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Activated carbon produced from palm fronds for elimination oxalic acid from polluted water sources

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Abstract.

The purpose of this study is to develop low-cost palm frond activated carbon (AC) for the environmentally friendly elimination of oxalic acid from aqueous solution. The methods used activated carbon, which is generated by calcining AC at 600°C until it burns. The methods used activated carbon, which is generated by calcining AC at 600°C until it ignites. The samples were tested using FTIR, transmission electron microscopy, and nitrogen adsorption-desorption. Oxalic acid was adsorbed in a batch method with 0.5 g (AC) and 100 mL of solution at initial values ranging from 10 to 40 mg/L. Oxalic acid was adsorbed in a batch method with 0.5 g (AC) and 100 mL of solution at initial values ranging from 10 to 40 mg/L. Temperature, concentration, and time all have an effect on adsorption capacity. Thermodynamic parameters were determined, adsorption kinetics were assessed using pseudo-first and pseudo-second-order computational models, and adsorption isotherms were fitted with the Langmuir and Freundlich models. Peaks at 1450-1300 cm^{-1} and 3300-3800 cm^{-1} in the FTIR suggest OH stretching and functionalization (AC). AC's N_2 adsorption isotherm has a surface area of 72.8 m^2/g, a pore size of 1.87 nm, and a pore volume of 1.8755 cm^3/g. The highest adsorption capacity is 89.056 mg/g. The elimination of oxalic acid was 98%. The adsorption process was spontaneous and less random, as demonstrated by negative thermodynamic characteristics ΔS°(-13.6, ΔH°-19.42), and ΔG°(-79.2 kJ/mol). Palm frond AC has a vast surface area and is highly porous, allowing it to successfully remove over 98% of harmful organic acids from polluted water. The findings of this study demonstrate that activated carbon can be effectively used as one of the best-quality, low-cost, readily available, eco-friendly bio-sorbents that are also economically beneficial in the long term.

Keywords: Oxalic acid, activated carbon, Palm frond, Adsorption; Kinetic,

1. Introduction

Oxalic acid the most abundant dicarboxylic acid, is present in both soil and water. Oxalic acid is used in industry as an agent or ligand in the sweetening and fermentation of corncobs to produce ethanol, the depolymerization of lignocellulose to produce xylose from beechwood, and the adsorption of various heavy metals to increase the brightness and hardness of paper industry products. It is also utilized for photocatalytic activation as well as rust removal and precipitation in the metalworking industry. Apart from this, Oxalic acid is an exhaust byproduct of automobiles. It can potentially pollute the environment as a result of the processes described above. (Şentürk, et al.2024) Adsorption methods are widely preferred due to their low cost and convenience of use employed flay ash, an adsorbent derived from thermal power plants, to extract Oxalic acid. Similarly, investigated the adsorption kinetics of an activated carbon-fly ash mixture to separate Oxalic acid (Ilgen, et al.2023). Along with the adsorption mechanisms, potential uses, difficulties, and recommendations. (Sharma *et al.* 2022). Organic contaminants, are not readily biodegradable. Activated carbon made from affordable orange peel waste ash using a simple calcination procedure to remove heavy metal ions Cu(II) from aqueous solution. The low-cost activated carbon adsorbent had a maximum copper ion adsorption capability of 20 mg/g for removing heavy metal ions like Cu (II) from aqueous solutions. Furthermore, it is characterized by high efficiency, the availability of natural sustainable adsorbents that are easy to treat, and cost-effectiveness. Adsorption is recommended as a technology to treat water and remove heavy metal ions. Activated carbon was created from palm fronds through calcination and burning until it became coal, and industrial and agricultural solid waste had economic value. (Faiad et al., 2022). Activated carbon, which magnetically generated orange peels as the precursor and $ZnCl_2$ as the activating agent, was used to remove acid orange 7 dye from water, and the resultant surface area was satisfactory (Bukhari et al.2022). Eosin dye was adsorbed in an aqueous medium using lemon peel, a natural sorbent. Using lemon peel as a bio-sorbent, adsorption was used to get rid of the anionic dye eosin. By comparing all of the bio-sorbent parameters, the monolayer adsorption capacity that is appropriate for the exothermic adsorption process was shown, indicating that lemon peel is an accessible and reasonably priced bio-sorbent for the removal of eosin dye from aqueous media. The aim of this study is to demonstrate the novelty removal and purification of oxalic acid from polluted water sources using activated carbon produced from palm fronds, SEM, BET, and FTIR analyses were performed. The influence of adsorbent mass, oxalic acid content, and shaking time on the preconcentration process was investigated. The adsorption isotherm parameters. Kinetic and thermodynamic research was investigated.

