

# Synthesis of Carbon Dots Using Fish Scale for the Effective Adsorption of Amoxicillin from Aqueous Solution

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**Abstract:** The effective adsorption of antibiotics from aqueous solutions has been a major challenge for environmental protection and public health. This work involved the synthesis of a carbon dots nanoparticle from fish scale waste for the purpose of antibiotic adsorption. X-ray diffraction (XRD), scanning electron microscopy (SEM), energy dispersive X-ray (EDX), and Fourier transform infrared (FTIR) analyses were used to characterize the synthesized fish scale carbon dots (FCD). Adsorption experiments were conducted to test the synthesised adsorbent's capacity to adsorb amoxicillin. The ideal parameters was determined using Response Surface Methodology (RSM) design, which resulted in a 95.82% removal efficiency at 32 minutes of contact time, 16 mg/L of amoxicillin concentration, and 0.15 g/L of FCD dosage. Additionally, the adsorption experiments showed that the adsorption rate was high at the lowest concentration of 10 mg/L, with a dosage of 0.15 mg and at time 45 min. The pseudo-second order model fit the kinetics data the best. Moreover, the Langmuir model provided the best fit for isothermal data. Findings from this research suggested that the FCD synthesized could be highly efficient for amoxicillin removal from liquid phase.

**Keywords:** Adsorption, Carbon Dots, Amoxicillin, Optimization, Isotherm, Fish Scale.

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## I. INTRODUCTION

Emerging pollutants have the potential to permanently harm aquatic and human life, even at low concentrations in the environment. Emerging pollutants are relatively broad class of unregulated compounds including pharmaceuticals, personal care products, endocrine disrupting compounds and hormones (Boshir *et al.*, 2017). Pharmaceutical compounds have garnered attention as emerging pollutants because of their detrimental effects on the environment. Because antibiotics are so widely used, both by humans and by animals, special attention has been given to them among other pharmaceutical compounds.

The overuse and improper disposal of antibiotics leads to the development of antibiotic resistance, which reduces the ability of medications to effectively treat bacterial infections. The Antibiotic-resistant bacteria are a major danger to public health, economic growth, and food security, according to the World Health Organization (WHO, 2021). In the decades

since antibiotics were discovered, the use of antibiotics in medical, veterinary, and agricultural medicine has been connected to environmental contamination of a number of regions, including drinking water, groundwater, surface water, municipal sewage, soil, vegetables, and sludge. Antibiotic resistance rises as a result, and there are negative ecological consequences (Hanna *et al.*, 2018). Additionally, the use of antibiotics promotes the development of genes or bacteria resistant to antibiotics, which can pass from the environment to humans. Antibiotic-resistant bacterial infections are considered to be a major cause of treatment failures in human medicine, as well as a factor in increased morbidity, mortality, and lengthening of illness duration (Merlin, 2020). Therefore, creating a potent adsorbent is essential (Mossab *et al.*, 2020).

Since carbon dots (CDs) have unique properties and applications, they have emerged as one of nanotechnology's greatest gifts. The carbon atoms in CDs are  $sp^2$  and  $sp^3$ , and functional groups or polymer chains are heavily coated on

their surfaces (Xia *et al.*, 2019). High photoluminescent quantum yield, excellent electron conductivity, resistance to photodecomposition, variable excitation and emission attributes, excellent solubility in aqueous media, excellent biocompatibility, long-term chemical stability, low toxicity, and a large effective surface area-to-volume ratio are just a few of the remarkable qualities that have piqued the interest of researchers (Mansuriya and Altintas, 2021; Dinc and Gunhan, 2020). CDs are easily functionalized due to the abundance of functional groups on their surface. Additionally, they possess incredible sensing qualities like selectivity, specificity, and multiplex detectability. Functional groups (amine, carboxyl, hydroxyl, etc.) and polymer chains are widely distributed on the surface of CDs, which helps explain their exceptional solubility in aqueous solutions and ease of functionalization with other nanomaterials in terms of area-to-volume ratio (Xia *et al.*, 2019). The essential sp<sup>2</sup>/sp<sup>3</sup> carbon skeleton of CDs frequently displays an amorphous carbon form or graphite lattice because of differences in their degree of carbonization (Namdari *et al.*, 2017). Moreover, CDs' physico-chemical characteristics are easily modifiable to suit their intended purpose or application (Tuerhong *et al.*, 2017).

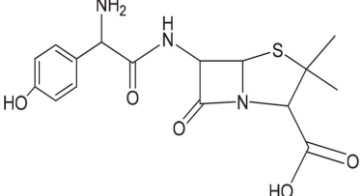
According to Ngulde *et al.* (2022) biomass is the collective term for organic materials derived from living matter or mixes of inorganic and organic components. In addition to living things like plants and animals, biomass also includes waste wood, sludge, and animal waste. Another name for it is stored energy. It is an organic substance derived from both plants and animals that is renewable. It is a potential energy source. Biomass, which is mostly made up of carbohydrates, has less problems storing energy than other renewable energy sources like solar and wind (Schlemmer *et al.*, 2021). Biomass is widely available from a variety of sources and has many uses in the context of sustainable development.

The chemical formula for the generic drug amoxicillin (AMX) is C<sub>16</sub>H<sub>19</sub>N<sub>3</sub>O<sub>5</sub>S. Amoxi-cillin is a semi-synthetic antibiotic that is a member of the penicillin family's β-lactam

antibiotic class (Abdellah *et al.*, 2023). Because of its pharmacological and pharmacokinetic characteristics, this medication is used to treat and prevent bacterial infections of the respiratory, gastrointestinal, urinary, and skin (Armando *et al.*, 2016; Ighalo *et al.*, 2021). It has been demonstrated to be effective against a broad range of infections caused by gram-positive and gram-negative bacteria. As indicated in Table 1, functional groups like -NH<sub>2</sub> and -OH give the chemical structure of amoxicillin its amphoteric qualities (Aaron *et al.*, 2022). Research indicates that the human body excretes more than 80% of amoxicillin through urine within two hours of consumption. Because of its widespread use and comparatively rapid egestion, amoxicillin is one of the antibiotics found in wastewater that is most frequently reported. Because of their direct biological effect on microorganisms, this phenomenon poses a risk because it produces antimicrobial-resistant bacteria (ARB), which have been shown to be transmissible from animals to humans (Aaron *et al.*, 2022). If antibiotic resistance is allowed to spread unchecked, it could make routine surgeries and other modern medical procedures too risky. Antibiotic resistance could therefore result in the death of up to 10 million people a year starting in 2050 (WHO, 2021). Therefore, creating an efficient adsorbent is essential. The purportedly serious risks to human health and the environment associated with water containing antibiotics have prompted a surge in research into efficient water treatment technologies.

Adsorption has been recommended as one of the best treatment methods for removing antibiotics from water because it has a track record of success (Al-Musawi *et al.*, 2023). There have been recent attempts to use biomass wastes as raw materials to create carbon compounds from them. The main ingredients of biomass waste, which is an organic carbon source found in nature, are protein, ash, cellulose, lignin, hemicellulose, and a few other substances. Biomass waste offers a plentiful, secure, sustainable, and environmentally friendly carbon source for the production of carbon-dots (Kang *et al.*, 2020).

