Tikrit Journal of Engineering Sciences

IRAQI Academic Scientific Journals | TJES Tikrit Journal of Engineering Sciences

Article | Tikrit Journal of Engineering Sciences (2026); 33(1): 1266

Open Access

The Role of Some Agricultural Waste as Adsorbent in Removing Paracetamol from Simulated Wastewater

Zainab A. Naser, Lahieb Faisal M. A. *

Environmental Department, Engineering College, Al-Mustansiriyah University, Baghdad, Iraq.

Emails:
Zainab A. Naser | Lahieb Faisal M. A.

Abstract:
The presence of residual pharmaceuticals in the aquatic system is a significant concern for ecological risk, requiring the advancement of sustainable remediation technology. This study investigates the adsorptive performance of local agricultural wastes—sawdust (SD) and olive stones (OS)—as ecofriendly biosorbents and substitutes for commercial activated carbon (AC) for the paracetamol (PC) removal from simulated aqueous solutions. The adsorbents were characterized using Fourier Transform Infrared Spectroscopy (FTIR) and Scanning Electron Microscopy (SEM). This revealed a highly porous morphology and various active functional groups. Batch adsorption experiments were evaluated to determine the influence of pH, adsorbent dosage, contact time, and temperature. The results demonstrated that the process of adsorption is highly pH-dependent, with maximum removal achieved at an optimal pH of 7. At equilibrium, the removal efficiencies reached up to 92.17% for SD and 89.25% for OS, compared to 94% for AC, using optimal dosages of 1.5 g, 1.25 g, and 1.25 g, respectively. Equilibrium data were well-fitting by the Langmuir model (R^2 > 0.99), suggesting a monolayer adsorption mechanism with maximum capacities (q_m) of 4.748, 4.531, and 5.621 mg/g for AC, SD, and OS, respectively. A kinetic study showed that the process followed a pseudo-second- order model (R^2 > 0.99), indicating that chemisorption is the rate-limiting step. Thermodynamic analysis revealed positive enthalpy ΔH° values, confirming the endothermic nature of the process, while the spontaneity increased with temperature. Overall, this study highlights the potential of utilizing undervalued agricultural biomass as a cost-effective and efficient biosorbent for pharmaceutical wastewater treatment.

Keywords:
Adsorption; Agricultural waste; Biosorption; Olive stones; Paracetamol removal; Sawdust; Sustainable wastewater treatment.

Highlights:
- Optimal removal of PC was achieved at pH 7 and 90 min.
- Agricultural waste was effectively utilized as biosorbents, achieving PC removal (up to 92.17%).
- The Langmuir model best describes the equilibrium data (R2>0.99).
- The adsorption mechanism follows pseudo-second-order kinetics.
- Positive ΔH° proves that the biosorption process is endothermic.

Corresponding Author*:

Lahieb Faisal M. A.
Environmental Department, Engineering College, Al-Mustansiriyah University, Baghdad, Iraq.

Article History:

Received:	30	Jun.	2023
Received in revised form:	03	Feb.	2024
Accepted:	05	Mar.	2024
Final Proofreading:	06	Jun.	2026
Available online:	07	Jun.	2026

Citation:
Naser ZA, Lahieb Faisal MA. **The Role of Some Agricultural Waste as Adsorbent in Removing Paracetamol from Simulated Wastewater**. *Tikrit Journal of Engineering Sciences* 2026; **33**(1): 1266.

https://doi.org/10.25130/tjes.33.1.33

1.INTRODUCTION

Pollution of natural ecosystems disrupts biological balance, adversely affecting organisms through various pathways. Anthropogenic activities, such as the discharge of untreated sewage or toxic waste into aquatic bodies, pose a severe threaten many life forms and plants in the region [1,2]. In the last years, there was an increase in the rate of contamination with medical waste in rivers, lakes, and even groundwater. The reason for this increase is the consumption of large quantities of medicinal products. The dangers of water pollution are not limited to the neighborhoods where they live, but their impact extends to all aspects of life [3]. There are several ways for drugs to enter the environment, including human activity (such as getting rid of medications that are not used; drugs metabolites or their secretions that a human body is unable to absorb are eliminated via the toilet), field of agricultural (aquaculture and veterinary medicines and fodder additives in cattle breeding by dung diffusion within the ground as fertilizer that might seep into rivers and urban currents), and additionally produce (drugs continue to be industrialized) [4]. Halling-Sorensen et al. [5] and Jones et al. [6] recommended initiatives outlining possible sources and routes for the discharge of medication residue into the aquatic environment [5]. One of the most pollutants that are consumed mainly is paracetamol (PC). Physicochemical properties are mentioned in Fig. 1 [7]. Paracetamol is an analgesic and medicine to reduce fever utilized vastly in Iraq. Since it is a medicinal output that is not decomposed, it will not be biodegradable effectively. This will result in problems for health and the environment, as the remains will infiltrate into the supply of groundwater and wastewater and finally into drinking water [8]. Because the produce of pharmaceutical compounds is not decomposed, the effects can be hazardous, as it can impact not only the environment but also the life and health of humans and other creatures, mostly the life of aquatic creatures, as it may infiltrate open water such as lakes and rivers. A traditional sewage treatment, which utilizes physical, chemical, and biological techniques, is often unsuccessful in removing or decomposing the more significant number of these components, resulting in only partial elimination; henceforward, allowing sediment to build up in the supplies of drinking water [8]. Therefore, authors tend to use natural agricultural wastes as sustainable adsorbents, such as orange peels as a biosorbents [9], dried olive stone [10], rice husk [11], broad bean peels [6], modified orange peel [12], banana peels, lemon peels [13], walnut shells, and agro-waste. Others used different methods like adsorption processes, advanced oxidation, plasma-activated water, and others for various pollutant removals from water, like furfural, metronidazole antibiotic [8], mercury [2], heavy metal [3], etc. In recent years, however, detections of microcontaminants have been improved. In [14], most of these detected micropollutants are reported to be of low concentration, ranging from grams to nanograms per liter. However, these remains still exist and, over time, will gradually up and create an unintended effect in the long term [8]. The removal of paracetamol by biosorption is an effective treatment technique. Although activated carbons are preferred adsorbents, their widespread uses are restricted due to their high cost. Many researchers have made several attempts to find adsorbent substances from agricultural residues to be an effective and cheap alternative to activated carbon, such as olive stone, sawdust, husks of coffee, egg and rice, waste of apple, sugar beet pulp, peels of banana and orange, peels of citrus, and several materials of fruit [13–16]. Consequently, the goal of this work is to investigate how well sawdust, olive stone, and activated carbon can adsorb paracetamol from wastewater. Temperature, contact time, and solution pH were the variables that were varied in order to assess the biosorption capabilities of sawdust, olive stone, and activated carbon, in addition to an evaluation of the equilibrium isotherm's behavior for these biosorbents and paracetamol. Activated carbon, sawdust, and olive stones were each examined using Fourier Transform Infrared (FTIR) spectroscopy, Scanning Electron Microscopy (SEM), and relative surface nature and functional groups, mineral identification, and morphology of the adsorbents.

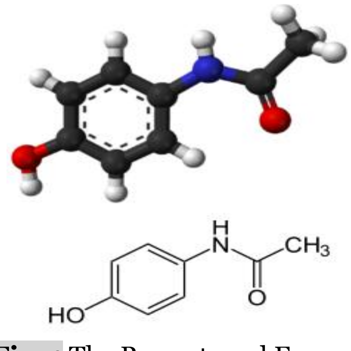


Fig. 1 The Paracetamol Formula.

