

ADSORPTION OF PHENOL AND POLYCHLORINATED BIPHENYL FROM LANDFILL LEACHATE USING COCONUT HUSK BIOCHAR*¹Abudu Ballu Duwiejuah, ¹Helena Asantewaa Asiedu, ²Elliot Haruna Alhassan¹Department of Biotechnology and Molecular Biology, Faculty of Biosciences, University for Development Studies, Tamale, Ghana²Department of Aquaculture and Fisheries Sciences, Faculty of Biosciences, University for Development Studies, Tamale, Ghana

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Abstract

Biochar has helped create possibilities for addressing the demand for environmentally acceptable and cost-effective adsorbents for adsorption. Removing phenol and polychlorinated biphenyl from landfill leachate is of great concern owing to the grave threat to soil, water resources and human health. This study investigated the efficiency of coconut husk biochar to adsorb phenol and polychlorinated biphenyl from landfill leachate. A total of 100 mL of the landfill leachate, with varied phenol and polychlorinated biphenyl initial concentrations, with contact times of 15, 30 and 45 minutes at temperatures of 30 and 35 °C and coconut husk biochar dosage of 0.50, 1.50 and 3.50 g. The removal efficiency of up to 70.08% for phenol and 73.33% for polychlorinated biphenyl was achieved at adsorption conditions of 30 °C and 35 °C with contact times of 15, 30 and 45 minutes. The coconut husk biochar adsorption capacity (mg/g) of phenol ranged from 0.41 to 0.74 and 0.13 to 0.36 for polychlorinated biphenyl. The adsorbent dosage influences the adsorption efficiency significantly. The increase in adsorption efficiency as the adsorbent dosage increased might be attributable to the coconut husk biochar's large surface area, which assisted in removing phenol and polychlorinated biphenyl from the landfill leachate. The adsorption efficiency decreased as temperature was increased from 30 to 35 °C for phenol, whilst for polychlorinated biphenyl, the adsorption efficiency increased using coconut husk biochar. Pseudo-second order was the best-fit model for phenol and polychlorinated biphenyl onto the coconut husk biochar. This study is unique as it offers fresh perspectives on how temperature and dosage affect removal efficiency by using a sustainable agrowaste adsorbent to uniquely study two chemically distinct pollutants and disclose varied adsorption behaviours based on the compound characteristics. Coconut husk biochar has the potential for adsorption of phenol and polychlorinated biphenyl from landfill leachate. Furthermore, it emphasises the promise of coconut husk biochar as an environmentally friendly, affordable substance for treating complicated wastewater flows.

Keywords

Adsorption, polychlorinated biphenyl, coconut husk biochar, landfill leachate, phenol, pseudo-second order

Introduction

Industrial effluent, which contained phenol, indiscriminately discharged into the environment, had a serious effect on the aquatic environment (Said et al., 2021). The majority of the polychlorinated biphenyls (PCBs) and phenols present in landfill leachate were derived from municipal, commercial, and industrial waste disposal activities. The improper disposal of obsolete cleaning products, disinfectants, treated wood materials, chemicals, tainted packaging, or industrial waste caused phenolic compounds to enter landfill leachate. Among the objects that included polychlorinated biphenyls that were brought to landfills as a result of improper disposal were outdated transformers, waste oils, capacitors, and other electrical components. The presence of phenols and polychlorinated biphenyls in landfills was generally correlated with the handling of e-waste, the disposal of electrical equipment, the handling of construction waste, petroleum refining, coal processing, and chemical production. Phenols in wastewater were the most harmful pollutant because they were very toxic to humans, organisms and the environment (Naguib and Badawy, 2020). At low concentrations, phenols were very toxic (Emenike et al., 2022). One of the most poisonous, mutagenic and carcinogenic pollutants that had been found in wastewater was polychlorinated biphenyl (Bu et al., 2020).