2.Materials and Methods

2.1 Materials and Chemicals

Palm frond waste ash (PFWA) was made on-site by gathering palm tree leaves in Sharoura City, Najran, Kingdom of Saudi Arabia, and using them as a raw material to make activated carbon AC by burning them in an oven. Chemical reagents were purchased from a chemical reagent company. All the reagents were of analytical grade.

2.2 Instruments

Spectrophotometric measurements were obtained using a Perkin-Elmer Lambda 35 spectrophotometer equipped with 1.0 cm3 quartz cells and an 8 nm/sec scan speed. A Jenway 1000 magnetic stirrer was used to combine the liquids. The surface functional groups of the samples were also determined. The nitrogen (N_2) adsorption-desorption isotherms at 77.5 K were ascertained using a surface area and pore size analyzer (Quantachrome Instruments NOVA 2200e). The sample's specific surface area and pore size distribution were calculated using the BET (Brunauer-Emmett-Teller) method.

2.3 Preparation and characterization of the adsorbent

Palm frond plant waste was collected at Sharurah, Najran, Saudi Arabia, and used to make activated carbon. Initially, the gathered fronds were cut into 1–5 cm pieces. They were then cleaned on with tap water, followed by distilled water, to eliminate any pollutants, dust, and fibers. The washed leaves are dried for eight hours at 100 degrees Celsius to remove any leftover moisture. Activated carbon is abbreviated to A.C.

2.4 Preparation of Activated Carbons

The activated carbons were prepared by using physical activation method Following the sample's drying and grinding, the operation was carried out for three hours in a nitrogen environment at various calcination temperatures of 600°C. To extract the oxygen from the sample, it was crushed and placed in a stainless-steel container. Following the carbonation technique, samples were collected and weighed. After being crushed and weighed again, the materials were sorted into containers, as illustrated in Figure 1.

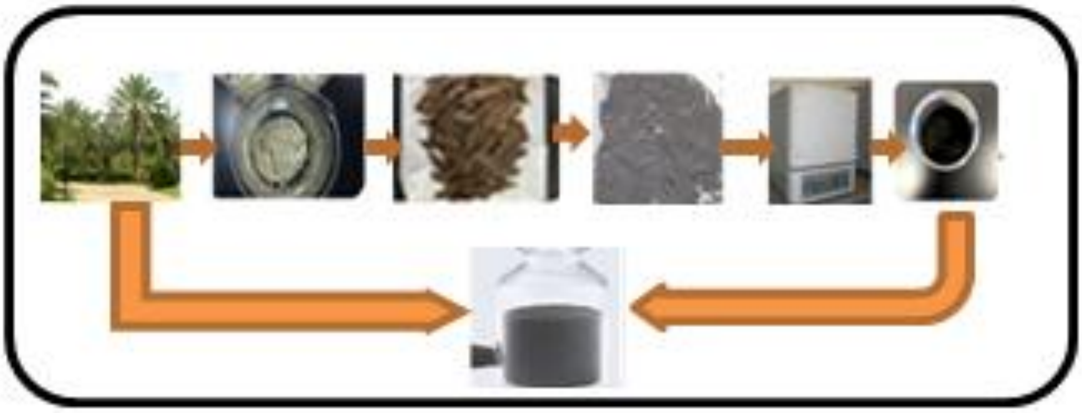

Figure 1: Physical activation of the adsorbent

2.5 preparation of Oxalic acid as an adsorbate

Oxalic acid was prepared by dissolving 4 g of the acid in distilled water in 1000 mL of double-distilled water, yielding a stock solution containing 1000 mg/L of oxalic acid.

2.6 Characterization

The activated carbon and oxalic acid were analyzed using the FTIR technique (Cary 630, Agilent; USA). Their FTIR spectra were obtained using KBr disks (sample: KBr; 1:200 w/w) over 4000-650 cm^{-1}.Brunauer-Emmett-Teller (BET) analysis (Quantachrome, Boynton, Florida, USA) was performed to explore the potential of A.C. produced from palm fronds. Chemically activated samples thermally treated at 600 °C had a surface area of 35.7 m^2/g, respectively, as indicated in Table 1. The data on activated carbon yield (Table 1) and surface features (Table 1) show that the activated carbon yield increases with surface area. SEM was used in conjunction with wet chemical analysis to investigate the materials' surface morphology. The micro-texture and elemental composition of the samples were determined using a VEGA II LMU (Tescan) scanning electron microscope equipped with INCA Energy 450/XT (Silicon Drift detector, SDD) and INCA Wave 700 (crystals: LiF, PET, TAP, LSM60, LSM200) EDS equipment.