2.MATERIALS AND METHODS

2.1.Adsorbate and Adsorbent Preparation and Description

A stock laboratory solution of PC was prepared by dissolving appropriate amounts of PC in distilled water to obtain the required concentration of 40 mg/L for this study. A UV-Vis spectrophotometer set to a maximum wavelength of 243 nm (λ max of 243 nm) was used to measure the concentration of PC. The adjustment of the desired initial solution pH was achieved by utilizing 0.1 M HCl or 0.1 M

NaOH. Sawdust (SD) and olive stone (OS) were gathered locally in Baghdad and prepared by cleaning, drying at 100°C for 24 hours, and crushing to a particle size of <0.6 mm mesh sieve. While activated carbon (AC) was purchased commercially from stores specialized in selling laboratory and medical materials (Fig. 2). The SD, OS and AC were characterized by Fourier transform infrared spectrophotometer (SHIMADZO FTIR, 800 series) and scanning electron microscope (SEM) (TESCAN MIRA3 FRENCH model) to estimate their relevant surface functional group and morphology.

(A) Sawdust (SD) before Grinding. (B) Sawdust (SD) after Grinding. (C) Olive Stone (OS) before Grinding.
(D) Olive Stone (OS) after Grinding. (E) Activated Carbon (AC).

Fig. 2 Types of Adsorbents.

2.2.Adsorption Study

Batch adsorption procedure was applied in order to assess the impact of pH (3–8), amounts of three sorbents (0.5- 1.5 gram), retention time (10-120 min), and temperature (298, 308, 318 and 328K). Batch experiments were carried out by shaking at about 200 rpm [17]. The concentration of the PC remaining was measured by computing the difference between the initial (C_i) and final (C_f) PC concentrations. The adsorption capacity (q_e mg/g) was calculated using the following equation [17,18]:

$$q_e = (C_i - C_f) \times (V/w) \qquad (1)$$

(V is the volume of the solution (L), and W is the mass of the adsorbent (g)).

2.2.1.Sorption Modeling

Studies on equilibrium adsorption were carried out to define the equilibrium relationship between the amounts of adsorbed PC (q_e) and its amount in the solution (C_e) at a specific temperature [17,18].

I.Langmuir Isotherm Model

This model is assessed on the assumption of single-layer adsorption upon a surface consisting of a fixed number of comparable sites. This model supposes regular adsorption energies over the surface and no adsorbate peregrination in the surface level. This model linear form [17,18]:

$$\frac{Ce}{q_e} = \frac{1}{bqm} + \frac{Ce}{qm} \qquad (2)$$

II.Freundlich Isotherm Model

This model is an empirical equation generally utilized to characterize the adsorption features for the heterogeneous surface [17,18]. The linear form is as follows:

$$\log q_e = \log K + 1/n \log C_e \qquad (3)$$

III.Adsorption Kinetic Models

Kinetic models, precisely pseudo-first- and pseudo-second-order kinetic forms, refine the mechanism of paracetamol adsorption by relating how the rate of adsorption behaves on its adsorbents through time. The models that are pseudo-first-order and pseudo-second-order, respectively [17,18]:

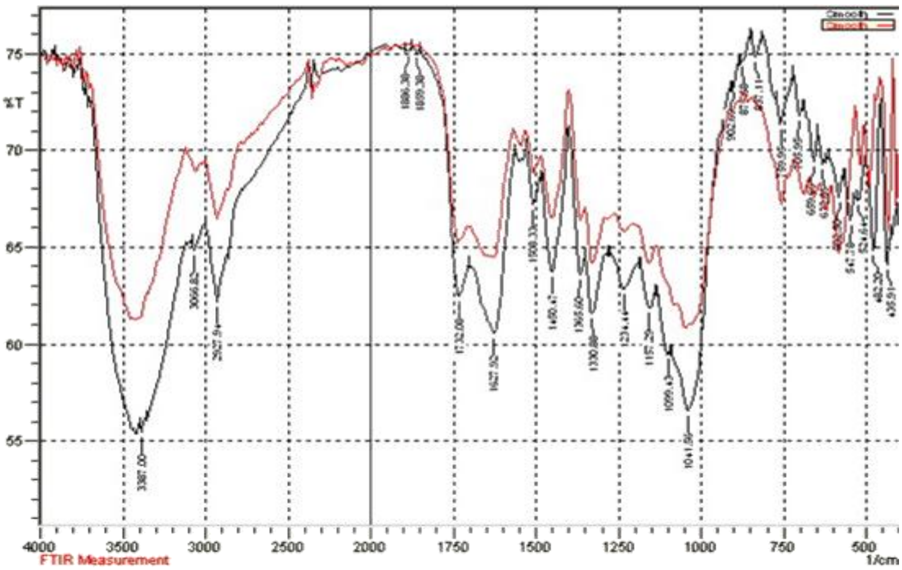
$$\ln (q_{eq} - q_t) = \ln q_e - k_1 t \qquad (4)$$