Table 1 Main characteristics of Amoxicillin

Empirical Formular	Chemical Structure	Average Molecular Weight (g/mol)
C <sub>16</sub> H <sub>19</sub> N <sub>3</sub> O <sub>5</sub> S		365.41

Many different scientists are still researching the substances and materials required for long-term adsorption water treatment. Therefore, it is crucial to create compounds that can effectively remove environmental pollutants; this cannot be emphasized enough. Historically, a wide range of activated carbon types have been employed for various adsorptive purposes. Bulk materials are useless for these purposes because of the restricted surface area that can be used for adsorption (Musa *et al.*, 2020). Thus, the goal of this study is to investigate the adsorption task at the nanoscale using fish scale carbon dots (FCD), where the removal

performance and adsorbent properties for the adsorption of numerous significant water contaminants, including amoxicillin, are being examined.

## II. MATERIALS AND METHODS

### ➤ Materials

The fish farm at Afe Babalola University provided the fish scale waste that was utilized. The amoxicillin was acquired from Sigma Aldrich in Germany, and the remaining reagents were of analytical quality. The surface functional

groups on carbon dots adsorbent were assessed using an atmospheric Fourier transform infrared (FTIR) spectrometer (Perkin Elmer 1750X, U.K.) with a wavelength range of 400 to 4000  $\text{cm}^{-1}$ . The XRD study for the assessment of crystallinity in the  $2\theta$  range of 4 to 90 degrees was recorded at room temperature using  $\text{Cu K}\alpha$  radiation. The structural and morphological properties of the as-synthesised carbon dots were investigated using energy dispersive x-ray spectroscopy (EDS) in combination with scanning electron microscopy (SEM, Hitachi S-3400N, Japan). After the adsorption procedure, the concentration of amoxicillin antibiotic (at  $\lambda = 225 \text{ nm}$ ) was measured using a UV-visible spectrophotometer (Lambda 35 PerkinElmer Life and Analytical Science, Singapore 139959, Singapore). For the experiment, double-distilled water was utilized.

#### ➤ Carbon dots Synthesis

A 2 g prepared sample of fish scale was mixed with 100 milliliters of distilled water. It was put into a Teflon-lined autoclave and tightly sealed after being vigorously mixed with a magnetic stirrer for fifteen minutes to ensure homogeneity. Allow it to cool to room temperature after six hours of heating at 120 degrees Celsius. Centrifuging it for 60 minutes at 2000 rpm removed the silt. The refined CD solution is filtered via a membrane filter with a pore size of 0.45  $\mu\text{m}$ . Store the sediment for characterisation after 30 minutes of drying at 120°C.

#### ➤ Amoxicillin Batch Adsorption using Carbon Dots

Response surface methodology (RSM) was used to improve three critical process parameters: the initial antibiotic concentration, the carbon dot dosage, and the reaction time. Antibiotic adsorption studies based on central composite design (CCD) were mathematically modeled and optimized using the application Design-Expert 13. The sorption of AMX was assessed in this work using the adsorption process variables concentration (A: 10–50 mg/L), carbon dots dose (B: 0.1–0.2 g), and reaction time (C: 30–90 min). In light of earlier research and potential real-world industrial wastewater scenarios, the previously mentioned independent variables in CCD were chosen. For AMX, twenty runs of the six-central-point, three-variable experimental design were acquired. Adsorption experiments were conducted at 25 °C in a 250 mL conical flask.

The percentage removal of the AMX antibiotic and its adsorption capacity were calculated using equations (1) and (2):

$$q_e = \frac{(C_0 - C_e)}{m} \times V \quad (1)$$

$$R = \frac{(C_0 - C_e)}{C_0} \times 100 \quad (2)$$

Where  $q_e$  and  $V$  are the adsorbent's adsorption capacity (mg/g) and the sample volume (L), respectively;  $R$  and  $m$  are the amoxicillin removal percentage and the adsorbent mass (g), respectively; and  $C_0$  and  $C_e$  are the initial (mg/L) and residual (mg/L) amoxicillin concentrations in the solution, respectively, after the adsorption process.

The equilibrium relationship between carbon dot as an adsorbent and amoxicillin as an adsorbate was examined using adsorption isotherms that were produced at starting concentrations ranging from 10 to 50 mg/L. The following is how the equilibrium studies were carried out: A 250 mL Erlenmeyer flask containing 0.05 g of adsorbent was filled with 50 mL of each solution. After an hour of adsorption at room temperature, the sample solution and adsorbent were separated by filtration, and the amount of leftover AMX was measured. Equations 3, 4, and 5 show how the Langmuir, Freundlich, and Redlich-Peterson isotherms were used to analyse the acquired equilibrium data.

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

$$\ln q_e = \ln K_F + \frac{1}{n} \ln C_e \quad (4)$$

$$\frac{C_e}{q_e} = \frac{1}{A} + \frac{B}{A} C_e^\beta \quad (5)$$

$K_L$  is the Langmuir constant associated with adsorption energy (L/mg),  $K_F$  is the Freundlich constant associated with adsorption capacity (mg/g), and  $q_{\max}$  is the monolayer adsorption capacity of the adsorbent (mg/g).  $B$  is the Redlich-Peterson isotherm constant (L/g),  $\beta$  is an exponent between 0 and 1, and  $A$  is a constant with the unit of (L/mg).  $C_e$  is the adsorbate's equilibrium liquid-phase concentration (mg/L), and  $q_e$  is the adsorbate's equilibrium loading onto the adsorbent (mg/g).

To perform sorption kinetics studies, 50 mL of a 20 mg/L amoxicillin solution was added to a 250 mL Erlenmeyer flask that contained 0.1 g of carbon dot biosorbent. Throughout the course of 0 to 60 minutes, the solution was shaken at various intervals. Content was filtered and equilibrium AMX concentrations were noted at each contact time. The kinetic data were analysed using the integral linearized form of pseudo-first order (equation 6), pseudo-second order (equation 7), Elovich (equation 8), and intra-particles (equation 9), respectively:

$$\ln(q_e - q_t) = \ln(q_e) - k_1 t \quad (6)$$

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{1}{q_e} t \quad (7)$$

$$q_t = \frac{1}{\beta} \ln(\alpha\beta) + \frac{1}{\beta} \ln(t) \quad (8)$$

$$q_t = k_{IP} t^{0.5} + C_{IP} \quad (9)$$

Where  $C_{IP}$  intercept represents the boundary layer thickness effect,  $\beta$  and  $\alpha$  are the Elovich constants corresponding to the extent of surface coverage and rate of

adsorption at zero coverage, respectively, and  $q_t$  represent the adsorption capacity at equilibrium and at time  $t$ , while intraparticle diffusion, pseudo first-order, and pseudo-second-order, are rate constants represented by  $k_{IP}$ ,  $k_1$ ,  $k_2$  respectively.

