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Process development for the removal of hazardous anionic azo dye Congo red from wastewater by using hen feather as potential adsorbent

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ABSTRACT

Removal of an anionic azo dye Congo red has been carried out from its aqueous solutions by using hen feathers as potential adsorbent. In the present paper, detailed chemical and physical analysis of hen feathers and its characterization through scanning electron microscope (SEM), X-ray diffractophotometer (XRD), and (infra red) IR measurements has been explained. The adsorption of an azo dye Congo red has been investigated onto the adsorbent hen feather employing batch technique at 30, 40, and 50°C temperature. Various essential factors like, adsorbent dosage, dye concentration, pH, and contact time affecting the extent of adsorption have been analyzed. On the basis of Langmuir adsorption isotherms, feasibility of the ongoing adsorption has been ascertained and thermodynamic parameters have been calculated. Attempts have also been made to verify Freundlich, Tempkin, and Dubinin-Radushkevich (D–R) adsorption isotherm models. The experimental data have been applied to the various isotherms and their constant parameters have been determined. The mean adsorption energy obtained through the D–R isotherm gave an understanding about the nature of the adsorption occurring in the removal process. Determination of various thermodynamic parameters such as free energy, entropy, etc. has been accomplished with the help of isothermal data. It has been established that spontaneous adsorption process is operative in the present case. The kinetic measurements indicate dominance of pseudo-second-order process during the adsorption. The investigation supports that the adsorbent hen feather is effective and efficient in removing the toxic dye from wastewaters.

Keywords: Adsorption; Hen feather; Congo red; Isotherm; Kinetics

1. Introduction

An increasing population and urbanization leads to rapid proliferation of industries and their pollution. Water pollution due to discharge of colored effluents from textile dye manufacturing and textile dye mills is one of the major environmental concerns in the world today. The strong colors imparted by the dyes cause esthetic and ecological problems to the aquatic ecosystems. Because of their complex molecular structures and large sizes, most of the dyes are considered nonoxidizable by conventional physical and biological

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treatments [1]. There are several techniques, which are aimed to preferential removal of different types of dyes from wastewater. The wastewater treatment through adsorption is much better than other physical techniques like, flocculation, froth flotation, etc. because of its efficiency and economy [2–6]. In order to bring cost-effectiveness in the water treatment processes, the focus of the research is to utilize industrial and agriculture waste materials as potential adsorbents [7–21]. In the last few years, several workers have tried different adsorbents such as rice husk [22–24], sugarcane bagasse [25], fibrous biomass [26], neem leaf [27,28], apple pomace and wheat straw [29], reverse micelles [30], and various other adsorbents [31–50] for the removal of organic pollutants from wastewater.

Congo red is a water soluble diazo dye with a solubility of 1 g/30 mL. It exists as brownish-red crystal and is stable in the air [51]. It is an anionic acidic dye, used in diagnosis of amyloidosis and in medicine as a biological stain. It acts as an indicator by changing to red-brown color in alkaline medium and to blue color in acidic medium. It is also used as a gamma-ray dosimeter since its coloration decays with the intensity of irradiation [52]. As a colorant, it is used to color cotton. Apart from its various uses, the dye poses significant toxicity towards humans and animals. Both, short time or prolonged contacts of the dye with eyes and skin cause severe irritation. On ingestion, it produces gastrointestinal irritation with nausea, vomiting, and diarrhea. It is carcinogenic and prolong use of the Congo red dye results into tumor formation amongst humans [53]. It may also cause blood clotting, and induce somnolence and respiratory problems [54]. It is therefore considered worthwhile to develop an easy, efficient, and economic process for the removal of the hazardous dye, Congo red using hen feather—an animal waste material, as adsorbent.

Hen feather exhibits excellent adsorption ability and due to its easy availability, nonsolubility, and nontoxic nature, it has been successfully used for the removal of some toxic metal ions [55–59] from the wastewater. Thus, utilizing hen feather for the removal of the toxic dye material, Congo red is a novel idea for the water treatment process.

2. Experimental

2.1. Materials and method

Congo red (Fig. 1) possesses, IUPAC name 3,3´{[1,1′-Biphenyl]-4,4´-diylbis(azo)}bis(4-amino-1-naphthalene sulfonic acid disodium salt), molecular formula $C_{32}H_{22}N_6Na_2O_6S_2$, and molecular weight 696.68. During spectroscopic studies, it exhibits significant absorption maxima in the visible region at λ_{max} 497 nm. The dye Congo red was procured from M/s Merck and its 0.01 M stock solution was prepared in double distilled water. All other reagents used were of analytical reagent grade. Hen feathers were procured from local poultry farm and activated before use as adsorbent.