Significant amounts of phenol-containing effluent were produced during production and use, endangering people, the environment, and other living things (Pavithra et al., 2023). Additionally, the USEPA designated it as a priority contaminant (Rushing and Santoro, 2022). The World Health Organisation classified phenol and its derivatives as high-risk pollutants because of their extreme toxicity to human health and aquatic life (Sas et al., 2020). Research showed that exposure to polychlorinated biphenyls caused reproductive toxicity, cancer, neurological disorders, endocrine disruption and deformity at low concentrations (Trojanowicz, 2020). The adsorption was one of the methods of phenol treatment in wastewater methods besides chemical oxidation (Solpan et al., 2020), biodegradation (Nazos et al., 2020), and others. The phenolic compounds were typically recovered and utilised in wastewater with medium and high concentrations of phenol using extraction, chemical precipitation, stripping, and other techniques (Cai et al., 2022). Due to the poor recovery economy, low phenol concentration, and high relative quantity, the low phenol wastewater was often treated using biodegradation, adsorption, catalytic degradation, and other techniques (Asghar et al., 2022). The high concentration of persistent organic contaminants (biphenyl) released into waterbodies polluted the water, which made it unsafe to drink and also had a harmful effect on the aquatic environment (Vasseghian

et al., 2021). Therefore, it was very necessary to eliminate them from the environment to minimise these dangers.

Adsorption was currently utilised to treat wastewater because it was inexpensive, simple to use, highly effective, and allowed for the use of a variety of solids as adsorbent materials and had been studied by researchers (Dotto and McKay, 2020). Biochar was generally produced from agricultural waste, and it was environmentally friendly and cheap (Enaime et al., 2020). Affordable and efficient biochar aided in the stabilisation of the environment (Emenike et al., 2022). Affordable biochar enhanced environmental stabilisation through pollution reduction and adsorption of contaminants, soil quality improvement, carbon sequestration, waste management enhancement, and cost-effective environmental remediation. Coconut husk was a cheap adsorbent for contaminants in wastewater (Adebayo et al., 2022). It proved effective in the removal of cadmium from 88.70% - 98.20%, chromium from 78% - 96% and lead from 95.71% - 99.29% (Duwiejuah et al., 2024). Most agricultural waste, including coconut husk, had been used as biochar to remove inorganic and organic contaminants from wastewater. There were now more serious environmental issues due to the massive amount of trash produced by agriculture.

Biochar had been widely used as an adsorbent to remove a variety of pollutants, including phenol, biphenyl, microplastics, heavy metals, and nutrients, from water and wastewater due to its inherent characteristics (Jagadeesh and Sundaram, 2023). The most typical agricultural wastes used in the production of biochar were rice straw, coconut husk, cotton stalk, and groundnut shells. The removal of pollutants from wastewater was facilitated by biochar's large surface area, high porosity, and a huge number of functional groups. The majority of the biomass in coconut husks was made up of hemicelluloses, cellulose, and lignin (Borel et al., 2021). Increasing the rate of lignin breakdown helped in this process, while increasing the rate of cellulose breakdown enhanced the porosity of the biochar (Jiang et al., 2020; Li et al., 2020). The aromatic, aryl ethers, esters (C=OOR'), carboxyl acid (COOH), isocyanide (CCH₃C), ketone (C=OR'), hydroxyl (OH), alkyl (CH₃), amide (C=ON), quinone, alkyl ether (OCH₃) group, and organosilicon compounds (SiO) were some of the groups included in this list (Nuryana et al., 2020; Sari et al., 2020). Coconut husk biochar was a cheap, simple, easy, readily available and green approach that could effortlessly be accepted for practical field application in the removal from the environment, making it a good candidate for contaminant adsorption (Duwiejuah et al., 2024). The potential of coconut husk biochar as an adsorption material for industrial use and environmental remediation was demonstrated by its surface properties. Coconut husk was usually discarded indiscriminately after consuming the nuts or drinking the water. In most countries, coconut husk was burnt, which led to serious environmental problems. The study assessed the effect of adsorption temperatures and adsorbent dosage on the removal efficiency of biochar produced from coconut husk for phenol

and polychlorinated biphenyl.