### III. RESULTS AND DISCUSSION

#### ➤ Characterization of Synthesized Carbon Dots

The carbon dots adsorbent that was synthesized was demonstrated using SEM, FTIR, and XRD techniques; the FTIR method was utilized to examine and identify the carbon dots' functional groups and to evaluate any chemical structural changes brought about by adsorption. Figure 1 displays the spectrum. The consistent absorption peaks at 3217 and 3250  $\text{cm}^{-1}$ , as well as the in-plane twisting swing and stretching of O–H groups, indicate that the generated

sample of fish scale carbon dots contains carboxylic groups (COO<sup>-</sup>). During AMX sequestration, the O–H group may serve as FCD's  $\pi$ -electron acceptors (Rahman *et al.*, 2021). The C–H stretching group is associated with the absorption bands at 2930 and 2963  $\text{cm}^{-1}$  (Pitmentel *et al.*, 2023). The peak at 2091 and 2117  $\text{cm}^{-1}$  that is attributed to –C–N indicates the presence of amino-containing groups, which is essential for streptavidin conjugation. The peak at 1636, 1625  $\text{cm}^{-1}$  represents the C=O stretching vibrations of the carboxylate group (Azam *et al.*, 2021). The C=C, C–N, and tertiary C=N stretching vibrations are responsible for the distinctive IR vibrations at 1413  $\text{cm}^{-1}$  and 1408  $\text{cm}^{-1}$ , respectively, whereas the stretching swings of the C–O stretching of the primary alcohol groups inside the FCD are linked to the peak at 1021 and 1025  $\text{cm}^{-1}$  (Mehdi *et al.*, 2020). The synthesized fish scale carbon dots' FT-IR spectra provide proof that the FCDs' surfaces contain amino (N–H), carboxyl (COO<sup>-</sup>), aryl (C<sub>6</sub>H<sub>5</sub>), and hydroxyl (OH) groups.

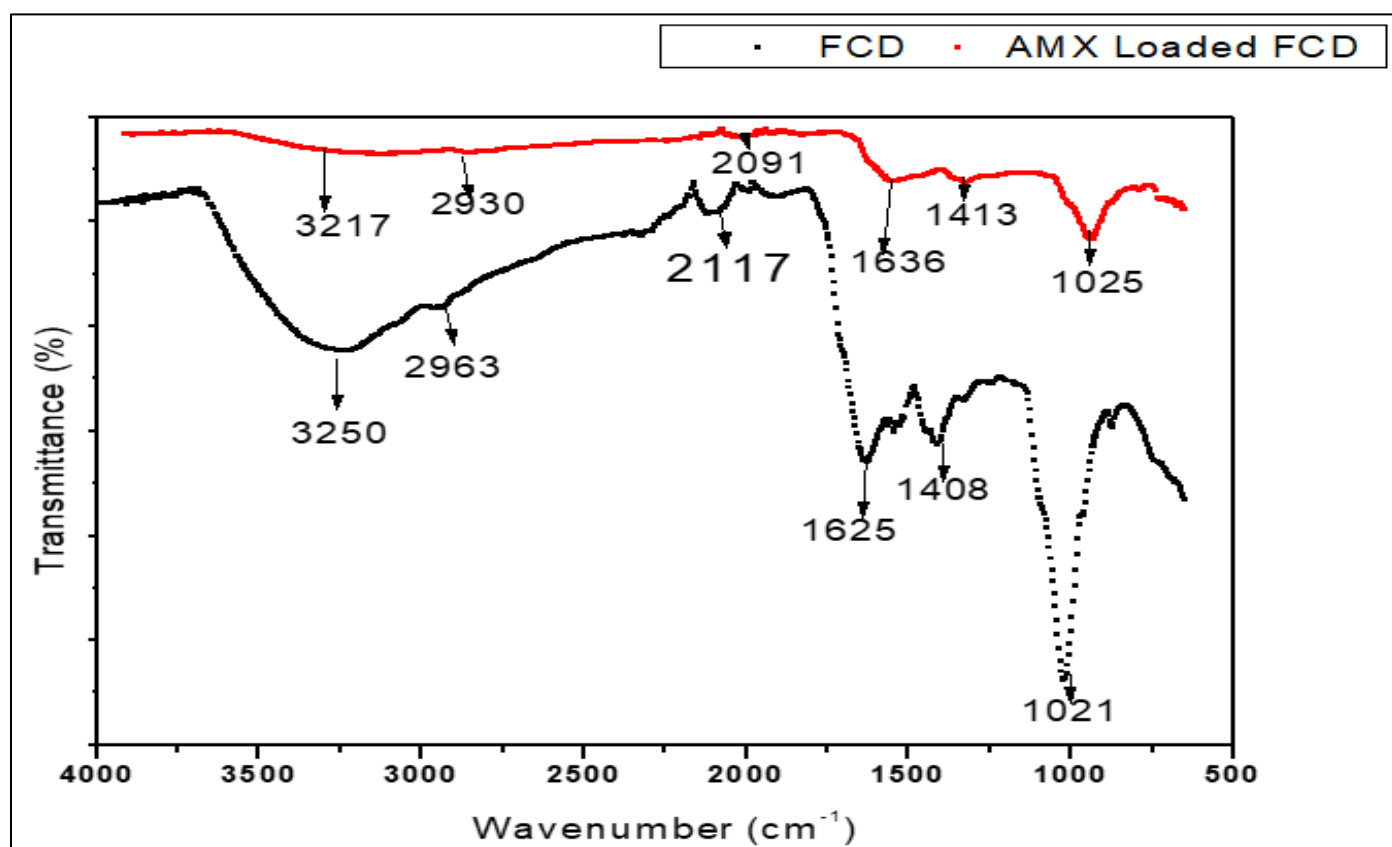


Fig 1 FTIR Spectra of the Synthesized FCD and AMX-Loaded

The synthesized FCD's mineral structure is determined by X-Ray Power Diffraction; Figure 2 shows the FCD loaded with AMX. Peaks located at around 21.03 and 28.07 degrees in Figure 2 are indicative of polymeric material and hydroxyapatite, respectively. Comparable results on the synthesis of hydroxyapatite nanoparticles and carbon nanodots from fish scale for use in biomedical applications were reported (Athinarayanan *et al.* in 2020). The FCD's peak at 29.02 corresponds to the (002) crystal plane, where (002)

stands for carbon that resembles graphite ( $\text{sp}^2$ ). This suggests that the majority of the FCD that was synthesized is crystalline (Tohamy *et al.*, 2023). AMX-loaded FCD diffraction pattern exhibits divergence and substantial alterations compared to FCD spectrum before AMX sequestration. Most of the peaks at 37.05, 50.62 and 60.89 were lowered or gone completely during AMX absorption process. This shows there is considerable interaction between the FCD biosorbent and the antibiotic.

