The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering and Mathematics (EPSTEM), 2025

Volume 37, Pages 474-486

ICEAT 2025: International Conference on Engineering and Advanced Technology

Modeling of the Adsorption Process of the Organic Pollutant from Synthetic Wastewater Using Different Adsorbents

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Abstract: In the field of water and wastewater treatment, several simplified models of fixed-bed dynamics, such as the Thomas and Yoon–Nelson models, are commonly used by researchers to fit adsorption breakthrough data. This study presents experimental data on the removal of oil and COD from synthetic wastewater using fixed-bed adsorption with various adsorbents, including powdered and granular activated carbon (PAC and GAC) and silica gel. The data were fitted using the Thomas and Yoon–Nelson models. Both models were applied to a fixed-bed column under varying inlet flow rates (1, 2, and 3 mL/min) and initial concentrations of oil (100, 600, and 800 ppm) and COD (2250, 14500, and 25000 ppm) to evaluate the performance of the adsorbents. The results showed that the Thomas model accurately described the adsorption behavior of oil and COD on all adsorbents. Notably, PAC achieved the highest correlation coefficients, with R^2 values of 0.97 for oil and 0.94 for COD, compared to the Yoon–Nelson model, which yielded R^2 values of 0.89 and 0.83 under a flow rate of 3 mL/min and initial concentrations of 50 ppm for oil and 1400 ppm for COD.

Keywords: Adsorption, Fixed bed column, Thomas model, Wastewater, Yoon-Nelson model

Introduction

One of the major global challenges is the continuous growth of the world population, which has significantly increased the demand for resources such as food, energy, and most importantly, clean water. This rising demand puts pressure on existing water sources and highlights the urgent need for sustainable water management and efficient wastewater treatment solutions (Hizkiyahu et al., 2025; Biswas et al., 2025). Water pollution caused by organic contaminants, especially from industrial wastewater, has become a critical environmental concern. As a result, many researchers are exploring various wastewater treatment methods to remove impurities such as organic and inorganic compounds, dyes, heavy metals, and solid wastes (Khader et al., 2024; Khader et al., 2022; Khader et al., 2021). The persistence and toxicity of these pollutants in wastewater require effective treatment technologies. Among these, adsorption has gained significant attention because of its simplicity, cost-effectiveness, and its ability to remove a wide range of contaminants using both batch and column systems. The adsorption process occurred where a substance (adsorbate) accumulates on the surface of another (adsorbent), is a fundamental phenomenon with applications in environmental cleanup, chemical separation, and catalysis

(Khader et al., 2022; Ali et al., 2024; Khader et al., 2023). To use the adsorption process in purification applications, it is essential to understand its mechanisms, including the mathematical modeling developed to illustrate and predict the breakthrough curve of the system (Khudhur et al., 2023; Khader et al., 2021). Developing and applying these models provides a quantitative framework for describing the kinetics and equilibrium of adsorption, helping researchers and engineers optimize system design and performance (Juela et al., 2021). Several analytical kinetic models have been adapted and developed for fixed bed systems to fit experimental breakthrough data under different kinetic parameters, such as Thomas, Yoon-Nelson, Bohart-Adams, Clark, Modified dose-response, and Wolborska models (Majd et al., 2022; Khazaal et al., 2022). Models like Bohart-Adams, Thomas, and Yoon-Nelson are often favored for their simplicity, although modifications are frequently needed to account for asymmetry in experimental data. The Thomas and Yoon–Nelson models were selected due to their simplicity, minimal data requirements, and wide applicability in fixed-bed column studies. Unlike the Bohart–Adams model, which primarily describes the initial part of the breakthrough curve, the Thomas and Yoon–Nelson models provide a more comprehensive description of the entire adsorption process, making them more suitable for performance prediction and design purposes. Advanced models incorporate factors like mass transfer, axial dispersion, and surface heterogeneity to improve predictive accuracy (Apiratikul & Chu, 2021; Omitola et al., 2022).

This study aims to recommend suitable mathematical models for the dynamic adsorption of synthetic wastewater containing light oil and Chemical Oxygen Demand (COD) into adsorbents, particularly powder and granular activated carbon (PAC, GAC), and silica gel. Additionally, the research analyzes the breakthrough curves using Thomas and Yoon–Nelson models, to identify the most appropriate model for analyzing the dynamic behavior in a continuous-flow fixed-bed column under different operating conditions, including inlet flow rates (1, 2, and 3 mL/min), oil concentrations (100, 600, and 800 ppm), and COD concentrations (2250, 14500, and 25000 ppm).

Materials and Methods

Adsorbents

The adsorbent, silica gel was purchased from Macherey-Nagel, Germany. The adsorbents, in both powdered and granular forms of activated carbon were obtained from Merck, Netherlands. All materials were used as received without further purification and were only dried at 60°C the remove all humidity. The Brunauer–Emmett–Teller (BET) method was employed to characterize their properties, as presented in Table 1.

Table 1. Properties of PAC, GAC, and silica gel adsorbents.

Properties	PAC	GAC	Silica gel
BET (m^2/g)	850	500	625
Pore diameter (nm)	3	3.2	3.5
Pore volume (cm^3/g)	0.76	0.61	0.7

Preparation of Wastewater

Distilled water and light oil were combined to create wastewater samples. Homogenizer equipment (CT13308, CROWN, China) was used to blend the mixture for 15 minutes at 15,000 rpm in order to achieve a regular diffusion of water and oil. The necessary concentrations of wastewater have been prepared in samples. An oil content analyzer (OCMA-550 Oil Content Analyzer, HORIBA, Australia) was used to measure the wastewater oil, and a COD analyzer (Thermoreactor RD 125, Lovibond, Germany) was used to measure the COD.

Experiments of Fixed-Bed Column Adsorption

A Pyrex glass tube with an inside diameter of 2 cm and a height of 30 cm was used as the fixed-bed column in which the continuous adsorption process was investigated. To stop the loss of adsorbents, a layer of glass wool was positioned at the bottom of the column. A peristaltic pump was used in fixed-bed adsorption to pump a sample of the generated water up from a container to the top of the column in order to prevent channeling from gravity. Samples were taken periodically from the bottom of the column. Figure 1 illustrates the schematic diagram of the continuous adsorption process.