2.7 Adsorption experiments

The factors considered in this study were initial concentration of oxalic acid, contact time (30, 60 ,90, and 120 min), effect of temperature (30, 40, 50, 60, 70). The adsorptions and initial concentration of adsorbate (10 to 40 mg/L) studies were performed in a batch system, using 100 mL Erlenmeyer flasks inside an incubator. Magnetic stirrers with a fixed setting to achieve a constant speed were used to ensure the contents of all the Erlenmeyer flasks were homogenous. (Jatoi *et al.*

2024). The following equations were used to determine the equilibrium adsorption capacity and the percentage removal for oxalic acid by using (Merine et al. 2024).

$$q_{e}= \frac{c_0-c_e}{W} XV \qquad (1)$$

$$R\% = \frac{c_o - c_e}{W} x100 \qquad (2)$$

Where q_e is the equilibrium adsorption capacity (mg/g); C_0 and C_i are the initial and equilibrium concentrations (mg/L) of the oxalic acid solution, respectively; v is the volume of the initial solution (L) used for sorption; and W is the weight of the adsorbent (g). The percent removal (% R) was calculated by using following Equation

2.7 Kinetic Adsorption

To find the equilibrium period and the kinetic reaction that occurred, 0.5 g of sorbent was employed at 80 °C. The adsorption process lasted anywhere from 20 to 120 minutes. The adsorption kinetics were estimated using two different kinetic models: the pseudo-first-order and pseudo-second-order models.

3.Results and Discussion

3.1 FTIR spectroscopic studies

FTIR analysis Figure 2a,b shows for activated carbon produced after burning at the following wavelengths: 1453 cm^{-1} (C=C stretch), 1175 cm^{-1} (C-H bending vibration), 1617 cm^{-1} (C=O acid stretching).FTIR analysis was utilized to investigate the overall changes in the structure of oxalic acid AC caused by oxalic adsorption. As seen in the FTIR spectra of oxalic acid, the bandwidth due to the stretching vibrations of OH groups have shifted to the maximum at 3448 cm^{-1}. Furthermore, the absorption bands or shoulders that emerged between 1710 and 1630 cm^{-1} (max at 1697 and 1638 cm^{-1}) were attributed to stretching vibrations of C=O bonds and deformation bending vibrations of the water molecule. The weak absorption bands that emerged in the 1450-1300 cm^{-1} range (max at 1407, 1375, and 1328 cm^{-1}) were associated with a combination band containing stretched vibrations of C=O bonds and deformation vibrations of OH groups (Darweesh et al. 2023).

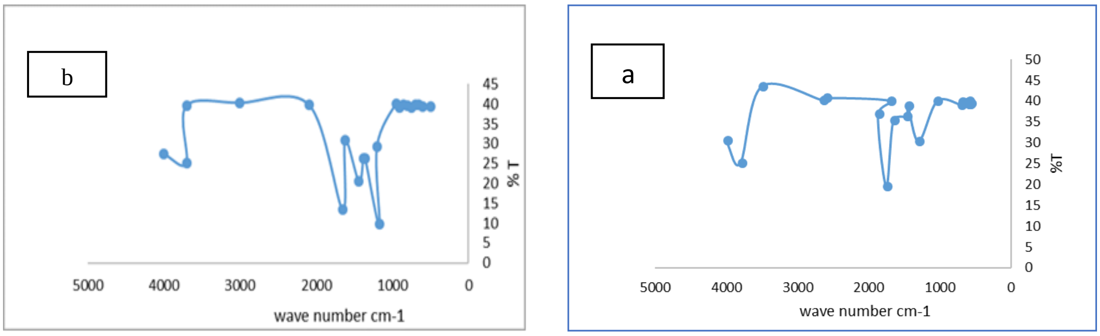

Figure 2 a). FTIR of Activated carbon b) Activated carbon with oxalic acid

3.2 Scanning Electron Microscope (SEM)

Waste activated carbon AC produced from palm frond samples were glued with petroleum wax on a glass plate, and gold was sprayed thinly for SEM examination. The activated carbon AC surface was covered with gold particles that were placed inside the gold depositing machine's vacuum chamber. The glass panel was also made conductive by the application of special conductive solutions. Scanning electron micrographs of activated carbon AC surfaces prior to burning and activated carbon AC conversion are shown in Figure 3 a, b. The findings showed that the activated carbon AC surface was uneven and rough (Figure 3a) and Figure 3b reveal the morphology of activated carbon AC obtained from of palm fronds and the activated carbon AC after oxalic acid adsorption, respectively, demonstrating that the morphology of the activated carbon AC was severely destroyed after calcination and that asperities on its surface were almost totally erased. (Khalil et al,2024).