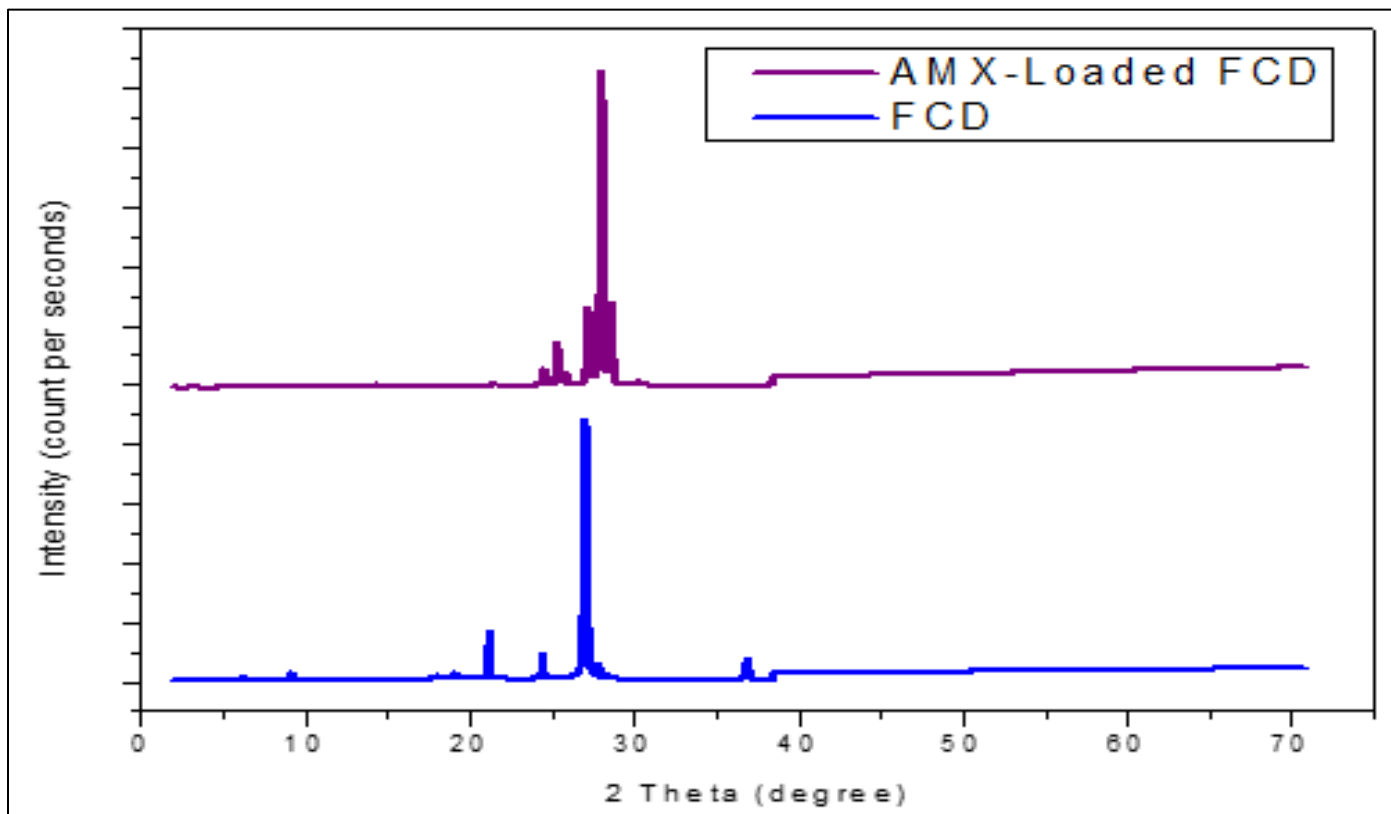


Fig 2 X-Ray Power Diffraction of the Synthesized FCD and AMX-Loaded FCD

Figure 3 shows the FCD and AMX-loaded FCD composites' SEM (scanning electron microscope) pictures. A rough and uneven surface was visible in the image of the unloaded FCD solids (Figure 3(a)). Following the sequestration of AMX antibiotics, a notable alteration in the

structure of FCD is seen (Figure 3(b)). The presence of AMX molecules occupying the vacant pores presumably signifies the restricted concentration of bound AMX and the uneven distribution of polar functional groups on the FCD composite surface.

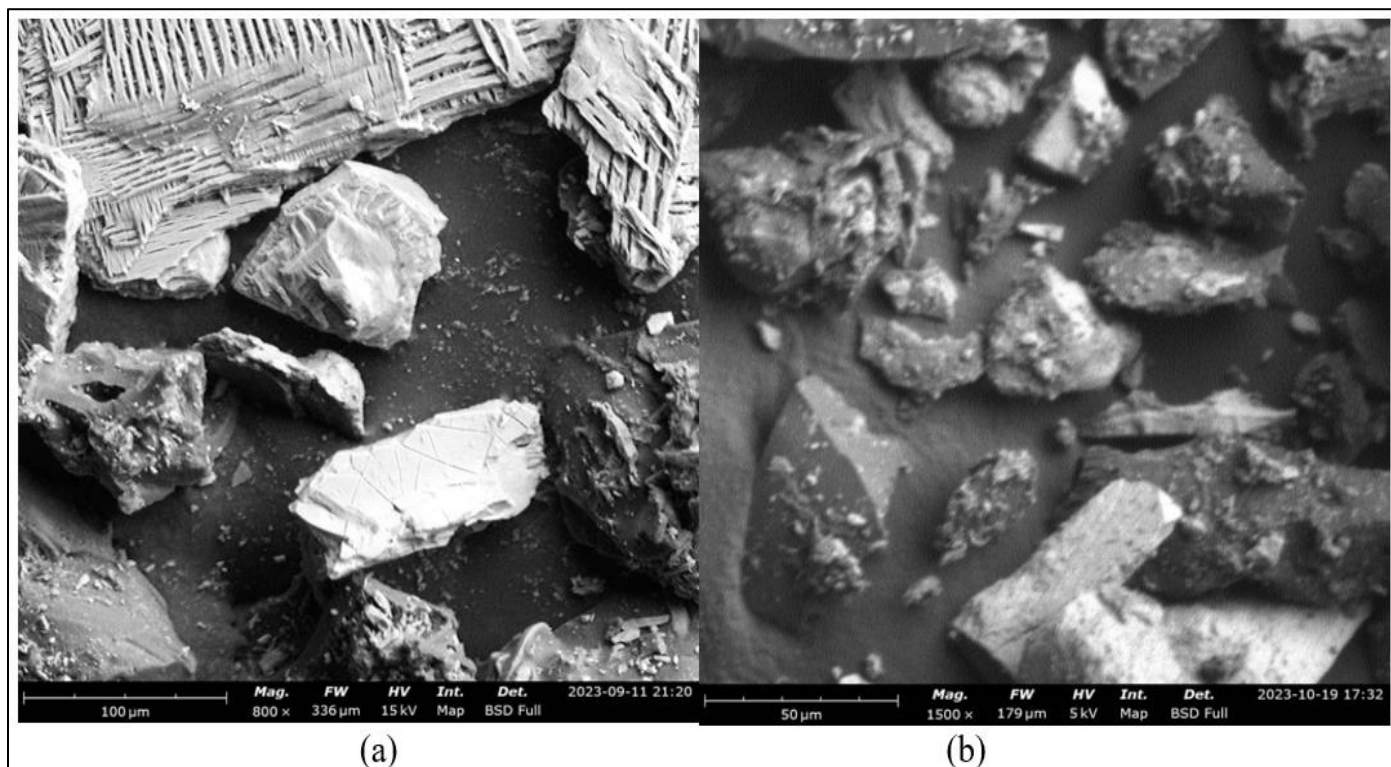


Fig 3 Scanning Electron Microscopy of FCD (a) Before Adsorption (b) After Adsorption of Amoxicillin.

➤ *The Statistical Analysis and Model Fitting*

The central composite design (CCD) framework, combined with the experimental, predicted, and residual data in the AMX sequestration by FCD, formed the foundation for the optimization studies conducted on amoxicillin absorption from liquid phase environments. Tables 2 offer an overview

$$\%Removal = 81.08 + 3.67A - 14.88B - 0.7570C - 0.5502AB - 0.8223AC + 0.1627BC - 6.02A^2 - 0.5247B^2 + 5.00C^2 \quad (10)$$

The real independent variable values in this case are denoted by the letters A for the FCD dosage, B for the initial AMX concentration, and C for the contact time. The experimental data of the normal distribution and the correlation coefficient R<sup>2</sup> between the actual and predicted values for % AMX elimination are critical considerations for statistical analysis. Figures 4a and 4b, respectively, display the typical likelihood and normal probability curve for studentized residuals. If the experimental data are linear, the

of the data obtained at different experimental circumstances. There was a range of 58.75% to 99.06% removal efficiency. Equation 10 is the quadratic model that was created by using regression analysis to determine the relationship between the independent factors and the response.

residual distribution is considered to be normal (Adeyi *et al.*, 2023). It is evident that there are no outliers and that the experimental points for AMX entrapment procedures are consistently distributed, on the normal line. With an estimated correlation coefficient R<sup>2</sup> of 0.9460 between the experimental and predicted values for AMX entrapment, the model could only explain 4.67% of the whole variation in the response.