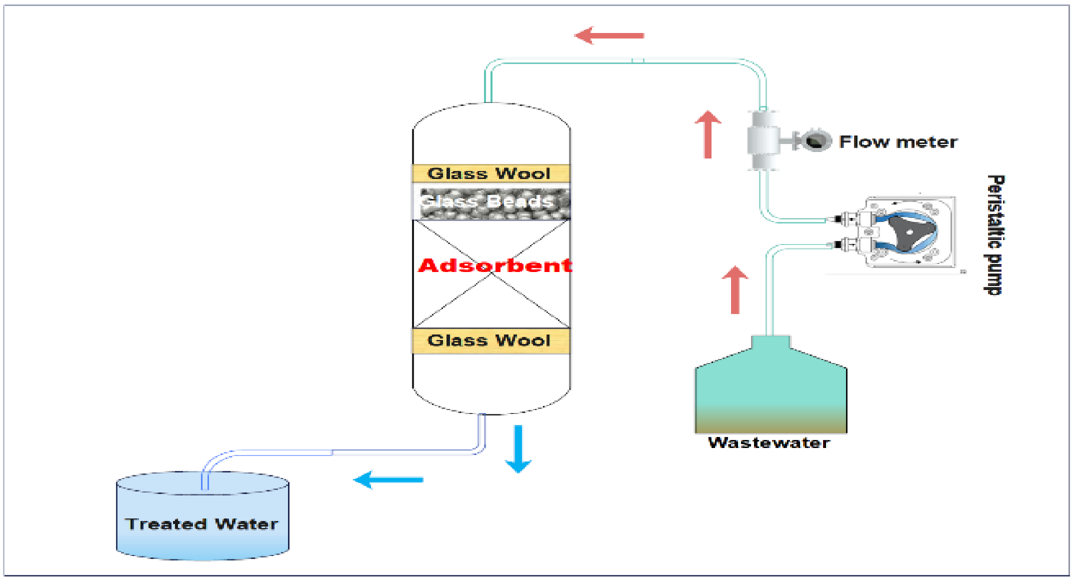


Figure 1. Schematic of the experiment setup of the fixed-bed adsorption column.

Modeling and Analysis of Column Data

To predict the breakthrough behavior and describe the adsorption performance of the fixed-bed column system, the experimental results are analyzed using the Thomas and Yoon–Nelson models. These models are widely applied to simulate and predict breakthrough curves in adsorption processes and provide key parameters for fixed-bed continuous systems, serving as a foundation for designing practical, large-scale applications (Gong et al, 2015; Salman et al., 2011).

Thomas Model

Modeling the key behavior of fixed-bed adsorption systems is crucial for designing and optimizing industrial-scale separation and purification processes. The Thomas model, developed by Thomas (1944), is one of the most widely used theoretical frameworks for predicting breakthrough curves in continuous flow adsorption systems (Dima et al, 2024). It assumes second-order reversible reaction kinetics based on the Langmuir isotherm and ignores axial dispersion and external mass transfer limitations, making it particularly useful for systems operating under ideal plug flow conditions (Al Kindi et al., 2023). Using a mathematical model to describe the breakthrough performance of a fixed bed column system is necessary. The Thomas model suggests that adsorption equilibrium is best represented by the Langmuir isotherm and that the adsorption process follows pseudo second-order reversible reaction kinetics (Chen et al., 2012). The Thomas model can be written in linear form as shown below (Chu, 2020):

$$\ln\left(\frac{C_o}{C_t} - 1\right) = \frac{k_{TH}\, q_o\, m}{Q} - k_{TH}\, C_o\, t$$

where C_0 and C_t represent the initial and final concentration of oil or COD (mg/L), k_{TH} is the Thomas model constant (mL/min.mg), q_o is the maximum adsorption capacity of the bed (mg/g), m is the adsorbent mass (g), Q is the volumetric flow rate (mL/min) and t is the total flow time (min). The values of k_{th} and q_o can be calculated by the linear plot of ln ((C_0/C_t)-1) Vs. t.

Yoon-Nelson Model

The Yoon–Nelson model, developed in 1984 by Yoon and Nelson, is considered one of the simplest models for describing breakthrough behavior in fixed-bed adsorption systems. It is valued for its straightforward approach, as it does not require detailed information about the physical properties of the adsorbent, the characteristics of the adsorbate, or the design parameters of the adsorption bed (Yagub et al., 2015; Belat et al., 2022; Baral et al., 2009). The model assumes that the rate of decrease in the probability of adsorption for each adsorbate molecule is proportional to both the probability of adsorption and the probability of breakthrough. The linear form of the Yoon–Nelson model is given by the following equation (Belat et al., 2022):

$$ln\left(\frac{C_t}{C_o - C_t}\right) = k_{YN}\, t - \tau k_{YN}$$

Where τ is the time (min) calculated by an intercept of the linear plot $ln\left(\frac{C_t}{C_o - C_t}\right)$ Vs. t (min), which is required for 50% adsorbate breakthrough. The rate constant (k_{YN} min^{-1}) of this model can be calculated from the slope of the plot.

Results and Discussion

Adsorption modeling using Powdered Activated Carbon (PAC)

Regarding PAC, the experimental data were applied to the Thomas model and Yoon-Nelson model at several flow rates (1, 2, and 3 mL/min) and initial concentrations of oil and COD of 50 ppm and 1400 ppm in wastewater, respectively. For the Thomas model, the associated parameters with this model, such as the Thomas rate constant (k_{th}), the maximum solid phase concentration of oil and COD (q_o, in mg/g) and R^2 values were calculated from the plot of ln ((C_o /C_t) -1) Vs. t as demonstrated in Figure 2. Results indicated that the plots are significantly linear at high flow rates of oil and all studied flow rates of COD, having a high value of R^2, which advocated for the validity of this model. The Yoon-Nelson model was also applied to the experimental data by plotting ln (C_t/(C_o-C_t)) Vs. t. The result of the Yoon-Nelson model is represented in Figure 3, and the plots corresponding to the different flow rates are shown. The plot does not exhibit linearity at all flow rates because it is not supported by a high value of the correlation coefficient. Thomas' model is better at fitting the experimental data than the Yoon-Nelson model at different flow rates. But, both the Thomas model and Yoon-Nelson model at different concentrations are valid with a high value of correlation factor as shown in Figures 4 and 5, respectively.

Table 2 presents the kinetic parameters for oil and COD adsorption onto PAC using the Thomas and Yoon–Nelson models in a fixed-bed column. It noted that the Thomas model demonstrated strong agreement with experimental data, with R^2 values ranging from 0.8942 to 0.9782 for oil and 0.9117 to 0.9644 for COD. Increasing the flow rate (from 1 to 3 mL/min) led to an increase in both the rate constant (k_{TH}) and adsorption capacity (q_o), indicating improved mass transfer due to reduced contact time. The adsorption capacity also increased significantly with higher inlet concentrations, particularly for COD, reaching up to 586.230 mg/g, suggesting that PAC possesses a high number of available active sites for pollutant removal.

Table 2. Kinetic modeling parameters of oil and COD adsorption onto PAC in a fixed-bed column using Thomas and Yoon–Nelson models.