2.2. Material development

Procured hen feathers were first thoroughly washed with tap water and detergent several times. Washed feathers were rinsed in double distilled water for about 2–3 h and then dried in an oven. With the help of scissor, soft barbs of the feathers were neatly cut into very fine pieces of approximately 0.1 mm length and hard stems are discarded. The finely cut barbs of hen feathers were once again rinsed by double distilled water and to oxidize the adhering organic impurities these were dipped in hydrogen peroxide solution (30% w/v) at room temperature for 24 h. The resulting material was then dried in an oven at 100°C to remove the moisture and stored in vacuum desiccators, until required.

2.3. Instrumentation

Chemical analysis of activated hen feathers was done by standard methods. Its surface area was determined by surface analyzer Quantasorb Model QS-7. The porosity was measued by mercury porosimeter and specific gravity bottles were employed for density measurements. For further characterization of the hen feathers, scanning electron microscopy was performed using a Philips SEM 501 electron microscope, Philips X-ray diffractophotometer coupled with nickel-filtered Cu-α-radiations was used for X-ray measurements and IR spectral studies were carried out on infrared spectrometer (HP FT-IR).

All pH measurements were done on a microprocessor-based pH meter, model number HI 8,424 (M/s Henna Instruments, Italy). Concentration of the dye

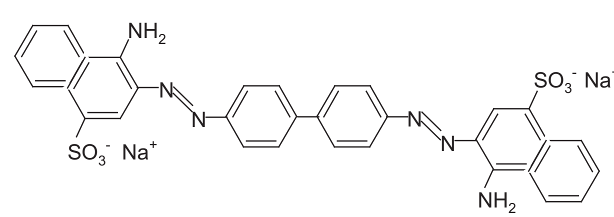

Fig. 1. Structure of Congo red.

solutions were estimated using absorbance recorded on UV/VIS spectrophotometer model number 117 (M/s Systronics, Ahmedabad, India) over the wide wavelength range 200–700 nm.

2.4. Adsorption studies

Batch technique was performed to observe the effects of pH, amount of adsorbent, adsorbate concentration, contact time, and temperature. For adsorption study, 25 mL of the dye solutions of desired concentration was taken into 100 mL volumetric flasks and a fixed amount of hen feathers were added into it. The conical flask was then agitated on a mechanical shaker at an optimum pH and desired temperature to achieve equilibrium. When equilibrium was thought to have been established, the supernatant was filtered through Whattman filter paper (No 1) and the amount of dye adsorbed was monitored spectrophotometrically at λ_{max} 497 nm.

2.5. Kinetic studies

Kinetic studies were carried out in a series of closed volumetric flasks, each of 100 mL capacity. In every volumetric flask, 25 mL of the dye solution of known concentration was taken with definite pH, temperature, and known amount of adsorbent. Each flask was shaken for a fixed time interval and filtered. Filtrates thus obtained were analyzed spectrophotometrically to determine the equilibrium concentration of the dye.

3. Results and discussion

3.1. Characterization of adsorbent

Hen feather possesses acidic nature as determined by immersing its weighed quantity in 25 mL of distilled water (pH 7.0) in a 100 mL airtight measuring flask. The solution was stirred and left undisturbed for about 24 h. The solution was then filtered and pH value of the resultant solution was found to decrease.

The chemical analysis of activated hen feathers revealed that proteins with almost 82% contents are major constituents of hen feathers and other constituents like fat, crude fiber, lysine, methionine, cysteine, calcium, magnesium, selenium, zinc, etc. are present in small quantities. The raw feather possesses a very low digestibility due to the high keratin contents and the strong disulfide bonding of the amino acids. The chemical constituents of hen feather are clearly portrayed in Table 1. Physical parameters like porosity, density, and surface area of the activated hen feathers have been ascertained by standard procedures and values obtained are 74%, 0.3834 g.mL^{-1}, and 1170.6 cm^2.g^{-1}, respectively.