$$t/q_t = (1/ k_2 q^2_{eq}) + (t/ q_{eq}) \qquad (5)$$

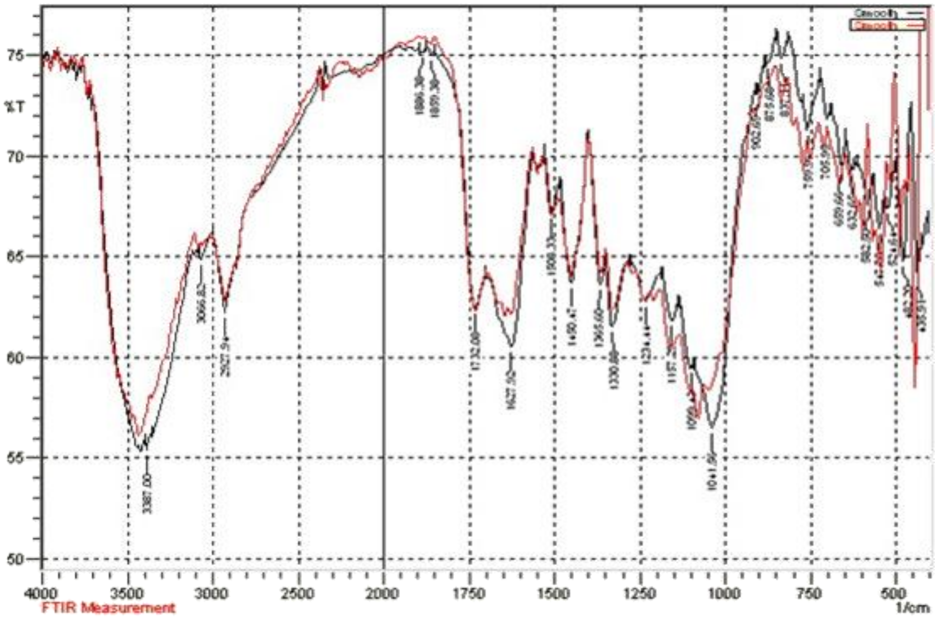
3.RESULTS AND DISCUSSION

3.1.Overview of Activated Carbon, Sawdust, and Olive Stones Properties

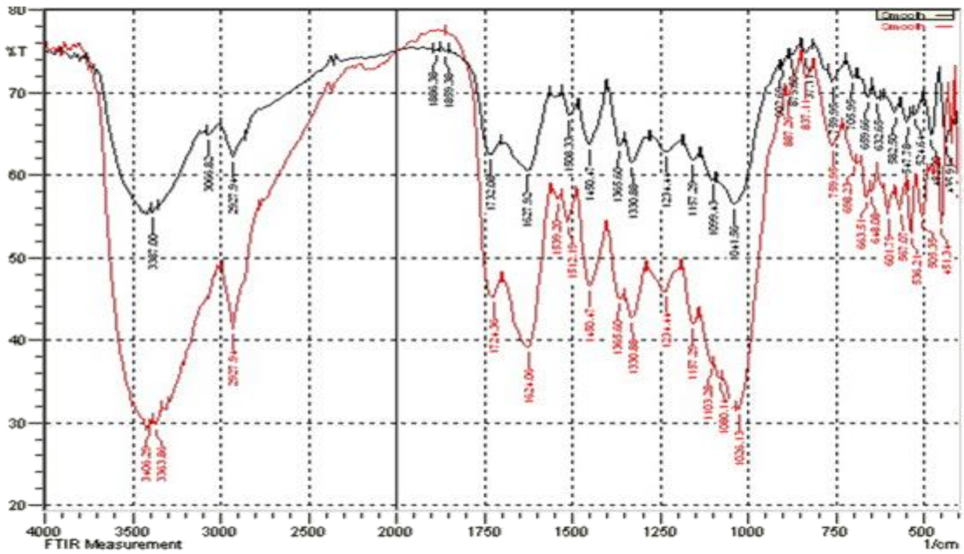
These sorbents' FTIR spectra (Fig. 3 (A, B, and C display FTIR of AC, SD, and OS, respectively)) and Scanning Electron Microscopy (SEM) are displayed in Fig. 4.



(A) Displays FTIR of AC.



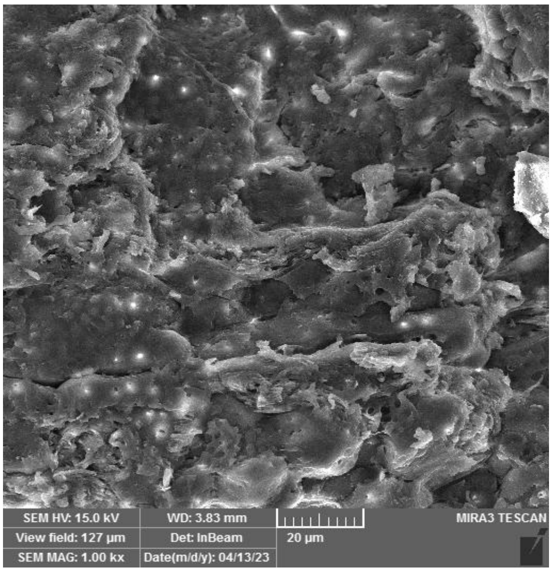
(B) Displays FTIR of SD.



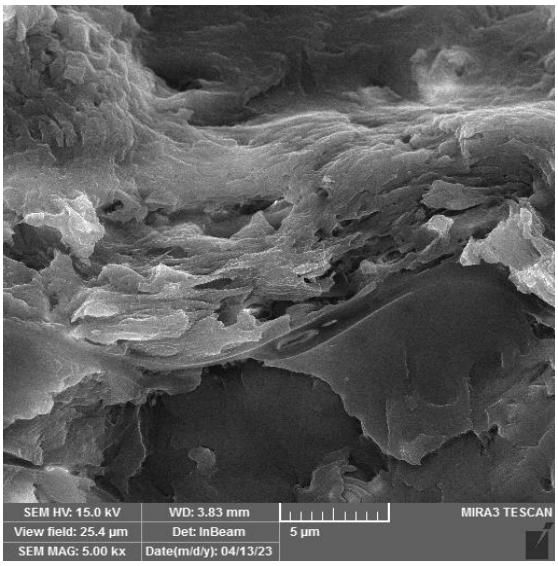
(C) Displays FTIR of OS.

Fig. 3 FTIR of AC, SD, and OS Raw and Loaded PC.

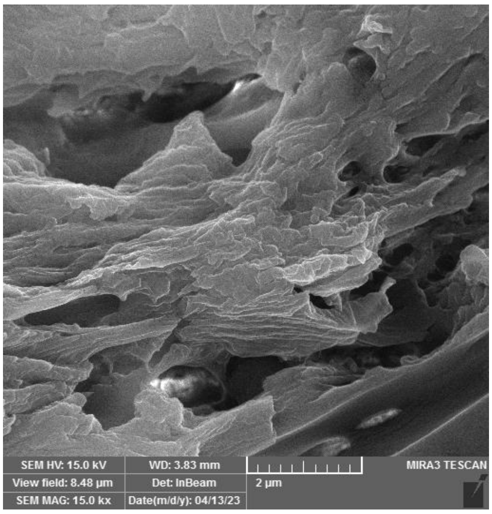
The FT-IR analysis provides a direct method for identifying the functional groups on the adsorbent surfaces within the 400–4000 cm^{-1} range (using a SHIMADZO FTIR, 800 series spectrophotometer, biosorbents were studied). The spectral pattern of loaded paracetamol (PC) showed variations in the peak absorption because of the process of adsorption when compared to that of unloaded (PC). All spectra display a broad range between 3387.00 cm^{-1} and 2927.94 cm^{-1}, which corresponds to the O-H strain vibrations. The chemical composition of the three different types of these adsorbents—whose primary constituents are hemicelluloses, cellulose, and lignin—is used to interpret the FTIR spectra. The aromatic nature of lignin distinguishes it from other polymers. This spectrum also shows two stretching peaks, the first of which can be attributed to C-H bending at 902.89 cm^{-1} (in sample A), 759 cm^{-1} (in sample B), and 837.11 cm^{-1} (in sample C), and the second of which can be attributed to aromatic ring stretching at 1732.08 cm^{-1} (in sample A), 1627.92 cm^{-1} (in sample B), and 1624 cm^{-1} (in sample C). In contrast, a broad band between 1732.00 cm^{-1} and 1041.0 cm1 was attributed to C-O, which is found in aromatic rings and also relates to the stretching of C-H. These recorded shifts in wave numbers confirm the formation of chemical bonds between the PC molecules and the adsorbent surface, providing experimental evidence for a chemisorption mechanism. Fig. 4 (A, B, and C) displays scanning electron microscopy (SEM) of the adsorbent. The surface morphology and porosity of the substance utilized for PC molecules adsorption are examined using the SEM. According to the SEM pictures, the adsorbent showed signs of being porous, having a large number of heterogeneous pores, having an uneven surface, and aggregating particles of different sizes and shapes. The presence of pores facilitates the passage of PC molecules into the adsorbents during the sorption of PC molecules from solution [18,19]. The adsorbents were generally found to be suitable for the adsorption of PC from aqueous solution due to their porous nature.



A) AC



B) SD



C) OS

Fig. 4 Displays SEM of AC, SD, and OS.

3.2.pH Impact on Three Types of Sorbents

The pH influence of the three types of sorbents was examined by varying pH values from 3 to 8 (at 30±5 °C). Shown in Fig. 5 is the way in which we assess the removal capacity percentage of PC and pH of the solution, using about one gram of each for 1 hr contact time. The removal of paracetamol was high at a pH range of 6-7 with both AC and sawdust, and at pH 7 with dried olive stone. The outcome is consistent, utilizing the data acquired by [13] Employing different activated carbons with modified chemical surfaces for the sorption of paracetamol, by [5]; and by [15]. So, the optimum pH was chosen as 7 in other experiments.