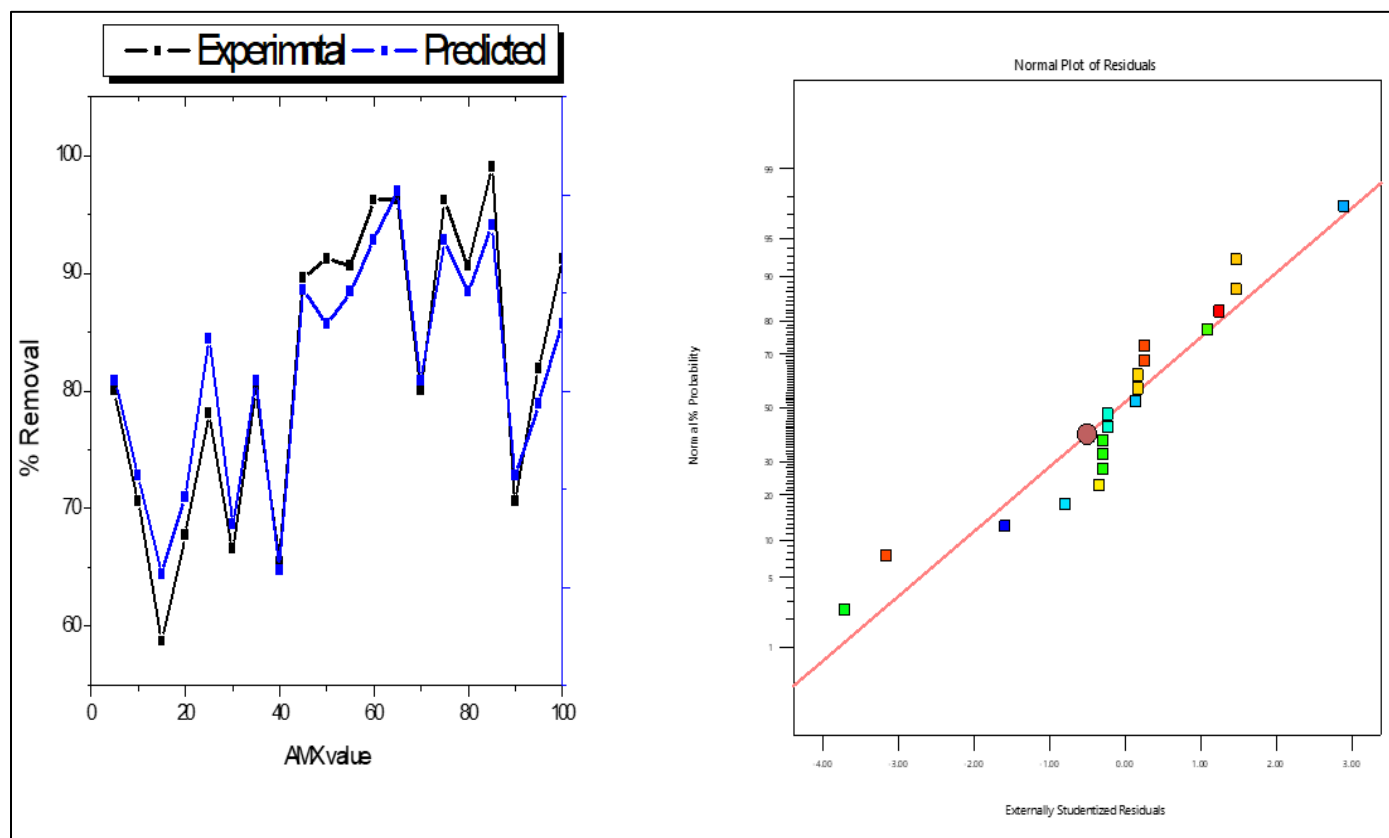


Fig 4 (a) Experimental vs Predicted Value and (b) Normal Probability Plot of Residuals for % AMX Removal

Table 2 Experiment Design of Experimental and Predicted Results on Removal of Amoxicillin

Run	A: FCD dosage	B: Concentration	C: Reaction time	Removal extent (%)		
	g	mg/L	min	Experimental	Predicted	Residual
1	0.15	30	45	80.00	81.08	-1.0800
2	0.15	30	45	70.63	71.39	-0.7649
3	0.1	50	30	58.75	61.31	-2.5600
4	0.2	50	30	67.75	69.19	-1.4400
5	0.15	30	60	78.13	85.33	-7.2000
6	0.2	50	60	66.63	66.36	0.2717
7	0.15	30	45	80.00	81.08	-1.0800
8	0.1	50	60	65.50	61.77	3.7300
9	0.1	10	30	89.63	90.31	-0.6766

10	0.15	30	30	91.25	86.84	4.4100
11	0.1	10	60	90.63	90.11	0.5183
12	0.15	10	45	96.25	95.44	0.8100
13	0.2	10	30	96.25	100.39	-4.1400
14	0.15	30	45	80.00	81.08	-1.0800
15	0.15	10	45	96.25	95.44	0.8100
16	0.1	10	60	90.63	90.11	0.5183
17	0.2	10	60	99.06	96.90	2.1600
18	0.1	30	45	70.63	71.39	-0.7649
19	0.2	30	45	81.88	78.73	3.1500
20	0.15	30	30	91.25	86.84	4.4100

• *Results of the Analysis of Variance*

The p-value makes it possible to see the significance of value of each element as well as the interactions between them, as the ANOVA analysis in Table 3 shows. The significance value of each factor and the interaction between the factors are indicated by the p-value. If the absolute probability p-value shows a coefficient less than 0.05, meaning that the results have a confidence level of at least 95%, then the associated factors are confirmed to have a substantial impact on the response. The model's 19.48 F-

value indicates that it is significant. The likelihood that noise is the source of this kind of high F-value is 0.01%. P-values for model terms less than 0.0500 are considered significant. In this instance, the important model terms are A, B, A<sup>2</sup>, and C<sup>2</sup>. When a value exceeds 0.1000, the model terms become meaningless. The signal to noise ratio is measured with sufficient precision. A ratio greater than 4, that is 14.175, which indicates that the signal is sufficient, is preferred. Using this proposed paradigm is one way to work with the design space.