Table 1
Chemical constituents of hen feathers

Constituents	Percent by weight
Crude protein	82
Fat	6
Ash	4
Crude fiber	0.6
Lysine	1.8
Methionine + cysteine	4.9
Metals (Ca, Mg, Se, Zn, etc.)	0.5

The surface morphology of hen feather was analyzed on the basis of SEM photographs and it was found that feather possesses shaft/needle like shape. Smooth stripe along the parallel section and a branch knot on the vertical section can easily be seen in the photographs, which further confirmed its smooth and compact surface. To investigate the crystalline nature of hen feathers, XRD measurements were carried out. The characteristic diffraction peak at $2\theta \approx 9.8^\circ$ corresponds to the α-helix structure and peaks at 19.5 and 21.2°, indexed as the β-sheet crystalline structure, were found available for the hen feathers. The IR spectrum of the hen feathers exhibited two primary bands corresponding to proteins. The bands at 1,600–1,700 cm^{-1} for the amide I and 1,500–1,560 cm^{-1} for amide II arose from specific stretching and bending vibrations of the protein backbone. The presence of protein constituents in hen feather was ascertained by the amide I and amide II bands appear at 1,641 and 1,531 cm^{-1}, respectively. Stretching vibrations of C–H in methylene and C–O of ether bond are attributed by bands at 2,966–2,877 cm^{-1} and 1,110 cm^{-1}, respectively.

3.2. Adsorption studies

3.2.1. Effect of pH of solution

To determine the optimum pH for the removal of the dye Congo red, the adsorption studies were carried out over a wide pH range of the dye ranging from 2.0 to 11.0 as depicted in Fig. 2. It was observed that on keeping the acidic solutions of Congo red for longer time some precipitation occurred during adsorption studies, which was observed in the form of

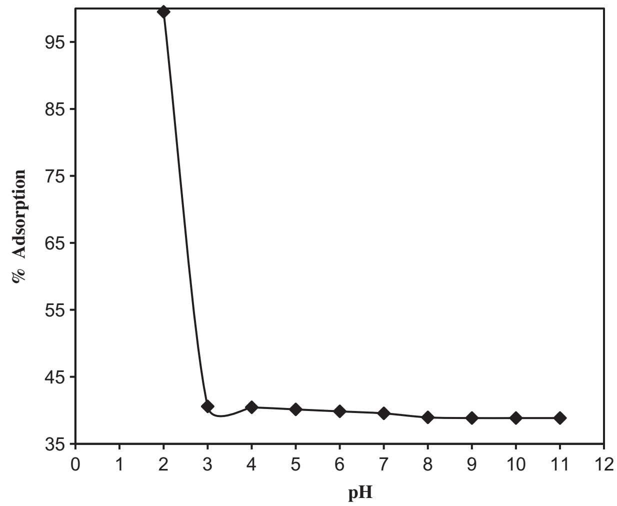

Fig. 2. Effect of pH for the uptake of Congo red (Concentration = 10×10^{-5} M) by hen feathers (dosage = 0.070 g/25 mL).

colloidal suspension or suspended particles of the dye. While, at pH 7.0 and above, the solution remained clear despite keeping over night. Hence, for all subsequent adsorption studies of Congo red, pH 7.0 was selected.

3.2.2. Effect of dye concentration

The adsorption experiments were carried out in the concentration range of the dye ranging from 4×10^{-5} to 10×10^{-5} M at a fixed pH 7.0 and temperature 30, 40, and 50˚C. Fig. 3 depicts that the amount of the dye adsorbed per gram increases with the increase in concentration. It is also observed that the rate of removal of the Congo red is faster at high concentration and increases with increasing concentration and temperature. An increase in adsorption of the dye with the rise in temperature reveals the endothermic nature of the ongoing process. Since maximum uptake of the dye was achieved at 10×10^{-5} M, therefore 10×10^{-5} M concentration of the dye was selected for all subsequent studies.

3.2.3. Effect of amount of Hen Feathers

To study the effect of amount of hen feathers on the adsorption of Congo red, batch experiments were conducted at 30, 40, and 50˚C. In the 25 mL of 1×10^{-4} M Congo red solution at fixed pH, 0.010–0.115 g of amount of hen feather was added. Fig. 4 apparently shows an increase in the adsorption capacity with the increase in the dosage of the adsorbent. From the graph, it was found that, when the amount of adsorbent increased from 0.010 to 0.070 g, the adsorption capacity increased to almost double. The most favorable adsorption was observed for 0.070 g of adsorbent at each temperature. Hence, all the subsequent studies were carried out at 0.070 g of the hen feather.

3.3. Adsorption isotherm studies

Successful application of the adsorption technique demand studies based on various adsorption isotherm models [60] because adsorption isotherm models