3.3.Effect of Various Amounts of Sorbents

In order to find the optimum amount of various sorbents, different amounts were taken from 0.5-1.5 gm at pH 7 and 1 hr. contact time (at 30±5°C). Fig. 6 presented the result of this experiment. Because of the fixed concentration of paracetamol, the sorption of the drug increased as the amount of sorbent rose; a greater surface area, or site of sorption, was made available by increasing the amount of adsorbent. [15,16]. The optimum amounts of all sorbents were taken as 1.25 gm of AC, 1.25 gm of olive, and 1.5 gm of sawdust in all subsequent experiments.

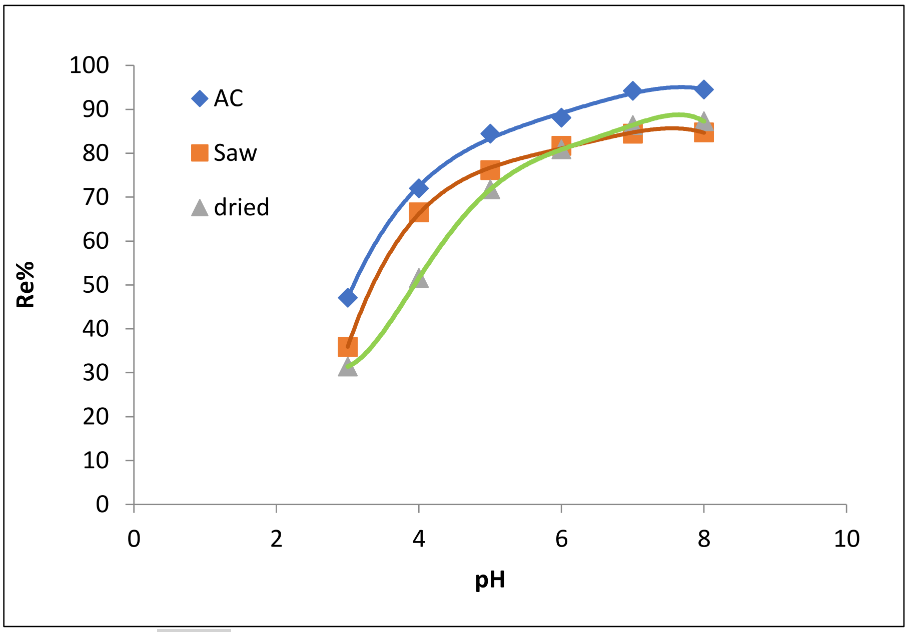


Fig. 5 The pH Impact on Three Types of Sorbents.

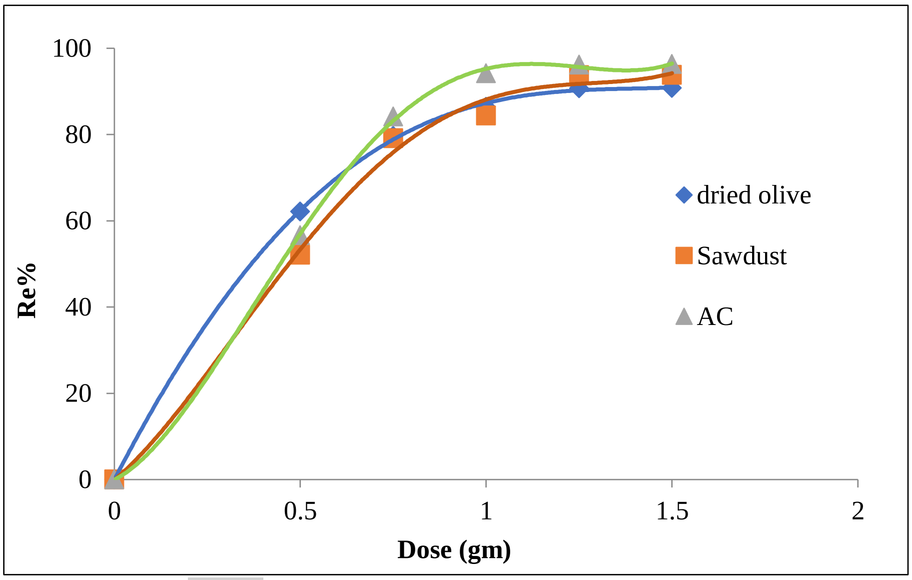
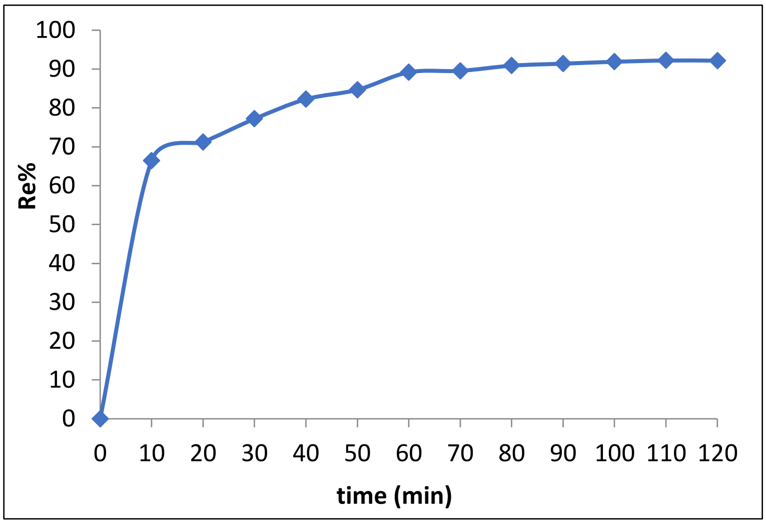


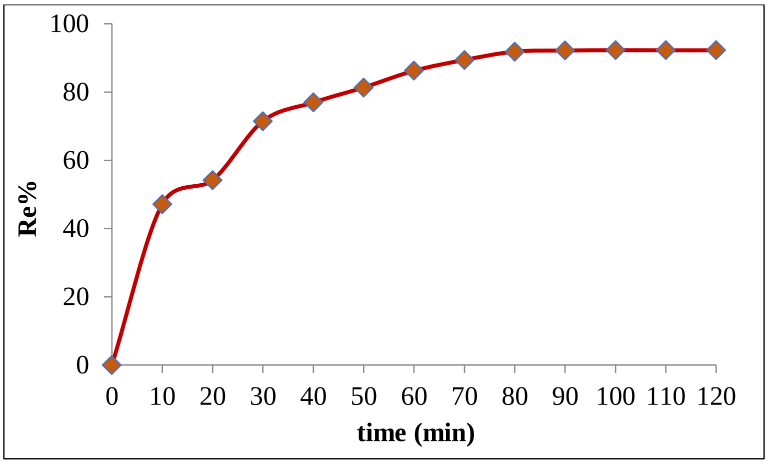
Fig. 6 Effect of Various Amounts of Sorbents.

