Isotherm and Kinetic Study of Engine Oil Adsorption on to Crushed Chicken Feathers

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Abstract: Adsorption of engine oil using chemically activated chicken feathers was investigated with the aim of evaluating the efficiency, kinetics, and isotherm behaviour. Batch adsorption experiments were conducted using varying contact times (10–50 minutes) and adsorbent dosages (10 g and 20 g). The adsorption performance was evaluated based on percentage of adsorption capacity, while equilibrium data were analysed using Langmuir, Freundlich, and Temkin isotherm models. Results showed that adsorption efficiency increased with both contact time and adsorbent dosage. At 10 g dosage, efficiency increased from 44% to 76%, while at 20 g dosage, efficiency rose from 56% to a maximum of 98% at 50 minutes, indicating that higher adsorbent mass enhances oil removal due to increased availability of active sites. Isotherm analysis revealed that the Langmuir model provided the best fit ($R^2 = 0.9048$), suggesting monolayer adsorption on a relatively homogeneous surface with a maximum adsorption capacity (Q_{max}) of 138.888 mg/g. The Temkin model showed moderate agreement ($R^2 = 0.7064$), indicating decreasing adsorption heat with surface coverage, while the Freundlich model exhibited poor fit ($R^2 = 0.5123$), suggesting that multilayer adsorption was not dominant. The results demonstrate that adsorption is primarily governed by physisorption mechanisms involving hydrophobic interactions and surface entrapment within the keratin structure of the feathers. Increased dosage significantly improved performance, while contact time influenced the transition from rapid surface adsorption to diffusion-controlled uptake. This study demonstrates that chemically activated chicken feathers are an effective, sustainable, and low-cost adsorbent for engine oil removal, exhibiting high adsorption efficiency and strong conformity to the Langmuir isotherm, highlighting their potential application in wastewater treatment and oil pollution remediation.

Keywords: *Chicken Feather; Engine Oil; Adsorption Isotherm; Kinetics; Langmuir Model; Oil Remediation.*

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I. INTRODUCTION

Environmental pollution arising from petroleum-based products remains a global environmental and public health concern. Each year, large quantities of oil enter aquatic and terrestrial environments through industrial discharge, leakage, transportation accidents, engine maintenance, and improper disposal practices [1]. Oil contamination severely affects water quality, reduces light penetration, disrupts gas exchange, destroys aquatic habitats, and leads to long-term ecological degradation due to the persistence of petroleum hydrocarbons in sediments and soils [2]. Heavy oils such as engine oil present even greater challenges because of their high viscosity, complex formulation, and slow natural degradation rate [3].

Traditional remediation techniques such as chemical dispersants, mechanical recovery, and synthetic sorbents,while effective in specific conditions, are often associated with high cost and environmental concerns. Synthetic sorbents such as polypropylene pads and polyurethane foams are widely used due to their high oil uptake capacity but suffer from disadvantages including non-biodegradability, secondary waste generation, and environmental persistence [4]. These limitations have intensified the search for sustainable, biodegradable, low-cost materials capable of efficient oil remediation.

Natural, waste-derived sorbents have gained increasing attention as environmentally friendly alternatives. Agricultural residues, plant fibers, and animal-derived wastes offer desirable characteristics such as biodegradability, hydrophobicity, and abundant availability [5]. Among these, chicken feathers, a major by-product of the global poultry industry, have emerged as a promising oil sorbent. With over 5 million tons generated annually worldwide [6], feather disposal poses significant waste management challenges, often resulting in incineration or landfilling which are practices that contribute to pollution and greenhouse gas emissions.

Chicken feathers are composed of approximately 90% keratin, a fibrous, insoluble protein known for its hydrophobic, chemically resistant, and mechanically strong nature [7]. The unique hierarchical structure of feathers including hollow quills, barbs, and barbules provides a high surface-to-volume ratio and capillary channels ideal for oil adsorption [8]. These intrinsic properties make chicken feathers an attractive, low-cost, natural sorbent capable of removing oil from contaminated water.

