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Removal of Dibenzofuran from aqueous solution by sugarcane bagasse-based biochar

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ABSTRACT

Dibenzofuran (DBF) has been considered an environmental risk due to its high toxicity and risks to human health and ecosystems. Among wastewater treatment technologies, the adsorption process has emerged as a potential solution to remove organic pollutants efficiently, including dibenzofuran, in wastewater. The study aims to investigate the feasibility of sugarcane bagasse-based biochar for DBF removal through adsorption. Biochar characteristics showed a high specific surface area of up to 498.97 m²/g and abundant functional groups on the material surface, resulting in high removal performance of DBF with average adsorption efficiency and adsorption capacity reaching maximum values of 98.43% and 96.77 mg/g, respectively. The optimum parameters were suggested for DBF removal: pyrolysis temperature of 700°C, contact time of 50 min, biochar dosage of 0.5 g/L, and DBF concentration of 40 mg/L. Furthermore, the results of adsorption kinetics and adsorption isotherms indicated that the adsorption process benefits DBF removal. Pseudo-second-order model and Langmuir model can describe the DBF removal process due to the best fit to experimental data ($R^2 > 0.98$). Based on these findings, sugarcane bagasse-based biochar could be utilized efficiently to remove DBF from wastewater.

1. INTRODUCTION

Over the past few decades, rapid economic growth via global industrialization and urbanization has accelerated environmental concerns including air, water, and soil contamination. Human activity, especially industrial production releases huge amounts of polluted wastewater and drains into the natural water system, causing threat to human health and ecosystems. Among the contaminants of the aquatic environment, persistent organic pollutants (POPs), including polychlorinated dibenzofurans (PCDFs) and polychlorinated dibenzo-p-dioxins (PCDDs), as dioxins and furans for short, are

pollutants of extremely high environmental impact due to their very high toxicity to human organisms (Ying et al., 2009; Förstner et al., 2016; Baran et al., 2021). Miguel Dopico and Alberto Gómez reported in 2015 that annual dioxin emissions in the world were about 17,226 kg, equivalent to about 287 kg-TEQ (Dopico et al., 2015). Dibenzofuran (DBF) and its derivatives, dioxin-like compounds, are considered persistent organic pollutants (POPs). Recently, DBF has drawn environmental issues due to their high toxicity and risks to both human health and ecosystems (Kishida et al., 2010). However, conventional wastewater treatment methods have

not been effective in efficiently removing these compounds. Therefore, effective and simple processes for treating DBF and PCDDs/Fs from polluted wastewater are urgently required for proper environmental management (Vallejo et al., 2015). New treatment approaches have been proposed to remove those contaminants from wastewater including adsorption, ozonization, and advanced oxidation processes (AOPs), etc. (Smirnov et al., 1996; Vallejo et al., 2015), which can treat efficiently those pollutants in the aqueous environment. Among the new treatment processes, using the biochar from agricultural waste as an adsorbent to remove DBF, PCDDs/Fs is very promising due to not only its adsorption ability but also its renewable sources and low cost.

In recent years, lignocellulosic biomass has emerged as a significant renewable resource due to its eco-friendly and low-cost materials and availability. Biomass is considered a biodegradable fraction of products, waste, and residue from biological origin, which is very promising for its high-value utilizations. Biochar with a prosperous source of carbon derived from biomass, especially from agricultural wastes, has been an increased global interest in energy generation and environmental applications. Biochar produced commonly from the pyrolysis process has unique characteristics, such as high porosity, functional groups large surface area, and high cation exchange capacity. Those properties make biochar suitable for various applications, including the efficient removal of various contaminants from wastewater. Types of contaminants and process treatment are a function of experimental parameters including pyrolysis temperature, types of biomass, residence time, pretreatment method (Yaashikaa et al., 2020).

