

## AMOXICILLIN REMOVAL FROM WASTEWATER USING SRI LANKAN ACTIVATED CARBON: A KINETICS STUDY

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**ABSTRACT:** This research explores the kinetics of amoxicillin adsorption using activated carbon produced from Sri Lankan coconut shells. Batch adsorption experiments were performed, and the obtained data were analyzed using various kinetic models, including the pseudo-first-order, pseudo-second-order, liquid film diffusion, and intra-particle diffusion models. Among these, the pseudo-second-order model provided the best fit, indicating that chemisorption is the dominant mechanism. The results demonstrated that increasing the adsorbent dosage enhances the adsorption efficiency. Furthermore, the intra-particle diffusion model revealed a lower rate constant during the later phase, indicating that the adsorption rate significantly slows down at this stage. This suggests that intra-particle diffusion acts as the rate-limiting step. In contrast, the liquid film diffusion model presented a poor fitting, indicating external mass transfer resistance insignificantly affecting the adsorption process. These results provide the necessary hints toward optimizing water treatment processes related to the removal of such antibiotics as amoxicillin

*Keywords:* activated carbon, adsorption, Amoxicillin, kinetic model

### 1. INTRODUCTION

Antibiotics are essential drugs used for the treatment of bacterial infections. However, their wide application has raised concerns about environmental pollution and related health impacts. Pharmaceuticals enter wastewater from a range of sources, such as healthcare facilities, pharmaceutical manufacturing processes, and residential use, thus contaminating natural water sources like rivers and lakes and, unfortunately, even drinking water (Khan *et al.*, 2020). Such pollution exacerbates the global crisis of antibiotic resistance through the selection and spread of antibiotic-resistant bacteria and related resistance genes (Muteeb *et al.*, 2023). Sri Lanka, being a developing country with rapid industrialization, is burdened by issues related to wastewater management and control of antibiotic pollution. Although the law prohibiting the sale of antibiotics without prescriptions has been in place since 1986, non-implementation has resulted in self-medication and inappropriate use of antibiotics by healthcare providers for diseases where antibiotic treatment is not indicated (Samaraweera *et al.*, 2019).

Various types of adsorbents are being used for a wide range of applications, including naturally available materials, treated materials like activated carbon, manufactured sorbents such as zeolites and polymeric resins, and agricultural or industrial by-products. (Jayathunga and Amarasinghe, 2009; Wang *et al.*, 2021) Activated carbon, characterized by its high surface area and significant adsorption capacity, has demonstrated efficacy in the removal of antibiotics from wastewater (Neolaka *et al.*, 2023). The material's porous configuration facilitates the adherence of antibiotics via weak Van der Waals interactions, with the degree of adsorption being affected by various parameters, including pH, temperature, and contact duration (Singh *et al.* 2022). A range of antibiotics, such as tetracyclines, ciprofloxacin, norfloxacin (Ahmed & Theydan, 2014), macrolides, and metronidazole (Ahmed & Theydan, 2013), has been effectively eliminated from wastewater through the utilization of activated carbon. Also, Zha *et al.* (2013) showed organobentonite's effectiveness in removing amoxicillin from wastewater. The rate of adsorption and the factors that influence the process were studied under adsorption kinetics. It focuses on understanding how adsorption behaves over time, including the initial adsorption rate, the time taken to reach equilibrium, and the factors that affect these rates. The study of adsorption kinetics is essential for the design and optimization of adsorption processes in a wide range of applications such as environmental remediation, chemical separation, etc. This study aims to analyze the kinetics of antibiotic adsorption onto activated carbon.

## 2. METHODOLOGY

### 2.1 Materials

In this study, granular activated carbon (GAC) purchased from Haycarb PLC in Sri Lanka was utilized as the adsorbent. GAC has mean diameter of 1185  $\mu\text{m}$ , a bulk density of 450  $\text{kg}/\text{m}^3$ , and a true density of 1720  $\text{kg}/\text{m}^3$ , which were measured. Additionally, the surface area is 683.14  $\text{m}^2/\text{g}$ , and the pore size is 2.28 nm (Amarasinghe, 2007). A synthetic solution of amoxicillin, using amoxicillin trihydrate powder with 99.7% purity provided by the State Pharmaceutical Manufacturing Corporation, Sri Lanka, was used as the adsorbate. The concentration of amoxicillin in the solution was measured at its maximum absorbance wavelength of 235 nm using a UV spectrophotometer (SP-UV-500DB).