Although previous studies have demonstrated the potential of chicken feathers for sorbing Engine Oil, diesel, and edible oils, fewer studies have focused on engine oil, a heavier and more viscous petroleum derivative. Engine oil's viscosity, additive composition, and chemical stability influence sorption behavior and may require different sorbent characteristics than those effective for lighter oils. As a result, research exploring the performance of waste-derived sorbents particularly untreated or minimally processed chicken feathers on engine oil adsorption remains limited.

The development of eco-friendly sorbents aligns with global sustainability objectives and circular economy principles emphasizing waste valorization, environmental protection, and resource recovery [9]. By converting chicken feather waste into a functional sorbent, this study not only addresses environmental concerns associated with oil pollution but also presents a sustainable solution for managing feather waste.

II. MATERIALS AND METHODS

A. *Material*

In this study, engine oil was used as the contaminant, while washed, dried, and crushed chicken feathers served as adsorbent material. During the preparation and treatment procedures, reagents including distilled water, sodium hydroxide (NaOH), and acetone were employed. Standard laboratory glassware, filtration and stirring tools, measuring devices, and appropriate PPE were all part of the experimental setup to guarantee accuracy and safety.

B. *Methods*

- *Preparation and Activation of Chicken Feathers*

Chicken feathers were thoroughly washed with distilled water to remove adhering impurities and subsequently sun-dried to a constant weight. The dried feathers were then crushed into fine particle sizes and transferred into a clean beaker. A measured volume of acetone was added, and the mixture was stirred until a uniform paste was obtained. The resulting mixture was filtered, and the residue was oven-dried at 40°C to constant weight.

For chemical activation, 4 g of sodium hydroxide (NaOH) was dissolved in 1 L of distilled water to prepare the activating solution. The prepared NaOH solution was then introduced into the pretreated feather sample and subjected to continuous stirring using a magnetic stirrer for 20 minutes to ensure proper activation. The treated sample was subsequently filtered and oven-dried again to constant weight.

The final activated chicken feather material exhibited a lighter coloration and increased brittleness, indicating successful modification of its physicochemical properties.

- *Batch Adsorption Experiments*

To investigate the effect of contact time, a constant adsorbent mass of 10 g of activated chicken feathers was introduced into the oil samples and agitated at different time intervals of 10 to 50 minutes. After each agitation period, the mixtures were filtered, and the recovered feathers were dried to constant weight and reweighed.

For the effect of adsorbent dosage, varying masses of activated chicken feathers (10 g and 20 g) were added to separate beakers containing 50 mL of engine oil. The mixtures were agitated at contact times from 10 to 50 min. Following agitation, the samples were filtered, and the recovered adsorbents were dried and weighed to determine the final mass.

The amount of engine oil adsorbed was determined from the difference between the final and initial masses of the adsorbent, expressed as:

$$M_{ads} = M_{final} - M_{initial} \quad (1)$$

- *Adsorption Capacity and Efficiency*

The equilibrium adsorption capacity, q_e (mg/g), representing the amount of engine oil absorbed per unit mass of adsorbent at equilibrium, was obtained from:

$$q_e = \frac{(C_o - C_e)V}{m} \quad (2)$$

Where C_o (mg/L) is the initial oil concentration, C_e (mg/L) is the equilibrium oil concentration, V (L) is the volume of the solution, and m (g) is the mass of the adsorbent.

The adsorption efficiency, representing the percentage removal of engine oil, was determined using.

$$Efficiency\ (\%) = \frac{C_o - C_e}{C_o} \times 100 \quad (3)$$

- *Adsorption Isotherm Study*

To understand the nature of adsorption and the surface properties of the chicken feather adsorbent, isotherm studies were conducted and evaluated at 10 g and 20 g dosages respectively over contact times from 10 to 50 min.

- *Freundlich Isotherm Equation:*

$$q_e = K_f C_e^{\frac{1}{n}} \quad (4)$$

- *Linear form (by Taking Logarithms):*

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

Where K_f is the Freundlich constant (adsorption capacity) and 1/n is the adsorption intensity.