Sugarcane bagasse, an agricultural waste, is the fibrous lignocellulosic residue of sugar production. It is estimated that about 1.4 million tons of bagasse are produced annually in the Mekong Delta. Many publications have reported that biochar from various biomass sources were used to remove pollutants from aqueous solutions (Kalderis et al., 2008). It was found that sugarcane bagasse, among a few biomass sources, has shown good performance in the treatment of various pollutants (Creamer et al., 2014; Ding et al., 2014; Gan et al., 2015; Divband Hafshejani et al., 2016; Zhang et al., 2018; Vimal et al., 2019; Bai et al., 2021). Although biochar showed widespread application prospects in wastewater treatment, the utilization of biochar for DBF removal, and PCDDs/Fs from aqueous

solutions is hindered by limited publications. Thus, this work focuses exclusively on evaluating the efficacy of sugarcane bagasse biochar as an adsorbent for DBF adsorption in an aqueous solution through various parameters such as contact time, initial DBF concentration, biochar dosage, and solution pH. Different types of biochar were characterized using different analytical techniques including Fourier transform infrared (FT-IR) and scanning electron microscope (SEM). The adsorption behavior was clarified by adsorption kinetic models and isotherm models. This result can contribute to an understanding of this research field and suitable utilization of biochar to enhance the removal efficiency of dioxin and dioxin-like compounds from wastewater, to provide an adequate technical reference for further large-scale applications.

2. MATERIALS AND METHOD

2.1. Materials

In this work, the raw material for biochar preparation was sugarcane bagasse obtained from juice drink traders in Ninh Kieu District, Can Tho City. Dibenzofuran (purity 99%) and Ethanol (purity 99.5%) were used from Xilong Chemical Co., Ltd, China. The pH was adjusted with 1M HCl and NaOH solutions.

2.2. Preparation and characterization of biochar

Sugarcane bagasse waste was collected and preserved in the best possible condition. It was washed and dried at 105°C for 24 hours. It was then pyrolyzed in a muffle furnace at various temperatures (500, 700, and 900°C) for 2h with a heating rate of 10°C/min. The material obtained was washed with deionized water several times until the pH of the residue water was close to neutral. Finally, it was dried at 105°C for 24 hours.

Biochar was characterized by different modern analytical methods. The specific surface, micropore, and mesopore size distributions of the samples were examined by Brunauer-Emmett-Teller (BET) and the equation Berret-Joyner-Halenda (BJH) method; the internal morphologies and structure features were observed by a scanning electron microscope (SEM) by a JOEL JCM 700. The Fourier-transform infrared spectroscopy (FT-IR) was to determine specific links and the surface functional groups of the material in the wave number ranging between 500 and 4000 cm^{-1} in the mid-infrared region using Frontier FT-IR/NIR (Perkin Elmer). The pore

structure of the biochar was detected by N₂ adsorption/desorption isotherms at 77 K. The weight loss (TG signals) and weight loss rate (DTG signals) were determined in a temperature range between 0 and 1000°C through thermogravimetric analysis (TGA) of biomass sample which was performed on Setaram Labsys Evo instrument in N₂ gas. The concentrations of DBF were determined at λ_{max} = 280 nm by UV-Vis spectrophotometer (Spectro UV-Vis Double Beam UVD-3500).

2.3. Adsorption experiments

The batch adsorption investigations were conducted to evaluate the influence of different variables on the adsorption performance, including pyrolysis temperature DBF concentration, adsorption time, sample weight, and adsorption temperature. In more detail, 10 mg of biochar was put into 10 ml of DBF at different initial concentrations ranging between 10 and 80 (mg/L), while the effect of adsorption time was investigated from 10 to 80 min. The change in DBF levels was determined by a UV-Vis spectrophotometer at 280 nm. For each experimental point, three separate experiments were performed to test the reproducibility of the results. The removal efficiency (R) and the adsorption capacity (q_t) at contact time (t) were determined by Equations (1) and (2) as follows.

$$R (\%) = \frac{C_0 - C_t}{C_0} \times 100 \quad (1)$$

$$Q_t \left(\frac{mg}{g} \right) = \frac{(C_0 - C_t) \times V}{w} \quad (2)$$

where C₀ (mg/L) and C_t (mg/L) are the initial and concentrations (mg/L) at contact time (t), V(L) represents the solution volume and w(g) is the mass of biochar used.