Materials and Methods

Research design

The study was a factorial experiment design where landfill leachate from Ghalahi treatment ponds (latitude 9.441 and longitude -0.759), Sagnarigu Municipality was collected, and analysed for the initial concentration of phenol and polychlorinated biphenyl. The temperatures tested were 30 and 35 °C, residence time of 15, 30 and 45 minutes and the quantities of coconut husk biochar used varied between certain ranges (for instance, 0.50 g, 1.50 g and 3.50 g for every 100 mL of solution). The percent removal effectiveness of phenol and polychlorinated biphenyl from water solutions served as the dependent variable. A total of 100 mL of the landfill leachate, with varied phenol and polychlorinated biphenyl initial concentrations, was used with contact times at different temperatures and coconut husk biochar dosages. A total of 36 elutes were obtained and taken to the Ecological Laboratory of the University of Ghana for analysis.

Leachate collection

The leachate was taken from a landfill site at Gbalahi, Sagnarigu Municipality in Tamale, where wastes were dumped. The leachate was filtered using a conical flask and Whatman filter paper with a particle retention of 125 mm and then put into 35 mL plastic bottles using a glass funnel and labelled clearly. The initial concentrations of phenol of 1.27 mg/L and 0.60 mg/L for polychlorinated biphenyl were recorded.

Collection of coconut husk and biochar preparation

The coconut husks were taken from a coconut vendor at Tamale, Ghana. The coconut husk was gathered and dried under the sun for 1 week. The coconut husk was then put into the Else Barrel Stover pyrolyser and lit with fire, and a chimney was put into the chamber to serve as a passageway for smoke and also prevent oxygen from entering the chamber. The coconut husk was allowed to burn for 10 minutes. The burnt coconut husk was poured on the zinc and allowed to cool for collection and storage. The charred coconut husk was crushed to reduce its size using a mortar and pestle and then strained with 2 mm standard sieve.

Adsorption experiment

A dosage (0.50 g, 1.50 g and 3.50 g each) of the coconut husk biochar was accurately weighed using an electronic weighing scale and then mixed with 100 mL of the phenol and polychlorinated biphenyl contaminated landfill leachate in a conical flask. The samples were clearly labelled and then located in a laboratory water bath and agitated at contact times of 15, 30 and 45 minutes and temperatures of 30 °C and 35 °C. The leachate samples were then filtered and transferred into 35 mL plastic bottles via a glass funnel. Measurements were made of the phenol and polychlorinated biphenyl concentrations in the sampling solution.

Determination of phenol and polychlorinated biphenyl

Ten (10) mL of the leachate sample was measured in a 100 mL graduated cylinder and transferred into another 500 mL separatory funnel. Five (5) mL of ammonium chloride (NH₄Cl) was added, and a stopper was placed on the funnel. Ammonium chloride was employed to stabilise analytical conditions by maintaining ionic strength, controlling pH, improving conductivity, and enhancing reliable and precise measurement. One content of phenol reagent powder to each separatory funnel and shake to dissolve the reagent. The one phenol 2 reagent powder pillow content was then added to each separatory funnel and shaken vigorously for 30 seconds. The stopper was removed and the layers were allowed to separate. The bottom chloroform layers turned yellow to amber colour to detect the presence of phenol. The chloroform layers were drained to obtain the water phase. The prepared sample was inserted into the spectrophotometric cuvette (sample cell), and the phenol content was recorded. The level of phenol was determined using ultraviolet-visible (UV-vis) spectroscopy based on Beer–Lambert’s Law. The leachate’s PCB concentration was examined using gas chromatography and an electron capture detector.

Modelling of Data

To plan sorption-based experiments, it was necessary to model the adsorption isotherm since it described the distribution of phenol and polychlorinated biphenyl between the landfill leachate and coconut husk biochar as a function of pollutant concentration. The concentration of phenol and polychlorinated biphenyl on the adsorbent surface rose as the biochar entered aqueous solution, reaching its maximum at equilibrium, at which point the ions were equally distributed between the solid and aqueous phases. Reported phenol and polychlorinated biphenyl processes of adsorption onto affordable adsorbents were frequently explained using the Langmuir and Freundlich isotherms. The rate at which adsorption occurred was investigated by adsorption kinetics. The method through which molecules or particles attached to a solid or liquid surface was known as adsorption. The pseudo first order model was a popular method for describing the kinetics of solute adsorption onto an adsorbent. The least squares regression method (Chen et al., 2022) was used to determine the absorption of phenol and polychlorinated biphenyl.