	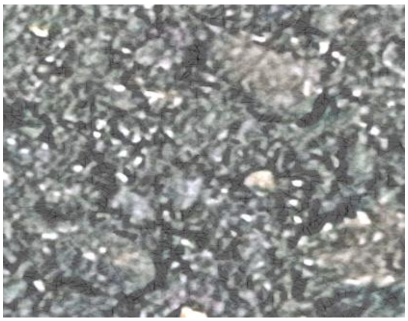
(a) Activated carbon (AC)	(b) activated carbon (AC) after adsorption oxalic acid

Figure 3: SEM images of (a) activated carbon (AC) (b) activated carbon (AC)with oxalic acid

3.3 Nitrogen Adsorption Desorption Analysis

Table 1: BET of Activated Carbon (AC)

Activated Carbon	Surface area (m^2/g)	Pore Size (nm)	Pore Volume (cm^3/g)
	72.8345	1.8755	0.068302

3.1 Characterization of Activated Carbon as an adsorbent

Brunauer–Emmett–Teller (BET) analysis loop in the p/p^0 value range of 0.68 to 0.8, which is linked to capillary condensation, a property of mesoporous materials. As per the International Union of Pure and Applied Chemistry, this indicates that Activated Carbon is a mesoporous substance having pores smaller than 50 nm. The functionalized silica's surface area, pore size, and pore volume were calculated using BET analysis to be 72.83 m^2/g, 1.875 cm^3/g.

The study of adsorption

3.4 Effect of initial oxalic acid concentrations

The effect of the initial concentration of oxalic acid, which is shown in Figure 4, reveals the equilibrium adsorption of oxalic acid on activated carbon. It indicates that the adsorbed amount increases very marginally at increasing concentrations, with a vertical increase at low concentrations and a horizontal plateau at higher values. As the initial concentration of oxalic acid increased from 10 to 40 mg/L, the adsorption capacity at equilibrium (q_e) increased from 33 mg/g to 78 mg/g, as shown in Figure 4. The highest value of 7.1 mg/g was recorded at 30 mg/L of oxalic acid; at 400 mg/L, it fell to 1.05 mg/g. As the mass transfer driving force increased with the initial concentration, oxalic acid adsorption increased as well; 97.20% was the highest percentage of oxalic acid removal attained. (Chauke *et al.* 2024).

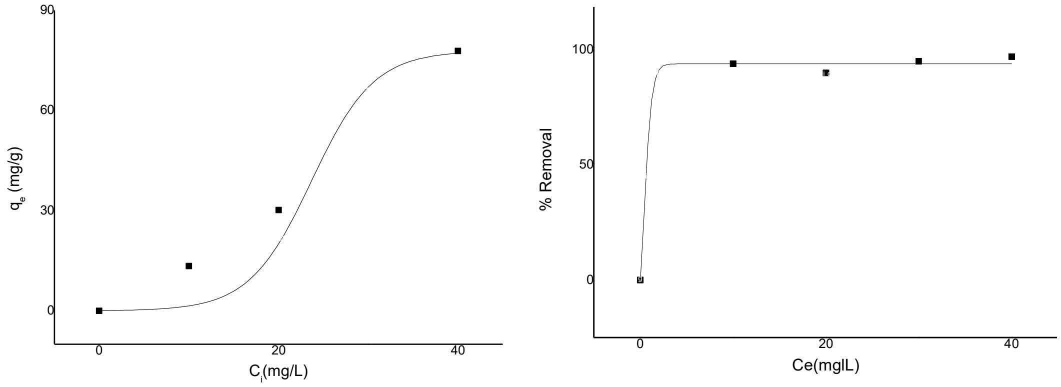

Figure .4. Effect of initial concentration of adsorption and % removal of Oxalic acid

3.5 Effect of Temperature

The adsorption of oxalic acid onto activated carbon was studied at 70, 80, 90, and 120 degrees Celsius, beginning with a 40 mg/L solution concentration. As demonstrated in Fig. 5, the adsorption of oxalic acid onto activated carbon increased with temperature, from 4.2 mg/g at 70°C to 4.91 mg/g at 80°C.The degradation of the adsorbent affected its surface chemistry, increasing the availability of active functional groups while lowering the adsorption of oxalic acid ions. Furthermore, the links shifted in favor of the desorption process as temperatures rose. Because oxalic acid leaked into the solution phase from the surface, reducing adsorption capacity, the thickness of the boundary layer reduced as temperature increased (Aslam et al., 2024a,b). The highest percentage of oxalic acid removal attained was 98%