2.4. Adsorption kinetic and isotherm models

The kinetic study determines the time influence on the adsorption capacity of the adsorbents and the possible adsorption behaviors that occurred in the adsorption process. Determining adsorption behavior is necessary to predict the solid-liquid sorption interaction. The kinetic adsorption investigations were conducted from 10 to 50 min at 40 mg/L and room temperature. The mixtures were shaken at 120 rpm, samples were filtered out and analyzed by UV-Vis spectrophotometer to determine DBF residual concentration. The kinetic pseudo-first-order (PFO, equation 3), pseudo-second-order (PSO, equation 4), Elovich (equation 5), and intraparticle diffusion (equation 6) models (Tovar et al., 2021; Wang & Guo, 2020; Wang,

Zhang, et al., 2021) were used to describe the adsorption process.

$$Q_t = Q_e \left[1 - \exp \left(-\frac{k_1 t}{2.303} \right) \right] \quad (3)$$

$$\frac{t}{Q_t} = \frac{1}{k_2 Q_e^2} + \frac{t}{Q_e} \quad (4)$$

$$Q_t = \frac{1}{\beta} \ln(\alpha \beta t + 1) \quad (5)$$

$$Q_t = k_i t^{0.5} + C \quad (6)$$

where Q_t (mg/g) denotes the adsorption capacity at a time; t(min) is adsorption time, k₁ (1/min) is the PFO rate constant; k₂ (1/g.min) is the PSO rate constant; α (mg/g.min) is the constant and β (g/mg) represents the exponent in the Elovich equation; k_i refers the intraparticle diffusion rate constant (mg/g.min^{0.5}).

Adsorption isotherms were investigated to evaluate the quantity of DBF adsorbed at equilibrium; the isotherm can provide useful information to determine possible adsorption levels with the biochar treatment. Determination of the adsorption equilibrium can contribute fundamental physiochemical data for the feasibility evaluation of the sorption process as a unit operation. Furthermore, the data is useful for mathematical models to predict the performance of the adsorption process. The isotherm study was conducted by taking a series of solutions with initial DBF concentrations of 10 to 50 mg/L, and an optimum adsorbent dosage of 2 g/L. The mixtures were shaken at 120 rpm, and after reaching equilibrium, samples were collected and then analyzed to determine the residual DBF concentration. The measured data were fitted to the isotherm models of Langmuir (equation 7), Freundlich (equation 9), and Dubinin-Radushkevich (D-R model, equation 10) as presented follows (Tovar et al., 2021; Wang et al., 2021).

Langmuir models

$$Q_e = \frac{K_L Q_m C_e}{1 + K_L C_e} \quad (7)$$

Where Q_m refers to the theoretical maximum adsorption capacity (mg/g); and K_L denotes the Langmuir equilibrium constant related to surface heterogeneity; therefore, it refers to adsorption strength. A separation factor (or equilibrium parameter), R_L, a dimensionless constant that describes the characteristics of the Langmuir isotherm, is defined as follows.

$$R_L = \frac{1}{1 + K_L C_0} \quad (8)$$

The value of R_L shows the type of the isotherm: unfavorable ($R_L > 1$), linear ($R_L = 1$), favorable ($0 < R_L < 1$), or irreversible ($R_L = 0$) (Wang et al., 2021).

Freundlich model

$$Q_e = K_F C_e^{1/n} \tag{9}$$

where K_F (mg/g.(L/mg)^{1/n}) and n represent the Freundlich rate constant regarding to adsorption capacity and adsorption intensity, respectively.

Dubinin-Radushkevich model (D-R model)

$$Q_e = Q_0 \cdot \exp(-K_{DR} \varepsilon^2) \tag{10}$$

$$\varepsilon = RT \left(1 + \frac{1}{C_e}\right) \quad ; \quad E = \frac{1}{\sqrt{2K_{DR}}}$$

Where K_{DR} (mol²/kJ²) is the D-R rate constant related to adsorption energy, E (kJ/mol) is the average adsorption energy per molecule of adsorbate, ε denotes the Polanyi adsorption potential, R is the ideal gas constant, 8.314 J/(mol.K), and T is the absolute temperature (K).

3. RESULTS AND DISCUSSION

3.1. Biochar characterization

The basic physical and chemical properties of biochar samples pyrolyzed at various temperatures are listed in Error! Reference source not found.. It should be noted that the carbon content of biochar samples was considerably higher than that of biomass. In contrast, the oxygen fraction of biochar was considerably lower compared to that of raw material. The lower oxygen content and O/C ratio may cause less functional groups in porous materials. Furthermore, the specific surface area and pore volume of the material treated at high temperatures are significantly higher than those prepared at 500°C. In terms of pore size, three porous materials are mainly based on micropore structure, and the size is reduced as pyrolyzed temperature increases. The very low fraction of silica compared to the other elements in sugarcane bagasse could be under the limit of detection of the analyzer causing it not to be found in the result.