Calculation for the adsorption efficiency of coconut husk biochar for phenol and polychlorinated biphenyl

The adsorption efficiency calculation was represented mathematically as:

To determine the adsorption efficiency percentage, it was represented as

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

$$Q_e = \frac{C_i - C_f}{m} \times V \quad (2)$$

where C_f and C_i were the final and initial levels of phenol and polychlorinated biphenyl (mg/L), V was the phenol and polychlorinated biphenyl solution volume (L) and M was the coconut husk biochar (g).

Langmuir adsorption isotherm

The model could be demonstrated in a linear form mathematically. Below was the equation for Langmuir isotherm (Inbaraj et al., 2021).

$$\frac{C_e}{Q_e} = \frac{1}{K_L q_{max}} + \frac{C_e}{q_{max}} \quad (3)$$

where C_e was the adsorbate equilibrium concentration (mg/L), K_L was the constant of Langmuir and q_{max} (mg/g) was the adsorption maximum capacity.

R_L was the separation factor that helped to found the nature of the sorption process.

$$R_L = \frac{1}{1 + K_L C_i} \quad (4)$$

if $R_L = 1$ was linear, $R_L > 1$ was unfavourable adsorption, $R_L = 0$ was irreversible and when $0 < R_L < 1$ was considered favourable (Misran et al., 2022).

Freundlich adsorption isotherm

The mathematical representation of the Freundlich model in a linear equation was in the form;

$$\log q_e = \log K_F + \frac{1}{n} \log C_e \quad (5)$$

where q_e (mg/g) was the quantity of pollutant adsorbed onto the coconut husk biochar at equilibrium, C_e (mg/L) was the adsorbate equilibrium concentration, K_F was the constant of Freundlich, n and $1/n$ denoted the adsorption density and adsorption intensity, respectively.

The Freundlich model favourability was determined by n values that ranged from 1 to 10, which signified favourable and $n < 1$ signified adsorption that was unfavourable (Misran et al., 2022).

Pseudo first order model

The mathematical pseudo first order representation was:

$$\log(q_e - q_t) = \log q_e - \frac{K_1}{2.303} t \quad (6)$$

Pseudo second order model

This model could be calculated in linear equation form as;

$$\frac{t}{q} = \frac{1}{K_2 q_e^2} + \frac{1}{q_e} t \quad (7)$$

where q_t and q_e were the quantities of the adsorbate adsorbed (mg/g) at a time and equilibrium, respectively, t was the time (min), q was the adsorption efficiency (mg/g), K_1 was the pseudo first order constant, and K_2 was the pseudo second order constant.

Statistical Analysis

The micro soft excel was used to calculate the experimental data of the isotherm and kinetics models.

Results and Discussion

Adsorption efficiency of phenol and polychlorinated biphenyl onto coconut husk in leachate at 30 °C and 35 °C

The coconut husk biochar affinity for phenol and polychlorinated biphenyl in the landfill leachate was good. The adsorption efficiency of coconut husk biochar for phenol in the landfill leachate with a temperature of 30 °C ranged from 51.18 to 70.08% at 15 min, 52.76 to 68.50% at 30 min and 54.33 to 68.50% at 45 min (Table 1). The adsorption efficiency of polychlorinated biphenyl in the landfill leachate with a temperature of 30 °C ranged from 36.67 to 55% at 15 min, 41.67 to 65% at 30 min and 48.33 to 73.33% at 45 min (Table 1).

The coconut husk biochar adsorption efficiency of phenol in the landfill leachate with a temperature of 35 °C ranged from 55.90 to 65.3% at 15 min, 44.90 to 62.21% at 30 min and 47.24 to 60.99% at 45 min (Table 1).