Table 3 Results of the Analysis of Variance for the Sequestration of Amoxicillin

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	2664.14	9	296.02	19.48	< 0.0001	significant
A	151.52	1	151.52	9.97	0.0102	significant
B	1975.79	1	1975.79	130.00	< 0.0001	significant
C	6.50	1	6.50	0.4276	0.5279	
AB	2.60	1	2.60	0.1713	0.6877	
AC	5.82	1	5.82	0.3826	0.5500	
BC	0.2277	1	0.2277	0.0150	0.9050	
A <sup>2</sup>	118.09	1	118.09	7.77	0.0192	significant
B <sup>2</sup>	0.7730	1	0.7730	0.0509	0.8261	
C <sup>2</sup>	83.41	1	83.41	5.49	0.0412	significant
Residual	151.98	10	15.20			
Lack of Fit	151.98	4	38.00			
Pure Error	0.0000	6	0.0000			
Cor Total	2816.12	19				

R<sup>2</sup>= 0.9460; Adjusted R<sup>2</sup> = 0.9275; Predicted R<sup>2</sup> = 0.8957; Adeq. Precision = 14.175

The interactions between the variables were identified and the ideal concentration of AMX to produce the highest adsorption value was confirmed by applying a graphical representation of the response surface approach for the percentage removal of antibiotics with regard to the three components. The AMX strength surface plots against the FCD dosage, initial concentration, and contact time are displayed in Figure 5. The effects of the following factors on the AMX sequestration process: FCD dosage and contact

time at constant concentration; adsorbent dose and initial concentration at constant reaction time; and FCD dosage and contact time at constant concentration. The percentage clearance of AMX increases with an increase in FCD dose and a drop in concentration. Reaction time reduces and adsorption rate rises with increasing FCD dose. Furthermore, for higher reaction times and lower concentrations, the percentage elimination of FCD rises.

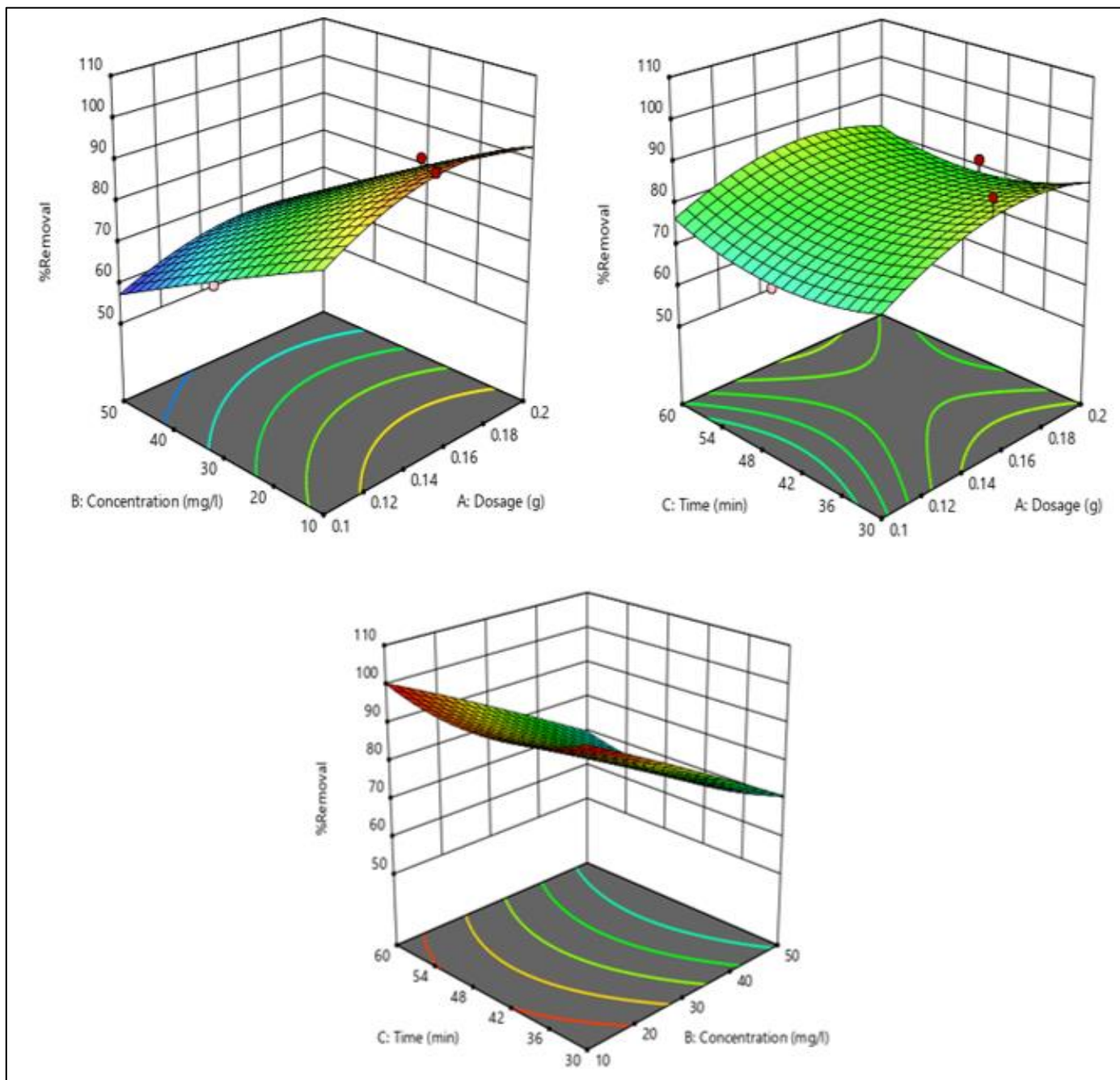


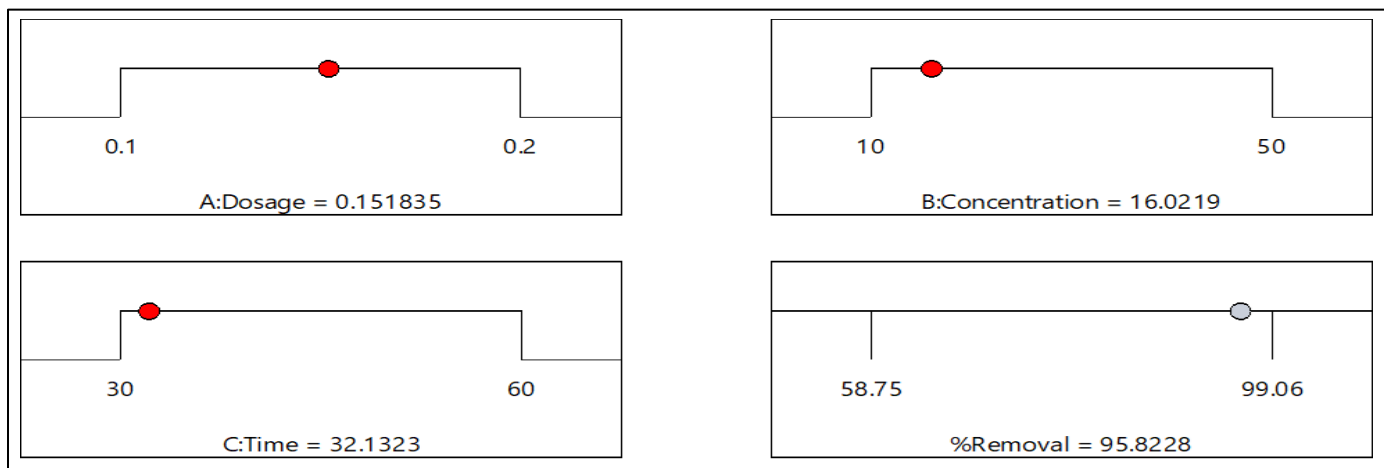
Fig 5 The % Removal of Amoxicillin Antibiotic as a Function of FCD dose, Initial Concentration, and Contact Time in Three-Dimensional Response Surface Plot.

