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Equilibrium Study Of Citric Acid Modified Chicken Feathers for Cd+ Adsorption From Aqueous Solution

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ABSTRACT

This present study aimed at the efficient removal of cadmium ions from aqueous solution using citric acid modified chicken feathers. The chicken feathers were washed, ground, defatted with chloroform, dried, and modified with 1M citric acid. The Citric acid Modified Chicken Feathers (CMCF) were used for the adsorption of Cadmium ions. The adsorption process was conducted using the batch method at various factors such as pH, adsorbent dosage, contact time, and temperature. The properties of the samples before and after the adsorption process were analyzed using the Fourier Transform Infrared (FTIR). The results obtained were studied with the isotherms, which revealed a significant increase in the adsorption capacity of the CMCF. The FTIR graphs depicted some changes after the defatting of the Raw Chicken Feathers, the protein-associated peaks –1625, 1524 and 1237 cm^{-1} were more prominent after the defatting process as the fat/lipid removal reduced the interference. Also, the equilibrium study of the adsorption process with CMCF was best fitted into the Temkin Isotherm model with a correlation coefficient of 0.999. However, Freundlich Isotherm model was also close, with a correlation coefficient of 0.989. It could be exerted that the adsorption trend of the CMCF was best described by the Freundlich and pseudo second-order kinetic models. Moreover, the thermodynamic parameters showed that the process of adsorption of Cd+ by the CMCF adsorbent was spontaneous and endothermic. Hence, the adsorbent CMCF can be used as a low-cost alternative to other commercially used adsorbents for the removal of Cd ions from wastewater.

Keywords: modified, chicken feathers, citric acid, cadmium ions, Freundlich isotherm, Langmuir Isotherm, Temkin model.

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1. INTRODUCTION

The environmental and health hazards associated with heavy metal pollution, especially cadmium, demand sustainable and eco-friendly remediation technologies. Recently, researchers have begun exploring low-cost biosorbents made from Agricultural waste materials as viable alternatives to conventional adsorbents [1,2,3]. Cadmium is notorious for its high toxicity and persistence even at minute concentrations [4, 5]. Human exposure to cadmium can cause damage to bones and kidneys. Usually, water contamination by this heavy metal can be released from industrial processes such as electroplating and mining [6]. Conventional methods for removing heavy metals, such as chemical precipitation and ion exchange, are effective but costly and can generate additional pollutants, exacerbating environmental harm [7]. Alternatively, biosorption presents a greener solution by harnessing natural materials to absorb contaminants. Chicken feathers, a readily available and inexpensive byproduct of the poultry industry, are particularly promising due to their keratin-rich composition, which can be chemically modified to enhance metal-binding capabilities, offering a sustainable solution for heavy metal removal. Despite the growing body of research on biosorption, there remains a significant gap in our understanding of how citric acid modification affects the adsorption of cadmium by chicken feathers. Specifically, uncertainties linger regarding the optimal modification conditions and the overall efficiency of cadmium removal under varying operational parameters. Consequently, this study seeks to answer the question: Can citric acid-modified chicken feathers serve as an effective biosorbent for cadmium ions, and what are the key factors that can influence the adsorption process?

A thorough review of existing literature indicates that although numerous studies have investigated biosorption using agricultural wastes and chemically modified biomaterials, this study presents a novel approach by utilizing citric acid-modified chicken feathers for Cd ion removal, filling a knowledge gap in the field. This gap in the research highlights the need for a thorough empirical investigation into the feasibility and performance of this novel biosorbent.

A systematic experimental methodology was adopted to address this research gap. The chicken feathers were first defatted and modified with citric acid. A series of batch adsorption experiments was carried out to investigate the effects of pH, contact time, and initial cadmium concentration on the adsorption process and determine the equilibrium conditions. This study investigates the potential of citric acid-modified chicken Chicken Feathers to remove cadmium (Cd) ions from aqueous solutions.

The importance of this research lies in its ability to investigate new methods for treating wastewater sustainably. By clarifying the processes involved in adsorption and pinpointing key operational factors, this study seeks to deliver essential knowledge that can guide the creation of effective, environmentally friendly remediation systems for water contaminated with cadmium.

2. MATERIALS AND METHODS

Materials

All the chemicals used were of analytical reagent grade, purchased from Bridge Head Market, Onitsha, Anambra State, Nigeria. These chemicals include:
Cadmium Nitrate ($Cd(NO_3)_2\,4H_2O$), Lead Chloride ($PbCl_2$), Manganese Sulphate ($Mn(SO_4)H_2O$), Sulfuric Acid (H_2SO_4), Nitric Acid (HNO_3), Citric Acid, Chloroform, Sodium Hydroxide (NaOH) Hydrogen Chloride (HCL), Deionized water. Other materials used are: Whatman filter paper, Beakers, Reagent bottles, Conical flask, Pipette, Sieve. Hydrochloric acid and Sodium hydroxide were used to adjust the solution pH. Deionized water was used throughout the experimental studies.

Preparation for Adsorbent

The adsorbents (Chicken Feathers) were procured from the slaughterhouse at Relief Market, Owerri, Imo State. They were washed with detergent, rinsed with deionized water, and then dried. After drying, they were crushed and sieved with a 425 μm sieve to get a desired particle size.

Figure1. Chicken Feathers after washing.

Figure2. Chicken Fathers after.

Figure 3. Oven drying of Chicken Feathers .

Figure 4. Grounded chicken Father during.

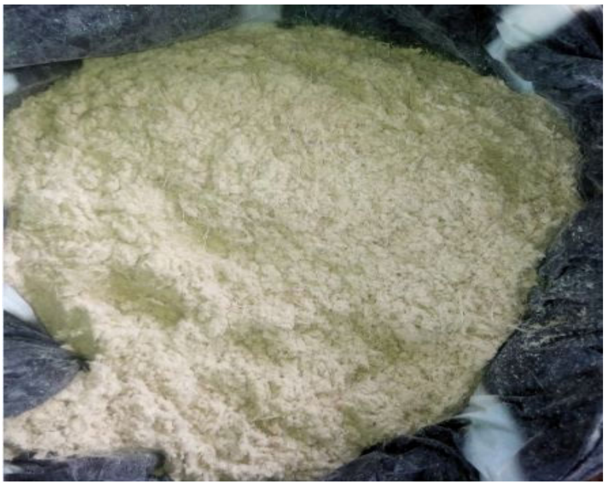

Figure 5. 425 µm grounded Chicken Feathers.

Defatting of the Adsorbent

Defatting was performed by immersing the pulverized chicken feather samples in chloroform at a ratio of 100 g: 500 ml 2. The weighed sample was placed in a beaker and treated with chloroform. The mixture was stirred thoroughly and left to stand for 72 hours, consequently giving rise to the formation of distinct layers. The sample was filtered, washed with deionized water, and dried in an oven.