The SEM image in Error! Reference source not found. (a) exhibits the surface morphology of the **Table 1. Basic characteristics of various materials**

Sample	C (wt.%)	O (wt.%)	Si (wt.%)	S _{BET} (m ² /g)	Pore volume (cm ³ /g)	Pore size (nm)
Biomass	48.85	51.15	-	-	-	-
BC500	79.05	20.01	0.52	151.79	0.07	1.19
BC700	80.86	16.88	0.47	497.91	0.17	0.94
BC900	78.31	21.45	0.24	498.97	0.18	0.97

biochar. The biochar surface is rough with a rich porous structure and an irregular honeycomb-like structure which consists of a carbonaceous skeleton (Hafshejani et al., 2016; Ghani et al., 2013). The rich porous structure of biochar is consistent with the high specific surface area of those materials. That surface pore structure was developed during carbonization. The water vapor released and organic substances in biomass carbonized formed the pore structure and pore channels clearer at high temperatures.

FT-IR analysis is to determine the appearance of the functional groups available on the surface of adsorbents. The FT-IR spectra of the biochar samples were investigated in the wavenumber region from 4000 to 400 cm⁻¹. There were adsorption peaks at around 3440 cm⁻¹, which may be primarily characteristic of the stretching vibration band of the hydrogen bond (-OH) in carboxyl, phenols, and alcohols from the biochar. The characteristic peak at around 1618 cm⁻¹ was caused by the stretching vibration of the C=C bond which means that olefin or the aromatic ring skeleton may exist on biochar surface. The peak at 1226 – 1049 cm⁻¹ may indicate the presence of the C–O bond vibration of carboxyl bands that indicated the activity of carboxyl oxygen atoms occurred, while 557 cm⁻¹ was attributed to the C – X (halogen) stretching vibration. According to Error! Reference source not found. (b), BC700 has fewer functional groups compared to two other materials, while the content of olefin or aromatic ring and carboxyl group in BC900 increases due to the increasing relative intensity for a peak around 1618 cm⁻¹ and 1226—1049 cm⁻¹.

The thermogravimetric analysis curve of sugarcane bagasse biomass is shown in Error! Reference source not found.. The thermal decomposition of biomass material mainly took place in two stages. In the first stage, the weight loss from 0 to 150°C was 6.65% due to the drying and dehydration process which was mainly due to the moisture content of the sample. The second stage occurred between 150 and 1000°C with a mass reduction of nearly 68% due to the volatilization of small molecular gases.

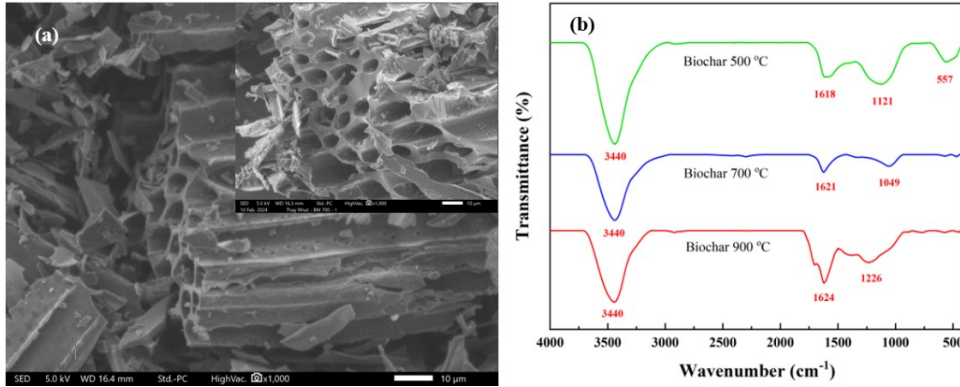


Figure 1. SEM micrographs of BC700 (a) and FT-IR spectra (b) three pyrolysis temperatures