The coconut husk biochar adsorption efficiency of polychlorinated biphenyl in the landfill leachate with a temperature of 35 °C ranged from 43.33 to 71.67% at 15 min, 53.33 to 66.66% at 30 min and 43.33 to 66.66% at 45 min (Table 1). The current study showed the adsorption efficiency of phenol decreased with increasing adsorption temperature from 30 to 35 °C, which means the process of adsorption was exothermic. The adsorption efficiency of polychlorinated biphenyl increased, which means the adsorption process was endothermic. As the solution's viscosity decreased, the kinetic energy rose, causing the diffusion rate to increase and the retention of pollutants on the adsorbent to improve (Vievard et al., 2023). The increase in the rate of adsorption efficiency of polychlorinated biphenyl molecules diffusing through the adsorbents' outer limits and into their interior pores occurred as the temperature rose. The surface of biochar could create aromatic carbon more quickly at higher temperatures, which improved the surface properties for adsorbing a wide variety of contaminants. A similar study by El-Bery et al. (2022) using activated carbon produced from lignocellulosic agricultural wastes, to remove phenol, and found a decrease in removal efficiency as the temperature increased from 25 to 45 °C. This was a result of a weak physical link between the adsorbent (coconut biochar) and the adsorbate, which resulted in the partial removal of the phenol molecules from the porous carbon structure. The current study proved that the removal efficiency was influenced by adsorption temperature.

Effect of dosage of coconut husk biochar on the removal of phenol and polychlorinated biphenyl

It was observed that increasing the biochar dose improved the adsorption percentage of phenol and polychlorinated biphenyl. This was a result of the large surface area of coconut husk biochar, which assisted in removing phenol and polychlorinated biphenyl from the landfill leachate and the electrostatic interaction between the coconut husk biochar and phenol and polychlorinated biphenyl. Coconut husk biochar contained various surface functional groups on the surface which included aromatic, aryl ethers, alkyl ether (-O-CH₃) group, esters (-C=OOR'), carboxyl acid (-COOH), iso-cyanide (-C-CH₃-NC), ketone (C=OR'), hydroxyl (-OH), amide (-C=O-N), alkyl (-CH₃), quinone, and organosilicon compounds (Si-O) (Nuryana et al., 2020; Sari et al., 2020). The aromatic functional groups that included oxygen, high carbon content, and high porosity of biochar were just a few of the characteristics that might impact biochar's structure (Ambaye et al., 2021). Its stable molecular structure, porosity and surface area all encouraged the adsorption of contaminants on it. The phenol and polychlorinated biphenyl initial concentration also had an impact on the adsorption efficiency during the process of adsorption. According to Vievard et al. (2023) increased cohesive forces among the molecules in solution or an excess of pollutants in comparison to the available sites of adsorption may both contribute to a decrease in the adsorption rate when the initial contaminant concentration rises. The current study proved that increasing the adsorbent dosage increased the removal efficiency.

Langmuir adsorption isotherm for coconut husk biochar

The adsorption maximum capacity (Q_{max} mg/g) for phenol was 0.0023 mg/g and polychlorinated biphenyl was 0.0032 mg/g at 30 °C and 15 min (Table 2). At 30 °C and 30 min, the Q_{max} of phenol was 0.0027 mg/g and polychlorinated biphenyl was 0.0036 mg/g. At 30 °C and 45 min, the Q_{max} of phenol was 0.0016 mg/g and polychlorinated biphenyl was 0.0042 mg/g (Table 2). At 35 °C the Q_{max} of phenol was 0.0010 mg/g and polychlorinated biphenyl was 0.0038 mg/g (Table 2). At 35 °C and 30 min, the Q_{max} of phenol was 0.0024 mg/g and polychlorinated biphenyl was 0.0018 mg/g (Table 2). Again at 35 °C and 45 min, the Q_{max} of phenol was 0.0021 mg/g and polychlorinated biphenyl was 0.0035 mg/g (Table 2).