Modification of the Adsorbent

The sample was modified by treating it with citric acid for 6 hours, followed by filtration, rinsing with deionized water, and oven drying. The objective of this modification was to increase the sample's capacity to bind metals in aqueous solutions [8].

Adsorption Studies

The adsorption capacity studies were conducted by contacting the citric acid modified adsorbent CMCF with Cd metal ion in a 100 mL Erlenmeyer flask with stopper. Batch adsorption of cadmium ion onto CMCF adsorbent was investigated in simulated aqueous solution at various operating conditions; solution pH (1–8), initial concentration (5–100 mg/L), temperature (293–473K), sonication time (80 min) and dosage (0.3-1.8 g). Each adsorption experiment was carried out on a mechanical shaker and were agitated at 300 rpm. The agitated samples were filtered using filter paper and the concentration of cadmium ion was measured in the filtrates. Afterwards, the remaining Cd2+ concentrations after adsorption were measured by atomic absorption spectrophotometer (210 VGP Atomic Absorption Spectrophotometer (AAS)).
The amount of equilibrium adsorption, Qe and percentage removal, % R were calculated with Equations (1) and (2) [9].

$$Q_e = (C_0 - C_e) \times V/m \quad (1)$$

$$\%\ \text{adsorbed} = (C_0 - C_e)/C_0 \times 100 \text{ --} \quad (2)$$

Where V is the volume of the solution (ml) and m is the mass of CMCF adsorbent (g).
Also, from equation 2, C_0 and initial concentration of heavy metal while C_e is the final concentration of Cd ion. The liquid-phase concentration of Cd2+ at initial and equilibrium (mg/L) is represented as Co and Ce, whereas V (L) and M (g) are the volume of the adsorbate solution and mass of the used adsorbent. The adsorption isotherm of the experiments was modeled with linear form of Langmuir, Freundlich, Temkin, and Radushkevich (D–R) isotherms as represented in Equations (3)– (6) [10, 11, 12] to fit the equilibrium data for Cd2+ adsorption at room temperature.

$$C_e/Q_e=C_e(1/Q_m)+1/bQ_m \quad (3)$$

$$\log Q_e=\log k_f+1/n\log C_e \quad (4)$$

$$Q_e= a + b\ln C_e \quad (5)$$

$$\ln Q_e=\ln Q_0-\beta\, E^2 \quad (6)$$

Where Qe is the amount of adsorbate adsorbed per unit mass of adsorbent (mg/g), Qm is the maximum adsorption capacity (mg/g), Ce is the equilibrium concentration of metal ion and dye in the solution (mg/L), KL is Langmuir constant related to the affinity of binding sites (L/mg) and is the measure of adsorption energy. The parameters KF and n are Freundlich constants which can be regarded as the capacity and intensity of adsorption, respectively. B is the Temkin constant related to the heat of adsorption (kJ/mol), and KT (L/mg) was the equilibrium binding constant relating to the maximum binding energy. KDR (mol2/kJ2) is a constant related to the mean adsorption energy; and ε is the Polanyi potential, R (8.314 J/mol. K) is universal gas constant, T (Kelvin) is absolute temperature, E (kJ/mol) is mean free energy of adsorption. Ks is Sips equilibrium constant (L/mg), and 1/n is Sips model exponent. If the value for 1/n is < one, it shows that it is a heterogeneous adsorbent, while values closer to or even one indicates that the adsorbent has relatively more homogeneous binding sites [13] Looking at Langmuir model, to evaluate the favorability of the adsorption system.

Effect of pH:

0.3g of the adsorbent (chicken feathers) was added to 30 cm3 of aqueous solution having a conc. of 5mg/l at different pH of 1,3,5,7, and 8 in a conical flask. The pH value was adjusted using a 1M solution of HCL. The resultant solution with the adsorbent was corked in a 50 ml bottle and agitated at 300 rpm on an orbital shaker for 80 minutes and filtered, and the filtrate was analyzed on the AAS machine.

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Effect of Temperature

0.3g of the CF adsorbent was added to 30 cm^3 of aqueous solution of 5mg/l conc. and the Effect of Temperature at different values of 20, 40, 60, 80, and 100 ^{0}C was conducted in a water bath. A 50 ml solution containing the adsorbent was sealed and heated in a water bath to the desired temperature for 20 minutes. The solution was then agitated at 300 rpm for 80 minutes, filtered, and the resulting filtrate was analyzed using Atomic Absorption Spectroscopy (AAS).

Effect of Adsorbent Dosage

This was achieved by adding different proportions of adsorbents such as 0.2, 0.6, 1.0, 1.4, and 1.8g to 30 cm^3 of aqueous solution of 5 mg/l conc. The adsorbent-containing solution was distributed into 50 ml bottles, sealed, and subjected to agitation at 300 rpm for 80 minutes using an orbital shaker. Following agitation, the mixture was filtered, and the resulting filtrate was analyzed for metal content using Atomic Absorption Spectroscopy (AAS).

Data Analysis

The adsorption capacity, Qe, was calculated using the following mass balance relationship equation:
$Q_e = (C_0\text{-}C_e) \times V/m$, where
V = the volume of the solution (ml)
m = the mass of CMCF adsorbent (g)
The percentage adsorption of Cd metal ions from solutions was calculated as follows:
% adsorbed = $(C_0\text{-}C_e)/C_0 \times 100$
Where C_0 = Initial concentration of Cd heavy metal, and C_e = Final concentration of Cd heavy metal.

Langmuir Isotherm

The Langmuir isotherm [14] is expressed as:
$C_e/Q_e = C_e (1/Q_m) + 1/bQ_m$
Were,
Q_e = the equilibrium value of the Cd metal ions adsorbed per unit weight of CMCF adsorbent
C_e = the equilibrium concentration of the Cd adsorbate.
b = Relates the affinity between the CMCF adsorbent and the Cd adsorbate.
The favourability of the isotherm depends on the dimensionless constant factor R_1, which is given by:
$R_L=1/1+K_L*C_0$
C_0=Initial concentration
If $R_L=0$, it shows that the adsorption isotherm is irreversible, and if $0<R_L<1$ then it shows that Langmuir adsorption isotherm is favourable.

Freundlich Isotherm

Freundlich isotherm equation is expressed as:
$\log Q_e = \log k_f + 1/n \log C_e$
were,
k_f =The adsorption coefficient, which characterizes the strength of adsorption
C_e =The equilibrium concentration of the Cd adsorbate
Q_e= The equilibrium value of the Cd ion adsorbed per unit weight of CMCF adsorbent.