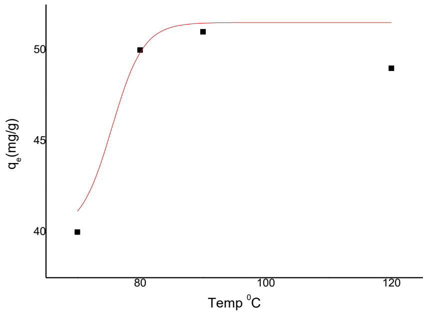

Figure. 5 Effect temperatures for oxalic acid adsorption and percentage % removal

3.6 Effect of contact time on adsorption efficiency

Time effect on oxalic acid adsorption is shown in Figure 6 which illustrates the relation between the efficiency and time of oxalic acid adsorption, as well as the capacity and time of oxalic acid adsorption. Oxalic acid adsorption effectiveness and capacity improved with time, there were two phases to the oxalic acid adsorption process using Activated Carbon the initial reaction stage, which lasted from the start to the thirty-minute mark, and the subsequent stage. Surface adsorption was the main reaction in the first stage, which accelerated the adsorption reaction and enhanced its capacity and efficiency. The adsorption reaction was comparatively slow in the second reaction stage and was dominated by gradual adsorption. In 90 to 120 minutes, it steadily decreased. Oxalic can be readily adsorbed by Activated Carbon because of its mesoporous nature, which includes a high mass transfer driving force during the early phases of adsorption and a large number of active sites. Nonlinear adsorption results from the accumulation of a significant amount of oxalic on the Activated Carbon surface over time, which decreases the number of active sites and oxalic movement. The highest percentage of oxalic acid removal attained was 92.1%

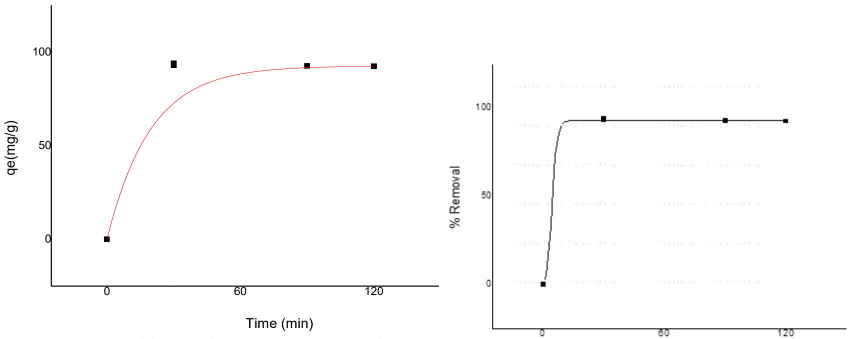

Figure 6. Effect of contact time of oxalic adsorption onto Activated Carbon

3.7 Adsorption Isotherms

The adsorption isotherms were determined using two isotherm models: Freundlich and Langmuir. As shown in Figures 7 and 8, these two models were suitable for oxalic acid adsorption on activated carbon. Table 2 lists the data outcomes. The R^2 values served as correlation coefficients for the isotherm equations that determined the adsorption process. In this investigation, the Freundlich and Langmuir isotherm models were used.

3.8 Langmuir Isotherm

The Langmuir isotherm is based on the assumption of homogeneous adsorption. The findings showed that, for the adsorption examined in this work, the Langmuir model performed better than the Freundlich model. This implied that there was homogeneity in the adsorption process. The highest amount of oxalic acid that could be adsorbed was (89.5 mg/g). Which exceeded or was equivalent to previously released data (Table 2). The Langmuir constants, b and q_{max}, which were associated with the adsorption energy and maximum adsorption capacity, respectively, were computed using the slope and intercept. The following equation represents the Langmuir isotherm, which shows monolayer adsorption (ASIF, et al.2024).

$$\frac{C_e}{q_e} = \frac{1}{q_{max}.b} + \frac{1}{q_{max}} .Ce \qquad (3)$$

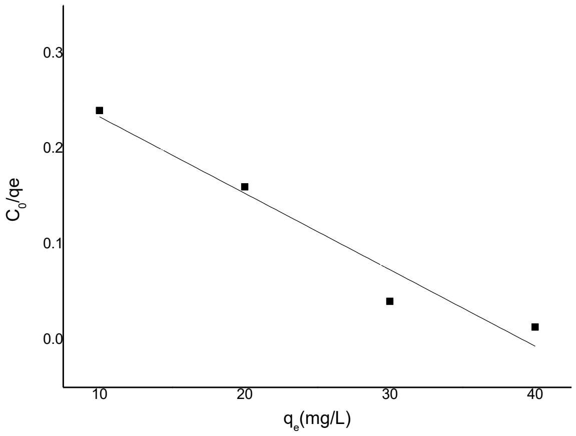

Figure. 7. Linear Langmuir isotherm adsorption of Oxalic acid onto Activated Carbon