3.4.The Retention Times Impact

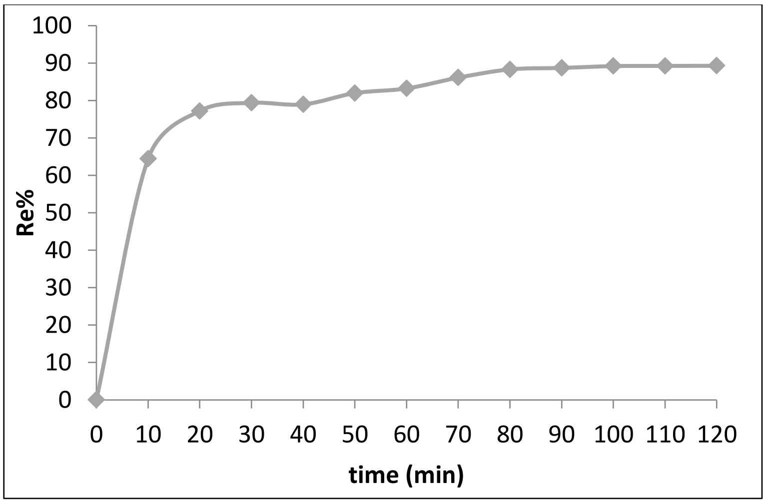
Fig. 7 (a, b, and c) demonstrated that the rise in removal efficiency over the first hour (the experiment worked out at 2 hr. mixing) was because at the beginning the surface area of all sorbents that were utilized in this search (AC, SD, and OS) was blank and the gradient of solute concentration was quite high; the removal became steady until the equilibrium condition, which was reached after 90 minutes. The result is in line with what was found by Ferreira et al. [14], who employed dende coconut mesocarp activated carbon [19] to extract paracetamol from water.



(a)



(b)

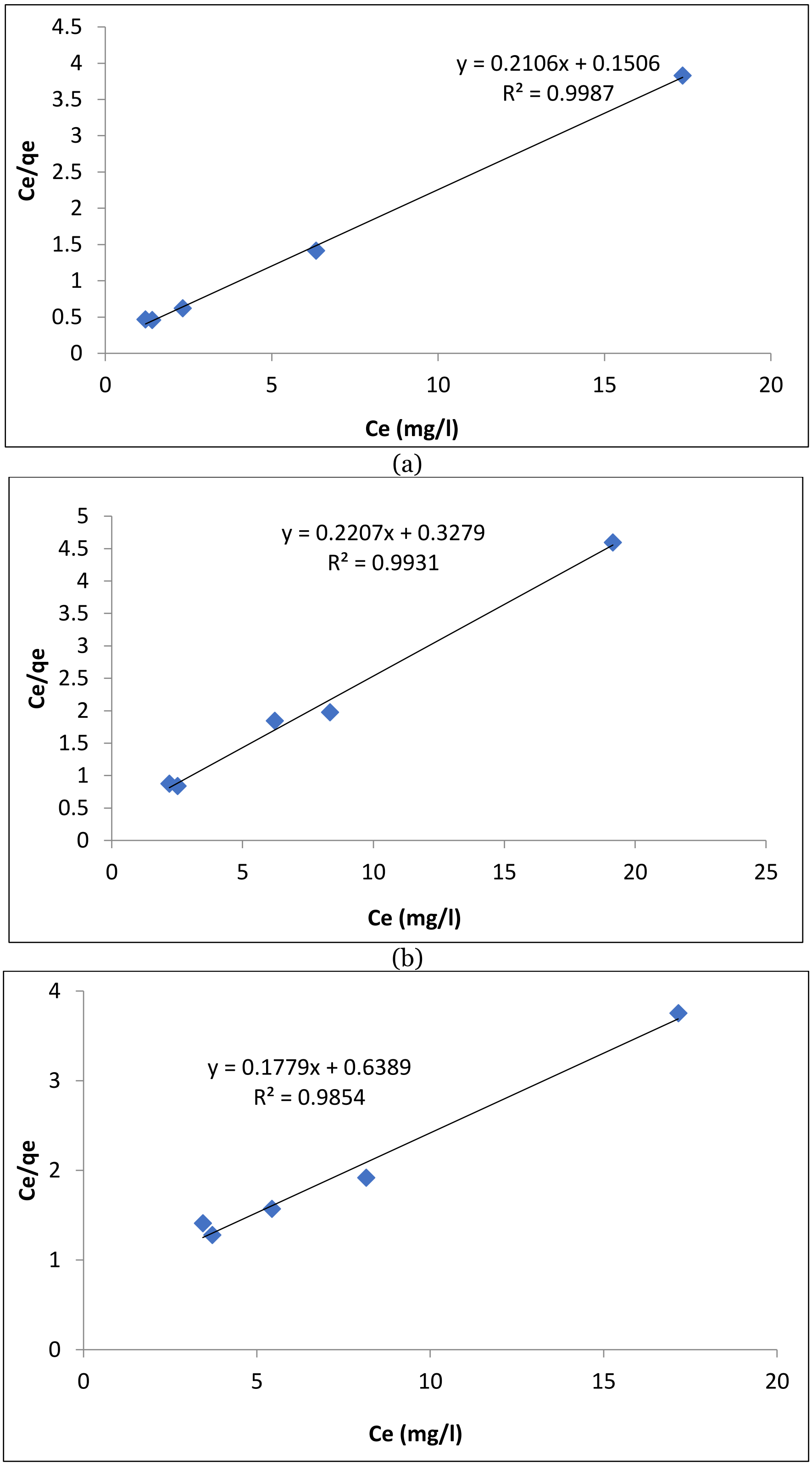


(c)

Fig. 7 Influence of Contact Times (a: AC; b: SD; and c: OS).

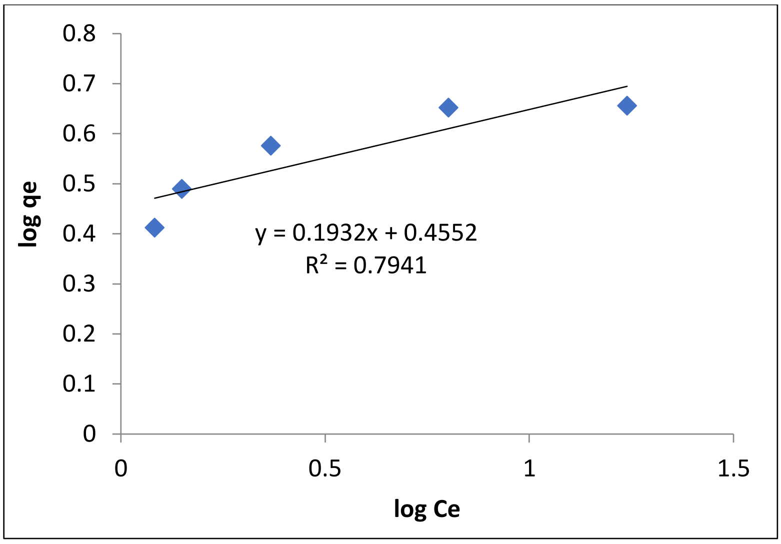
3.5.Modeling of Sorption Result

The equilibrium and kinetic outcomes established from the experiments of adsorption were analyzed by the isotherm (Langmuir and Freundlich) and kinetic (pseudo-first and pseudo-second order) models previously defined in Section 2.2.1. The outcomes of all forms are offered in Fig. 8, Fig. 9, and Table 1. From Table 1 it appears that Langmuir equation is more appropriate to the data of experiential learning than the Freundlich model, while Fig. 10 and Table 2 show the outcomes of the kinetic models listed later.