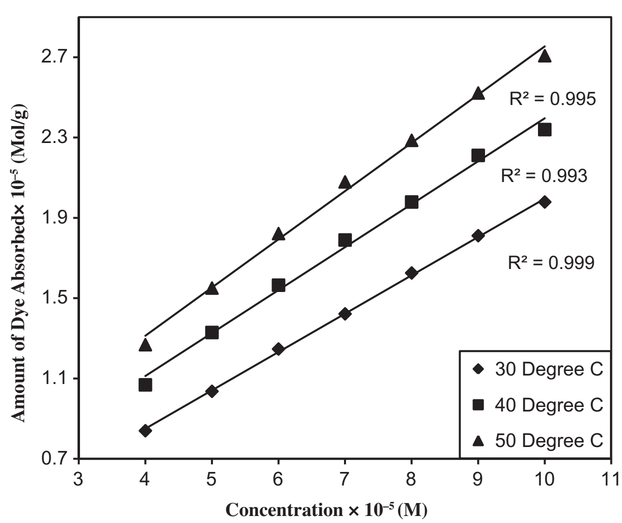

Fig. 3. Effect of concentration for the uptake of Congo red (pH 7.0) by hen feathers (dose = 0.070 g/25 mL) at different temperatures.

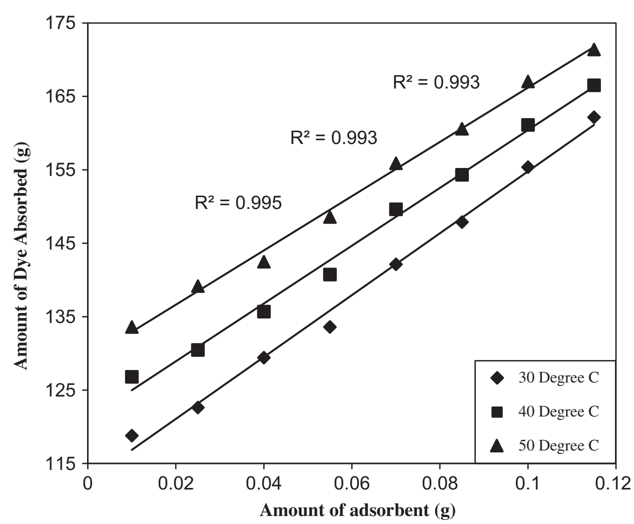

Fig. 4. Effect of amount of adsorbent for the uptake of Congo red (pH 7.0, concentration = 10×10^{-5} M) by hen feathers at different temperatures.

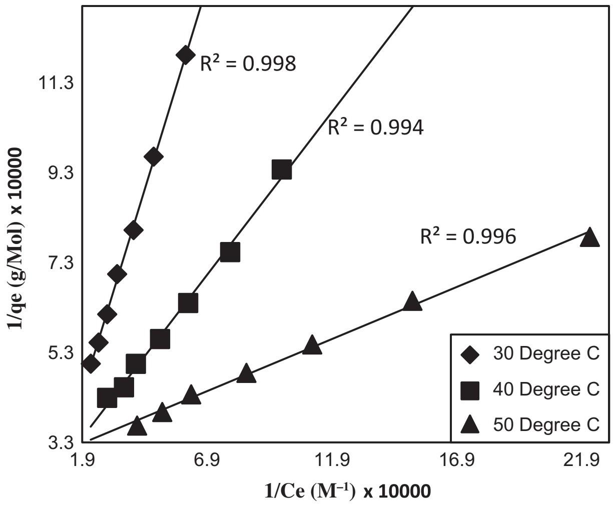

Fig. 5. Langmuir adsorption isotherm for Congo red (pH 7.0)—hen feather (0.070 g/25 mL) system at different temperatures.

clearly depict the relationship of amount adsorbed by a unit weight of adsorbent with the remaining concentration in the solution. Hence, the dye uptake data gathered at 30, 40, and 50˚C was applied to the popular Langmuir, Freundlich, Tempkin, and D–R adsorption isotherm models.

3.3.1. Langmuir adsorption isotherm

The Langmuir isotherm model is chosen for the estimation of maximum adsorption capacity of the adsorbents corresponding to complete monolayer coverage on their surface. The well-known linear form of Langmuir's adsorption isotherm equation (Eq. (1)) was applied for the removal of Congo red by hen feathers.

$$\frac{1}{q_e} = \frac{1}{q_o} + \frac{1}{bq_oC_e} \tag{1}$$

where q_e is the number of moles of solute adsorbed per unit weight at concentration C, C is the molar concentration in the bulk fluid phase.

The $1/q_e$ vs. $1/C_e$ plots at 30, 40, and 50˚C gives straight lines with regression coefficient values close to unity in each case (Fig. 5). This indicates unimolecular layer formation of the dye over adsorbent and there is no transmigration of the dye in the plane of the surface of the hen feathers. The Langmuir constants b and Q_o obtained by the straight lines are presented in Table 2, and used for the calculation of thermodynamic parameters and feasibility of the ongoing adsorption process.