• *Optimization Condition for AMX Sequestration Process*

The main aim of the current study is to determine the optimal conditions to enhance the AMX removal efficiency (R (%)) of FCD adsorbent. The contact time, FCD dosage, AMX concentration, and removal efficiency were all set within ranges using the Design-Expert software's numerical optimization menu to maximize the maximum suitability function. Figure 6 illustrates the desirability function and the optimal value of each variable. As can be observed, the best circumstances for amoxicillin absorption were discovered to be 0.15 g of FCD dose, a concentration of 16 mgL<sup>-1</sup> for AMX, and a clearance efficiency of 95.82% at 32 minutes. The response surface methodology's usefulness for determining optimal settings was validated by the desire function of 1.00,

which showed favourable conditions for AMX removal by FCD adsorbent (Taiwo *et al.*, 2023). Replica tests were carried out in the lab at the anticipated ideal conditions in order to validate the model.

The ideal parameters for AMX were an initial concentration of 16 mg/L, a dosage of 0.15 g of FCD adsorbent at 32 minutes, and a predicted removal percentage of 95.823%. The estimated AMX removal percentage of 95.823% with a 0.213% error was satisfied with the experimental removal percentage of AMX (95.61%). This study indicates the applicability and validation of quadratic polynomial models utilized in improving the sequestration of AMX antibiotics.



Desirability = 1.000

Fig 6 Optimal Conditions RSM Design Plot for AMX Sorption.

➤ *Kinetic Analyses and Adsorption Equilibrium*

Three isotherms' models—the Langmuir, Freundlich, and Redlich-Peterson models—were used to analyze the equilibrium exploration in order to establish the relationship of the contacts between the FCD adsorbent and amoxicillin molecules. The Langmuir, Freundlich, and Redlich-Peterson isotherm plots that depict AMX adsorption are displayed in Figure 7. The linear and nonlinear model parameters were determined for the studied temperatures of 25 °C using the slopes and intercepts of the corresponding graphs. Table 4 displays the correlation coefficient ( $R^2$ ) as well as additional isotherm parameters obtained from the fitting curves of the Langmuir, Freundlich, and Redlich-Peterson models. The Langmuir model is better adapted to describe adsorption

isotherms than the Freundlich model from the outcome. The results show that the adsorbent is uniformly distributed, and that the adsorption film is covered in a single layer. Conversely, the maximum single layer adsorption capacity, or  $q_m$ , is defined as the total FCD capacity for AMX adsorption. Moreover, when the intensity ( $n$ ) value of adsorption is greater than 1, the AMX entrapment process is beneficial (Tohamy *et al.*, 2023). The best isotherm for liquid phase AMX uptake is the Langmuir model, which has the highest R-square values as depicted in Table 4. The most likely explanation for the antibiotic AMX's sequestration in this study is the Langmuir model, which depicts a hybrid homogeneous system of adsorption.

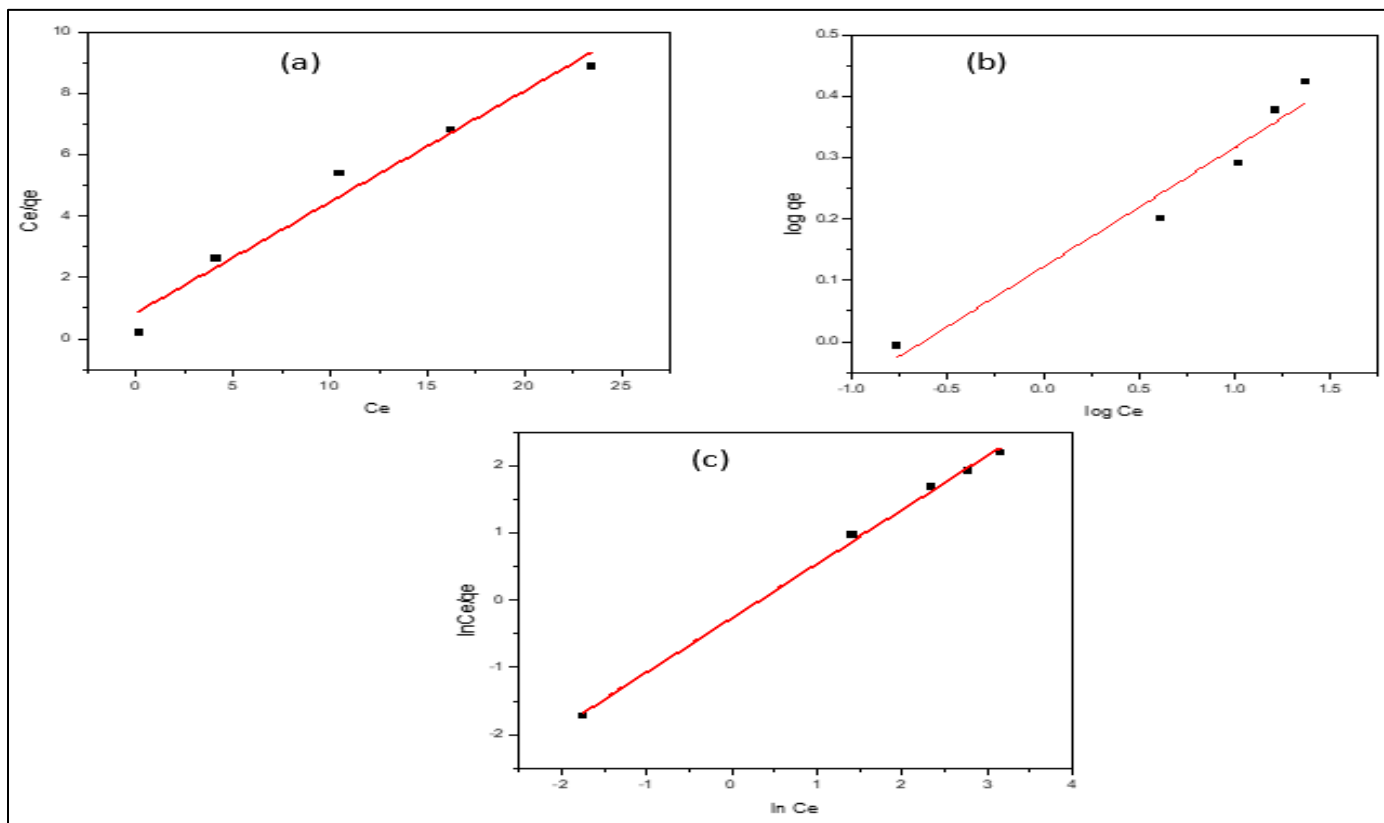


Fig 7 Amoxicillin Adsorption Isotherm for (a) Langmuir, (b) Freundlich, and (c) Redlich-Peterson

Table 4 Equilibrium Parameters of Amoxicillin Removal onto Carbon-Dot

Isotherm Models					
Langmuir		Freundlich		Redlich-Peterson	
$q_m$ (mg/g)	2.7586	$K_F$ (L/mg)	1.3233	$K_{RF}$	1.3233
$K_L$ (mg/g)	0.4435	$n$	5.1361	$\alpha$	1.0000
$R_L$	0.1013			$\beta$	0.8053
$R^2$	0.9976	$R^2$	0.9610	$R^2$	0.9706

An evaluation of the kinetic research of the process adsorption looked into the removal rate, the adsorption mechanism, and the rate-determining phase. Figure 8 shows the outcomes of the kinetic model for AMX adsorption using intra-particles and pseudo-first, pseudo-second, and pseudo-Elovich orders. Table 5 summarizes the model constants. The excellent agreement between the estimated and experimental  $q_e$  values indicates that the findings are consistent with the pseudo-second order kinetics. The pseudo-second order kinetics model yielded the highest  $R^2$  value of almost 1.00, indicating that the model is applicable and suggesting that AMX is absorbed by FCD through chemical adsorption. This is due to the fact that sharing or exchanging electrons between adsorbents and adsorbates generates valence forces. The

removal of the AMX may be due to the FCD's several binding sites, such as carboxylate and hydroxyl groups, which can interact with it through hydrogen bonding and electrostatic contact. Correlation coefficients more than 0.9 suggest multilayer adsorption and show that the Elovich model also adequately fits the experimental data.

