works is by examining how atoms react to radiation. Before being put in sample containers for analysis, the materials were first crushed into pellets smaller than 75 microns (Margui et al., 2016).

Adsorption-coagulation of the wastewater

A jar test was used to assess the adsorption-coagulation efficacy at 24 °C room temperature. Four grams of powdered activated carbon (SCBPAC) were combined with a one-liter sample of paint wastewater (PW) and swirled. The liquid was mixed rapidly for five minutes then slowly for fifteen minutes to encourage floc formation in order to provide uniform mixing throughout the flocculation process. To aid with settlement, the flocs were given a 60-minute window to aggregate. After sedimentation, the wastewater supernatant (TPW1) was gathered and subjected to routine analytical techniques for the measurement of phenol and a few other parameters. For SCBPAC weighing 6 g (TPW2) and 8 g (TPW3), the procedure was repeated.

Statistical analysis

A statistical analysis was performed on the result data to further validate the efficiency. The data was first subjected to normality check using Shapiro-Wilk as the size of the sample is small (27). Normality check shows that the null hypothesis (equal variance is assumed) should be accepted and hence, a parametric test (ANOVA) was conducted.



(a)



(b)

Plate 1: Sugarcane bagasse (a) after washing and (b) after carbonation

3. RESULTS AND DISCUSSION

3.1 X-Ray fluorescence

Table 1's chemical composition shows that the SCBPAC is composed of 0.24% iron oxide (Fe_2O_3), 15.92% aluminum oxide (Al_2O_3), and 54.8% silica (SiO_2). Adsorption in wastewater is mostly caused by the mixture of these substances. According to Koopi and Buazar (2019), Al_2O_3 's large surface area, outstanding physico-chemical characteristics, high dielectric strength, and thermal stability make it an ideal substrate for adsorption and an adsorbent agent for wastewater treatment.

Table 1: Chemical composition of SCBPAC

	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	K_2O (%)	TiO_2 (%)	P_2O_5 (%)	Na_2O (%)	LOI (%)
SCBPAC	54.8	15.92	0.24	1.06	2.02	0.01	0.25	0.18	10.60

3.2 Phenol result analysis

According to Table 2, the effluent had a phenol concentration of 1.11 mg/l, which is greater than what the FEPA deemed to be acceptable. As a result, it must be eliminated or reduced from wastewater before the water is released into the environment. For TPW1, TPW2, and TPW3, the treatment decreased the ion to 0.65 mg/l, 0.20 mg/l, and 0.15 mg/l, respectively

Table 2: Concentration of phenol in paint wastewater and the standards

PW (mg/l)	After treatment			FEPA (mg/l)
	TPW1 (mg/l)	TPW2 (mg/l)	TPW3 (mg/l)	
1.11	0.65	0.20	0.15	0.2

3.3 Removal efficiency for phenol

The percentage removal efficiency of the adsorbent/coagulant was evaluated using the equation 1 and are presented in Figure 1.



$$R = \frac{C_i - C_f}{C_i} \times 100\% \quad (1)$$

where R is the removal percentage of the coagulant (%), C_i and C_f are the initial and final concentrations of ion (mg/l).

The percentage removal efficiency varies from the minimum of 41.44% to the maximum of 86.49%, with coagulant TPW1 attaining 41.44% and TPW2 achieving 81.98%. In contrast, TPW3 was able to attain 86.49%, establishing it as the most preferred. In practical terms, this means that the more coagulant used the more effective it becomes.