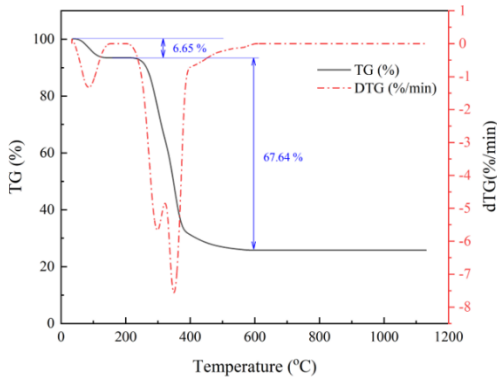


Figure 2. Thermal weight loss of sugarcane bagasse biomass

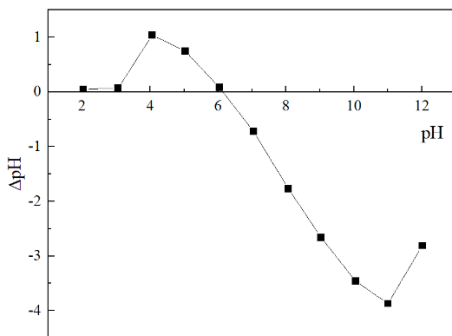


Figure 3. Point of zero charge (pHpzc) for BC700

The surface charge of the adsorbent was determined through the point of zero charge (pHpzc) investigation. pHpzc refers to the pH at which the net surface charge of the material reaches zero, meaning that the positive and negative charge on the surface balance. Error! Reference source not found. presents the pHpzc of sugarcane bagasse biochar as about 6.1, which means that the net surface charge of biochar is positive at the pH of the solution, which is lower than the pHpzc value, due to the adsorption of excess H⁺. Otherwise, the surface charge of the material is negative due to the desorption of H⁺.

3.2. Experimental investigation of DBF adsorption

3.2.1. Effect of pyrolysis temperature

Pyrolysis temperature refers to the temperature at which pyrolysis takes place. The temperature significantly affects the characteristics of the biochar as well as its adsorption performance. Error! Reference source not found. represents the influence of pyrolysis temperature on the DBF removal performance. The adsorption efficiency enhanced with an increasing pyrolysis temperature, reaching a peak of 97.9% at 700°C. This efficiency enhancement may be attributed to the increase in the specific surface area of biochar from 151.79 to 498.97 m²/g, resulting in more active sites of the adsorbent. However, biochar treated at 900°C has a removal performance slightly less than that at 700°C. It may be due to that the biomass pyrolyzed at high temperatures released more volatiles from the materials, causing a reduction in functional groups on the biochar surface which can interact well with the adsorbate. Therefore, it can be proposed that biochar treated at 700°C is suitable for DBF removal.

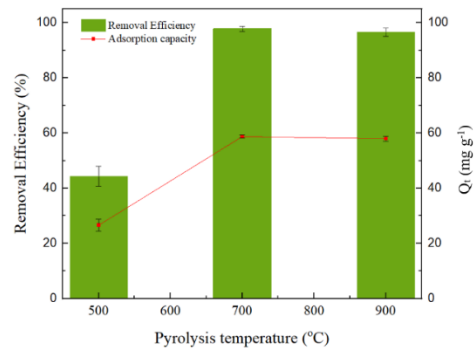


Figure 4. The effect of pyrolysis temperature on adsorption performance

3.2.2. Effect of DBF concentration

The initial adsorbate concentration significantly affects the adsorption performance since the interaction between the adsorbate in an aqueous solution and solid particles results in the transfer of the molecules from the solution to the solid surface. The DBF concentration is a key factor in determining an adsorbent material's adsorption performance. In the study, the range of initial DBF concentration varied from 10 to 50 mg/L, biochar dosage of 10 mg, and contact time of 60 min. It was evident from the results shown in **Error! Reference source not found.** (a) that the adsorption capacity of biochar enhanced considerably from 19.57 to 89.20 mg/g in the range of DBF concentration, while the removal efficiency was mainly unchanged with about 98% between 10 to 40 mg/L, then decreased to 89.67% at the concentration of 50 mg/L. This phenomenon may be due to the quantity of available active adsorption sites on the surface for DBF adsorption.