Kinetic model	Flow rate (mL/min)			Oil concentration (ppm)		
	1	2	3	100	600	800
Thomas						
k_{TH} ×10^4 (ml/min/mg)	9.8	13.28	21.5	5.41	0.98	0.679
q_o ×10^{-2} (mg/g)	29.51	34.72	28.96	45.34	178.45.	278.53
R^2	0.8942	0.9587	0.9705	0.9337	0.9758	0.9782
Yoon–Nelson						
k_{YN} (min^{-1})	7.98	7.81	8.1	5.54	6.29	6.87
τ ×10^{-2} (min)	3.75	6.88	9.87	7.56	46.49	78.69
R^2	0.8639	0.8975	0.8919	0.8723	0.9171	0.9585
	Flow rate (mL/min)			COD concentration (ppm)		
	1	2	3	2250	14500	25000
Thomas						
k_{TH} ×10^4 (ml/min/mg)	0.349	0.431	0.695	0.194	0.0479	0.0285
q_o ×10^{-3} (mg/g)	77.716	90.328	76.505	110.728	374.836	586.230
R^2	0.9407	0.9117	0.9432	0.9492	0.9585	0.9644
Yoon–Nelson						
k_{YN} (min^{-1})	8.08	6.40	6.60	6.54	6.51	6.77
τ ×10^{-2} (min)	3.76	6.90	9.88	191.18	1050.40	2257.50
R^2	0.883	0.8037	0.8369	0.8308	0.8993	0.9591

Furthermore, the Yoon–Nelson model showed reasonable predictive performance, with R^2 values between 0.8639 and 0.9585 for oil and 0.8037–0.9591 for COD. The breakthrough time (τ) increased with higher concentrations, indicating a longer effective usage time of the column before saturation. Higher (k_{YN}) values at initial stages reflect faster adsorption rates, followed by gradual stabilization. Therefore, the finding appeared that the Thomas model provided a more accurate fit to the experimental data, and PAC showed superior performance for both oil and COD removal, confirming its high adsorption efficiency and suitability for practical applications.

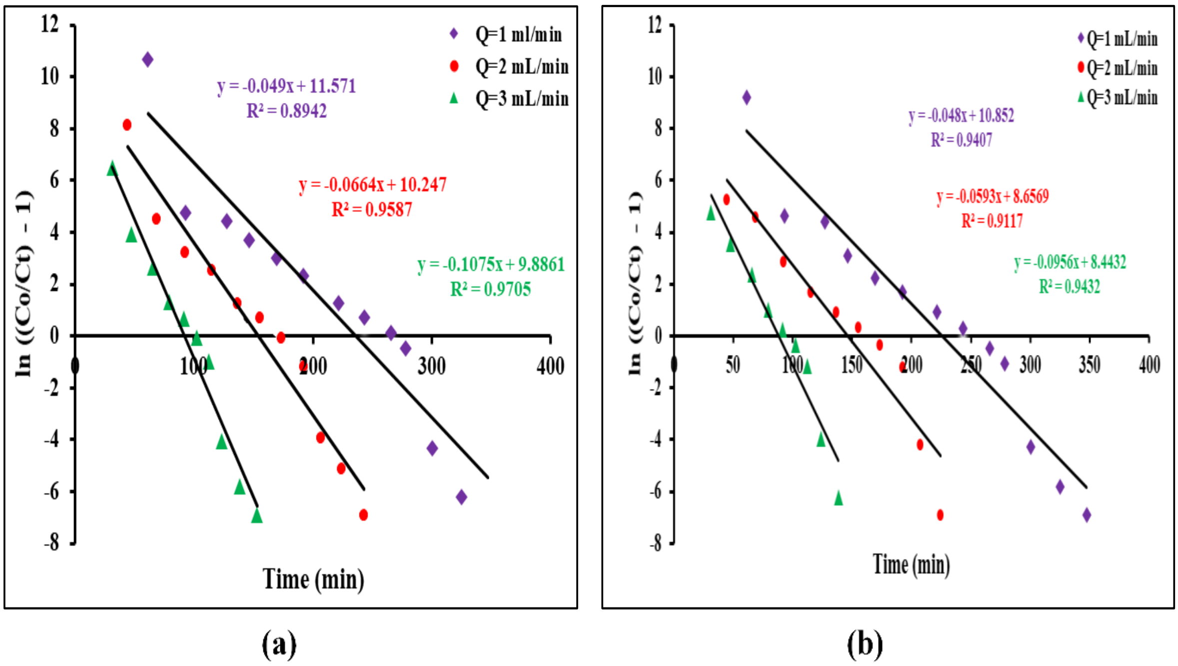


Figure 2. Thomas' kinetic model for (a) oil adsorption and (b) COD adsorption by PAC at different flow rates and initial oil concentration = 50 ppm and COD concentration = 1400 ppm.