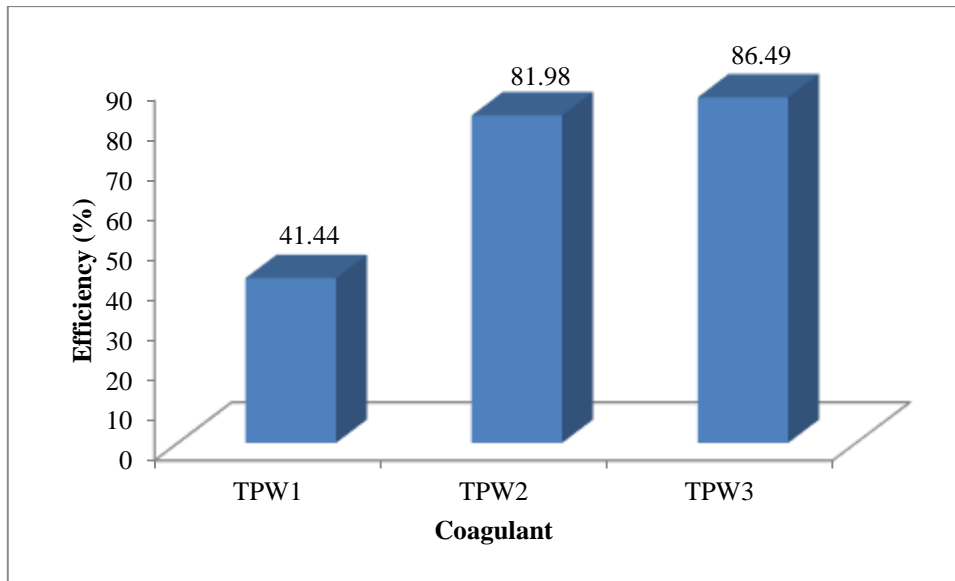


Figure 1: Percentage removal efficiency of the adsorbent

3.4 Result analysis and overall efficiency of other parameters

The concentration of other parameters in the wastewater is as shown in Table 3, with values ranges from 0.12 to 33.21 mg/l, 0.03 to 37.48 mg/l and 0.00 to 36.34 mg/l for TPW1, TPW2, and TPW3 respectively. The adsorbent/coagulant highest dosage (TPW3) completely removed Lead metal from the wastewater, while TPW2 and TPW1 only achieved 83.33 and 5.56 percentage removal efficiency. This further confirmed that the higher the dosage, the more efficient they becomes. Higher percentage removal efficiencies were recorded for BOD, COD, Nitrate, and Phosphate for all dosages.

However, the adsorbent/coagulant was unable to decrease the particles in the wastewater; instead, it increased them. For TPW1, TPW2, and TPW3, the turbidity increased from the original 5.6 NTU to 27.13, 8.76, and 24.34 NTU, respectively. The values of total dissolved solids (TDS) also increased exponentially. The failure to do post-filtration of wastewater following adsorption may be the cause of this.

The overall percentage removal efficiency of each dosage as depicted in Figure 2 shows that TPW1 only achieved 60.10%, while TPW2 achieved 75.55% removal efficiency. TPW3 had the highest removal efficiency, measuring 77.44%. It was observed that, the higher the dosage, the more efficient it becomes.



Table 3: Concentration of other parameters in paint wastewater and the standards

Parameter	PW (mg/l)	After treatment			FEPA (mg/l)
		TPW1 (mg/l)	TPW2 (mg/l)	TPW3 (mg/l)	
DO	2.5	7.30	6.20	7.10	>1
BOD	118.57	13.94	15.03	14.26	30
COD	288.79	33.21	37.48	36.34	80
Nitrate	162.48	0.12	0.19	0.14	20
Phosphate	15.24	3.46	2.24	3.05	20
Chloride	45.76	21.54	18.75	16.89	600
Lead	0.18	0.17	0.03	0.00	< 1
Nickel	0.33	0.26	0.21	0.24	< 1
Solids					
Turbidity (NTU)	5.6	27.13	8.76	24.34	--
TDS	181	811	812	1229	2000

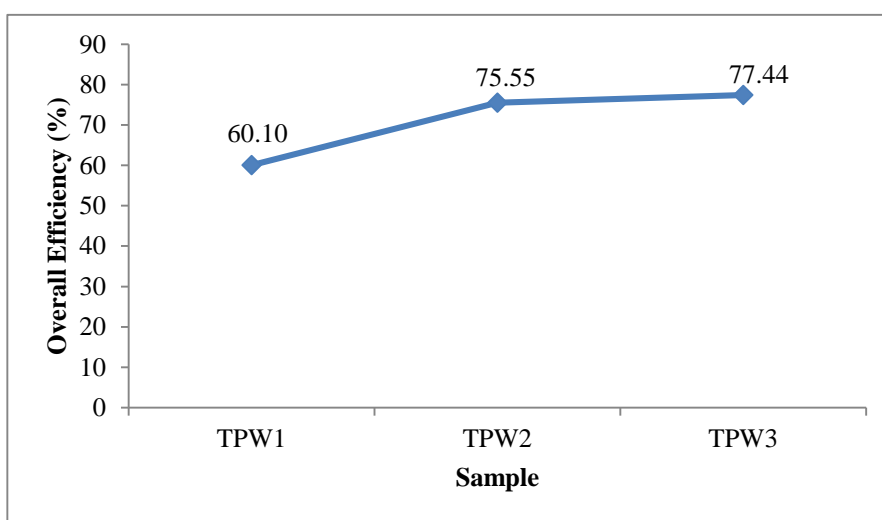


Figure 2: Overall percentage removal efficiency of the adsorbent

The test of normality indicated that the Sig. is 0.546 which means that the null hypothesis (equal variance is assumed) should be accepted. Equal variances are assumed with ANOVA which indicated that P-value is greater than 0.005 (0.306). The post hoc and multiple comparison tests on the coagulant dosages show that the difference between them is not that significant especially between TPW2 and TPW3. In conclusion, the level of insignificant among the coagulants shows that they are both efficient in the treatment while different level of efficiency was recognized.

4. CONCLUSION

The SCBPAC was used to absorb phenol and other parameters from paint effluent. The test conducted after adsorption verified that the content of phenol and other parameters had decreased, indicating that adsorption had taken place. According to the investigation and findings, the combination of silica oxide, aluminum oxide, and iron oxide, which makes up 70.96% of SCBPAC, is what causes adsorption in wastewater. The most effective dosage is 8 g of SCBPAC (TPW3), which outperformed TPW2 and TPW1 in terms of phenol removal efficiency (86.49%) and total removal efficiency (77.44%). The optimal dosage, according to the authors, is 8g of SCBPAC; the treated wastewater can then be filtered to lower TDS and turbidity. These findings demonstrate that SCBPAC is a cost-effective, sustainable, and



efficient adsorbent for phenol removal from industrial wastewater, with potential applications in large-scale wastewater treatment systems.