To identify the favorability and feasibility of the adsorption process, the dimensionless separation factor ''r'' was calculated by using following equation:

$$r = \frac{1}{1 + bC_o} \tag{2}$$

where b is the Langmuir constant and C_o is the initial concentration. The values of ''r'' were found less than unity and confirmed the feasibility of the process.

On the other hand, thermodynamic parameters change in free energy (ΔG_o), change in enthalpy (ΔH_o), and change in entropy (ΔS_o) were calculated using following equations:

$$\Delta G^{\circ} = -RT \ln b \tag{3}$$

$$\Delta H^{\circ} = -R \times \frac{T_2T_1}{T_2T_1} \times \ln \frac{b_2}{b_1} \tag{4}$$

$$\Delta S^{\circ} = \frac{\Delta H^{\circ} - \Delta G^{\circ}}{T} \tag{5}$$

where b, b_1, and b_2 are the equilibrium constants at 30, 40, and 50˚C, respectively. The evaluated thermodynamic parameters are presented in Table 3. The negative values of free energy (ΔG^{o}) indicate the feasibility and spontaneous nature of the ongoing process. The value of change in enthalpy (ΔH^{o}) is found to be positive confirms the endothermic nature of the process. The positive value of change in entropy (ΔS^{o}) is evident for increased randomness in the adsorption process and reveal good affinity towards the dye molecule [61].

Table 2
Values of langmuir constants for Congo red (pH 7.0)—hen feather (0.070 g/25 mL) system at different temperatures

$Q_o \times 10^{-5}$ (Mol/g)			$b \times 10^4$ (L/Mol)		
30˚C	40˚C	50˚C	30˚C	40˚C	50˚C
10.60	4.94	3.52	0.52	2.79	12.29

Table 3
Calculated Thermodynamic Parameters for the Adsorption of Congo red (pH 7.0)—over hen feathers (0.070 g/25 mL)

$-\Delta G^o$ (kJ Mol^{-1})			ΔH^o (kJ Mol^{-1})	ΔS^o (JK^{-1} Mol^{-1})
30˚C	40˚C	50˚C		
21.56	26.64	31.47	128.83	32.59

3.3.2. Freundlich adsorption isotherm

The fundamental assumption of the model is based on the affinities of the binding sites available on the adsorbent surface. Due to variation of interactions between the adsorbed molecules sites with stronger affinity are occupied first, and in this way multilayer setting of adsorbate molecules takes place. Equation describing Freundlich model for the adsorption of solutes from a liquid to a solid surface was applied for the present adsorption system:

$$\log q_e = \log K_F + (1/n) \log C_e \quad (6)$$

Here C_e denotes the equilibrium concentration (M) of the adsorbate, q_e, the amount adsorbed (g mol^{-1}), and K_F and n are the Freundlich constants related to the adsorption capacity and adsorption intensity of the adsorbate–adsorbent system, respectively. In order to verify Freundlich adsorption isotherm a graph taking log C_e on abscissa and log q_e on the ordinate was plotted at all the three temperatures [62]. The experimental data obtained in terms of log C_e and log q_e, found fit into straight lines with regression coefficients close to unity (Fig. 6). Values of Freundlich constants K_F and n are derived from the intercepts and slope of these straight lines, respectively, and presented in Table 4.

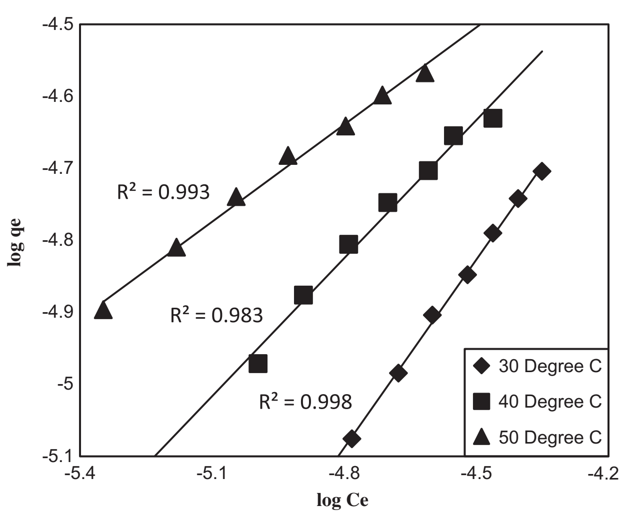

Fig. 6. Freundlich adsorption isotherm for Congo red (pH 7.0)—hen feather (0.070 g/25 mL) system at different temperatures.