- *Langmuir Isotherm Equation:*

$$\frac{C_e}{q_e} = \frac{1}{Q_{max}b} + \frac{C_e}{Q_{max}} \quad (6)$$

Where Q_{max} is the maximum monolayer adsorption capacity (mg/g) and b is the Langmuir constant related to adsorption energy (L/mg).

After equilibrium was reached, the residual engine oil concentrations were measured, and the adsorption capacity (q_e) was calculated. The data were then fitted to: (i) the Langmuir isotherm model, which assumes monolayer adsorption onto a surface with a finite number of identical sites; and (ii) the Freundlich isotherm model, which assumes multilayer adsorption on a heterogeneous surface. The isotherm constants (Q_{max}, b, K_f, 1/n) were obtained from the slopes and intercepts of the plots to determine the adsorption behaviour.

- *Temkin Isotherm Model:*

The Temkin isotherm is based on the idea that, during adsorption, the heat of adsorption does not remain constant as in the Langmuir model. Instead, it decreases linearly with surface coverage because of adsorbent–adsorbate interactions. Mathematically:

$$q_e = B \ln(A_T C_e) \quad (7)$$

Where q_e is the equilibrium adsorption capacity (mg g^{-1}); A_T is the Temkin isotherm equilibrium binding constant (L mg^{-1}); C_e is the equilibrium concentration of engine oil; and B = RT/b, where R is the universal gas constant, T is temperature (K), and b is the Temkin constant. Linearizing equation (7):

$$q_e = B \ln A_T + B \ln C_e \quad (8)$$

C. *Weight Analysis*

The adsorption efficiency of the chicken feathers was calculated based on the weight difference of the adsorbent before and after adsorption using the following formula:

$$Adsorption\ efficiency\ (\%) = \frac{W_f - W_i}{W_i} \times 100 \quad (9)$$

Where W_i is the initial weight of the chicken feathers (g) and W_f is the final weight of the chicken feathers after adsorption (g). All experiments were conducted in triplicate, and the average values were reported to ensure reproducibility

III. RESULTS AND DISCUSSION

A. *Effect of 10 g Adsorbent Dosage on Engine Oil Efficiency*

Table 1 10 g Dosage Adsorbent (Chicken Feather)

Time (minutes)	Adsorption Efficiency (%)
10	44
20	46
30	51
40	63
50	76

Table 1 shows the adsorption efficiency of chicken feathers (10 g dosage) for engine oil removal over 10–50 minutes. Efficiency increased progressively from 44% to 76%, reflecting the transition from rapid surface adsorption to slower, diffusion-controlled processes. Initially, a 44% uptake was recorded at 10 minutes, driven by high mass transfer and abundant vacant surface sites [10]. As surface coverage increased, efficiency rose modestly to 46% (20 min) and 51% (30 min), indicating a shift toward intraparticle diffusion [11]. A significant increase to 63% at 40 minutes suggests molecular rearrangement onto the feather's keratinous structure. Peak efficiency reached 76% at 50 minutes, signaling near-equilibrium conditions [12].

The results confirm that contact time is critical for maximizing the hydrophobic interactions and physical entrapment inherent to the feather's morphology. This emphasizes the potential of chicken feathers as a high-performance, low-cost bio-adsorbent for oil remediation.

B. *Effect of 20 g Adsorbent Dosage on Engine Oil Efficiency*

Table 2 20 g Dosage Adsorbent (Chicken Feather)

Time (minutes)	Adsorption Efficiency (%)
10	56
20	62
30	73
40	83
50	98

The adsorption performance of chicken feathers as a low-cost bio-adsorbent for engine oil removal was evaluated at a 20 g dosage over contact times from 10 to 50 min. The results show a consistently rising efficiency profile that approaches near-complete removal within the studied window, underscoring the strong capacity of feather keratin fibers to capture hydrophobic hydrocarbons. At 10 min, the system already achieves 56% removal, indicating a rapid initial uptake phase governed by abundant vacant sites and a high concentration driving force at the solid–liquid interface. By 20 min, efficiency increases to 62%, reflecting continued surface binding as external-film resistance diminishes and oil droplets interact more effectively with feather microstructures [13].