3.2.3. Effect of adsorbent dosage

Adsorbent dosage plays a crucial role in the adsorption process and significantly influences its performance. The quantity of adsorbent used is an important operating parameter for removing the amount of adsorbate from the aqueous solution. Generally, an increase in the quantity of adsorbent provides more available active sites and enhances the surface area, improving adsorption performance. The results of the investigation in **Error! Reference source not found.** (b) show removal efficiency and adsorption capacity at different biochar dosages from 0.25 to 1.25 g/L in solution with a DBF concentration of 40 mg/L and a contact time of 60 min. It can be seen that the adsorption capacity decreased considerably by 80% with the increase in biomass quantity. Additionally, the removal efficiency increased to the maximum value of 98.37% at 0.5 g/L, then decreased slightly with a further increase in biomass quantity used. This decrease may be caused by procedural and facility errors. Thus, the biomass dosage of 0.5 g/L was selected for further investigations.

3.2.4. Effect of adsorption time

The adsorption time refers to the duration of contact of DBF with biochar which is a crucial factor in an adsorption process. It is necessary to investigate the effect of adsorption time to determine the kinetics of the process thoroughly. The experimental investigation was conducted in a range between 10 and 80 min. With a starting DBF concentration of 40 mg/L and a biochar dosage of 0.5 g/L. The results in **Error! Reference source not found.** (c) found that the efficiency and adsorption capacity rose rapidly in the beginning stages of contact time and reached a peak at 50 min. with 98.37% and 78.69 mg/g, respectively. After 50 minutes, the removal efficiency decreased slightly and was mostly unchanged at 80 min. This phenomenon might be attributed to the higher number of active sites available on biochar for DBF adsorption during the initial stages. Then, the rate of desorption may increase, resulting in a slight reduction in the removal efficiency and adsorption capacity before reaching equilibrium. Thus, an adsorption time of 50 min was selected for further investigation.

3.2.5. Effect of solution pH

The pH of a solution might significantly affect the adsorption performance, particularly for adsorbents with charged surfaces. According to the pH_{pzc} investigation, the net surface charge of biochar reached zero at a pH of 6.1. **Error! Reference source not found.** (d) illustrates the effect of solution pH on the adsorption performance of sugarcane bagasse biochar towards DBF in the solution with the initial DBF level from 10 to 50 mg/L, biochar dosage of 0.5 g/L at 50 min. It can be seen that the adsorption of DBF declined with increasing the pH of the solution. Additionally, the impact of solution pH on the removal efficiency was less significant with increasing initial DBF concentration. At 50 mg/L, the efficiency was mostly unchanged, while it decreased significantly with the DBF concentration of 10 mg/L in a pH range from 2 to 12.