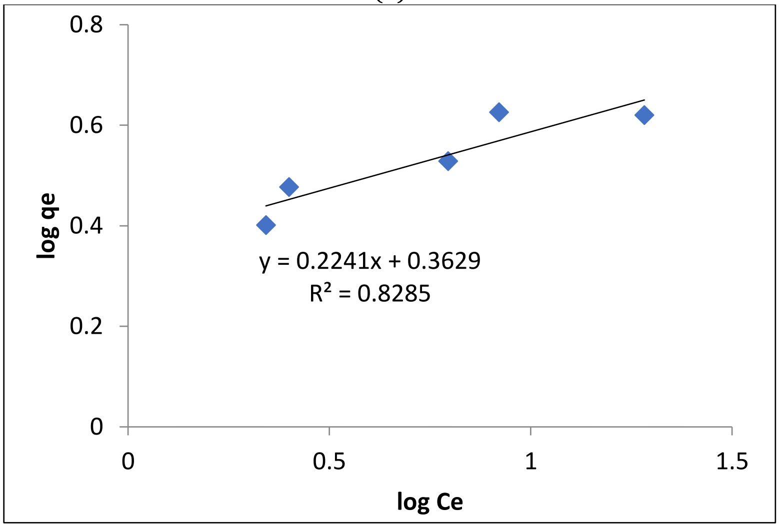


(a) (b) (c)

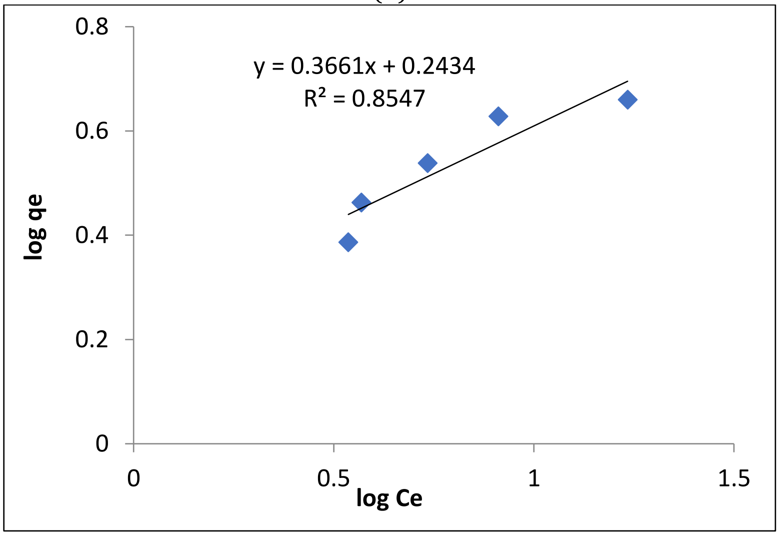
Fig. 8 Langmuir Model (a: AC; b: SD, and c: OS).



(a)



(b)



(c)

Fig. 9 Freundlich Model (a: AC; b: SD; and c: OS).

Table 1 Shows the Parameters of both Models.

Langmuir Model	Adsorbent			Freundlich Model	Adsorbent		
	SD	OS	AC		SD	OS	AC
R^2	0.993	0.984	0.998	R^2	0.828	0.854	0.794
q_m	4.531	5.621	4.748	1/n	4.462	2.731	5.176
b (1/mg)	13.82	8.80	31.53	K (mg/g)(1/mg)$^{1/n}$	2.310	1.751	2.852

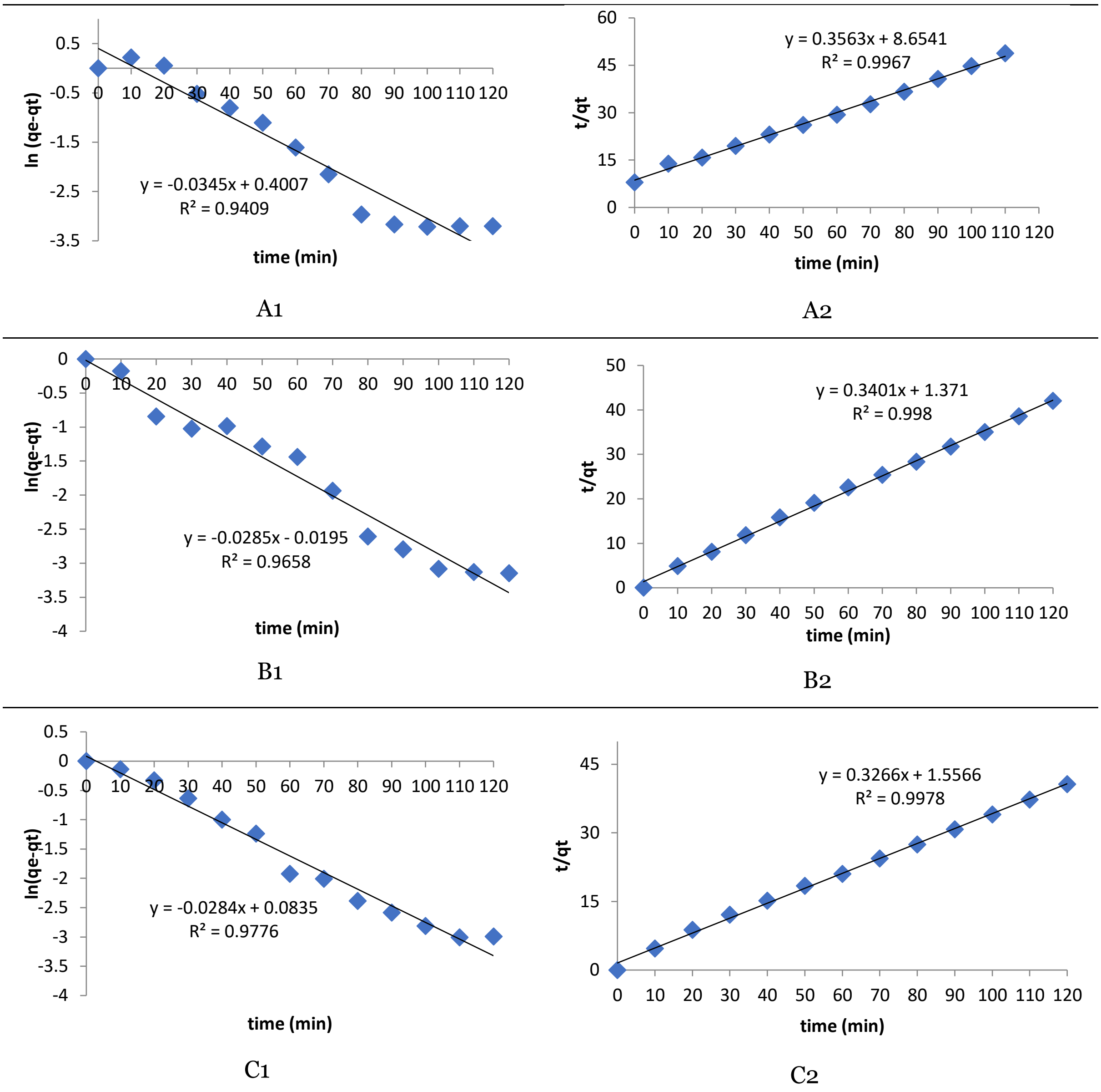


Fig. 10 Kinetic Models (1st and 2nd Order Pseudo Model: A1; A2: SD; B1; B2: OS and C1; C2: AC).

Table 2 Parameters of Kinetic Models.