The essential characteristics of the Langmuir isotherm can be expressed in terms of a dimensionless equilibrium parameter (R_L). This parameter is defined as follows;

$$R_L = \frac{1}{b_{CI}} \qquad (4)$$

where C_i is the initial concentration of Chromium (IV) The R_L value indicates that the adsorption is unfavorable: $R_L > 1$; linear: $R_L = 1$; favorable: $0 < R_L < 1$; or irreversible: $R_L = 0$. Table 1 lists the Langmuir and Freundlich isotherm model parameters and correlation coefficients for the adsorption of Oxalic acid ions on Activated Carbon. R_L was found to be 0.0037, 0.00018, 0.00012, and 0.0092. These results emphasized that the Langmuir isotherm was the best at describing the adsorption of Oxalic acid ions on the prepared Activated Carbon. The values of R_L were in the range of 0–1, which indicated that the adsorption of Oxalic acid onto the prepared Activated Carbon was favorable

3.9 Freundlich Isotherm

The Freundlich isotherm is an experimental model where K_f and n are Freundlich constants that represent adsorption capacity and adsorption intensity, respectively, and q_e represents the amount adsorbed per amount of adsorbent at equilibrium (mg/g), C_e represents the equilibrium concentration (mg/L), and so on. The adsorbate has an impact on them as well. One can determine the Freundlich equilibrium constants K_f and n by plotting ln q_e against log C_e which gives a straight line. The distribution of active centers on the surface and any factor that results in a decrease in the interaction between the adsorbent and the adsorbate with increasing surface density are explained by values of $n > 1$, which is the most common value and indicates that n values within the range of 1–10 are acceptable for adsorption. In the event that n falls between 1 and 10 (1/n is less than 1), oxalic acid have physically adhered to the silica fume ash. In the current investigation, n ranged from 1.1 to 10, indicating that metal ions were physically adsorbed onto the Activated Carbon. As seen in Fig. 8 and Table 2, it had a value of 1.11, and K_f had a value of 1.2. Equation (5) was used to compute the Freundlich constants K_f and n, (DIVAHAR, R., et al.2024)

$$\log q_e = \log K_f + \frac{1}{n} \log C_e \qquad (5)$$

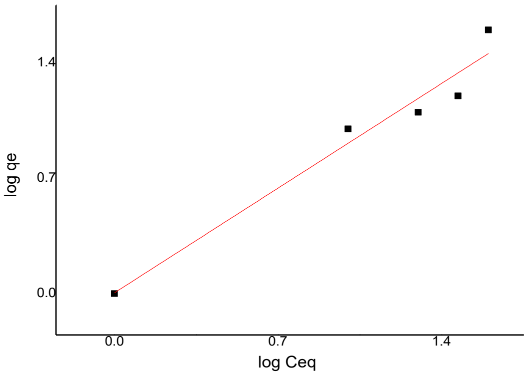

Figure. 8. Freundlich isotherm adsorption of Oxalic acid onto Activated Carbon

Table 2. Parameters of Langmuir and Freundlich isotherms for adsorption of Oxalic acid Activated Carbon

Langmuir			Freundlich		
q_{max} (mg/g)	b (L/mg)	R^2	n	K_f	R^2
89.5	0.08	0.98	1.11	1.20	0.94

3.10 Adsorption Kinetics

Kinetics of Adsorption A number of adsorption kinetic models, including the pseudo-first- and pseudo-second-order models, have been applied to comprehend the features and workings of adsorption, in addition to the rate-limiting phase in the process (Garg *et al*. 2023a,b).

$$ln(q_e - q_t) = lnq_e - k_1 \;.t \qquad (6)$$

where q_e and q_t (mg/g) are the amounts of Oxalic acid adsorbed onto Activated Carbon extracted from palm frond at equilibrium and time t, respectively; and K_1 (min^{-1}) is the rate constant of the pseudo-first-order kinetic model.

A straight line was obtained by plotting ln (q_e -q_t) against time. This straight line was used to determine -K_1, correlation coefficient R^2, and the theoretical value of q_e. Although the plot was linear and the calculated value (q_e, calc.) and experimental value (q_e, exp.) were not in agreement with each other, the values of the correlation coefficient for the pseudo-first-order kinetic model were smaller than those of the pseudo-second-order kinetic model. Thus, the adsorption kinetics for the pseudo-first-order kinetic model were poor, as shown in Fig. 9 and Table 3.