Additionally, lower values of  $\beta$  than  $\alpha$  indicate that the adsorption rate was higher than the desorption rate and confirm the feasibility of the model (Ahmad *et al.*, 2018). The intraparticle diffusion model was unable to produce a reasonable fit based on  $R^2$  values, despite the fact that the CIP's positive values suggest surface adsorption and a quicker starting rate (Table 5).

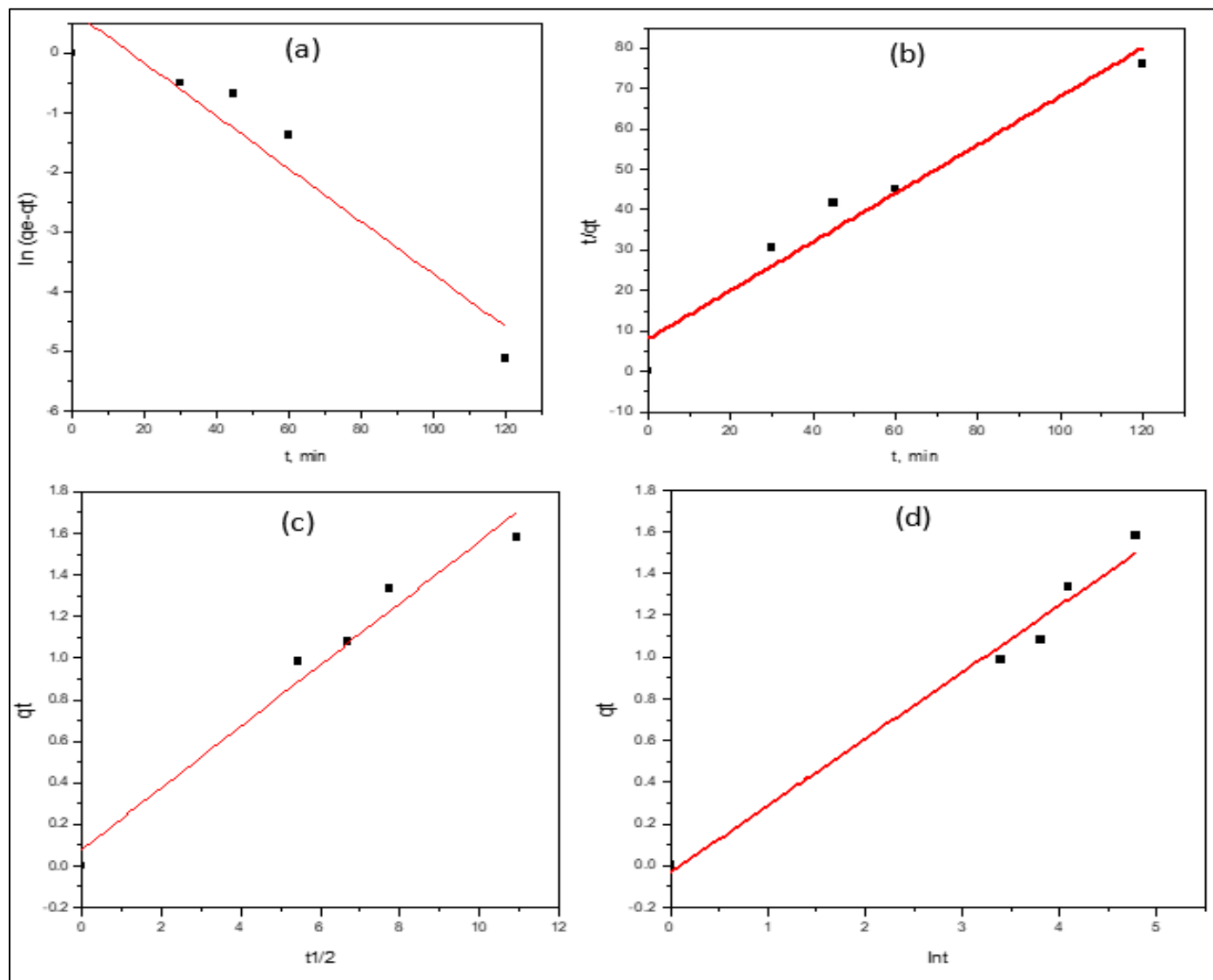


Fig 8 Kinetics Model of Amoxicillin (a) PFO, (b) PSO, (c) Intra Particle (d) Elovich

Table 5 Amoxicillin Removal Kinetic Parameters on FCD

Kinetic Models							
PFO		PSO		Elovich		IPD	
$q_{e,1}(\text{mg}\cdot\text{g}^{-1})$	4.64	$q_{e,2}(\text{mg}\cdot\text{g}^{-1})$	1.67	$a(\text{mg}\cdot\text{g}^{-1}\cdot\text{min}^{-1})$	3.1309	$C(\text{mg}\cdot\text{g}^{-1})$	0.0785
$k_1(\text{min}^{-1})$	0.0542	$k_2(\text{g}\cdot\text{mg}^{-1}\cdot\text{min}^{-1})$	0.0448	$b(\text{g}\cdot\text{mg}^{-1})$	0.2876	$k_{id}(\text{mg}\cdot\text{g}^{-1}\cdot\text{min}^{-1})$	0.1483
$R^2$	0.9509	$R^2$	0.9811	$R^2$	0.9132	$R^2$	0.9719

#### IV. CONCLUSION

In this work, a hydrothermal technique was used to manufacture carbon dots utilizing fish scale as the precursor biomass. Amoxicillin (AMX) was examined for its ability to bind to the synthetic fish scale carbon dot (FCD) in an aqueous solution. With the use of central composite design and response surface methodology (RSM), FCD was predicted to exhibit a high removal effectiveness of 95.82% at 16 mg/L concentration of AMX with 0.15 g of FCD after 32 minutes. Based on both expected and experimental results, the established optimum conditions for the antibiotic AMX were determined to be accurate with an error rate of only 0.21%. The experimental data was most well-fit by the Langmuir isotherm model parameters with the coefficient value of 0.9976. Kinetics experiment data fit a hypothesis of pseudo-second order model. Furthermore, the synthesized FCD biosorbent demonstrated potential in efficiently eliminating AMX from a liquid phase milieu. The outcomes showed FCD as a very promising replacement adsorbent for antibiotic-containing wastewater treatment.

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##### ➤ Disclosure Statement

The authors report there are no competing interests to declare.

##### ➤ Data Availability Statement

The data used to support the findings of this study are included within the article

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