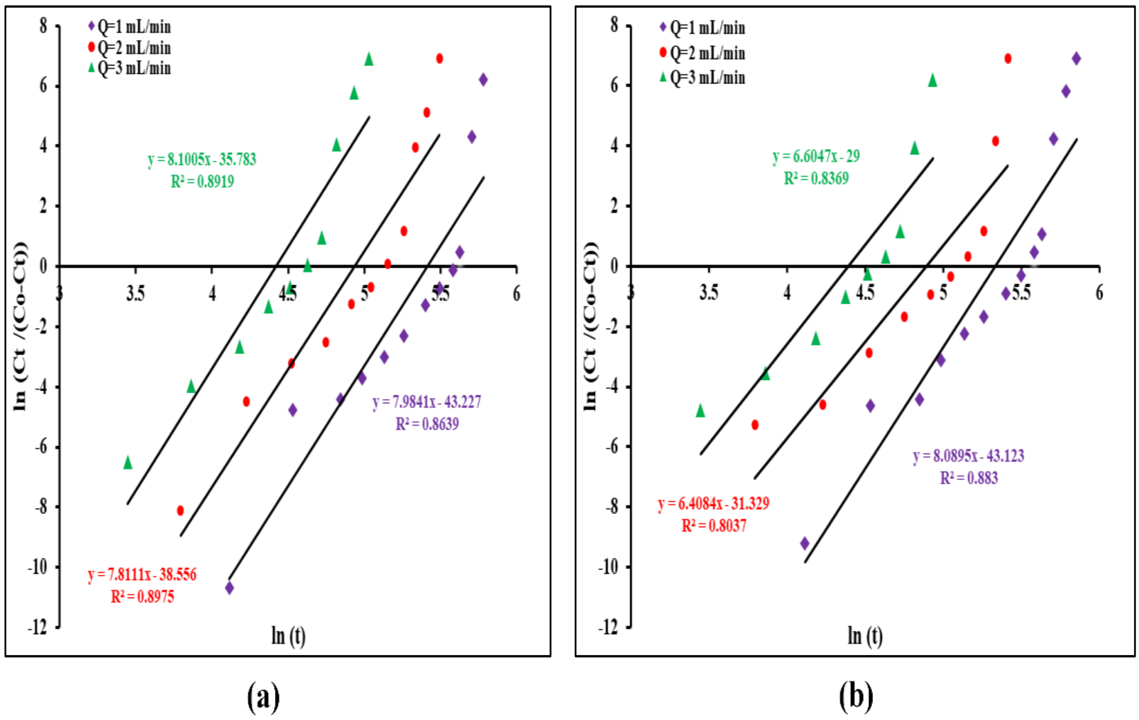
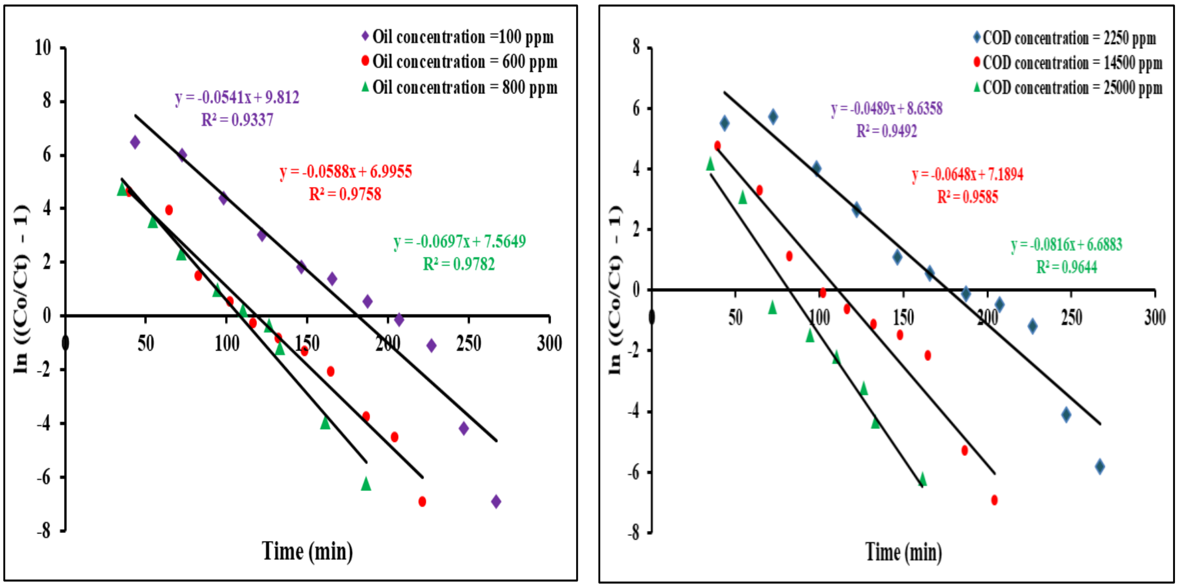
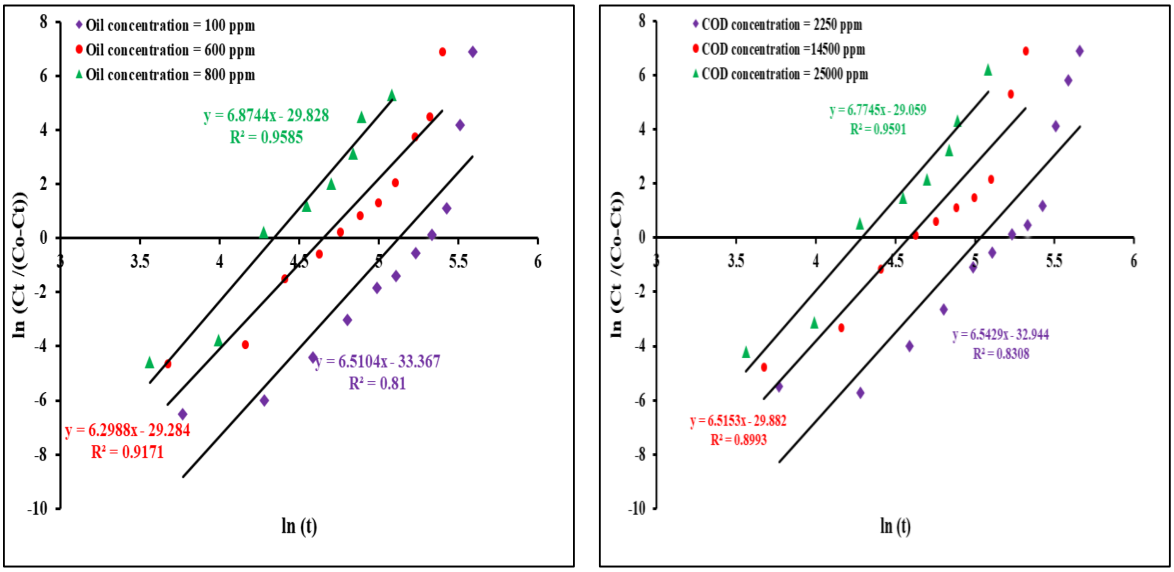


Figure 3. Yoon-Nelson s' kinetic model for (a) oil adsorption and (b) COD adsorption by PAC at different flow rates and initial oil concentration = 50 ppm and COD concentration = 1400 ppm.



(a) **(b)**

Figure 4. Thomas' kinetic model for (a) oil adsorption and (b) COD by PAC at different initial concentrations and flow rates = 1 mL/min.



(a) **(b)**

Figure 5. Yoon-Nelsons' kinetic model for (a) oil adsorption and (b) COD by PAC at different initial concentrations and flow rates = 1 mL/min.

Adsorption Modeling Using Granular Activated Carbon (GAC)

