

PAVO CRISTATUS FEATHER POWDER AS AN ECO-FRIENDLY AND LOW COST MATERIAL FOR MITIGATION OF Pb(II) IONS FROM WATER

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ABSTRACT Mitigation of Pb(II) ions from water using economic method is an important research area to combat the pollution due to lead ions Pb(II) in water as it have severe toxic effects in human beings. In present work, Pristine *Pavo Cristatus* feather powder (PCFP) has been employed for removal of Pb(II) ions and the process of adsorption was optimized through four level Box Behnken design (BBD) of response surface methodology (RSM) over a broad range of pH (3.0–9.0), initial lead ion concentration (20–100 mg/L), contact time (20–180 min) and temperature (297 K to 333 K). Different isotherms were applied to confirm the type of adsorption. Langmuir maximum removal efficiency was 121.95 mg/g for lead ions adsorption onto PCFP at optimal values of pH 6; adsorbent dose 20 mg/L; temperature 303 K and contact time 120 minutes obtained from batch studies. Pseudo-second-order reaction model showed good applicability for kinetic studies. Thermodynamic parameters were also evaluated to check feasibility and nature of adsorption. The optimal parameters obtained for maximum Pb(II) ions adsorption were at pH = 6.31, initial Pb(II) ion = 43.79 mg/L, contact time = 119.51 minutes and temperature = 59.67 °C. The experimental and predicted values were found to be in good agreement with each other.

Keywords: Adsorption, Response surface methodology, Langmuir isotherm model, Lead, *Pavo Cristatus* feather powder.

1. INTRODUCTION

Water pollution because of lead and other metal ions causes serious human health hazards and environmental implications. These heavy metal ions may enter into all living systems including human beings through food, air and water. Small concentrations of these heavy metal ions have severe toxic effects in human beings (Yavuz et al., 2007). In addition, these heavy metal ions may enter into water

streams and soil and adversely affect yield, growth and quality of the crops (Garba et al., 2016; Naseem and Tahir, 2001). Pb(II) is noxious metal found in earth's crust. Human activities such as mining, manufacturing and burning fossil fuels are the main reasons behind its occurrence in the environment. Lead poisoning effects in children are irreversible and may lead to brain damage, kidney problems, hyperactivity, juvenile delinquency learning & behavioral problems and

impaired hearing (Raikar et al., 2015; Das et al. 2014). Toxicological effects of lead on adults are liver, kidney, reproductive system & brain damage (Annadurai et al., 2002; Farhan et al., 2013; El-Ashtoukhy et al., 2008). Excessive exposure of lead leads to insomnia, anemia, muscles weakness, irritability, headache and renal damage (Alam et al., 2012; Azouaoua et al., 2013; El-Wakil et al. 2014).

According to Indian standard for drinking water (BIS, 1981), environmental protection agency (EPA, 2008) and world health organization (WHO, 1996) desirable amount of Pb(II) ions in drinking water are 0.01, 0.015 & 0.05 mg/L respectively. As per the various investigations in different parts of world, Pb(II) ions concentration in ground water was found to be more than the permissible levels. Ground water samples from different districts of Punjab, India were found to contain lead more than the permissible value (The Tribune, 2018). As per another report in Business Standard (March, 2018) underground water samples were found to be polluted with high concentration of lead in an e-waste dumping site at Krishna Vihar in Delhi, India. On 7 Jan, 2016, Flint, Michigan, was declared to be in state of emergency due to its drinking water contamination with lead (CNN, 2016). Water samples from a number of Hong Kong's housing estates were found to be contaminated with lead which exceed WHO standards (SCMP, 2015). In Kolkata (India), 150 out of 250 blood samples of kids were tested positive for high levels of lead. Daily use items such as lead pencils, cheap plastic mugs, toys, cheap crayons and colors, wall paints are to be blamed for this lead poisoning (The Times of India, 2013). Annually, painted idols were immersed in rivers and lakes in India which increases the lead levels in water sources (The Wall Street Journal, 2015). As many studies confirm the

presence of lead(II) in ground water in Indian as well as global scenario, there is pressing requirement of economic and feasible water treatment methods that local residents can adopt to get water suitable for drinking and cooking purposes.