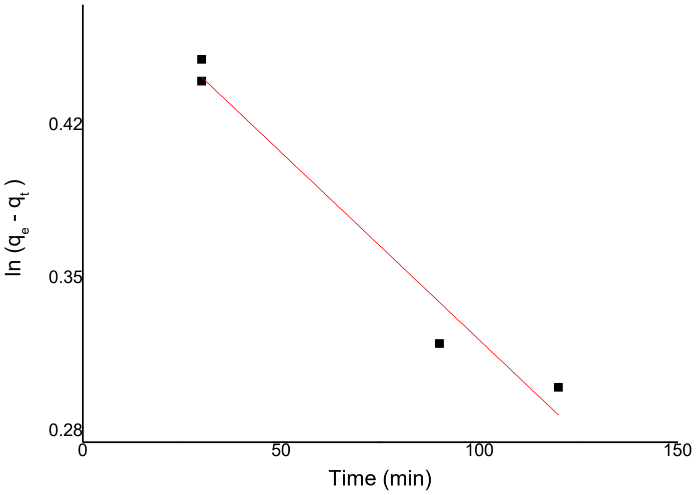

Figure. 9. Pseudo-first-order plot for adsorption of Oxalic acid ions onto Activated Carbon

Pseudo-second-order reaction

Second-order pseudo reaction. The chemisorption process, which involves the exchange of electrons between the adsorbate and adsorbent as a result of valence forces, is what drives the pseudo-second-order kinetic model of adsorption. The following relationship was used to assess equilibrium adsorption:

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

To ascertain the values of k_2 and qe, calc, Figure 10 was utilized. The behavior over the complete contact time range was more likely to be predicted by this model. The pseudo-second-order kinetic model's R^2 value was extremely near or even equal to unity, as seen in Table 3. Additionally, the experimental (q_e, exp.) values and the computed equilibrium adsorption capacity values (q_e, calc.) agreed closely, suggesting that the oxalic acid adsorption process onto Activated Carbon followed the pseudo-second-order model kinetics at all initial oxalic concentrations (ALKORBI *et al*. 2024)

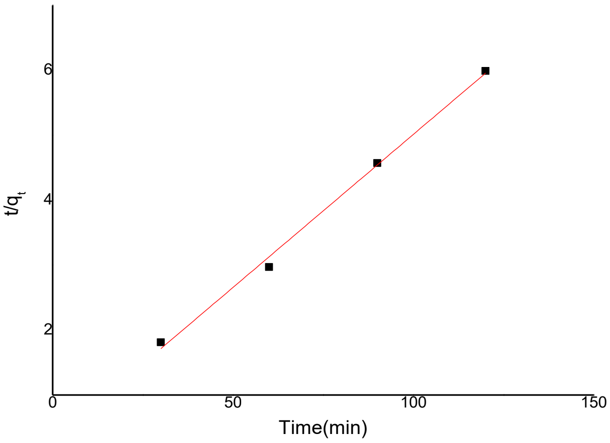

Figure. 10. Pseudo-second-order plot for adsorption of Oxalic acid ions onto activated carbon

Table 3. Kinetic parameters and correlation coefficients of two kinetic equations for different initial Oxalic acid concentrations on acid Activated Carbon

q_e.exp (mg/g)	First-order kinetic mode			Second-order kinetic mode		
	q_e,cal (mg/g)	K_1 (min)	R^2	q_e,cal (mg/g)	K_2 (g/g(min))	R^2
87.9	0.493	0.0017	0.95	85.9	0.16	0.99

3.11 Thermodynamic Parameters

The thermodynamic parameters that determined the process were the changes in the standard enthalpy (ΔH°), standard entropy (ΔS°), and standard free energy (ΔG°) due to the transfer of a unit mole of solute from the solution onto the solid–liquid interface. The values of ΔH° and ΔS° were calculated using the following equations:

$$lnkc = \frac{\Delta S}{R} - \frac{\Delta H}{RT} \qquad (8)$$

$$\Delta G = -RTlnK \qquad (9)$$

Where R is the universal gas constant (8.314 J/mol.K); T (K) is the absolute temperature in Kelvin, and Kc is the linear adsorption distribution coefficient, which is defined as follows: $K_c = C_o/C_e$, where C_o and C_e (mg/L) are the initial adsorbate concentration and concentration of the adsorbate remaining in the liquid phase at equilibrium, respectively. ΔG° is the free energy of adsorption, ΔH° (kJ/mol) is the enthalpy change, and ΔS° (J/mol. K)) is the entropy change.