Temkin Isotherm

The Temkin adsorption isotherm [15] was expressed as:
$Q_e = a + b\ln C_e$
Were,
Q_e=The amount of Cd adsorbed at equilibrium
C_e=The equilibrium concentration of the Cd adsorbate
b =Corresponding to the heat of adsorption, which is the slope
a=The equilibrium binding constant

Dubin-Radushkevich (DKR) Isotherm:

This was expressed as:
$\ln Q_e = \ln Q_0 - \beta E^2$
$E = RT(1+1\backslash C_e)$
The mean adsorption energy $E = 1/\sqrt{2}\beta$

3. RESULTS AND DISCUSSION

Effect of Defatting on the Chicken Feathers

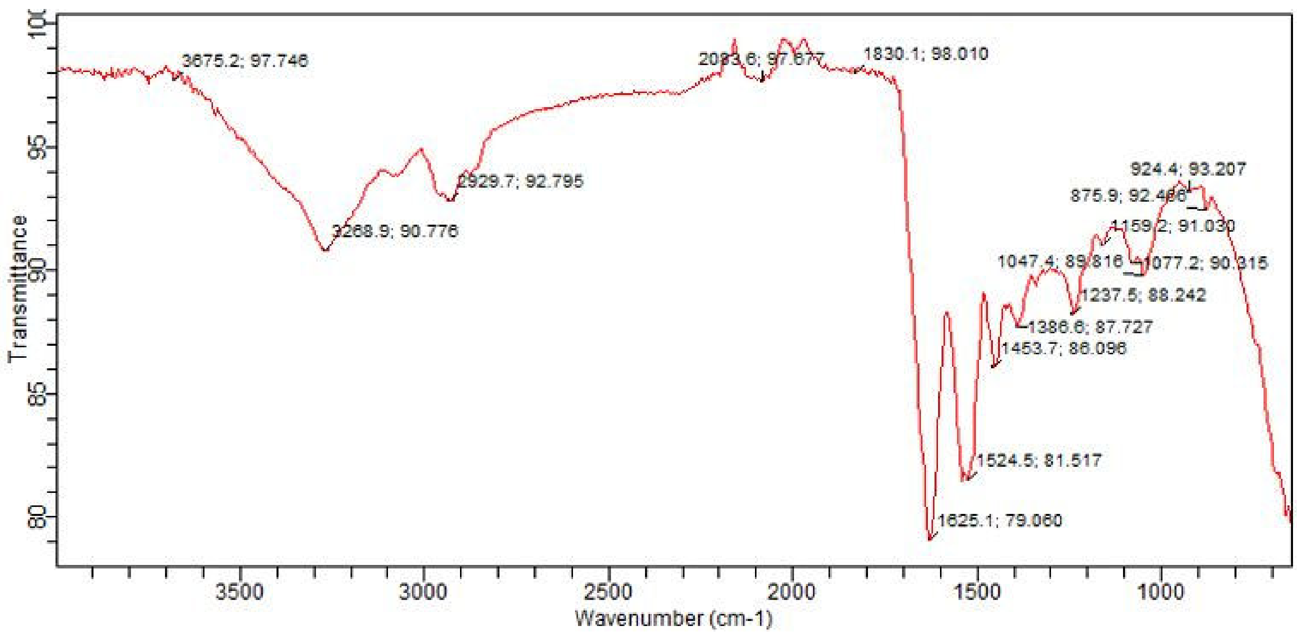

Figure 5. FT-IR Spectra for Unmodified/Undefatted Chicken Feathers.

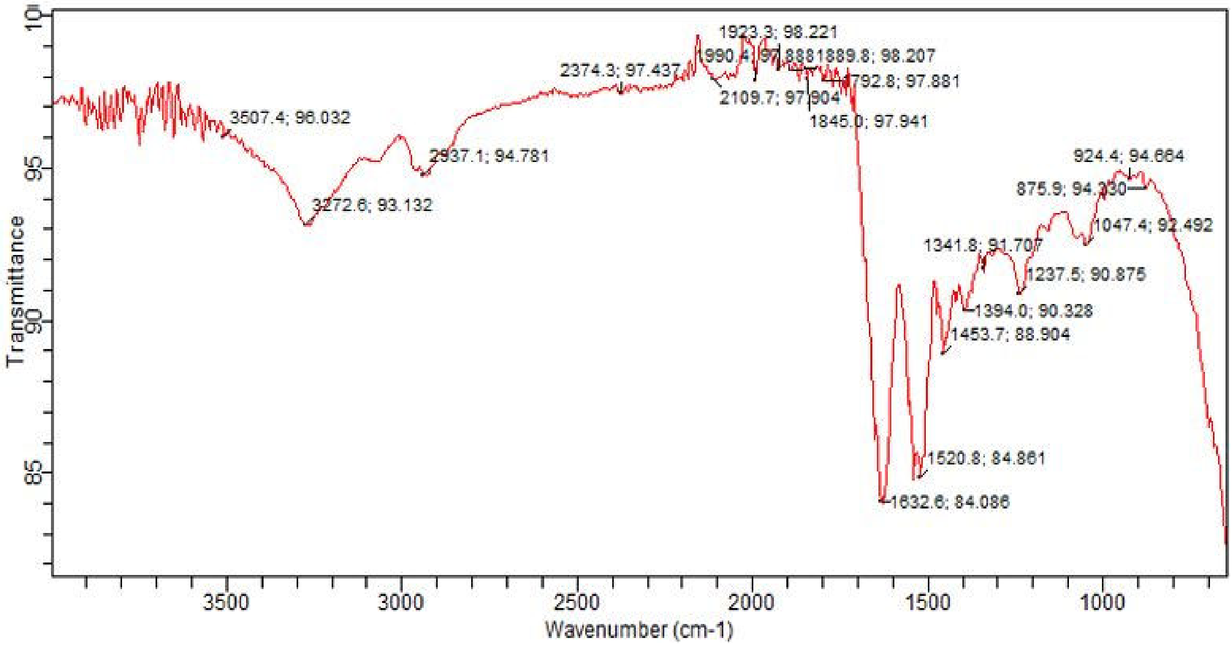

Figure 6. FT-IR Spectra for Unmodified/Defatted Chicken Feathers.