A more pronounced improvement is observed between 20 and 30 min, where efficiency reaches 73%. This interval typically marks the transition from dominantly surface adsorption to intraparticle diffusion and pore filling [11], as oil components migrate into accessible feather porosity and inter-fibrillar voids. At 40 min, the system attains 83% removal, indicating that a large fraction of the keratinous sites are now occupied and the mass-transfer zone has penetrated deeper into the sorbent bed. The approach to equilibrium is evident by 50 min, where efficiency peaks at 98%; incremental gains beyond this point would be marginal because the remaining sites are fewer, less accessible, or energetically less favorable [14].

The time-trend (56 → 62 → 73 → 83 → 98%) is characteristic of adsorption systems where an initial fast stage is followed by a slower, diffusion-limited stage as the system approaches saturation. Practically, these data suggest that 40–50 min is an operationally efficient contact-time window at 20 g dosage, delivering very high removals without excessive residence time. Mechanistically, the strong performance at 20 g arises from (i) greater site density (higher sorbent-to-solute ratio), which lowers residual equilibrium concentration in the liquid, (ii) enhanced collision frequency between oil and sorbent due to increased effective surface area, and (iii) multiple retention pathways—hydrophobic interactions, van der Waals forces, and physical entrapment within fibrous matrices. Overall, the findings confirm that increasing the chicken-feather dosage to 20 g markedly enhances oil removal efficiency and accelerates the approach to equilibrium, supporting its viability as a sustainable, inexpensive sorbent for oily wastewater treatment [15], [16].

C. Estimation of Kinetic Parameters of Adsorption Models for 20 g Dosage

- *Freundlich Isotherm Model*

Table 3 Freundlich Isotherm Parameters

Parameter	**Value**
n	0.1281
Kf	4.69×10^{-9}
R^2	0.5123

The Freundlich isotherm was applied to engine oil adsorption on chicken feathers (20 g dosage) to examine surface heterogeneity and capacity. Experimental data yielded an adsorption intensity (n) of 0.1281, a Freundlich constant (K_f) of 4.69×10^{-9}, and a correlation coefficient (R^2) of 0.5123. The n value of 0.1281, being significantly below 1, indicates unfavorable or weak cooperative adsorption [17], suggesting the adsorbent surface lacks energetically strong binding sites under these conditions.

The low K_f value of 4.69×10^{-9} reflects a limited relative adsorption capacity, likely due to structural constraints within the feather matrix or insufficient active site development [18]. Furthermore, the R^2 of 0.5123 shows the model only moderately fits the data, explaining only 51% of the adsorption variance. This weak correlation suggests that the Freundlich model is not the most appropriate descriptor for this system; alternative models, such as Langmuir or Temkin, may better capture the specific monolayer or adsorbate–adsorbent interactions occurring [19]. Overall, these parameters characterize the process as having low interaction intensity and capacity at a 20 g dosage, necessitating further model refinement or process optimization to enhance the viability of chicken feathers for oil remediation.