The values of ΔH° and S° were calculated from the slope and intercept of the plot for log K versus Temp in Kelvin and it is shown in Figure 11. Table 4 lists the data that were gathered for the thermodynamic parameters. The exothermic character of the adsorption is indicated by the negative value of ΔH°. Furthermore, a negative value of ΔS° suggests that either an associative or dissociative mechanism may be at work during the adsorption reaction. When ΔS° is negative, it indicates that the adsorption process involved an associative mechanism. In this instance, the adsorption occurred as a result of the adsorbent and adsorbate forming an activated complex. The entropy ΔS° value's sign indicated whether the adsorbate's state at the solid/solution interface became more or less random (ΔS° > 0) as the adsorption process progressed. In contrast, a negative value for ΔG° with rising temperature suggested that the adsorption was spontaneous and that its spontaneous nature was inversely related to temperature. (Alsaiari *et al*. 2024).

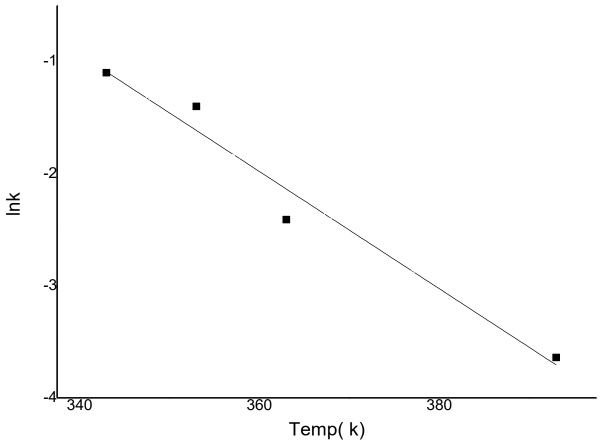

Figure. 11. Thermodynamic behavior of adsorption of Oxalic acid ions onto Activated Carbon

Table 4. Thermodynamic parameters for adsorption of Oxalic acid onto Activated Carbon

T (K)	%Removal	ΔG° (kJ/mol)	ΔH° (kJ/mol)	ΔS° (j/mol. k)
343	93	-62.73	-19.429	-13.6
353	90	-79.2		
363	95	-87.5		
393	98	-10.12		

Table 5. Previous studies as comparison with present sorbents

sorbents Adsorbent	Adsorption capacity Oxalic acid (mg/g)	References
Mg-Al LDH	573	ALKU Journal of Science 2024, Sayı 6(1): 80-95
Chicken egg shells	0.763	Journal of Biomedical Engineering and Informatics, 2016, Vol. 2, No. 2
Activated carbon produced from palm frond	89	Present study

4. Conclusion

The goal of this research is to demonstrate the innovative removal and purification of oxalic acid from polluted water sources using high-purity activated carbon derived from palm fronds. The chemical and structural properties of activated carbon were evaluated using various methods, revealing a specific surface area and pore size of 72.8345 m²/g, pore diameters of 1.8755 nm, and a pore volume of 0.068302 cm³/g. The removal of oxalic acid from aqueous solutions was then investigated. The strength of this research is that the activated carbon demonstrated excellent cycle adsorption performance with a dosage of 0.5 g/L, an initial activated carbon concentration of 40 mg/L, an equilibrium adsorption time of 90 minutes, and a chemisorption mechanism following pseudo-second-order kinetics. Activated carbon adsorption capability increases with temperature, with an optimal reaction temperature of 120°C. Adsorption was guided by both the Langmuir and Freundlich models, with the Langmuir model yielding the maximum predicted adsorption capacity of 89.79 mg/g. The novelty of this study is the process suggested appears to have potential applications in the manufacturing of natural adsorbents derived from various plants. The results show that activated carbon produced from palm fronds has a strong capability for eliminating toxic organic acids, such as oxalic acid, as a low-cost alternative to commercial adsorbents. This study is unique in that the proposed approach appears to have potential uses in the production of natural adsorbents obtained from various plants. The results show that activated carbon made from palm fronds can effectively remove harmful organic acids like oxalic acid, making it a cheaper option compared to commercial adsorbents. Future possibilities can be expanded by claiming that the adsorption performance of activated carbon mesoporous materials was superior, despite the fact that only oxalic acid was tested in this study. A recommendation. Future research is expected to look into the removal of mixed organic acids from polluted water sources and wastewater using activated carbon derived from palm fronds, which is an affordable and widely available adsorbent for extracting organic acids from wastewater. Its enormous surface area makes it an ideal material for a variety of applications, including catalysts and adsorbents.

Conflict of Interest

All authors approve the final manuscript and declare that there is no conflict of interest. The data that support the findings of this study are available from the corresponding author upon reasonable request.

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