3.3.3. Tempkin adsorption Isotherm

Following linear form of Tempkin isothermal model is expressed as:

$$q_e = k_1 \ln k_2 + k_1 \ln C_e \quad (7)$$

where q_e is the amount of adsorbate adsorbed per unit mass of adsorbent at equilibrium (mol g^{-1}), C_e is the final concentration at equilibrium (mol L^{-1}), k_1 is the Tempkin isotherm energy constant (L mol^{-1}) related to the heat of adsorption, and k_2 is the Tempkin's isotherm constant. The applicability of Tempkin adsorption isotherm in the ongoing adsorption process was verified by sketching plot of ln C_e as function of amount adsorbed at equilibrium [63] and straight lines are obtained at all the temperatures (Fig. 7), suggesting thereby uniform distribution of binding energy arising due to interaction of the dye molecules with hen feathers. The straight lines obtained from the graphs are helpful in determining the Tempkin constants presented in Table 5.

3.3.4. D–R adsorption Isotherm

Dubinin–Radushkevich (D–R) model [64] suggests the porosity and heterogeneous surface of the adsorbent. This model has been used to distinguish between chemical and physical adsorptions, and also chosen to estimate mean free energy of the adsorption. The linear form of D–R Isotherm modal is expressed as:

$$\ln C_{ads} = \ln X_m - \beta\epsilon^2 \quad (8)$$

where X_m is the maximum adsorption capacity, is the activity coefficient related to mean sorption energy, and ϵ is the Polanyi potential, which is equal to:

Table 4
Values of Freundlich constants for Congo red (pH 7.0)—hen feather (0.070 g/25 mL) system at different temperatures

n			K_F		
30˚C	40˚C	50˚C	30˚C	40˚C	50˚C
1.14	1.56	2.22	0.123	0.017	0.003

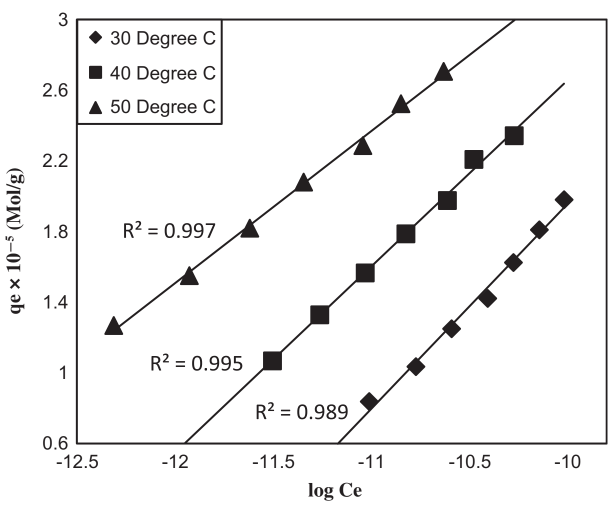

Fig. 7. Tempkin adsorption isotherm for Congo red (pH 7.0)—hen feather (0.070 g/25 mL) system at different temperatures.

$$\epsilon = RT\ln\left(1+\frac{1}{C_e}\right) \tag{9}$$

where R is the gas constant and T is temperature in Kelvin. On the basis of Eq. (8) slopes of straight lines of graphs between ln C_{ads} against ϵ^2 (Fig. 8) give activity coefficients (β) and intercept yields adsorption capacities (ln X_m) at 30, 40, and 50˚C (Table 6). The values of obtained was used to calculate mean sorption energy by following expression:

$$E = \frac{1}{\sqrt{-2\beta}} \tag{10}$$

At 30, 40, and 50˚C the values of E have been calculated about 9, 11, and 13 kJ/mol indicating thereby dominance of chemisorption in the ongoing adsorption process [65,66].

3.4. Kinetic studies

3.4.1. Effect of contact time

The effect of contact time was monitored at 6×10^{-5} and 10×10^{-5} concentrations of the dye, 7.0 pH, and 0.070 g of amount of hen feather. From the data (Fig. 9), it can be examined that the dye equilibrium was attained in first 3 h of the contact time. The kinetics of adsorption process showed an increase in adsorption capacity with the increasing temperature. These results once again confirm the endothermic nature of the ongoing process.

3.4.2. Adsorption rate constant study

To interpret the specific rate constant of the adsorption process the following Ho–Mckay pseudo-second-order rate expression was applied [67].