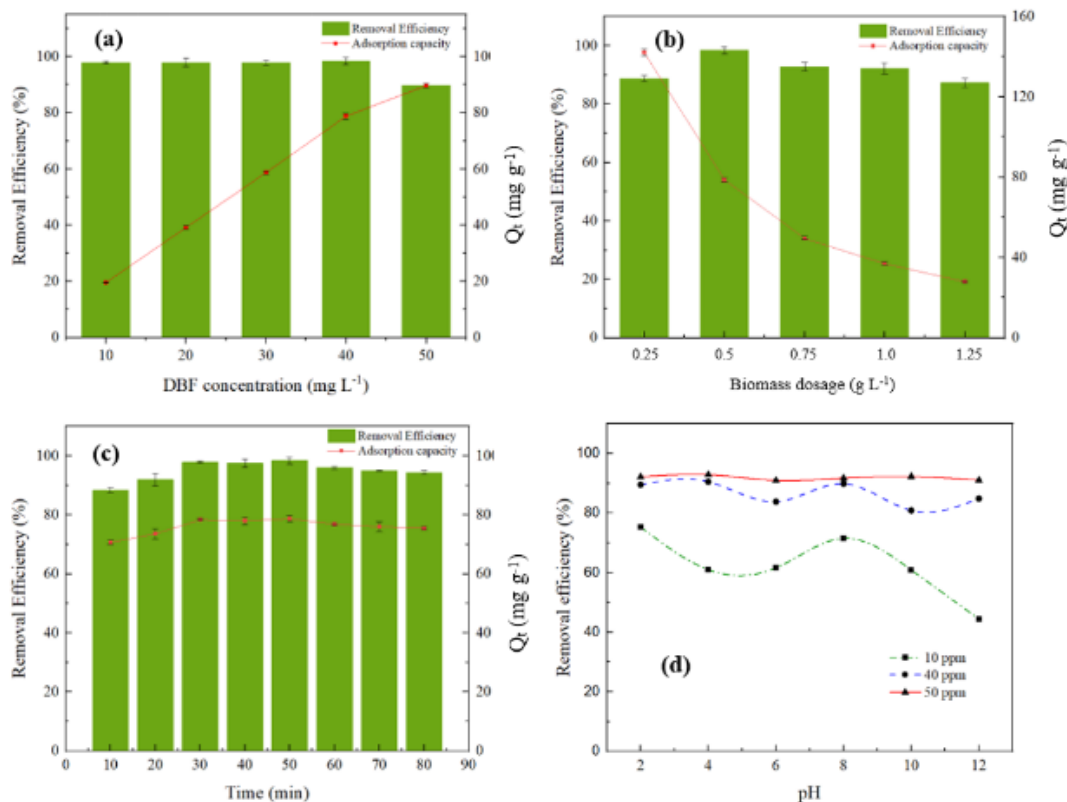


Figure 5. Effect of operating parameters: DBF concentration (a); Biomass dosage (b); contact time (c); solution pH (d)

3.2.6. Adsorption kinetics

Adsorption kinetic investigations were conducted to determine the rate at which the adsorption process occurs over time to understand and describe the mechanisms and factors that govern the adsorption process. In this work, the adsorption kinetics of DBF onto sugarcane bagasse-derived biochar was determined by using pseudo-first-order model (PFO), pseudo-second-order model (PSO), Elovich model, and intraparticle diffusion model at contact time ranging from 0 to 80 min, initial DBF concentration of 40 mg/L, biochar dosage of 0.5 g/L. Those models were described by a nonlinear method, which may provide more accurate estimations compared to the linearization process (Y.-S. Ho, 2006a; Y. S. J. P. J. o. E. S. Ho, 2006b; Kumar & Sivanesan, 2006; El-Khaiary et al., 2010). The results of the adsorption kinetic study are presented in **Error! Reference source not found.** and **Error! Reference source not found.** PFO and PSO kinetic models showed a higher value of the coefficient of determination (approximately 0.996) compared to the other models for DBF adsorption by biochar. The PFO model assumes that the rate of

the sorption process reduces linearly with the increase in adsorption capacity. Additionally, the initial adsorbate concentration is high, the adsorption process mainly occurs in the initial stage, and there are a few active sites on the adsorbent surface (Wang & Guo, 2020).

PSO kinetic model assumes that the interaction between adsorbate and adsorbent is the rate-limiting step, and this model is usually used to describe chemical adsorption (Divband Hafshejani et al., 2016). Furthermore, the PSO model is applied for the adsorption process at a low initial adsorbent concentration, at the final stage, and with abundant active sites on the adsorbent surface. Additionally, the equilibrium adsorption capacity value ($Q_{e(cal)} = 78.537$ mg/g) estimated from the PSO model fitted very well with the measured value ($Q_{e(exp)} = 78.75$ mg/g). Therefore, a low initial DBF concentration of 40 mg/L and the good fit of adsorption capacity obtained from the experimental data and PSO model would indicate that the DBF adsorption by sugarcane bagasse-derived biochar can be described well by the PSO model, and chemical adsorption is the rate controlling mechanism.

3.2.7. Adsorption isotherms

Adsorption isotherms describe how the amount of adsorbate on solid surface varies with adsorbate concentrations in the bulk phase at a constant temperature. The adsorption isotherms can provide valuable insights into the adsorption behavior and a good understanding of the interaction between the adsorbate and adsorbent. In this work, three isotherm models, including Langmuir, Freundlich, and Dubinin-Raduskovich (D-R), were applied to describe the DBF adsorption by sugarcane bagasse biochar. The results of those models are shown in **Error! Reference source not found.** and **Error! Reference source not found.**

It was observed that the Langmuir model with a higher value of R^2 (0.99) showed a better fit for the adsorption process in the work. It implies that the monolayer adsorption of DBF on a homogeneous surface of sugarcane bagasse biochar may be represented for the adsorption process. The

maximum adsorption capacity calculated from the Langmuir model was 102.13 mg/g, which is greater than the actual maximum adsorption value obtained from the experimental investigations. This difference may be due to the limit of DBF level used in the experiment. Additionally, the value of the separation factor was lower than 1, which means that adsorption isotherm is favorable in this study. R^2 values of the Freundlich model and the D-R model were greater than 0.95. The n value of the Freundlich model is an empirical constant, where a higher n indicates a greater adsorption capacity. In the study, the n value was 3.163 (in a range of 1–10) indicating that sugarcane bagasse-based biochar could efficiently adsorb low-concentration of DBF, which favors its treatment (Inyang et al., 2016; Wang et al., 2021). The average adsorption energy is necessary to predict the type of adsorption and its value was 4.67 indicating that the DBF adsorption in the study was dominated by physisorption.