Low and negative values for coconut husk biochar maximum adsorption capacity indicated that the phenol and polychlorinated biphenyl adsorption from the leachate did not follow the Langmuir isotherm, indicating that they did not adhere to monolayer adsorption on the surface of coconut husk biochar. Similar studies conducted using different agricultural waste reported the Q_{max} of phenol to be 500 mg/g for wheat husk (Al Rawi et al., 2023). The R^2 value of Langmuir of the pollutant (phenol and polychlorinated biphenyl) at 30 and 35 °C was all less than 1 (Table 2). From the results attained in

Table 1. Adsorption efficiency of coconut biochar for 15, 30 and 45 mins at 30°C and 35°C

Pollutant	Dosages (g)	15 min at 30°C	30 min at 30°C	45 min at 30°C
		Percentage (%)	Percentage (%)	Percentage (%)
Phenol	0.50	51.18	52.76	54.33
	1.50	65.35	54.33	60.63
	3.50	70.08	68.50	68.50
Polychlorinated biphenyl	0.50	36.67	41.67	48.33
	1.50	46.67	56.67	53.33
	3.50	55.00	65.00	73.33

Pollutant	Dosages (g)	15 min at 35°C	30 min at 35°C	45 min at 35°C
		Percentage (%)	Percentage (%)	Percentage (%)
Phenol	0.50	55.91	44.90	47.24
	1.50	60.63	53.54	54.33
	3.50	65.35	62.21	62.99
Polychlorinated biphenyl	0.50	48.33	53.33	43.33
	1.50	53.33	56.67	60.00
	3.50	71.67	66.67	66.67

Table 2. Langmuir and Freundlich models of the results

Pollutant	Temp.	Estimate of the Langmuir Isotherm				Estimate of the Freundlich Isotherm			
		Q _{max} (mg/g)	K _L (l/mg)	R _L	R ²	1/n	n	K _F (mg/g)	R ²
Phenol	30°C	0.0023	-0.32	0.87	0.10	3.83	0.26	628.93	0.96
Polychlorinated biphenyl	30°C	0.0032	-0.25	0.45	0.96	4.51	0.22	3358.15	0.10
Phenol	30°C	0.0027	-0.35	0.83	0.51	3.12	0.32	416.68	0.68
Polychlorinated biphenyl	30°C	0.0036	-0.17	0.50	0.89	2.92	0.34	1098.50	0.10
Phenol	30°C	0.0016	-0.38	0.79	0.88	4.50	0.22	1423.64	0.96
Polychlorinated biphenyl	30°C	0.0042	-0.12	0.53	0.61	1.85	0.54	349.70	0.72
Phenol	35°C	0.0010	-0.43	0.73	0.91	7.39	0.14	9698.40	0.99
Polychlorinated biphenyl	35°C	0.0038	-0.14	0.52	0.63	2.11	0.47	481.39	0.75
Phenol	35°C	0.0024	-0.44	10.01	0.92	4.26	0.23	486.74	0.98
Polychlorinated biphenyl	35°C	0.0018	-0.19	0.49	0.68	4.46	0.22	1.00	0.83
Phenol	35°C	0.0021	-0.44	0.71	0.88	4.58	0.22	671.89	0.96
Polychlorinated biphenyl	35°C	0.0035	-0.16	0.51	0.10	2.77	0.36	1085.43	0.97

this study, the coefficient of determination (R^2) was observed to decrease as the temperatures increased. The current study showed that the Langmuir model was not a better fit for phenol and polychlorinated biphenyl in the coconut husk biochar. Similar research was conducted in which the R^2 ranged from 0.9900 to 0.9980 (Inbaraj et al., 2021).

The R_L values ranged from 0.45 to 10.01 (Table 2). The maximum adsorption capacity of phenol and polychlorinated biphenyl onto coconut husk biochar at 30 °C and 35 °C were low. The R_L was observed to be $R_L > 1$ for phenol and polychlorinated biphenyl generally, inferring that the process of adsorption was unfavourable except at 30 °C and biochar dosage of 0.50 g, the R_L was < 1 , implying that the process of adsorption was favourable on the coconut husk biochar (Misran et al., 2022).