Adsorption is a time saving, simple and user-friendly method to adsorb of toxic metal ions from solutions (Kyzas et al., 2015). Various adsorbents have been reported in literature for toxic metal ions adsorption from aqueous solutions but their use is restricted because of certain limitations like high cost, poor efficiency and other environmental implications (Akpomie et al., 2013). It is more important and exigent to find cost effective materials for metal ions adsorption. The main aim of the current study was to utilize *Pavo Cristatus* feather powder (PCFP), an economical material for effective removal of lead ions from water. *Pavo Cristatus* (Peacock) feathers are widely used in ayurveda to treat diseases like hiccups, vomiting, and respiratory disorder etc. (Kotrannavar et al., 2012). To best of our knowledge, this work is the first to report of application of *Pavo Cristatus* (Peacock) feathers as an adsorbent for lead mitigation. To increase the effectiveness of the experiment, to reduce process inconsistency, time and overall costs, RSM was used in current study for optimizing the operational variables (Niad et al. 2016; Kamsonlian and Shukla, 2013).

2. MATERIALS AND METHODS

2.1 Chemicals and preparation of solutions

Lead nitrate, sulphuric acid and sodium hydroxide were of AR grade (E. Merck Ltd., India). Stock solution of lead ions (1000 ppm) was prepared in double

distilled water. Solutions of concentration (20-100 mg/L) were further prepared. 0.1N HNO₃ & NaOH were taken to alter the pH.

2.2 Characterization

Scanning electron microscope (SEM) (JEOL), FTIR spectrophotometer (Shimadzu), energy dispersive x-ray spectroscopy (EDX) & BET surface analyzer (Quanta chrome Autosorb) were used to analyze the textural, elemental composition, molecular structure & surface properties, respectively of the adsorbent.

2.3 Preparation of *Pavo Cristatus* feather powder

Pavo Cristatus feather were purchased from ayurvedic shop in local market, Gurugram, Haryana (India), washed thoroughly and dried at 100 °C till

constant weight was obtained. Washed and dried feathers were powdered to fine powder using mechanical grinder and stored in desiccator until used for adsorption studies.

2.4 Batch studies

The experiments were performed through shaking PPCF material with lead ions solution of desired concentration at 150 rpm. After shaking the bottles, PPCF was separated through filter paper. The remaining amount of lead in filtrate was determined by atomic absorption spectrophotometer (AA-6200, Shimadzu). Before each analysis, calibration of instrument was performed with standards supplied with instrument. The concentration of lead ions adsorbed per unit mass of adsorbent (q_e in mg/g) was determined by following equation:

$$q_e = (C_o - C_e) V/M \quad (1)$$

C_o = Initial concentration of Pb(II) (mg/L),

C_e = Final concentration of Pb(II) (mg/L),

q_e = Concentration of lead adsorbed per unit mass of PPCF (mg/g),

V = Volume of Pb(II) solution (L), M = Mass of adsorbent, PPCF (g).

3. RESULTS AND DISCUSSION

3.1 Characterization of *Pavo Cristatus* feather

3.1.1 SEM & EDX analysis

The surface topography of PPCF was studied by using SEM technique & the SEM images obtained before & after Pb(II) adsorption at x1000 magnification are given in Figure 1. The adsorbent shows a porous and irregular structure with vacant sites in Figure 1 (a). In Figure 1(b), it can be observed that vacant sites are filled by Pb(II) ions non-uniformly. So, it can be

concluded that the surface of PPCF has changed to a significant extent after adsorption of lead ions.