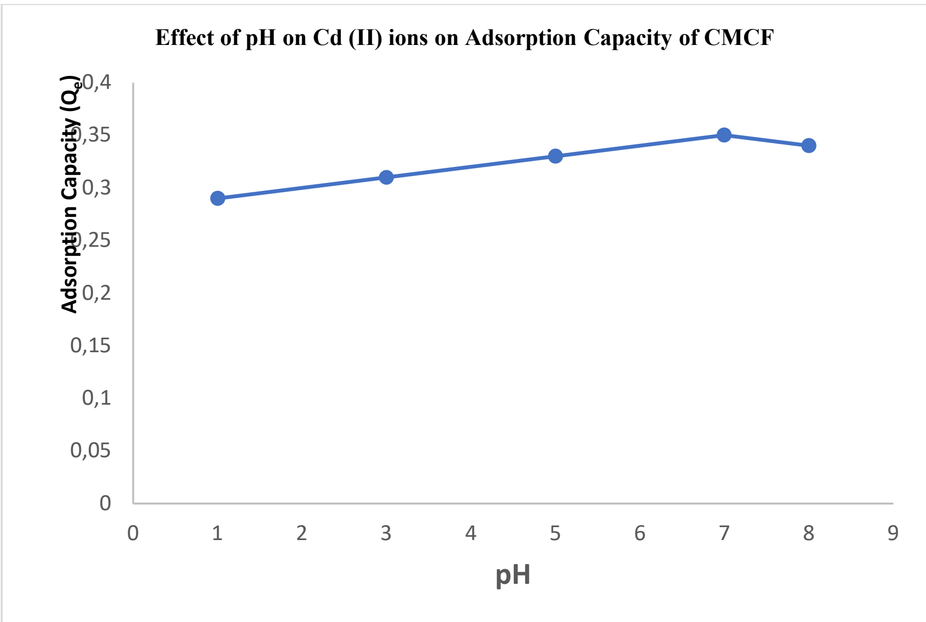

Figure 7. Adsorption Capacity of CMCF for Effect of pH on Cd (II) Ions.

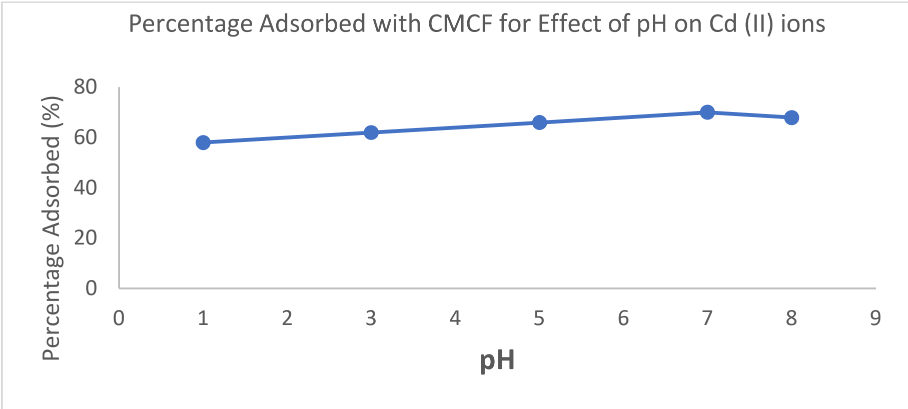

Figure 8. Percentage Adsorbed with CMCF for Effect of pH on Cd (II) ions.

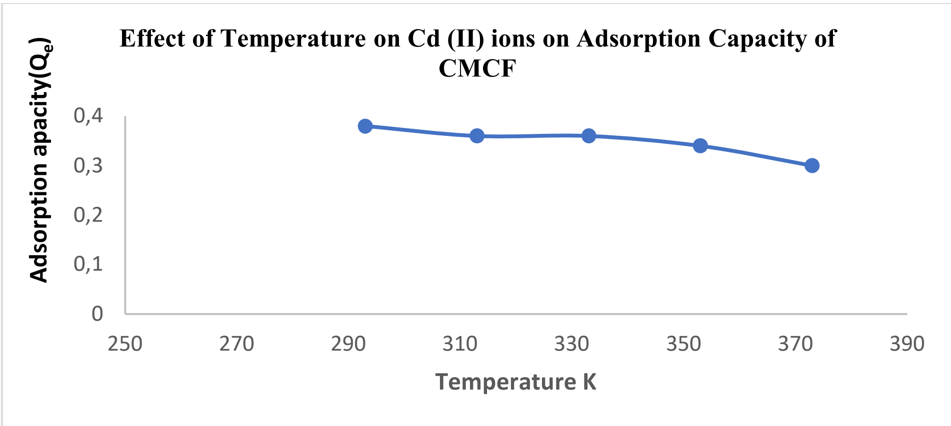

Figure 9. Adsorption Capacity of CMCF for Effect of Temperature on Cd (II) ions.

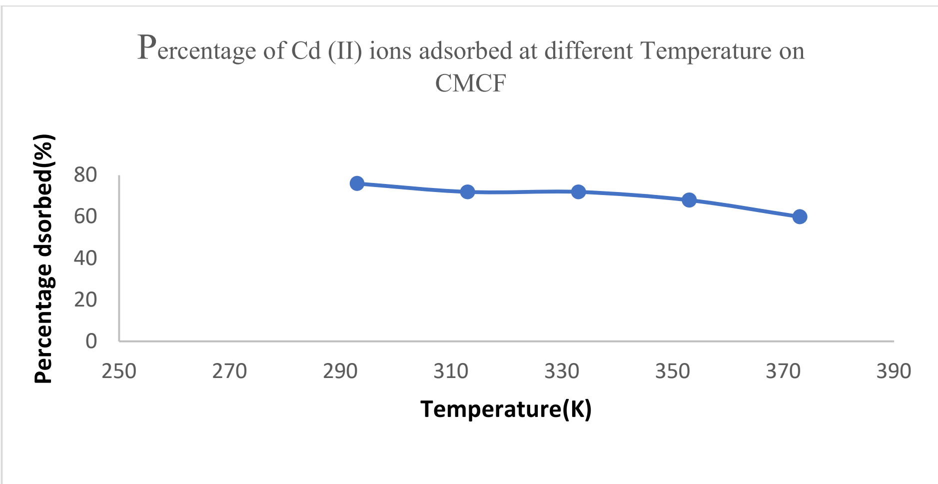

Figure10. Percentage Adsorbed with CMCF for Effect of Temperature on Cd (II) ions.