Freundlich adsorption isotherm

The $1/n$ results attained from the experiment for temperature 30 °C and 15 min, for phenol was 3.83 and for polychlorinated biphenyl was 4.51 (Table 2). At 30 °C and 30 min, the phenol and polychlorinated biphenyl were 3.12 and 2.92, respectively (Table 2). At 30 °C, the $1/n$ value for phenol and polychlorinated biphenyl were 4.50 and 1.85, respectively, at 45 min (Table 2). Also, at 35 °C and 15 min, the $1/n$ value attained from the experiment for the phenol and polychlorinated biphenyl was 7.39 and 2.11, respectively (Table 2). At 35 °C for 30 min, the $1/n$ value for the phenol was 4.26 and for polychlorinated biphenyl was 4.46 (Table 2). Again at 35 °C and 45 min, the $1/n$ values for the phenol and polychlorinated biphenyl were 4.58 and 2.77, respectively (Table 2). The n values attained from this experiment ranged from 0.14 to

Table 3. Pseudo first and second order results for coconut biochar

Pollutant	Kinetic parameters				
	Pseudo first order		Q_e (mg/g)	Pseudo second order	
	K_1 (min^{-1})	R^2		K_2 (min^{-1})	R^2
Phenol	0.0020	0.9999	0.5619	-0.1130	0.9996
Phenol	-0.0063	0.7500	0.6898	0.0430	0.9882
Phenol	-0.0008	0.7500	0.4108	0.0064	0.9998
Polychlorinated biphenyl	0.0093	0.9982	0.2839	-0.0050	0.9948
Polychlorinated biphenyl	0.0046	0.4524	0.2635	-0.0110	0.9864
Polychlorinated biphenyl	0.0102	0.9910	0.1329	-0.0002	0.9832
Phenol	-0.0057	0.5364	0.7430	0.1057	0.9863
Phenol	-0.0038	0.6516	0.6304	0.0761	0.9949
Phenol	-0.0013	0.5140	0.4866	0.0960	0.9980
Polychlorinated biphenyl	-0.0037	0.2766	0.3573	0.0106	0.9495
Polychlorinated biphenyl	0.0040	0.9997	0.224	-0.0030	0.9980
Polychlorinated biphenyl	-0.0025	0.7500	0.2194	0.0027	0.9969

0.54, and K_F (mg/g) ranged from 1.00 to 9698.398 (Table 2). The Freundlich isotherm R^2 for phenol and polychlorinated biphenyl was found to be less than 1 for 30 and 35 °C (Table 2). The Freundlich isotherm was applied to represent the adsorption of phenol and polychlorinated biphenyl from the landfill leachate onto the coconut husk biochar. The Freundlich model described the adsorbent's sorption of several heterogeneous surfaces that have tougher binding sites. The intensity of adsorption $1/n$ values obtained from the results based on the Freundlich calculation were above 1 for phenol and polychlorinated biphenyl onto the coconut husk, which indicated an unfavourable process of adsorption (Al Rawi et al., 2023). Stated that when $1/n$ was greater than 0, the adsorption process was favourable, when $1/n$ was greater than 1, the process of adsorption was unfavourable. It was easy to adsorb contaminants when $0.1 < 1/n < 1$ (Misran et al., 2022), indicating good and easy adsorption of biochar. The adsorption strength was represented by the Freundlich isotherm model's n value. The coefficient of determination R^2 obtained from the Freundlich equation of phenol and polychlorinated biphenyl of coconut husk biochar indicated that the Freundlich adsorption isotherm best fit the data. The Freundlich isotherm suggested that the coconut husk biochar was more susceptible to multilayer adsorption. A study showed that the R^2 ranged from 0.99 to 0.99 (Obaid, 2020).

Pseudo first and pseudo second order models for coconut husk biochar

The adsorption capacity (mg/g) of phenol ranged from 0.4108 to 0.7430, and 0.1329 to 0.3573 for polychlorinated biphenyl (Table 3). The rate constant, K_1 (min^{-1}) values found from the experiment for the pseudo first order of phenol and polychlorinated biphenyl ranged from -0.0008 to 0.0020, and -0.0037 to 0.0102, respectively (Table 3). Also, the coefficient of determination and R^2 of phenol and polychlorinated biphenyl