REFERENCES

- Anku, W. W., Mamo, M. A., and Govender, P. P. (2017). Phenolic Compounds in Water: Sources, Reactivity, Toxicity and Treatment Methods. *Intechopen*, pp. 13, <http://dx.doi.org/10.5772/66927>.
- Arni, A. L. (2018). Extraction and Isolation Methods for Lignin Separation from Sugarcane Bagasse: A Review, *Ind. Crop. Prod.* 115 330–339.
- Hanna, W., Wan, M., Nizam, K., Maulud, A., Shazwani, N., Sharil, S., and Mundher, Z. (2019). Spatial and Temporal Risk Quotient Based River Assessment for Water Resources Management. *Environmental Pollution*, 248, 133e144. <https://doi.org/10.1016/j.envpol.2019.02.011>
- Hasan, H.A., Saharuddin, S.N.D.M., and Muhamad, M. H. (2025). Unlocking the Potential of Polyvinyl Alcohol (PVA) as a Biocarrier for Enhanced Wastewater Treatment: A Comprehensive Review. *J. Water Process Eng.* 74, 107780. <https://doi.org/10.1016/j.jwpe.2025.107780>
- Huang, X., Wan, Y., Shi, B., and Shi, J. (2020). Effects of Powdered Activated Carbon on the Coagulation-flocculation Process in Humic Acid and Humic Acid-kaolin Water Treatment. *Chemosphere*, 238, 124637, 1-9. <https://doi.org/10.1016/j.chemosphere.2019.124637>
- Jafarinejad, S. (2020). A Framework for the Design of the Future Energy-efficient, Cost-effective, Reliable, Resilient, and Sustainable Full-scale Wastewater Treatment Plants. *Curr. Opin. Environ. Sci. Health*, 13, 91–100. <https://doi.org/10.1016/j.coesh.2020.01.001>
- Koopi, H., and Buazar, F. (2019). A Novel One-pot Biosynthesis of Pure Alpha Aluminium Oxide Nanoparticles Using the Macroalgae *Sargassum ilicifolium*: A Green Marine Approach. *Ceramics International*, 44, 8940–8945. <https://doi.org/10.1016/j.ceramint.2018.02.091>.
- Kosheleva, R. I., Mitropoulos, A. C., and Kyzas, G. Z. (2019). Synthesis of Activated Carbon from Food Waste. *Environ Chem Lett*, 17, 429–438. <https://doi.org/10.1007/s10311-18-0817-5>.
- Margui, E., Queralt, I., and Grieken, R.V. (2016). Sample Preparation for X-ray Fluorescence Analysis. *Encyclopedia of Analytical Chemistry*, 1–25. <https://doi.org/10.1002/9780470027318.a6806.pub4>.
- Rajan, M. J., and Anish, C. I. (2022). Role of Activated Carbon in Water Treatment. *Intechopen*, 1-17. <http://dx.doi.org/10.5772/intechopen.108349>
- Silalertruksa, T., and Gheewala, S. H. (2019). Competitive Use of Sugarcane for Food, Fuel, and Biochemical Through the Environmental and Economic Factors, *Int. J. Life Cycle Assess.* 1–13.
- Sun, X., Wang, C., Li, Y., Wang, W., and Wei, J., (2018). Treatment of Phenolic Wastewater by Combined UF and NF/RO Processes. *Desalination*, 355, 68–74, <http://dx.doi.org/10.1016/j.desal.2014.10.018>.
- Villegas, L. G. C., Mashhadi, N., Chen, M., Mukherjee, D., Taylor, K. E., and Biswas, N. (2016). A Short Review of Techniques for Phenol Removal from Wastewater. *Curr. Pollut. Reports*, 2, 157–167, <http://dx.doi.org/10.1007/s40726-016-0035-3>.
- Wang, C., Qian, F., Ji, S., Wang, J., Gao, M., Qin, H., and Wang, X. (2025). Occurrence, Transport, and Ecological Risk Assessment of Typical Organophosphate Flame Retardants (OPFRs) in Wastewater Treatment Plants (WWTPs): A Case Study in Suzhou, Eastern China. *Process Saf. Environ. Prot.* 198, 107063. <https://doi.org/10.1016/j.psep.2025.107063>
- Yousefi, M., Arami, S. M., and Takallo, H., Hosseini, M., Radford, M., Soleimani, H., and Mohammadi, A. A. (2019). Modification of Pumice with HCl and NaOH Enhancing its Fluoride Adsorption Capacity: Kinetic and Isotherm Studies. *Hum Ecol Risk Assess.* 25(6): 1508-1520. <https://doi.org/10.1080/10807039.2018.1469968>.
- Zurina, A. Z., Mohd Fadzli, M., and AbdulGhani, L. A. (2014). Preliminary Study of Rambutan (*nephelium lappaceum*) Seed as Potential Bio-coagulant for Turbidity Removal. *Advanced Materials Research*, 917, 96–105. <https://doi.org/10.4028/www.scientific.net/amr.917>.