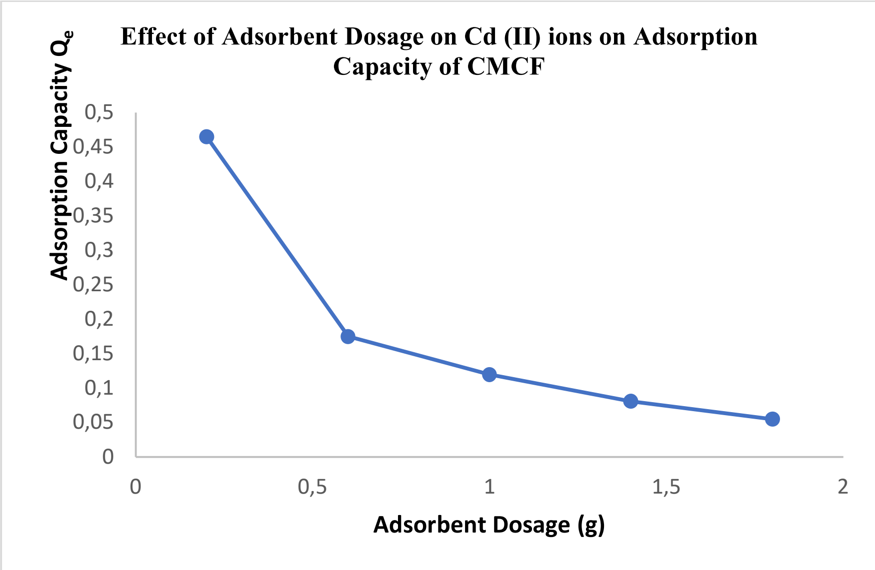

Figure 11. Adsorption Capacity of CMCF for Effect of Adsorbent Dosage on Cd (II) ion.

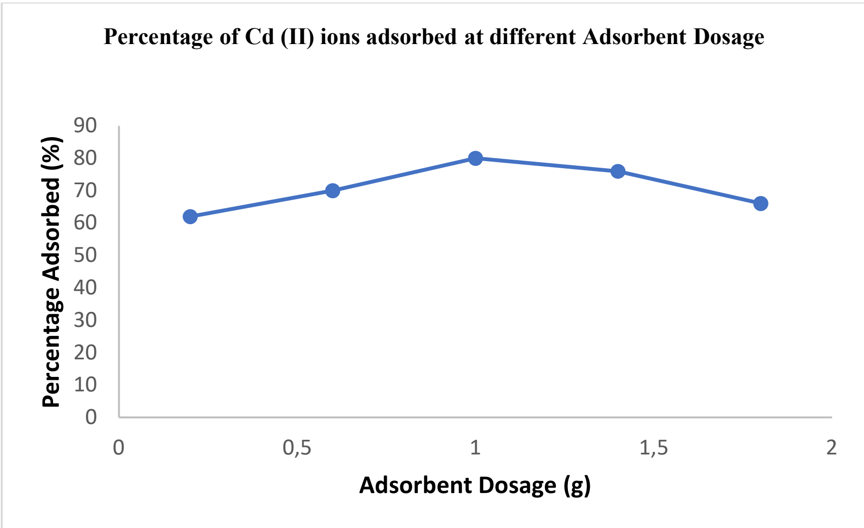

Figure12. Adsorption Capacity and Percentage Adsorbed with CMCF for Effect of Adsorbent Dosage on Cd (II) ion.

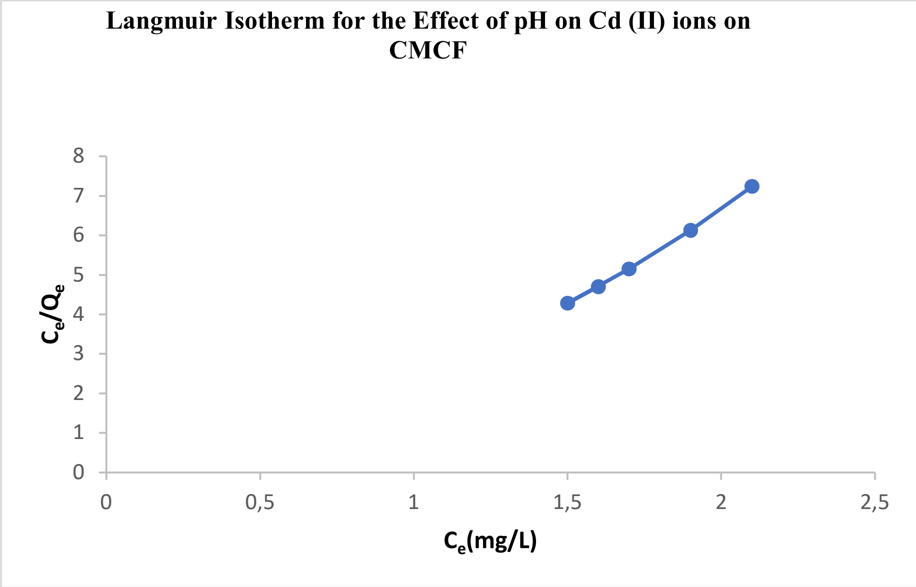

Figure 13. Langmuir Isotherm graph for the Effect of pH on Adsorption of Cd (II) ions on CMCF.

Langmuir Isotherm for Effect of Temperature

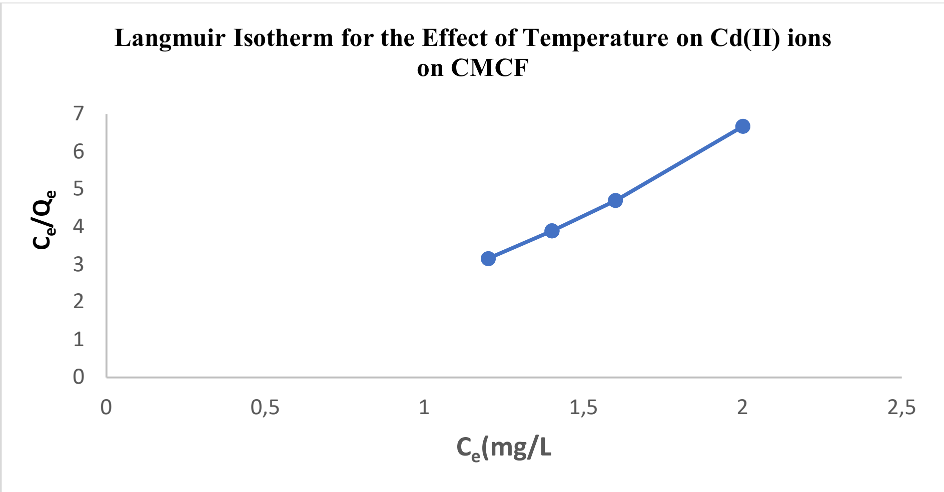

Figure 14. Langmuir Isotherm graph for the Effect of Temperature on Cd (II) ions for CMCF.