from the results obtained were all less than 1. According to Musah et al. (2022), the rate of change in adsorbate uptake at a given reaction time was believed to be directly proportional to the difference between the concentration and the adsorbate removal rate over time. The observed negative rate constant (K_1) values indicated that the concentration of the pollutant's adsorption decreased over time as the adsorption proceeded. The high rate implied that polychlorinated biphenyl was adsorbed onto the biochar surface rapidly. Similar research was conducted by Enaime et al. (2020) who observed a high-rate constant, which was as result of the pollutant absorbing onto the biochar surface rapidly. A similar study also revealed that the rate constant of phenol ranged from 0.0115 to 0.0287 (Xie et al., 2022). It was also observed that phenol and polychlorinated biphenyl had the highest R^2 values, which indicated a good fit of the pseudo-first model. A similar study showed that the coefficient of determination ranged from 0.6140 to 0.9000 (Al Rawi et al., 2023).

Pseudo-second order result of K_2 (min^{-1}) of phenol and polychlorinated biphenyl was -0.1130 to 0.1057 and -0.0110 to 0.0106, respectively (Table 3). The coefficient of determination, R^2 of phenol, and polychlorinated biphenyl from the results obtained were all closer to 1 (Table 3). The model may be used over the whole sorption process time range, with chemisorption serving as the rate limiting mechanism for phenol and polychlorinated biphenyl retention in the biochar produced from coconut husk. The pseudo second order coefficients showed greater R^2 values than the pseudo first order coefficients. Furthermore, the pseudo-second-order kinetic equation's saturation adsorption capacity error was smaller than the pseudo first order kinetic equation's (Li et al., 2023). The phenol and polychlorinated biphenyl adsorption process on biochar was better designated by the pseudo second order model, according to the results, which exhibited that the adsorption capacity of the material was mostly dependent on its

surface active sites. The mechanism of adsorption was chemical adsorption (Li et al., 2023), and phenol could be adsorbed chemically to the biochar surface. It was also observed that upsurging the temperature from 30 to 35 °C increased the rate constant K_2 (min^{-1}) phenol and polychlorinated biphenyl onto the coconut husk biochar. A similar study was conducted in which the rate constant (min^{-1}) ranged from 0.0404 to 0.0582 (Inbaraj et al., 2021). Generally, the coefficient of determination for phenol and polychlorinated biphenyl onto the coconut husk biochar had an excellent fit to the pseudo-second order model. It also signified that chemisorption was intricate in the elimination of phenol and polychlorinated biphenyl by the coconut husk biochar.

Conclusion

The study showed that temperature and adsorbent dosage influenced the adsorption efficiency. The adsorbent dosage influences the adsorption efficiency significantly. Coconut husk biochar has a good affinity for phenol and polychlorinated biphenyl in the landfill leachate. Pseudo-second order adsorption kinetics was the best fit model for phenol and polychlorinated biphenyl onto the coconut husk biochar. Coconut husk biochar exhibits different temperature-dependent adsorption behaviour for phenol and polychlorinated biphenyls. Treatment designs can be made more cost-effective by fine-tuning operational variables like temperature in response to target pollutants. Due to its low cost and local availability, coconut husk biochar is a viable and cost-effective adsorbent choice for leachate treatment facilities at landfills, particularly in low-resource environments. The results support the incorporation of biochar in multicontaminant wastewater treatment systems, fostering environmentally friendly and decentralised solutions. Improved removal of phenol and PCBs helps to purify groundwater and surface water, which has a direct positive impact on public health. Promotes waste valorisation by turning coconut husk into a valuable resource, fostering circular economy practices. Coconut husk biochar has the potential to be evaluated for the removal of phenol and polychlorinated biphenyl from landfill leachate.

Limitations and future implications

The study concentrated on laboratory-scale investigations, which may not accurately represent the complexity of field situations, such as variations in pollutant concentrations, competing ions, or natural organic matter that might impact adsorption efficiency. Additionally, the research focused on only two pollutants with low levels; further research is necessary to determine how well coconut husk biochar works against heavy metals or combinations of different contaminants. The ultimate integration of biochar regeneration, reuse, and use into hybrid treatment systems may improve economic viability and long-term sustainability, making it feasible for usage in industrial or community-level wastewater treatment facilities.

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Conflict of Interest

The author has no conflict of interest regarding this research article.

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