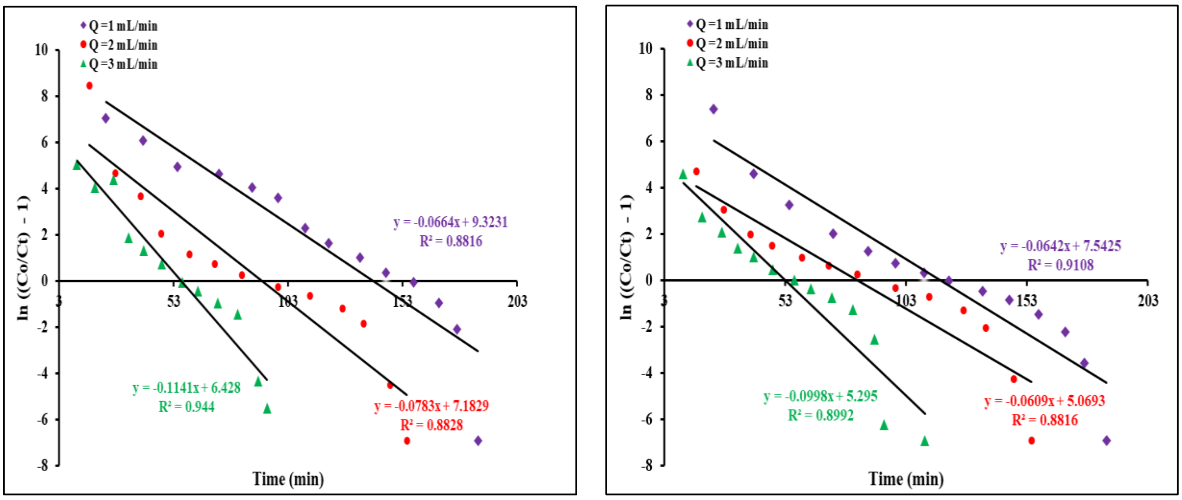
The adsorption kinetic data were also applied to the Thomas model and the Yoon-Nelson model at different flow rates (1, 2, and 3 mL/min), initial oil concentrations of 50 ppm and initial COD concentration of 1400 ppm. The various parameters associated with the Thomas model, such as Thomas rate constant (k_{th}), maximum solid phase concentration of oil and COD (q_o, in mg/g), and R^2 values, were calculated from the plot of ln ((C_o /C_t) -1) Vs. t (Figure 6) at different flow rates. Results indicated that the plots are significantly linear at high flow rates of oil and low flow rates of COD, having a high value of R^2, which advocated for the validity of this model.

The Yoon-Nelson model was also applied to the experimental data by plotting ln (C_t/(C_o-C_t)) Vs. t. The result of the Yoon-Nelson model is represented in Figure 7, and the plots corresponding to the different flow rates are shown. The plot does not exhibit linearity at all flow rates because that is not supported by a high value of the correlation coefficient. Thomas' model is better at fitting the experimental data than the Yoon-Nelson model at different flow rates. Whereas Thomas' model at different concentrations is valid with a high value of correlation factor, the Yoon-Nelson model is valid at high concentrations as shown in Figures 8 and 9, respectively.

Table 3 presents kinetic parameters for oil and COD adsorption using GAC under similar experimental conditions. It was observed that the Thomas model showed good accuracy with R^2 ranging from 0.8816 to 0.9675 for oil and from 0.8816 to 0.9622 for COD. The increase in k_{Th} with flow rate (up to 22.82×10⁴ mL/min/mg) confirms improved external mass transfer under higher flow conditions. Adsorption capacity (q_o) also increased with higher concentrations, confirming GAC's strong pollutant uptake ability. Regarding the Yoon–Nelson model, the fit was acceptable but slightly lower than that of Thomas. R^2 for oil ranged from 0.7394 to 0.9071, and for COD from 0.7946 to 0.9176. Higher values of τ at increased concentrations suggest that effective column usage time is extended with higher inlet loads. The kinetic constant (k_{YN}) values supported fast initial adsorption followed by slower breakthrough phases. Therefore, it was noted from the results that the GAC demonstrated reliable adsorption performance, especially at higher concentrations. The Thomas model gave a better fit than Yoon–Nelson, supporting its use for GAC-based column modeling.

Table 3. Kinetic modeling parameters of oil and COD adsorption onto GAC in a fixed-bed column using Thomas and Yoon–Nelson models.

Kinetic model	Flow rate (mL/min)			Oil concentration (ppm)		
	1	2	3	100	600	800
Thomas						
k_{TH} ×10^4 (ml/min/mg)	13.28	15.66	22.82	7.96	1.12	1.22
q_o ×10^{-2} (mg/g)	17.55	20.64	17.74	27.03	104.11	89.68
R^2	0.8816	0.8828	0.944	0.9315	0.9085	0.9675
Yoon–Nelson						
k_{YN} (min^{-1})	5.1691	5.2904	4.4805	5.9854	3.6886	4.2753
τ ×10^{-2} (min)	3.82	7.07	10.18	7.78	48.17	84.47
R^2	0.7394	0.8953	0.8462	0.8816	0.8276	0.9071
	Flow rate (mL/min)			COD concentration (ppm)		
	1	2	3	2250	14500	25000
Thomas						
k_{TH} ×10^4 (ml/min/mg)	0.46	0.44	0.72	0.26	0.50	0.045
q_o ×10^{-2} (mg/g)	403.85	515.04	459.59	634.98	2134.73	2424.40
R^2	0.9108	0.8816	0.8992	0.9263	0.935	0.9622
Yoon–Nelson						
k_{YN} (min^{-1})	5.3604	3.8772	4.19	4.9779	3.7535	4.2797
τ ×10^{-2} (min)	106.60	196	282.43	196.15	1092.83	2426.14
R^2	0.8786	0.7946	0.7809	0.85428	0.8651	0.9176



(a) **(b)**

Figure 6. Thomas' kinetic model for (a) oil adsorption and (b) COD adsorption by GAC at different flow rates and initial oil concentration = 50 ppm and COD concentration = 1400 ppm.

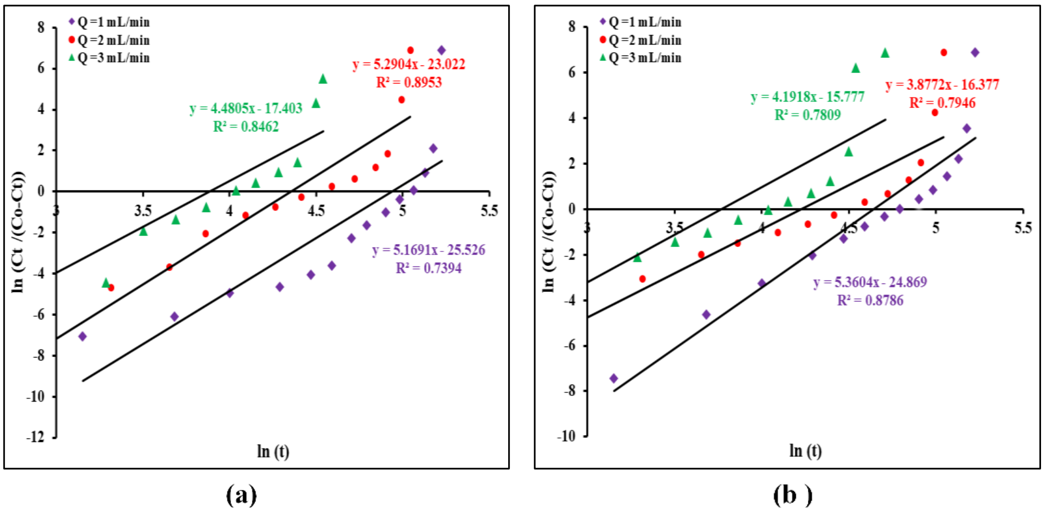


Figure 7. Yoon-Nelsons' kinetic model for (a) oil adsorption and (b) COD adsorption by GAC at different flow rates and initial oil concentration = 50 ppm and COD concentration = 1400 ppm.