Langmuir Isotherm for Effect of Adsorbent Dosage

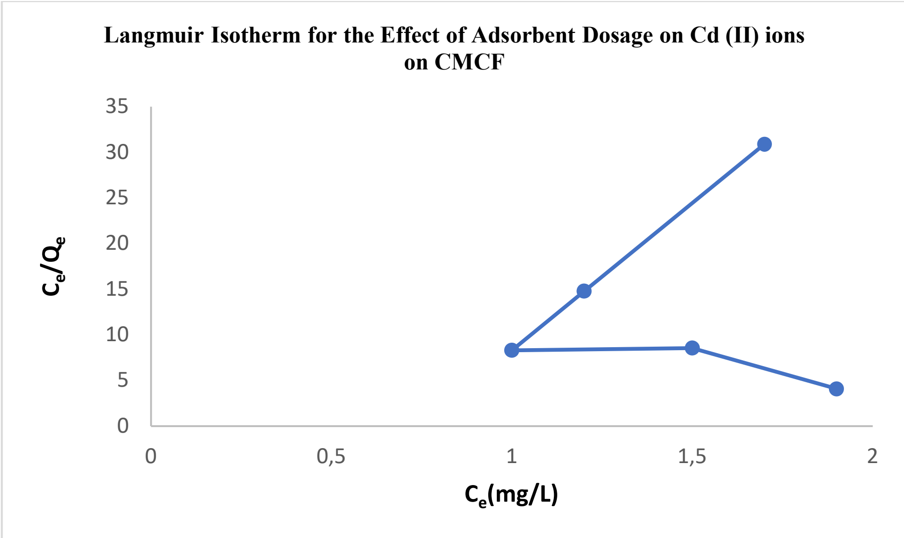

Figure 15. Langmuir Isotherm graph for the Effect of Adsorbent Dosage on Cd (II) ions for CF.

Freundlich Isotherm for Effect of pH

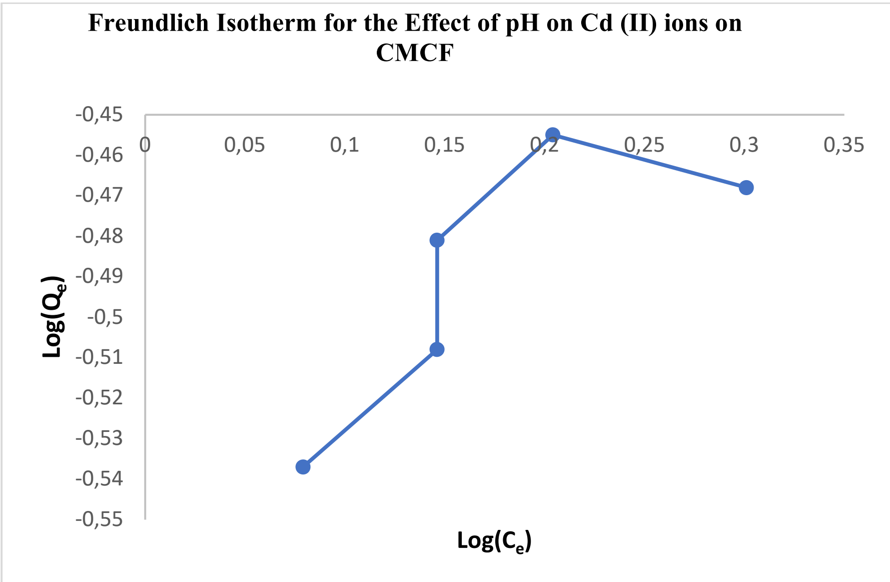

Figure 16. Freundlich Isotherm graph for the Effect of pH on Cd(II) ions for CMCF.

Freundlich Isotherm for Effect of Temperature

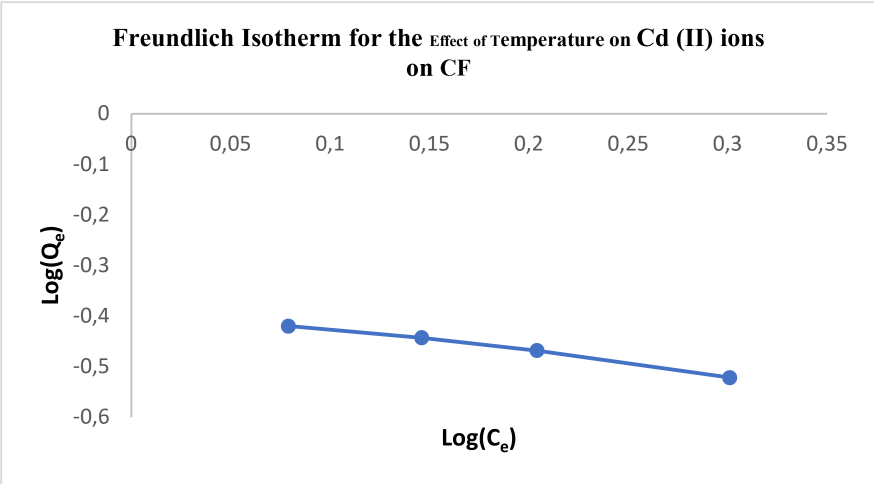

Figure 17. Freundlich Isotherm graph for the Effect of Temperature on the adsorption of Cd (II) ions on CMCF.

Freundlich Isotherm for Effect of Adsorbent Dosage

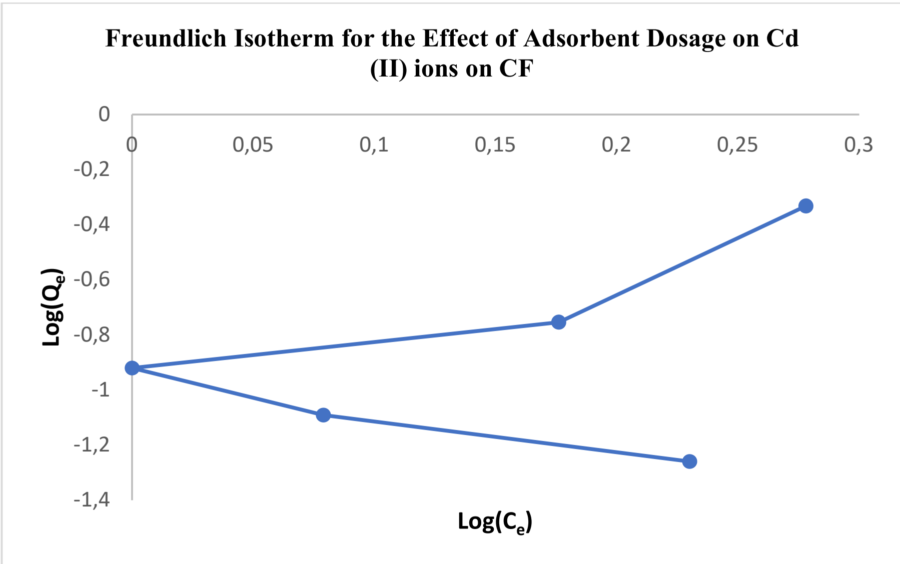

Figure 18. Freundlich Isotherm graph for the Effect of Adsorbent Dosage on Cd (II) ions for CMCF.