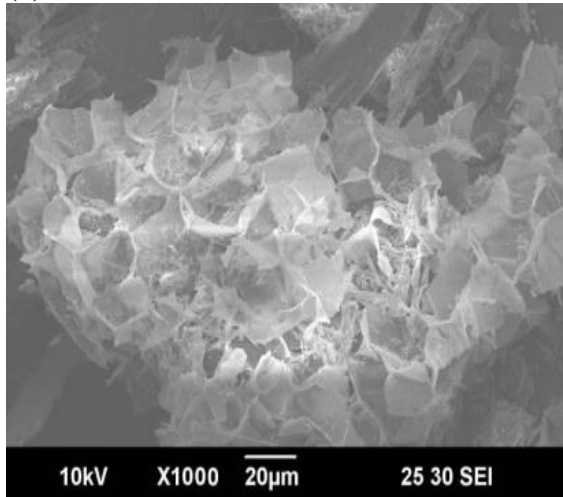
EDX analysis of PPCF before & after lead adsorption is given in Figure 1 and the elemental composition of the adsorbent so obtained is summarized in Figure 1 (c) & (d). EDX spectrum of PPCF (Figure 1c) did not display any characteristic peak for lead ions. However, PPCF after adsorption of lead ions display an additional peaks of Pb(II) at 2.4 and 10.5 KeV in EDX spectra (Figure 1d) which is displayed as 1.93% Pb(II) accumulation.

3.1.2 BET studies

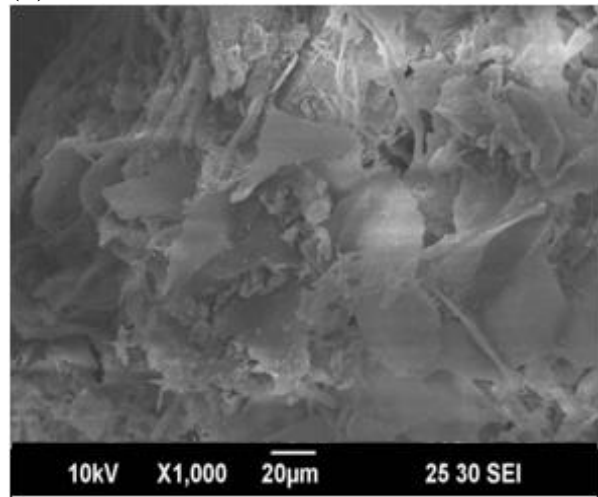
Specific surface area & pore size of PPCF was calculated through N₂ adsorption at 77 K. The BET (Brunauer-Emmett and Teller) model was applied on nitrogen adsorption isotherm to determine the total

specific surface area (Brunauer et al. 1938). The surface area and pore diameter were observed to be 12.89 m²/g and 4.6nm, respectively. The observed pore diameter was in the range of mesopores (2-50 nm) which was in favour of adsorption of lead ions on PPCF surface.

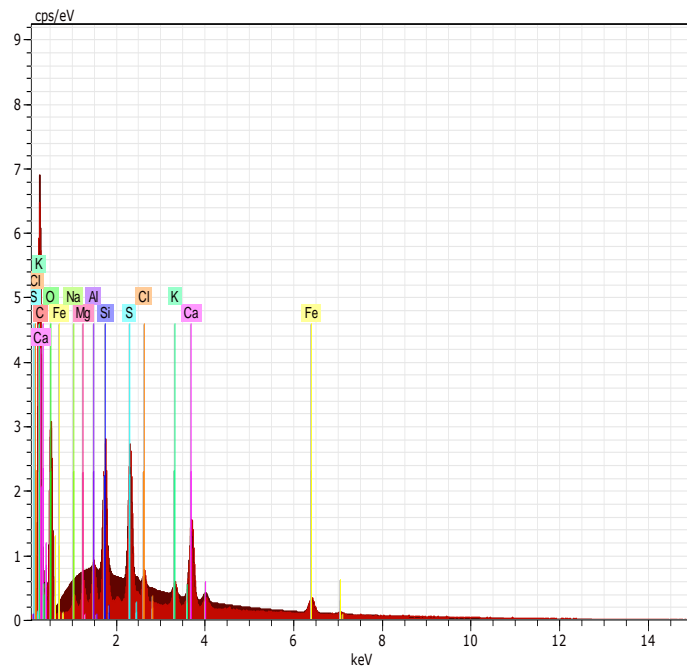
(a)



(b)