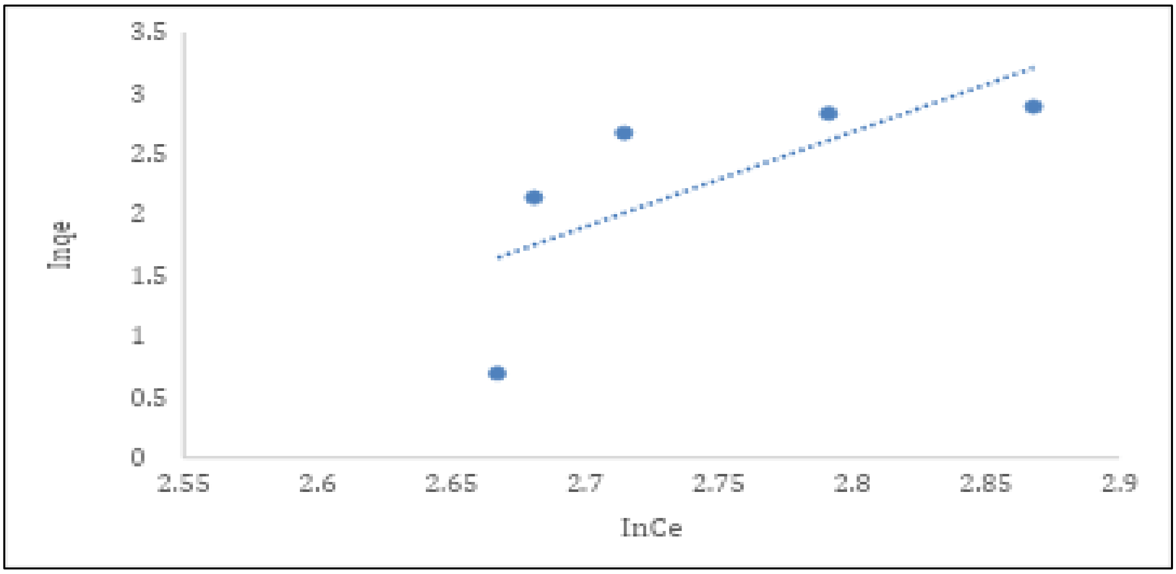

Fig 1 Curve fit of Freundlich Isotherm Parameters.

Fig. 1 illustrates the Freundlich isotherm analysis for engine oil adsorption on chicken feathers (20 g dosage). Regression of the linearized model yielded an $R^2 = 0.5123$, with a slope (1/n) of 7.8064, resulting in an adsorption intensity (n) of 0.1281. This low n value indicates unfavorable adsorption and weak interaction between the oil molecules and the adsorbent surface. The intercept ($\ln K_F$) produced a Freundlich constant (K_F) of 4.69×10^{-9}, confirming a low adsorption capacity and limited active site accessibility. The R^2 value suggests the model accounts for only 51% of the data variance, indicating that while it captures general trends, it fails to fully represent the system's complexity. Observed deviations between experimental points and the regression line suggest surface heterogeneity or multilayer mechanisms not adequately addressed by this model. Consequently, while the Freundlich equation provides an initial empirical overview, the moderate correlation suggests that alternative models, such as Langmuir or Temkin, are required for a more robust mechanistic description.

➢ *Langmuir Isotherm Model*

Table 4 Langmuir Isotherm Parameters

Parameter	Value
Qmax (mg/g)	138.888
b	7.59×10^{-7}
R^2	0.9048

The Langmuir isotherm model was applied to adsorption data to evaluate the maximum capacity Q_{max} and surface interaction characteristics as shown in Table 4. Results yielded a Q_{max} of 138.888 mg/g, indicating a high density of active sites capable of accommodating significant pollutant loads at saturation. This suggests the material is well-suited for large-scale wastewater treatment applications [20]. The Langmuir constant (b) was 7.59×10^{-7}, reflecting a relatively weak binding affinity. This low value indicates that the process is dominated by physisorption rather than chemisorption, which may favor adsorbent regeneration and reuse despite potentially lower efficiency at trace contaminant concentrations [21].

The model showed a high correlation with experimental data ($R^2 = 0.9048$), confirming that the mechanism primarily involves monolayer adsorption on a homogeneous surface with uniform energy distribution. In summary, the high Q_{max} and strong statistical fit ($R^2 > 0.9$) identify this material as an effective candidate for bulk oil removal, though its low affinity constant suggests better performance in high-concentration streams than in trace-level remediation [19].