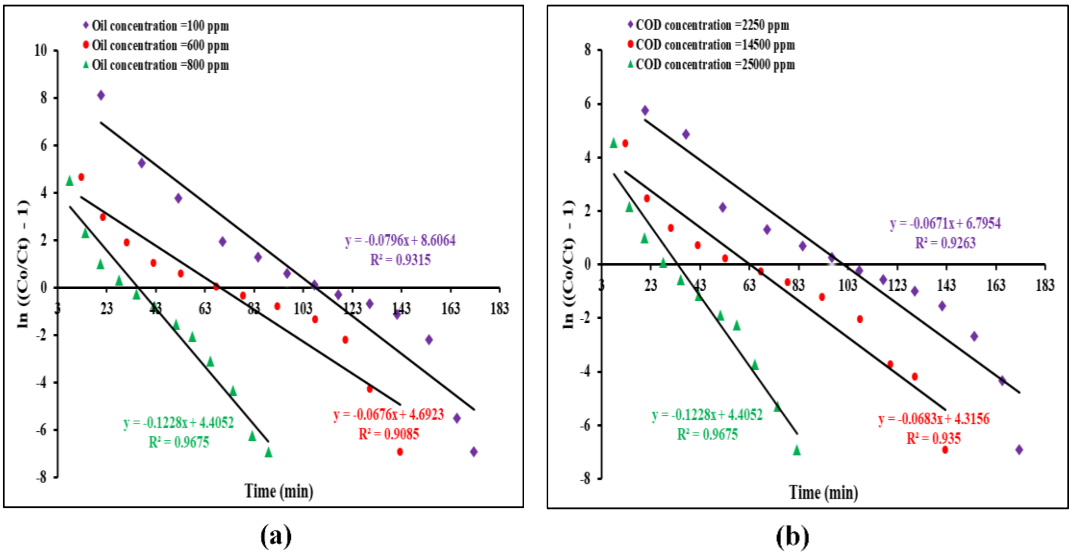


Figure 8. Thomas' kinetic model for (a) oil adsorption and (b) COD by GAC at different initial concentrations and flow rates = 1 mL/min.

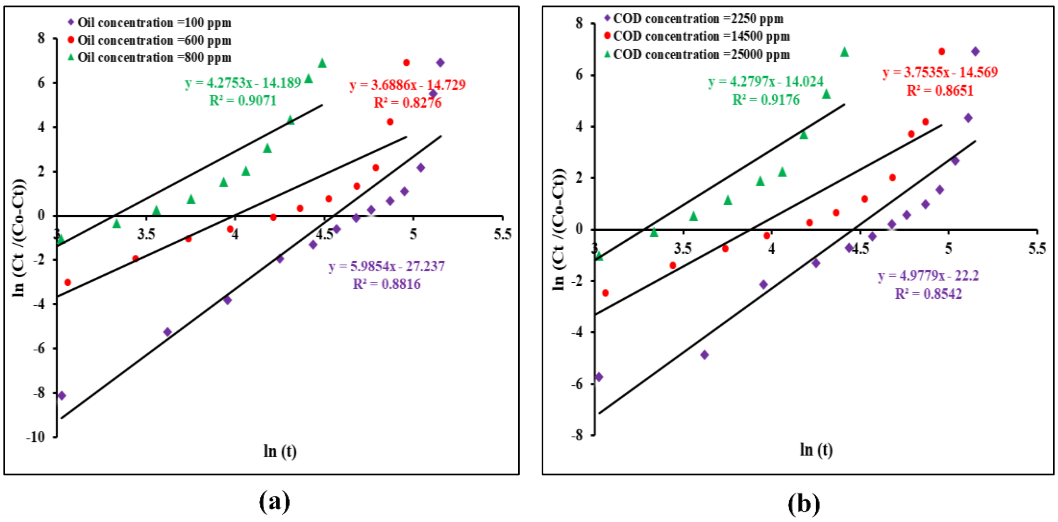


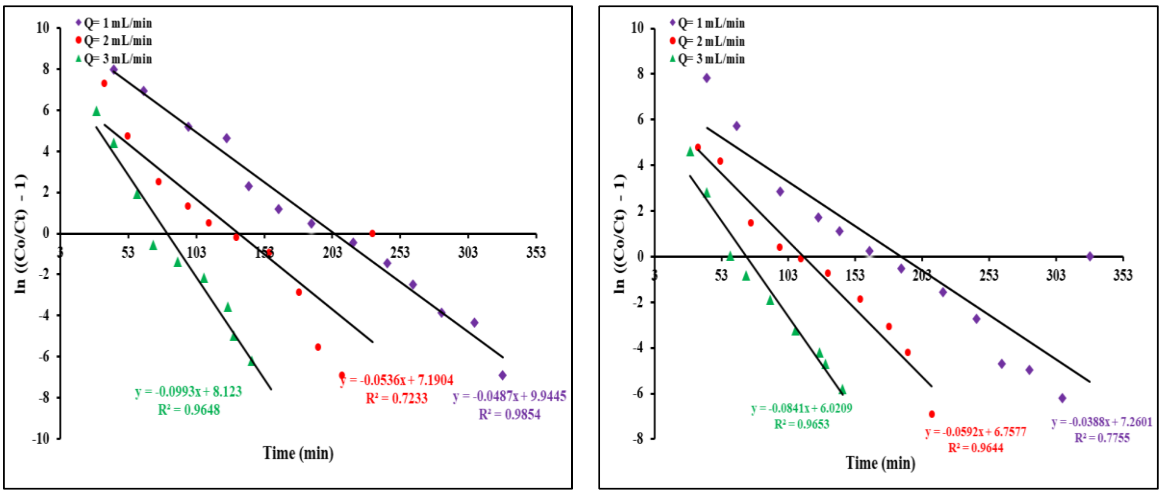
Figure 9. Yoon-Nelsons' kinetic model for (a) oil adsorption and (b) COD by GAC at different initial concentrations and flow rates = 1 mL/min.

Adsorption Modeling Using Silica Gel

The adsorption kinetic data were also applied to the Thomas model and Yoon-Nelson model at the different flow rates (1, 2, and 3 mL/min) and at initial oil concentration of 50 ppm and 1400 ppm initial COD concentration. The various parameters associated with the Thomas model, such as Thomas rate constant (k_{TH}), maximum solid phase concentration of oil and COD (q_o, in mg/g), and R^2 values, were calculated from the plot of ln ((Co /Ct) -1) Vs. t (Figure 10) at different flow rates. Results indicated that the plots are significantly linear at high flow rates of oil and COD, having a high value of R^2, which advocated for the validity of this model. The Yoon-Nelson model was also applied to the experimental data by plotting ln ($C_t/(C_o-C_t)$) Vs. t. The result of the Yoon-Nelson model is represented in Figure 11, and the plots corresponding to the different flow rates are shown. The plot also exhibits linearity at all flow rates, which is supported by a high value of the correlation coefficient. At the same time, both the Thomas model and the Yoon-Nelson model at different concentrations are valid with a high value of correlation factor, as shown in Figures 12 and 13, respectively. Table 4 presents the kinetic constants for oil and COD adsorption on silica gel at various flow rates and inlet concentrations. The Thomas model demonstrated strong fitting capability: for COD, R^2 values ranged from 0.8702 to 0.9821, while for oil, they ranged from 0.723 to 0.9778. The adsorption capacity (q_o) increased with an increase in concentration, reaching 148.64 mg/g for oil and 3521.44 mg/g for COD, indicating good performance of silica gel under higher pollution loads.