(c)



Element	Wt.%
Carbon	36.1
Sulfur	1.34
Iron	1.14
Calcium	1.38
Oxygen	58.88
Silicon	1.16

(d)

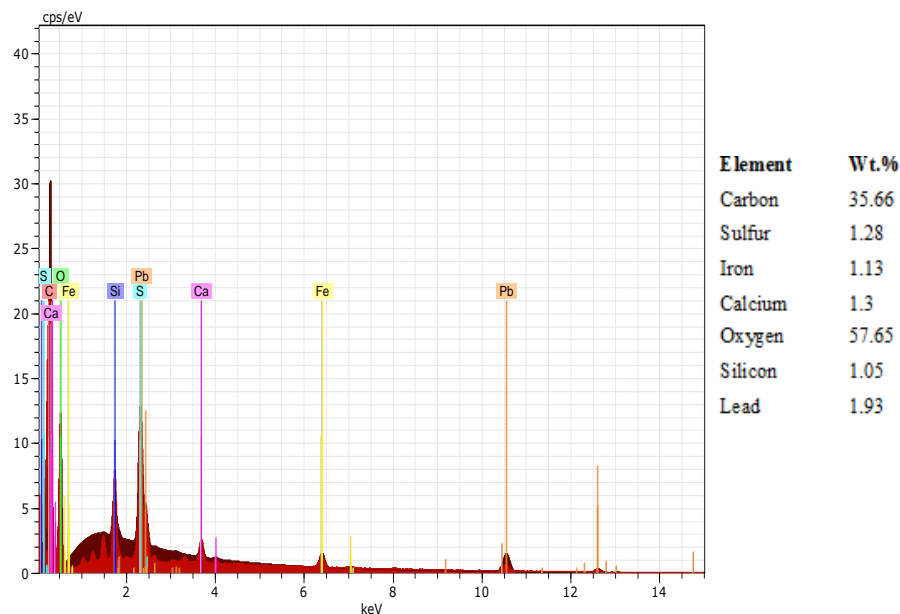


Figure 1. SEM and EDX images of adsorbents (a) *Pavo Cristatus* feather powder (PCFP) (b) *Pavo Cristatus* feather powder loaded with lead ions (c) *Pavo Cristatus* feather powder and (d) *Pavo Cristatus* feather powder loaded with lead ions

3.1.3 FTIR analysis

The FTIR analysis of the adsorbent, PPCF was carried out before & after lead adsorption. FTIR spectra of PPCF shows peaks at 1643, 1450, and 1373 cm^{-1} that may be ascribed due to C=O stretching vibration, asymmetric stretching vibration of $-\text{CH}_3$ and $-\text{CH}_2$ & C-O symmetric stretching vibrations of $-\text{COOH}$, respectively. FTIR spectra of PPCF show a new peak at 732.95 cm^{-1} after adsorption of bivalent lead ions, which indicated the formation of Pb-O bond. Also the intensity of adsorption band at 1373 cm^{-1} was decreased and shifted to 1363 cm^{-1} (Figure 2). The appearance of new peak confirmed the chemical adsorption due to the formation of new chemical bond between metal ions and carboxylate group generated by the loss of proton on the surface.

3.2 Adsorption studies

3.2.1 Effect of pH

The study was carried out in the pH range of 1-9. Adsorption of lead on PCFP was found to increase as pH was increased from 1 to 6 (Figure 3a). At higher pH, lead ions were precipitated as a result of hydroxides formation. The optimal pH for maximum adsorption was found to be 6.

3.2.2 Effect of initial concentration

The adsorption efficiencies of the PCFP at different concentration of lead ions (20 to 100 ppm) are given in Figure 3b. The removal percentage decreased with increase in Pb(II) concentration. At the low ion concentration, utmost ions interact with the adsorption sites leading to maximum

adsorption in the solution. However, more lead ions may be present at higher concentration without being adsorbed

because of saturation of the active sites. 60 ppm concentration was taken for consequent experiments.