Adsorbent	q_e (exp.) mg/g	Pseudo-first-order			Pseudo-second-order		
		q_e (cal.) mg/g	K_1 (g/mg.min)	R^2	q_e (cal.) mg/g	K_2 (g/mg.min)	R^2
SD	2.46	1.5	-0.0345	0.940	2.81	0.015	0.996
OS	2.90	0.981	-0.0285	0.965	2.94	0.084	0.998
AC	3.00	1.09	-0.0284	0.977	3.06	0.069	0.997

Table 2 demonstrates that the values of experience uptake and the theoretical amounts of q_e (cal) matched; in the case of a pseudo-second-order form, qe (exp). Additionally, 0.9967, 0.9980, and 0.9978 were the relationship coefficients (R^2) for sawdust, olive stone, and AC, respectively, implying that a comprehensive pseudo-second-order process may be used to describe this sorption process.

3.6.Influence of Temperature Changes and Isotherm of Thermodynamics

In order to know if the reaction of sorption is exothermic or endothermic in nature, it is necessary to study the influence of different temperatures (298, 308, 318, and 328 K). Parameters of thermodynamics are calculated by these equations [17,18]:

$$\ln k_d = \left(\frac{\Delta S^\circ}{R}\right) - \left(\frac{\Delta H^\circ}{RT}\right) \quad (6)$$

$$\Delta G^o = \Delta H^o - \Delta S^o T \quad (7)$$

These parameters of thermodynamics (ΔG^o, ΔH^o, and ΔS^o) are utilized to assess the temperature impact on the biosorption. Specifically, ΔG^o indicates the spontaneity degree, where more negative values signify a more thermodynamically spontaneous process

[19,20]. Based on basic thermodynamic concepts in an isolated system, it is assumed that energy cannot be gained or lost, while entropy represents the primary driver, and it indicates the direction of spontaneous change. To determine which process will occur naturally, environmental engineering practitioners must take into account both enthalpy and entropy considerations. [20]. The influences of the temperature change and all other parameters of thermodynamics are offered in Fig. 11, Table 3, and Table 4, respectively.

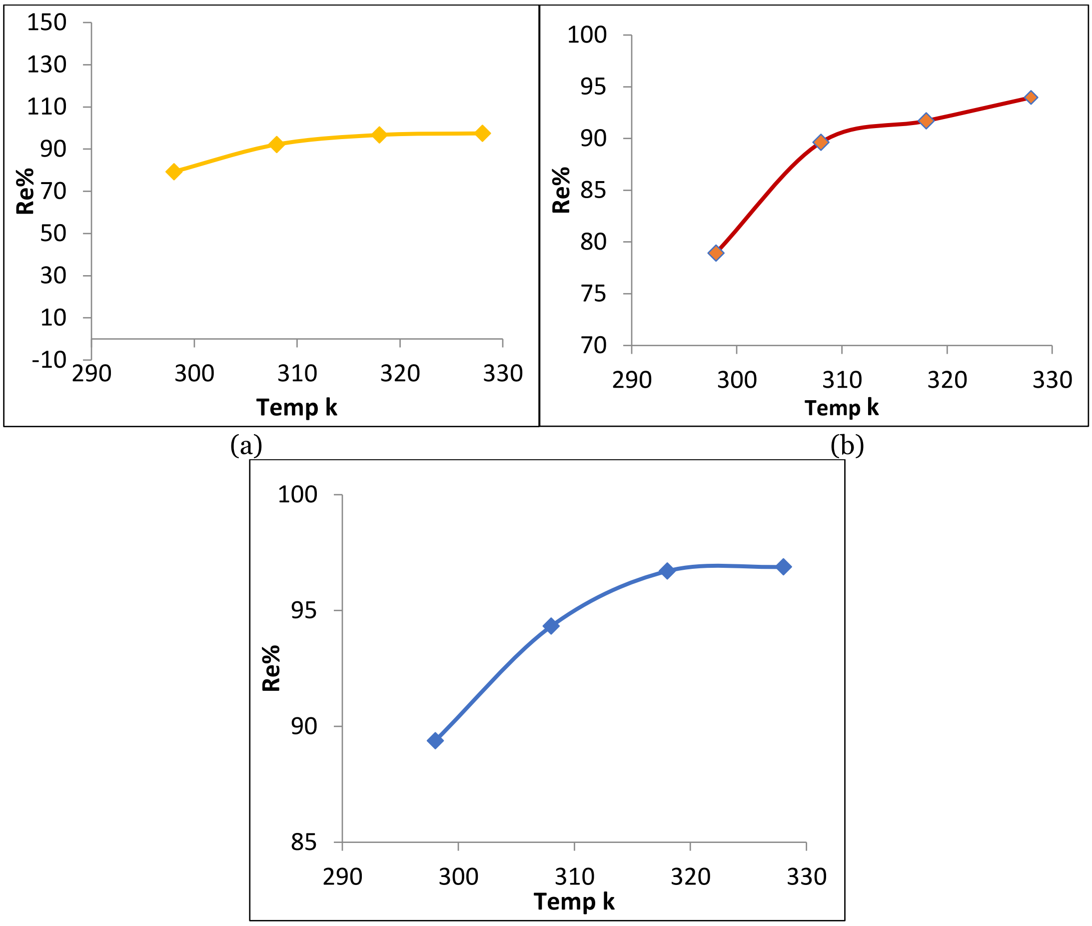


Fig. 11 The Impact of Various Temperatures on this Process: a: SD; b: OS; and c: AC.

Table 3 The Coefficients of Distribution at Several Temperatures by Three Adsorbents.

Adsorbent Types	k_d				R^2
	298k	308k	318k	328k	
SD	3.825	11.763	29.303	38.177	0.952
OS	3.745	8.636	11.048	15.563	0.936
AC	8.414	16.613	29.303	31.128	0.921

Table 4 Parameters of Thermodynamic.

Adsorbent Types	ΔH° (kJ/mol.)	ΔS° (J/mol. K)	ΔG° (kJ/mol.)			
			298k	308k	318k	328k
SD	63.911	226.947	-3.719	-5.989	-8.258	-10.528
OS	36.963	136.167	-3.615	-4.976	-6.338	-7.700
AC	36.803	142.169	-5.563	-6.985	-8.407	-9.828

The endothermic nature of the adsorption process is indicated by the positive values of ΔH° obtained, which explains why the adsorption efficiency increased with increasing temperature. Additionally, it was found that ΔG° became more negative as temperature increased, indicating that the spontaneity of the process is enhanced by high temperatures. This trend is further supported by the positive ΔS° values, which clarify the increase in randomness at the solid-solute interface during the biosorption process. [4].

4.CONCLUSIONS

The current work has examined the adsorptive performance of activated carbon (AC), sawdust (SD), and olive stones (OS) wastes as efficient biosorbents for paracetamol removal from simulated aqueous solution. The adsorption process of paracetamol on these sorbents is highly affected by the pH value, with an optimal pH of 7. By biosorbents dosage of 1.25 gm for AC, 1.5 gm for SD, and 1.25 gm for OS, with the removal efficiencies ranked as AC > SD > OS (at the time of contact, 90 min). The high specific surface area of the three biosorbents is an important factor in the process of biosorption; they indicate effective sorption sites that were utilized. The isotherm study's findings showed that the Langmuir model indicated that molecules of paracetamol form a monolayer on the surface of the three types of biosorption sites. At the optimal values of the experimental settings, the maximum paracetamol biosorption capacity onto activated carbon, sawdust, and olive stone was determined to be 4.748 mg/g, 4.531 mg/g, and 5.621 mg/g, respectively. Moreover, the pseudo-second-order reaction was established to be the most accurate representative model for the kinetic data, indicating that the biosorption process was chemisorption. Temperature is a significant factor that controls the adsorption process of various biosorbents. In this study, the biosorption capacities are significantly affected by an increase in temperature, indicating the process's endothermic nature. Finally, based on the findings, biosorption using various kinds of biosorbent agents was discovered to be an effective, sustainable treatment method for eliminating paracetamol contamination from aqueous solutions.