### 2.2 Batch Experiment

Kinetic studies were performed using five different dosages, 4mg/L, 8mg/L, 12mg/L, 16mg/L and 20mg/L of activated carbon mixed with amoxicillin solution which has initial amoxicillin concentration 50 mg/L. Samples were collected at regular intervals, and the remaining amoxicillin concentration was measured to monitor the adsorption process. The experiments were conducted until the amoxicillin concentration stabilized.

### 2.3 Analytical Techniques

The adsorption amount of the activated carbon was calculated as Equation 1,

$$Q_e = (C_0 - C_e) \frac{v}{w} \quad (1)$$

The adsorption capacity, denoted by  $Q_e$  (mg/g), was determined using Equation 1, which incorporates the initial concentration  $C_0$ , equilibrium concentration  $C_e$ , solution volume  $v$  (L), and adsorbent mass  $w$  (g).

Four models were applied in analyzing the experimental data in studying the adsorption mechanism: The pseudo-first-order adsorption kinetics are modeled using Equation 2, which assumes that the rate of adsorption is proportional to the difference between the equilibrium adsorption capacity and the amount of adsorbate remaining at time  $t$ . The pseudo-second-order kinetic model, as outlined in Equation 3, is used to describe chemisorption processes, where the adsorption rate depends on the availability of active sites on the adsorbent. The intra-particle diffusion model, depicted in Equation 4, considers the diffusion of the adsorbate into the pores of the adsorbent as a rate-limiting step during the adsorption process. The liquid film diffusion model is represented by Equation 5, which suggests that adsorption is influenced by the movement of the adsorbate through a boundary layer or film around the adsorbent particles.

$$\ln(Q_e - Q) = -k_1 t + \ln Q_e \quad (2)$$

$$\frac{t}{Q} = \frac{t}{Q_e} + \frac{1}{k_2 Q_e^2} \quad (3)$$

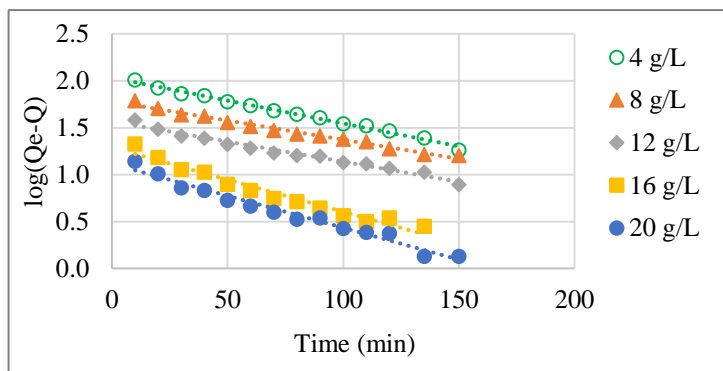
$$Q = K_i t^{0.5} + C \quad (4)$$

$$\ln\left(1 - \frac{Q}{Q_e}\right) = k_{fd} t \quad (5)$$

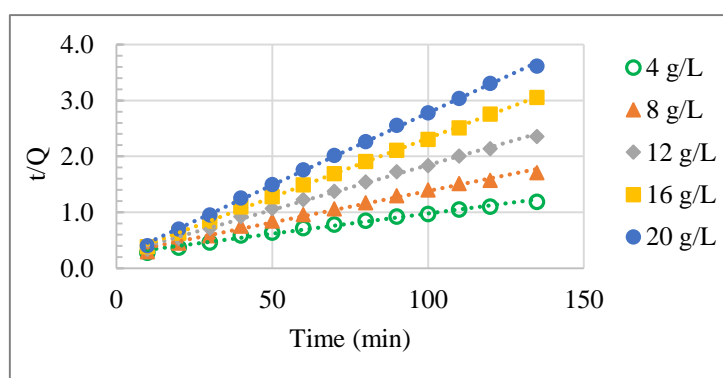
Where,  $k_1$  ( $\text{min}^{-1}$ ) is the rate constant of pseudo first- order kinetic model;  $k_2$  ( $\text{g}/(\text{mg}\cdot\text{min})$ ) is the rate constant of pseudo-second-order kinetic model;  $k_i$  ( $\text{mg}/(\text{g}\cdot\text{min}^{0.5})$ ) is the intra particle diffusion rate constant; and  $k_{fd}$  is rate constant for liquid film diffusion model.