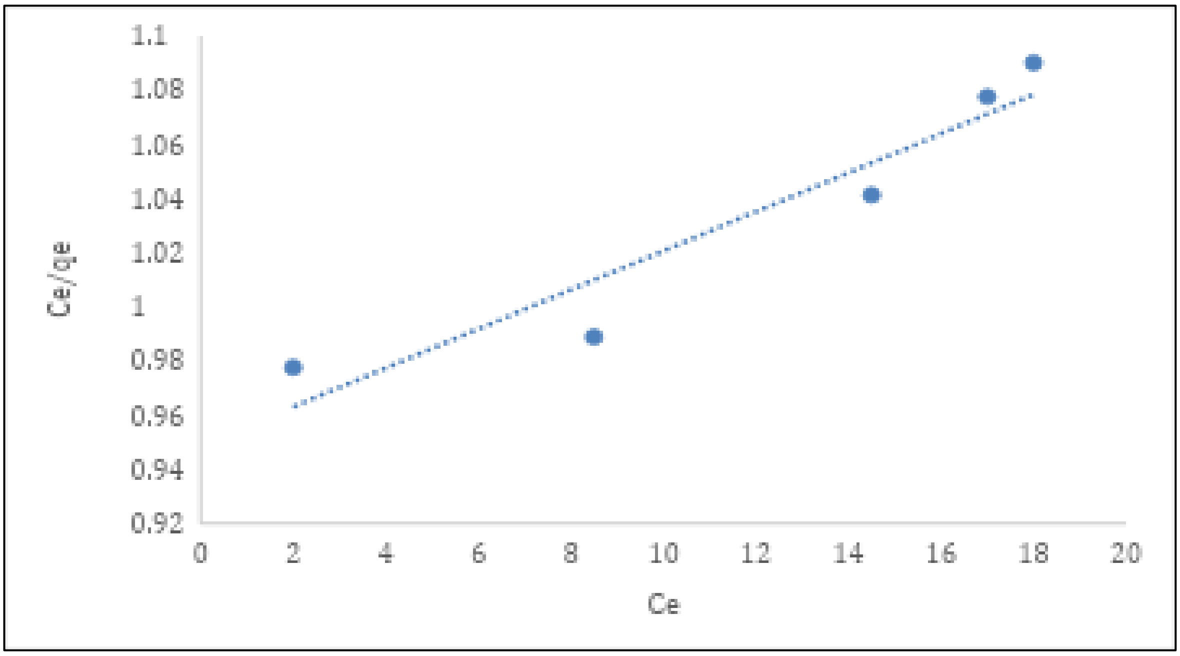

Fig 2 Curve Fit of Langmuir Isotherm Parameters.

Fig. 2 shows the adsorption equilibrium data evaluated using the Langmuir isotherm model, as represented by the linearized plot of C_e/q_e versus C_e. The regression equation obtained was $y = 0.0072x + 0.9486$, with a coefficient of determination ($R^2 = 0.9048$), indicating a very good fit to the experimental data. The slope corresponds to $1/Q_{max}$, while the intercept represents $1/(Q_{max} \cdot b)$, allowing direct estimation of the Langmuir constants. The closeness of the experimental data points to the fitted line demonstrates that the adsorption process follows the assumptions of the Langmuir theory, namely monolayer coverage of adsorbate molecules on a homogeneous surface with identical and energetically equivalent binding sites [22]. The trend of the data confirms that as C_e increases, the ratio C_e/q_e also increases linearly, reflecting gradual filling of adsorption sites until saturation is approached. In summary, the curve fit confirms that the Langmuir isotherm is an appropriate model for describing the adsorption system [23].

➢ *Temkin Isotherm Model*

Fig. 3 shows a linear relationship between the equilibrium adsorption capacity q_e and the natural logarithm of equilibrium concentration $\ln C_e$, indicating partial conformity of the adsorption system to the Temkin model. The positive slope obtained from the regression line confirms that adsorption capacity increases with increasing solute concentration, consistent with the theoretical basis of the Temkin isotherm.

Table 5 Temkin Isotherm Parameters

Parameter	**Value**
B	66.944
AT	6.77×10^{-1}
R^2	0.7064

The Temkin constant $B = 66.944$ suggests that the adsorption process is significantly influenced by the variation of adsorption energy with surface coverage. This relatively high value indicates that the decrease in adsorption heat with increasing coverage is gradual, implying that the adsorbent surface contains sites of varying energy levels rather than identical binding sites. This behavior is expected for biomaterials such as chicken feathers, which possess heterogeneous structures composed of keratin fibers, pores, and irregular adsorption domains.