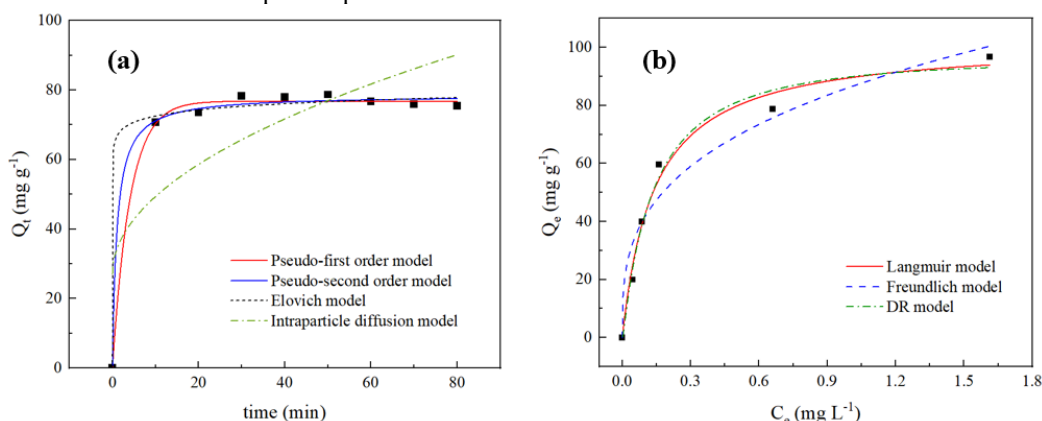


Figure 6. Adsorption kinetics (a) and adsorption isotherms fitting curves of DBF on sugarcane bagasse-derived biochar

Table 2. Kinetic parameters of DBF adsorption by biochar derived from sugarcane bagasse

Pseudo first order			Pseudo second order			Elovich model			Intraparticle diffusion		
Q_e (mg/g)	k_1	R^2	Q_e (mg/g)	k_2	R^2	a (mg/g·min)	b (g/mg)	R^2	k_i	C	R^2
76.81	0.246	0.997	78.537	0.012	0.996	$4.94 \cdot 10^{11}$	0.39	0.994	7.06	27.02	0.622

Table 3. Isotherm parameters of DBF adsorption by biochar derived from sugarcane bagasse

Langmuir model				Freundlich model			D-R model			
K_L	Q_m (mg/g)	R_L	R^2	K_F	n	R^2	Q_0 (mg/g)	E (kJ/mol)	R^2	
7.106	102.13	0.0028	-0.0139	0.996	86.304	3.163	0.953	96.1978	4.67	0.985

4. CONCLUSION

The study aimed to conduct a comprehensive investigation into the feasibility of sugarcane bagasse waste for Dibenzofuran removal from aqueous solution through the pyrolysis process. Biochar material from sugarcane bagasse showed

good characteristics with a specific surface area of about $498.97 \text{ m}^2 \text{ g}^{-1}$ and the appearance of abundant functional groups on the biochar surface. The results of biochar characterization were consistent with the high removal performance of DBF in the experimental study, with mean adsorption

efficiency and adsorption capacity reaching maximum values of 98.43% and 96.77 mg/g, respectively. In contrast, the theoretical maximum adsorption capacity of DBF by sugarcane bagasse-based biochar was 102.13 mg/g. The optimum operating parameters were suggested for DBF removal as pyrolysis temperature of 700°C, a contact time of 50 min, a biochar dosage of 0.5 g/L, and a DBF concentration of 40 mg/L. The adsorption mechanism was dominated by physisorption. This study can provide a scientific understanding of the utilization of biochar derived from agricultural wastes for the treatment of dioxin and dioxin-like compounds as well as organic contaminants in wastewater.

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CONFLICT OF INTEREST

The authors declare that they have no competing financial interests or personal relationships that could affect the work reported in this manuscript.

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