NOMENCLATURE

PC	paracetamol (pollutant/drug)
AC	Activated Carbon (adsorbent)
SD	Saw Dust (adsorbent)
OS	Olive Stone (adsorbent)
FTIR	Fourier Transform Infrared Spectroscopy (analytical technique)
SEM	Scanning Electron Microscopy (image technique)
λ_{max}	Maximum absorption wavelength (nm)
pH	Potential of Hydrogen (dimensionless)
R^2	Correlation Coefficient (dimensionless)
R	constant of the gas (8.314 J/mol. K)
The	temperature in Kelvin
t	time (minute)
b	constant of Langmuir isotherm (L/mg).
v	volume of sample (L)
w	weigh of adsorbent (gm)
K	constant of Freundlich isotherm (mg/g)
1/n	function of the adsorption strength in the process of adsorption (dimensionless)
Subscripts	
C_i	the adsorbate initial concentration (mg/L)
C_f	the adsorbate final concentration (mg/L)
C_e	the adsorbate equilibrium concentration (mg/L)
q_e; q_t	the PC quantity that adsorbed at equilibrium time (mg/g)
q_m	maximum single layer coverage ability (mg/g)
k_1	the constant rate kinetics of the pseudo-first order form (min^{-1})
k_2	the constant rate kinetics of the pseudo-second order form (g mg^{-1} min^{-1})
K_d	, the coefficient of ranking (ml/g) or (L/g)
Greek symbols	
ΔH^o	enthalpy change (kJ/mol)
ΔS^o	entropy change (J/mol. K)
ΔG^o	Gibbs free energy change (kJ/mol)

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Zainab A. Naser: Supervision, Resources, review. *Lahieb Faisal M.: Conceptualization, Methodology, Investigation, Writing– original draft preparation, Data Curation, Visualization, review & editing.

DECLARATION OF COMPETING INTEREST (Conflict of Interest)

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

ACKNOWLEDGEMENTS

The authors are grateful for the financial support towards this research by the Environmental Engineering Department, College of Engineering, Al-Mustansiriyah University (EV 23160).

REFERENCES

[1] Arroy PA, Joao CG, Barbosa C.G, Sousaana RR, Barros MA. **A Review on Environmental Monitoring of Water Organic Pollutants Identified by EU Guidelines.** *Journal of Hazardous Materials* 2018; **344**: 146–162.

[2] Evangelia S, Aikaterini V, Leonidas V, Aggeliki M, Eleni K. **Assessing the Ecological Effects of Water Stress and Pollution in a Temporary River - Implications for Water Management.** *Science of the Total Environment* 2018; **618**: 1591–1604.

[3] Weiwei DS, Zhimin Q. **Occurrence, Source Estimation and Risk Assessment of Pharmaceuticals in the Chaobai River Characterized by Adjacent Land Use.** *Science of The Total Environment* 2020; **712**: 134-525.

[4] Isabel V, Núria F, Jordi P, Antonio B, Carla B. **Mechanism of Paracetamol Removal by Vegetable Wastes: The Contribution of π-π Interactions, Hydrogen Bonding and Hydrophobic Effect.** *Desalination* 2011; **270**: 135–142.

[5] Halling B, Sorensen S, Lanzky PF, Ingerslev F, Lützhoft H, Jorgensen SE. **Occurrence, Fate and Effects of Pharmaceutical Substances in the Environment — A Review.** *Chemosphere* 1998; **36**: 357–393.

[6] Jones OAH, Voulvoulis N, Lester J. **The Occurrence and Removal of Selected Pharmaceutical Compounds in Sewage Treatment Works Utilising Activated Sludge Treatment.** *Environmental Pollution* 2007; **145**: 738–744.

[7] Norzila M, Muhammad FA, Sarifah FS. **Isotherm and Thermodynamic Study of Paracetamol Removal in Aqueous Solution by Activated**

Carbon. *ARPN Journal of Engineering and Applied Sciences* 2015; **10**(20): 9516–9520.

[8] Cabrita BR, Mestre A.S, Fonseca IM, Carvalho AP, Ania CO. **Removal of an Analgesic Using Activated Carbons Prepared from Urban and Industrial Residues.** *Chemical Engineering Journal* 2010; **163**(3): 249–255.

[9] Bhatnagara A, Minochaa AK, Mika S. **Adsorptive Removal of Cobalt from Aqueous Solution by Utilizing Lemon Peel as Biosorbent.** *Biochemical Engineering Journal* 2010; **48**: 181–186.

[10] Sylla AS, Ihammi A, Kirm I, Boussetta A, Benali K, Ainane T, et al. **Utilization of Olive Mill Solid Waste-Based Activated Carbon for the Effective Elimination of Phenolic Compounds in Olive-Mill Wastewater: A Study on Optimization, Kinetics, and Isotherms.** *Chemical Papers* 2026.

[11] Vasquez Llanos SA, Sausa Burga LL, Guevara Fernandez DN, Sanchez Purihuaman MN, Huangal Scheineder S, Carreño Farfan CR, et al. **Rice Husk Biochar as a Sustainable Adsorbent for Tetracycline Removal from Aqueous Solution by Using Taguchi Design Approach.** *Journal of Ecological Engineering* 2025; **26**(9): 382–399.

[12] Michael-Igolimau U, Abbey SJ, Ifelebuegu AO, Eyo EU. **Modified Orange Peel Waste as a Sustainable Material for Adsorption of Contaminants.** *Materials* 2023; **16**(3): 1092.

[13] Valentina B, Alessandro E, Liliana G, Juan CM. **Effect of Solution pH on the Adsorption of Paracetamol on Chemically Modified Activated Carbons.** *Molecules* 2017; **22**: 1–14.

[14] Ferreira RC, Couto KQ, Arroyo PA, Barros MA. **Effect of Solution pH on the Removal of Paracetamol by Activated Carbon of Dende Coconut Mesocarp.** *Chemical and Biochemical Engineering Quarterly* 2015; **29**(1): 47–53.

[15] Asim KD, Mahus D. **Fundamental Concepts of Inorganic Chemistry.** 2nd ed.

[16] Bankole DT, Oluyori AP, Inyinbor AA. **The Removal of Pharmaceutical Pollutants from Aqueous Solution by Agro-waste.** *Arabian Journal of Chemistry* 2023; **16**(5): 104699.

[17] Ruthven DM. **Principles of Adsorption and Adsorption Processes.**

[18] Giles CH, Macewan TH, Nakhwa SN, Smith D. **Studies in Adsorption. Part XI. A System of Classification of Solution Adsorption Isotherms, and its Use in Diagnosis of Adsorption Mechanisms and in Measurement of Specific Surface Areas of Solids.** *Journal of the Chemical Society* 1960; 3973.

[19] Abd Al Satar NH, Sachit DE. **Assessment of Hospital Wastewater Quality and Management In Bab-Al Muadham Region At Baghdad.** *Journal of Engineering and Sustainable Development* 2021; **25**: 44–50.

[20] Stephen GY, Sylvester O, Adejo PO, Boniface TI, Joseph A. **Kinetics and Mechanism of Oxidation-Reduction Reaction of Vanadium (V) Ion with Paracetamol.** *International Journal of Inorganic and Bioinorganic Chemistry* 2014; **4**: 40–44.