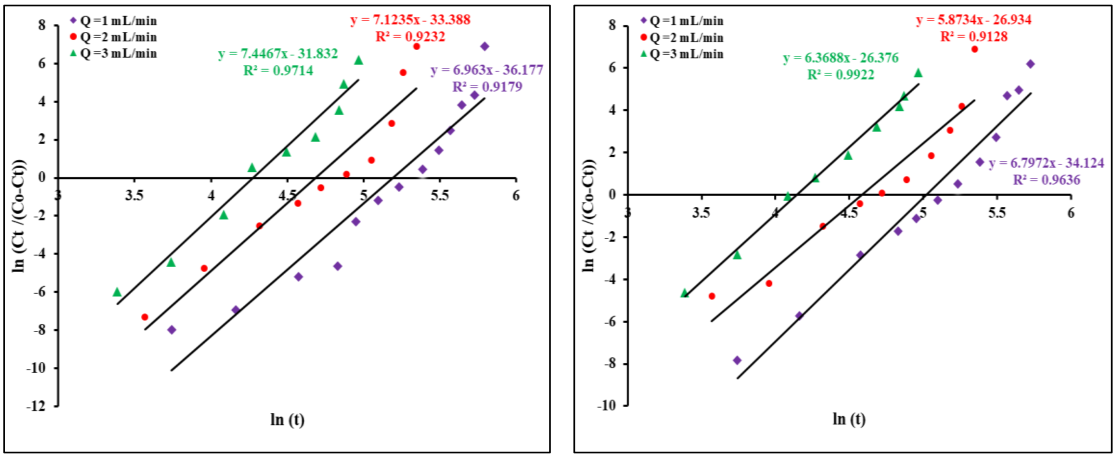
Table 4. Kinetic modeling parameters of oil and COD adsorption onto silica gel in a fixed-bed column using Thomas and Yoon–Nelson models.

Kinetic model	Flow rate (mL/min)			Oil concentration (ppm)		
	1	2	3	100	600	800
Thomas						
$k_{TH}\times10^4$ (ml/min/mg)	9.6	10.6	19.86	5.2	1.03	0.87
$q_o\times10^{-3}$ (mg/g)	25.88	30.52	25.76	34.77	129.37	148.64
R^2	0.985	0.723	0.9648	0.9411	0.9757	0.9778
Yoon–Nelson						
k_{YN} (min^{-1})	7.12	6.96	7.44	5.34	5.27	5.68
$\tau\times10^{-2}$ (min)	3.86	6.81	9.95	7.70	47.37	80.71
R^2	0.9232	0.9179	0.9714	0.7912	0.952	0.9616
	Flow rate (mL/min)			COD concentration (ppm)		
	1	2	3	2250	14500	25000
Thomas						
$k_{TH}\times10^4$ (ml/min/mg)	0.282	0.430	0.611	0.209	0.046	0.029
$q_o\times10^{-3}$ (mg/g)	643.20	706.23	620.17	808.78	2840.44	3521.44
R^2	0.9775	0.9644	0.9653	0.9821	0.9726	0.8702
Yoon–Nelson						
k_{YN} (min^{-1})	5.87	6.36	6.79	5.65	5.37	5.85
$\tau\times10^{-2}$ (min)	3.88	7.16	9.61	194.08	1068.63	2328.53
R^2	0.9128	0.9922	0.9636	0.9027	0.944	0.9756



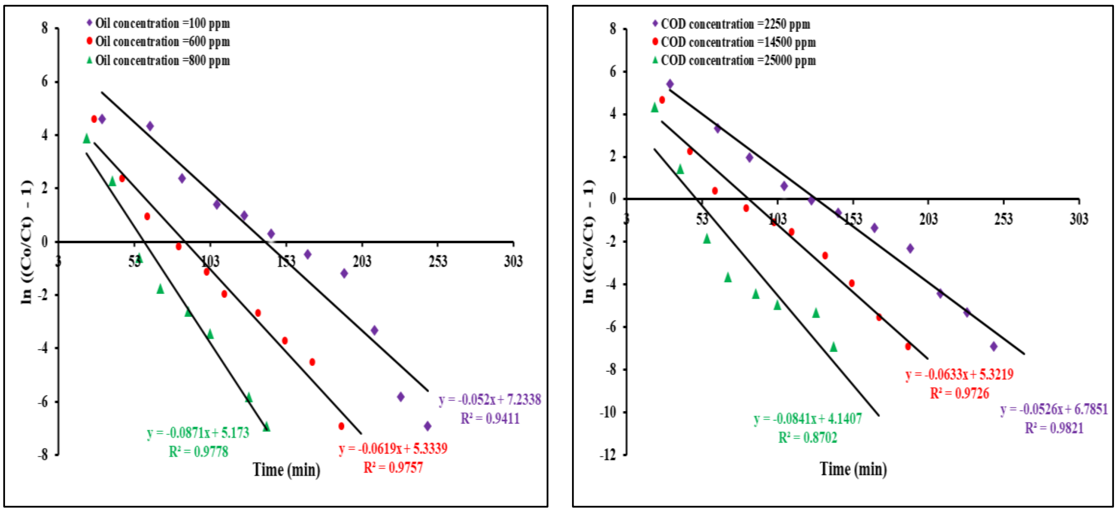
(a) **(b)**

Figure 10. Thomas' kinetic model for (a) oil adsorption and (b) COD adsorption by silica gel at different flow rates and initial oil concentration = 50 ppm and COD concentration = 1400 ppm.