## 3. RESULTS AND DISCUSSION

The experimental data were analyzed using both the pseudo-first order (Equation 2) and pseudo-second order (Equation 3) adsorption models. The strong correlation shown in Fig. 1 and Fig. 2 highlights the applicability of these models.



**Fig.1.** First order kinetic plot for amoxicillin adsorption on to activated carbon



**Fig. 2.** Second-order kinetic plot for amoxicillin adsorption onto activated carbon

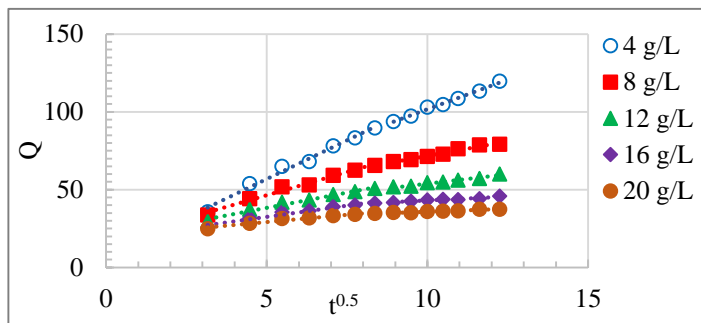
The kinetic parameters for first- order and second-order adsorption of amoxicillin onto activated carbon are summarized in Table 1.

**Table 1.** First order and second order kinetic parameters for amoxicillin adsorption

Activated carbon dosage (g/L)	First-order kinetic parameters		Second-order kinetic parameters	
	$k_1$ (l/min)	$R^2$	Rate constant $k_2$ (g/mg.min)	$R^2$
4	0.0049	0.9921	0.0002	0.9902
8	0.0041	0.9829	0.0005	0.9927
12	0.0043	0.9769	0.0011	0.9973
16	0.0068	0.9578	0.0021	0.9994
20	0.0068	0.9715	0.0034	0.9992

The plots indicate that the second-order kinetic model provides a better fit compared to the first-order model, which suggests that chemical adsorption plays a significant role in the adsorption process. “This chemisorption process involves the formation of chemical bonds between the amoxicillin molecules and the activated carbon surface, implying that both the concentration of the adsorbate and the number of active adsorption sites influence the rate of adsorption” (Moussavi *et al.*, 2013). Moussavi *et al.* also found that the adsorption of amoxicillin onto commercial activated carbon performed better under the pseudo second-order kinetic model.

Fig. 3 shows the outcomes when applying the intra-particle diffusion model (Equation 2.5) to the adsorption of amoxicillin onto activated carbon.



**Fig. 3.** Intra particle diffusion model for amoxicillin adsorption on to activated carbon

The parameters derived from the intra-particle diffusion model, as shown in Table 2, indicate that the diffusion rate decreases considerably in the later phase for all dosages of activated carbon. The lower intra-particle diffusion rate constant ( $k_{i2}$ ) in the latter phase than the intra-particle diffusion rate constant for the initial phase ( $k_{i1}$ ) suggests that this stage of the process is the rate-limiting step.

**Table 2.** The parameters of the intra-particle diffusion model for amoxicillin adsorption onto activated carbon

Activated carbon dosage (g/L)	$K_{i1}$ (mg/g.min <sup>0.5</sup> )	$R^2$	$K_{i2}$ (mg/g.min <sup>0.5</sup> )	$R^2$
4	9.9341	0.9848	7.6176	0.992
8	5.9671	0.9827	3.7542	0.9637
12	3.9035	0.9744	2.4246	0.9663
16	2.9006	0.9689	1.0349	0.8981

The data plotted for the liquid film diffusion model does not exhibit a strong fit. The low  $R^2$  value shows that the mechanism of liquid film diffusion is not the dominant one controlling the adsorption process in this system. Smaller particle sizes and larger surface area of activated carbon can facilitate faster adsorption kinetics. Therefore, diffusion within the pores becomes the rate-limiting step rather than the diffusion across the boundary layer.

#### 4. CONCLUSION

This study presents the adsorption kinetics of amoxicillin onto activated carbon from Sri Lankan coconut shells. Adsorption data were fitted to several models, with the pseudo-second-order model showing the best fit, indicating chemisorption as the primary mechanism. The intra-particle diffusion model suggests that diffusion within the particles is the rate-limiting step, with the adsorption rate decreasing in the later phase. In contrast, the liquid film diffusion model poorly fits, indicating that external mass transfer resistance is not a controlling factor. These findings highlight the role of intra-particle diffusion in improving amoxicillin removal from water using activated carbon.

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