Temkin Isotherm for Effect of pH

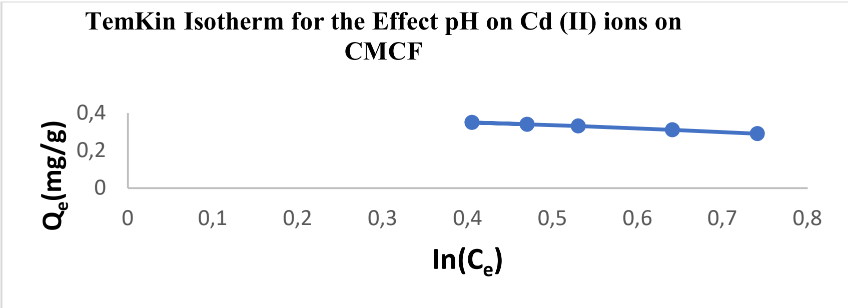

Figure 19. Temkin Isotherm graph for the Effect of pH on Cd (II) ions for CMCF

Temkin Isotherm for Effect of Temperature

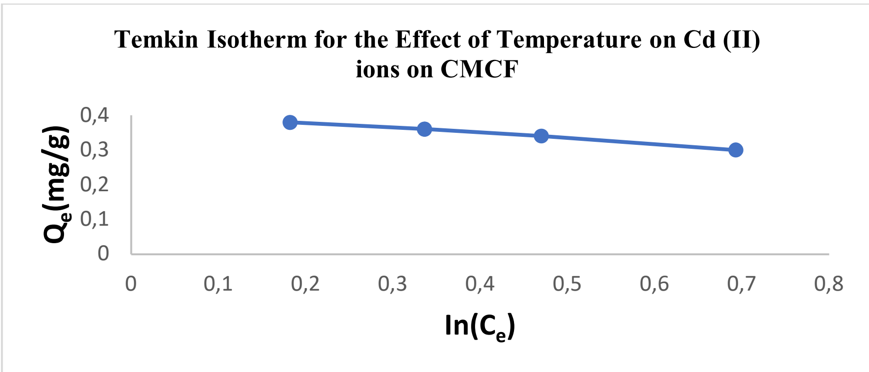

Figure 20. Temkin Isotherm graph for the Effect of Temperature on Cd (II) ions for CMCF.

Temkin Isotherm for Effect of Adsorbent Dosage

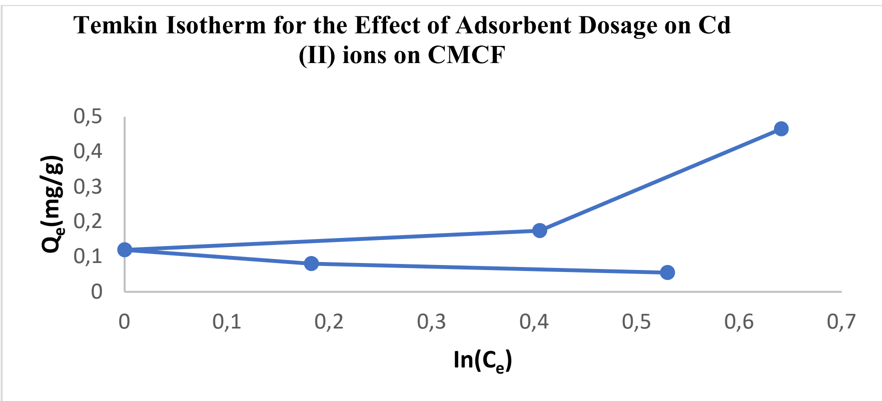

Figure 21. Temkin Isotherm graph for the Effect of Adsorbent dosage on Cd (II) ions for CMCF.

Figures 5 and 6 are the FTIR spectra of defatted and undefatted chicken feathers (CF) respectively which were recorded within a frequency range of 4000-650 cm-1, with 30 scans, 4 cm-1 resolution, and averaged over two replicate measurements. From Figure 5**,** The presence of the –OH group along with the carbonyl group confirms the presence of carboxylic acid groups in the biosorbent. The –OH, -NH, carbonyl, and carboxylic acid groups are important sorption sites. Also, the Aliphatic hydrocarbon C–H Stretching (2929 cm^{-1}) indicates the hydrocarbon chains from lipids present. After defatting the chicken feathers, the broadening of the –OH peak was observed in Figure 6. The defatted CF samples exhibited typical amide vibrations including amide A (N-H stretching), and amide I (C=O stretching, with a minor contribution from N-H bending which depicts the Keratinous protein in chicken feathers, also the C-N stretching, 1600-1700cm^{-1}), amide II and amide III (N-H bending and C-N stretching at around 1540 and 1240cm^{-1}, respectively) were observed. There is a distinct peak at 2929 cm^{-1} which indicated the C-H stretching in the aliphatic hydrocarbon of lipids and this in contrast with Figure 6 of the defatted CF where the peak appears weaker and broadened to 2937cm^{-1} which indicates a reduction in the lipid content. The significant changes on the CF are summarized in Table 1, below:

Table 1. Significant Changes After Defatting of the CF.

Functional Group	Raw Feathers	Defatted Feathers	Interpretation
O–H & N–H (3500–3200 cm^{-1})	~3675–3268 cm^{-1}	~3507–3272 cm^{-1}	Slight shift due to changes in hydrogen bonding.
C–H Stretch (2929 cm^{-1})	Strong peak	Weaker or shifted (~2937 cm^{-1})	Reduction in aliphatic lipids.
Amide I (1625 cm^{-1})	Strong peak	Slight shift (~1632 cm^{-1})	Minor protein conformational change.
Amide II (1524 cm^{-1})	Strong peak	Shifted (~1520 cm^{-1})	Possible alteration in keratin structure.
Amide III & C–O (1300–1000 cm^{-1})	Present (~1237, 1047, 924 cm^{-1})	Slightly intensified (~1341, 1237, 1047 cm^{-1})	Clearer protein signals after lipid removal.

Effect of Modifications on the CF Adsorbent

The modification of chicken feathers with citric acid has not only shown repeatable metal ion uptake capacities but also increased the capacity of the adsorbent. [8].

This increase could be seen in previous works in literature where the raw chicken feathers showed lower adsorption capacities than the modified ones. [16] in their work on "Adsorption and desorption properties of modified r and feather/polyfeathepropylene melt-blown filter cartridge of lead ion (Pb^{2+})" reported that, the modified feather/polypropylene filter cartridge exhibited higher Pb^{2+} adsorption capacity than feather/polypropylene filter cartridge and pure polypropylene filter cartridge in the whole dynamic adsorption process.