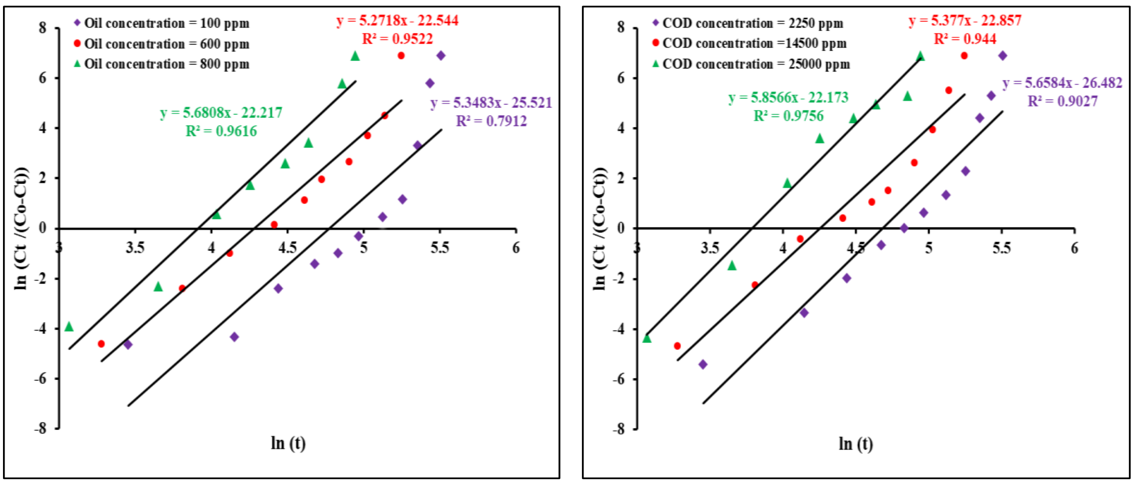
(a) **(b)**

Figure 11. Yoon-Nelsons' kinetic model for (a) oil adsorption and (b) COD adsorption by silica gel at different flow rates and initial oil concentration = 50 ppm and COD concentration = 1400 ppm.



(a) **(b)**

Figure 12. Thomas' kinetic model for (a) oil adsorption and (b) COD by silica gel at different initial concentrations and flow rates = 1 mL/min.



(a) **(b)**

Figure 13. Yoon-Nelsons' kinetic model for (a) oil adsorption and (b) COD by silica gel at different initial concentrations and flow rates = 1 mL/m

In regard to the Yoon–Nelson model, it also showed reliable performance with R^2 values >0.91 for COD and between 0.7912 and 0.9616 for oil. Breakthrough time (τ) increased with higher pollutant concentrations, indicating that higher loads can be handled effectively before the bed becomes saturated. The values of k_{YN} reflect fast kinetics at low concentrations, with a gradual reduction due to site saturation. Therefore, silica gel showed good adsorption potential, especially under high pollutant concentrations. These findings demonstrate that the Thomas model was more accurate than the Yoon–Nelson model, highlighting its ability to describe silica-based fixed-bed systems.

The comparison between the Thomas and Yoon–Nelson models revealed that the Thomas model provided a better fit to the experimental breakthrough data in most cases. This superior performance suggests that the adsorption process may follow pseudo-second-order kinetics and is significantly influenced by external and internal mass transfer mechanisms, as assumed by the Thomas model. In contrast, the Yoon–Nelson model, being more empirical and based on a simplified probabilistic approach, lacks consideration of such kinetic and transport phenomena, which may limit its predictive accuracy for complex adsorption systems. Therefore, the better performance of the Thomas model implies that the adsorption process is not solely governed by surface interactions but also by diffusion-controlled mechanisms, supporting the assumption of mass transfer limitations during the adsorption onto the examined material. Similar conclusions were reported by Lissy et al., 2025, who demonstrated that the Thomas model accurately described the breakthrough behavior of adsorbates due to its incorporation of kinetic and mass transfer effects, unlike the Yoon–Nelson model, which oversimplified the system dynamics.

The performance of adsorption models such as Thomas and Yoon–Nelson varies depending on the type of adsorbent and the operating conditions due to differences in adsorption kinetics, surface characteristics, and mass transfer mechanisms. Among the three adsorbents, PAC exhibited the best adsorption performance for both oil and COD due to its high surface area and microporous structure, typically exhibiting faster adsorption rates and greater capacity compared to silica gel, which has a more uniform but less porous surface. These differences affect how closely the assumptions of each model align with the actual behavior of the system. For example, the Thomas model, which assumes plug flow and second-order kinetics, may fit PAC data better under certain conditions due to the faster kinetics and more significant influence of mass transfer. Similarly, changes in flow rate and inlet concentration influence the contact time and saturation dynamics, which can shift the model's accuracy. Therefore, model performance is not only a function of mathematical formulation but also of how well the model represents the physicochemical nature of the adsorption system. GAC also performed well, particularly under high concentrations and flow rates. Silica gel, while less effective than carbon-based materials, still showed good performance, especially under high pollutant loads and can be considered a cost-effective option for moderate treatment needs. The Thomas model consistently provided a better fit than the Yoon–Nelson model, making it more suitable for modeling fixed-bed adsorption processes in practical applications.

Conclusion

The experimental data on the adsorption of oil and COD from synthetic wastewater by a fixed-bed system using different adsorbents (powder and granular activated carbon (PAC), (GAC), and silica gel) were fitted using the Thomas and Yoon–Nelson models. Both models were tested in a fixed bed column under conditions of fixed initial concentration of oil and COD 50 ppm and 1400 ppm, different inlet flowrate (1 mL/min, 2 mL/min, and 3 mL/min) and fixed inlet flowrate (1 mL/min), different inlet concentration of oil (100 ppm, 600 ppm, and 800 ppm) and different inlet concentration of COD (2250 ppm, 14500 ppm, and 25000 ppm). Based on the experimental results, the Thomas model fitted well when applying PAC, with a high correlation factor R^2 (0.97, 0.94) compared to the Yoon-Nelson model, which had correlation factors R^2 (0.89, 0.83) for oil and COD, respectively.

Recommendations

Recommend applying low-cost, eco-friendly, and modified adsorbents (e.g., biochar, agricultural wastes, nanomaterials) for enhanced adsorption capacity and sustainability. Employ techniques like SEM, FTIR, BET, and XRD to correlate surface properties with adsorption behavior. Utilize multiple kinetic models in a batch adsorption system (e.g., pseudo-second-order) and isotherm models (e.g., Langmuir, Freundlich, Temkin) to thoroughly understand the adsorption mechanism and capacity, comparing it with this work system (continuous adsorption system). Recommend adsorbents and processes that are scalable, low-cost, and environmentally benign for real-world wastewater treatment.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Conflict of Interest

* The authors declare that they have no conflicts of interest.

Funding

* There is no funding.

Acknowledgements or Notes

* This article was presented as an oral presentation at the International Conference on Engineering and Advanced Technology (ICEAT) held in Selangor, Malaysia on July 23-24, 2025.

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To cite this article:

Mohammed, T. J., Khader E. H., Khudhur R. H. & AlAmeri, M. T. (2025). Modeling of the adsorption process of the organic pollutant from synthetic wastewater using different adsorbents. *The Eurasia Proceedings of Science, Technology, Engineering and Mathematics (EPSTEM), 37,* 474-486.