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \tag{11}$$

where q_e and q_t are adsorption capacities at equilibrium and time t (Mol g^{-1}), respectively, and k_2 is the rate constant of the pseudo-second-order rate expression (g Mol^{-1} s^{-1}). The plot of t/q_t against time (Fig. 10) gave straight lines with regression coefficient values equivalent to almost unity, confirming thereby the pseudo-second-order kinetics of the ongoing process at all the temperatures. The values

Table 5
Values of Tempkin constants for Congo red (pH 7.0)—hen feather (0.070 g/25 mL) system at different temperatures

k_1 (L/Mol)			$k_2\times10^4$		
30˚C	40˚C	50˚C	30˚C	40˚C	50˚C
1.15	1.05	0.86	11.95	27.54	94.20

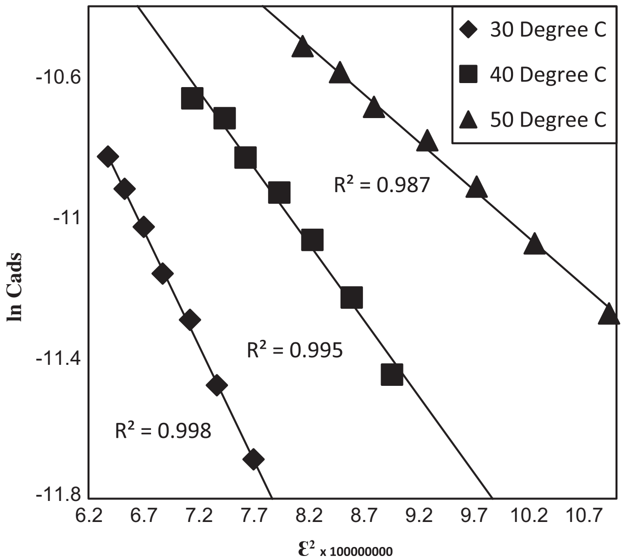

Fig. 8. D–R adsorption isotherm for Congo red (pH pH 7.0)—hen feather (0. 070 g/25 mL) system at different temperatures.

Table 6
Values of D–R constants for Congo red (pH 7.0)—hen feather (0.070 g/25 mL) system at different temperatures

$-\beta$ (Mol^2 J^{-2})$\times 10^{-9}$			$X_m \times 10^{-4}$ (Mol/g)		
30°C	40°C	50°C	30°C	40°C	50°C
6.0	4.0	3.0	12.77	5.45	2.53

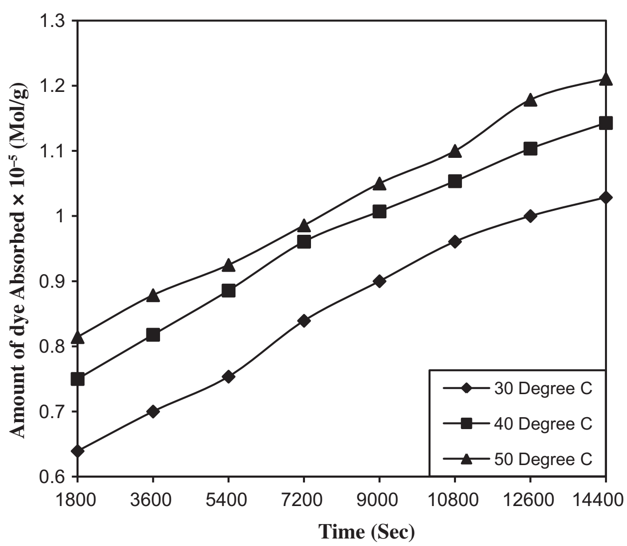

Fig. 9. Effect of contact time for the uptake of Congo red (pH 7.0, Concentration = 6×10^{-5} M) by hen feathers (0.070 g/25 mL) at different temperatures.

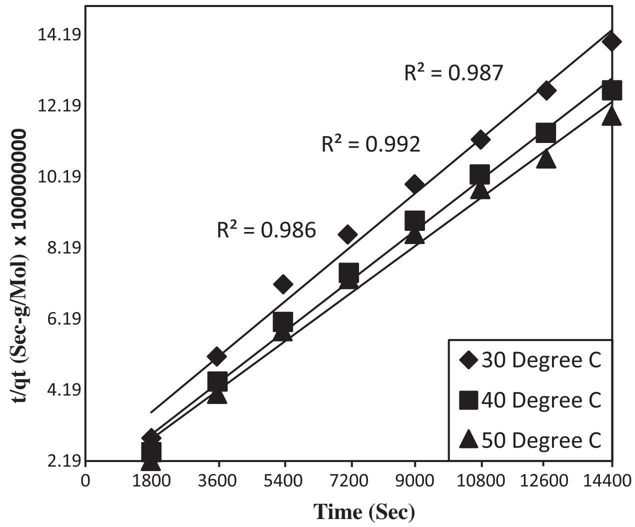

Fig. 10. Plot of time vs. t/q_t for Congo red (pH 7.0, Concentration = 6×10^{-5} M)—hen feathers (0.070 g/25 mL) system at different temperatures.