Effect of Adsorption Parameters on Chicken Feather

Effect of pH

The pH of the solution has a significant impact on the uptake of metals, since it determines the surface charge of the adsorbent, the degree of ionization, and the specification of the adsorbent [17, 18, 19]. The variation of pH affects its effectiveness, as the hydrogen ion itself is a tough competing adsorbate. Cadmium exists in different forms in aqueous solution, and the stability of these forms is dependent on the pH [20].

From Figure 7, the result showed that the adsorption of the cadmium was optimum at pH 7. This is in tandem with the findings of [21] in their research on "The effect of pH on removal of toxic metal ions from aqueous solutions using composite sorbent based on Ti-Ca-Mg phosphates" and reported that the overall findings from batch experiments demonstrated that at low pH values, the key mechanism accountable for the heavy metal removal from solutions is metal phosphate precipitation. An increase in pH generally leads to a decrease in the sorption ability of TiCaMgP and a sorption mechanism composed of ion-exchange and surface attraction.

Effect of Temperature:

The temperature dependence of the adsorption process is related to several thermodynamic parameters. The effect of temperature on the removal of cadmium ions by chicken feathers modified with citric acid was studied in the range of 293 - 373K. The results showed in Figure 10 indicate that low temperatures are in favour for the removal of this metal ion from waste water this result corresponds with the report of Horsfall et al (2005) in their work on Effect of Temperature on the Sorption of Pb2+ and Cd2+ from Aqueous Solution by Caladium bicolor (Wild Cocoyam) Biomass. And this may be due to the tendency for the metal ions to escape from the solid phase with an increase in temperature of the solution [22].

Effect of Adsorbent Dosage

The results of adsorbent dosage on the percentage removal of Cd ions. The results are further clarified in Figure 13. Initially, it was observed that the metal uptake of the cd heavy metal investigated increased with adsorbent dose of 0.2g up to 1g due to large adsorbent surface area and availability of more adsorption sites. This uptake reached an equilibrium at 1g then a decrease in metal uptake was observed after 1g up to 1.8g. This is as a result of the reduction of the binding sites on the adsorbents consequent to the saturation of the surface area, thereby hindering the uptake of more metal ions [23]. This observation is similar to that obtained by [24] their work on Sesame Husk as Adsorbent for Copper (II) Ions Removal from Aqueous Solution.

Adsorption Isotherms for Citric Acid Modified Chicken Feather (CMCF)

The results obtained by the adsorption of Cd (II) ions onto the CMCF were analyzed by the well-known models given by Langmuir, Freundlich, and Temkin isotherms.

Langmuir Isotherm for the CMCF

From the Langmuir Isotherm (1918), the term C_e/Q_e versus C_e was plotted, and the Q_{max}, K_L, and R^2 values were calculated. Langmuir parameters and correlation coefficients evaluated from the model indicate favorable conditions for the adsorption of heavy metal ions with these adsorbents [25].

The Langmuir Parameters for Effect of pH on the CMCF adsorbents are: $R_L=1/1+K_L*C_0$. Q_m(mg/g) = 0.350, KL = 0.314 and R2 = 0.997, while those Langmuir Parameter for Effect of Temperature for CMCF are Q_m(mg/g) = 0.360, KL = 0.081 and R2 = 0.0234, also the Langmuir Parameter for Effect of Adsorbent Dosage for CMCF are Q_m(mg/g) = 0.4650, KL = 0.1219 and R2 = 0.0140.

Freundlich Isotherm

The adsorption data obtained were also analyzed with the Freundlich isotherm model Freundlich, (1939) [26]. The linearized form of Freundlich isotherm was plotted according to log Q_e versus log C_e and the parameters K_F, 1/*n* and correlation coefficients R^2 were determined, where K_F and 1/n are characteristic constants that can be related to the relative adsorption capacity of the adsorbent (mg/g) and the intensity of adsorption, respectively. In summary, the Freundlich Parameters or constants for the Effect of pH for CMCF were given as follows:
K_F = 0.442, 1/n = -0.561 and R^2 = 0.995
Also, the Freundlich Isotherms constants /Parameter for the Effect of Temperature on CMCF were: K_F = 0.419, 1/n = -0.466 and R^2 = 0.986, while the Freundlich Isotherm constants /Parameter for Effect of Adsorbent Dosage on CMCF were K_F = 0.086, 1/n = 1.235 and R^2 = 0.158 as shown in the figures 16 and 17.

Temkin Isotherm

Temkin isotherm, Temkin M. I., P. V. (1940) was used to analyze the adsorption process by plotting Q_e versus lnC_e at these values: (M=0.3g, V=0.03L, T=273K) and from figures 19 to 21 the results gave the values of the Temkin Isotherm constants for the Effect of pH on Citric Acid Modified Chicken Feathers (CMCF) fig 19 as: $A_T(g^{-1})$ = 0.4237, B(J/mol) = -0.178 and R^2 = 0.997 and the Constants of the Temkin Isotherm for the Effect of Temperature on Citric Acid Modified Chicken Feathers (CMCF) fig 20 as: $A_T(g^{-1})$ = 0.411, B(J/mol) = -0.158, and R^2 = 0.993 while the constants for the Effect of Adsorbent Dosage on CMCF fig 21 are: $A_T(g^{-1})$ = 0.052, B(J/mol) = 0.361, and R^2 = 0.320

4. CONCLUSION

Citric Acid Modified Chicken Feathers (CMCF) can effectively be employed for the removal of cadmium ions from contaminated water sources. The modification enhanced the increased uptake of cadmium at pH 7. This is evident that metal ion adsorption on the adsorbent is highly dependent on the pH of the medium.
Moreover, the effect of temperature showed that there is a decrease in the adsorption process with an increase in temperature, and the optimum temperature was found to be 293K. This is due to the tendency for the metal ions to escape from the solid phase with an increase in the temperature of the solution. The maximum adsorption capacity of cadmium (II) by the CMCF was 0.465, and the optimum amount of adsorbent dose was found to be 1g. Initially, the metal uptake increased with adsorbent dose from 0.2g to 2.2g and reached equilibrium at 1g. It could be due to increased adsorbent surface area and availability of more adsorption sites. However, at 2.2g adsorbent dose, the metal ions adsorbed per unit weight of adsorbent decreased, which is because, at higher adsorbent dose, the solution ion concentration drops to a lower value of Q_e, indicating the adsorption sites remain unsaturated. Moreover, the equilibrium study of the adsorption process developed from the keratinous chicken feathers was best fitted into the Temkin Isotherm model, with a correlation coefficient of 0.999. While the Freundlich Isotherm model was also close, with a correlation coefficient up to 0.989. Hence, the adsorbents can be used as alternatives to other commercially used adsorbents for the removal of Cd ions from wastewater.

Recommendation

Further research should be carried out on the effect of co-adsorption from a bimetal solution of two heavy metals to investigate the adsorption of one metal in the presence of another.

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