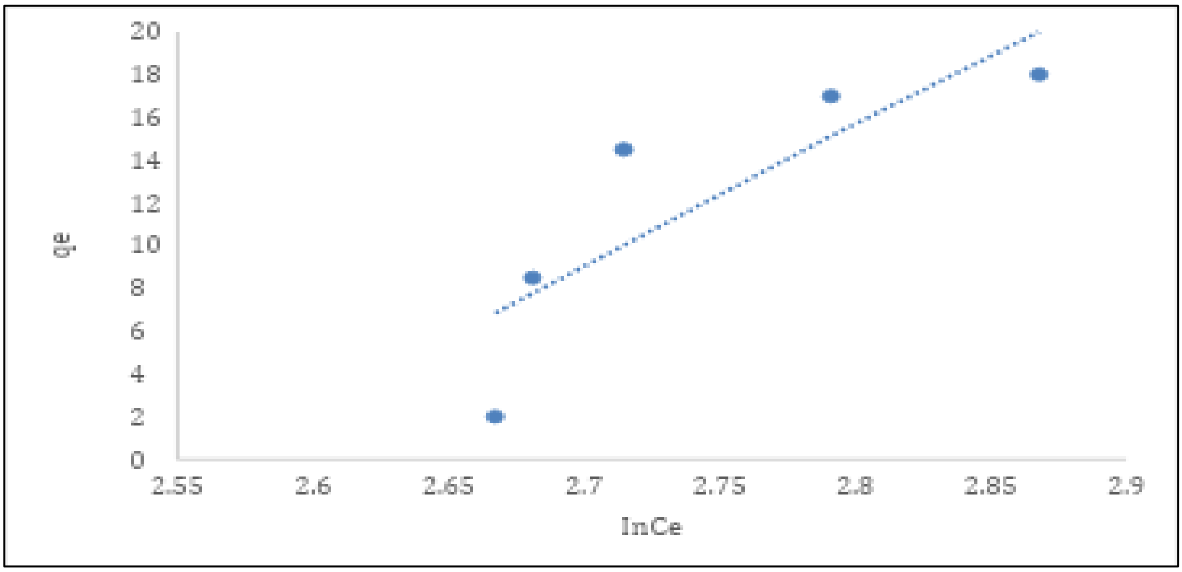

Fig 3 Curve Fit of Temkin Isotherm Parameters.

The equilibrium binding constant $A_T = 6.77 \times 10^{-1}$ reflects moderate adsorbate–adsorbent interaction strength. This suggests that while adsorption is favorable, the interactions are not extremely strong, supporting the dominance of physisorption mechanisms, including hydrophobic interactions and van der Waals forces. The coefficient of determination ($R^2 = 0.7064$) indicates only a moderate fit of the Temkin model to the experimental data. The noticeable scatter of data points around the regression line suggests that the assumption of a linear decrease in adsorption energy with surface coverage does not fully capture the complexity of the system. This deviation may be attributed to surface heterogeneity beyond linear energy variation, possible multilayer adsorption at higher concentrations, or diffusion limitations during equilibrium attainment.

IV. CONCLUSION

This study clearly demonstrates that chemically activated chicken feathers are a highly effective, sustainable, and low-cost adsorbent for the removal of engine oil from contaminated systems. The adsorption performance was strongly influenced by both contact time and adsorbent dosage, with efficiency increasing progressively due to enhanced availability of active sites and improved mass transfer dynamics. The maximum removal efficiency of 98% achieved at higher dosage confirms the excellent sorption capacity of the keratin-based structure, highlighting its suitability for high-performance oil remediation applications.

Isotherm analysis revealed that the Langmuir model provided the best fit to the experimental data ($R^2 = 0.9048$), indicating that adsorption predominantly occurs as a monolayer on a relatively homogeneous surface. This suggests that the adsorption process is governed primarily by physisorption mechanisms, including hydrophobic interactions, van der Waals forces, and physical entrapment within the fibrous matrix. The moderate agreement of the Temkin model further supports the presence of adsorbent–adsorbate interactions and a progressive decrease in adsorption energy with increasing surface coverage, reflecting the inherent heterogeneity of the feather structure. Furthermore, the weak correlation with the Freundlich model confirms that multilayer adsorption is not the dominant mechanism in this system.

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