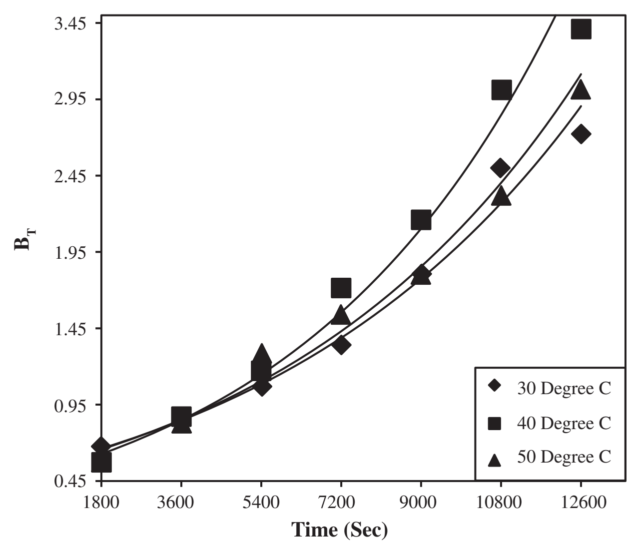

Fig. 11. Correlation of time vs. B_t for Congo red (pH 7.0, Concentration = 6×10^{-5} M)—hen feathers (0.070 g/25 mL) system at different temperatures.

of pseudo-second-order rate constants were estimated as 27.8, 20.0, and 63.1 g Mol^{-1} s^{-1}.

3.4.3. Rate expression and treatment of data

For an appropriate interpretation of the experimental data, it is highly essential to identify the steps in the adsorption process. The ingenious mathematical treatments recommended by Boyd et al. [68] and

Reichenberg [69] have been applied for elucidating the kinetics data. These mathematical treatments were found useful to distinguish between particle diffusion and film diffusion. During an efficient adsorption process of an organic/inorganic substance over an adsorbent, the possible successive steps are:

(1) Transport of the ingoing ions (adsorbate) to the external surface of the adsorbent (film diffusion).
(2) Transport of the adsorbate within the pores of the adsorbent except for a small amount of adsorption, which occurs on the external surface (particle diffusion).
(3) Adsorption of the ingoing ion (adsorbate) on the interior surface of the adsorbent.

Out of these three steps, the third step is considered to be very fast and does not signify the rate-limiting step in the uptake of organic compounds [70], whereas, the remaining two steps imparts following three possibilities:

- The Case I When external transport internal transport, where rate is governed by particle diffusion.
- The Case II When external transport internal transport, where rate is governed by film diffusion.
- The Case III When external transport internal transport, accounts for the transport of the adsorbate ions to the boundary and may not be possible within a significant rate, which later on give rise to the formation of a liquid film surrounded by the adsorbent particles with a proper concentration gradient.

A quantitative treatment of the sorption dynamics can be applied with the help of following expressions:

$$F = 1 - \frac{6}{\pi^2}\sum_{1}^{\infty}(1/n^2)\exp(-n^2 B_t) \tag{12}$$

where n is Freundlich constant and F is the fractional attainment of equilibrium at time t and is obtained by using following equation:

$$F = \frac{Q_t}{Q_\infty} \tag{13}$$

where Q_t and Q_∞ are amounts adsorbed after time t and after infinite time respectively. The other parameter B_t is known as time constant and obtained by following expression:

$$B_t = \frac{\pi^2 D_i}{{r_o}^2} \tag{14}$$

where B_t = time constant, D_i = effective diffusion coefficient of adsorbate in the adsorbent phase, and r_o = radius of adsorbent particles assumed to be spherical.

For every observed value of F, corresponding values of B_t were derived from Reichenberg's table. Fig. 11 do not show linearity, which reveals the rate determining process governing through film diffusion at all the temperatures (30, 40, and 50˚C).

4. Conclusions

The research work illustrated that the adsorbent material hen feather is highly efficient and has enormous potential to remove hazardous azo dye Congo red from its aqueous solutions. It was also found that the adsorption is very much dependent upon parameters like pH, contact time, amount of adsorbent, adsorbate concentration, and temperature. The highest adsorption of the Congo red can be achieved at 6×10^{-5} concentration, 7.0 pH, and 0.070 g quantity of hen feathers. The batch adsorption studies clearly suggested that the linearity was shown by the Langmuir, Freundlich, Tempkin, and D–R adsorption isotherm graphs. The calculated values of different thermodynamic parameters clearly indicated that the ongoing adsorption process is feasible, spontaneous, and endothermic in nature. The kinetic studies also exhibited that the ongoing adsorption process follows pseudo-second-order kinetics with film diffusion mechanism.

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