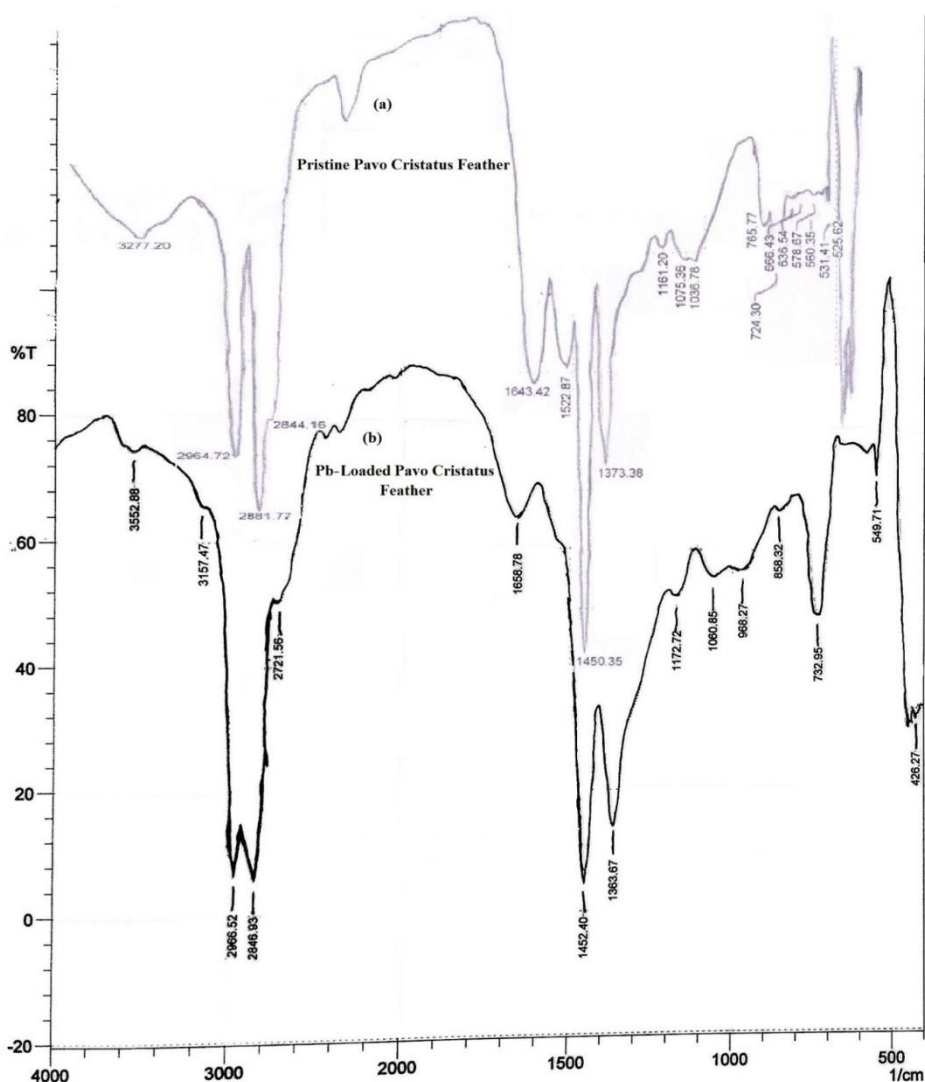


Figure 2. IR spectra of *Pavo Cristatus* feather powder and *Pavo Cristatus* feather powder loaded with lead ions

3.2.3 Effect of adsorbent dose

Adsorbent dose was taken from 10 to 50 mg/L under appropriate set of conditions i.e. initial concentration = 60 ppm; pH = 6; Temperature = 303 K; Contact time = 120 minutes. Maximum Pb (II) ion removal was found at 20 mg/L of PPCF and after that increase in dosage did not show any remarkable change in removal efficiency (Figure 3c). This might be owing to the saturation of adsorption

sites on PPCF surface. Therefore, 20 mg/L was taken as optimized dose for all experiments.

3.2.4 Effect of contact time

The lead ions adsorption increased with increase in contact time at pH 6 for a fixed concentration of lead ion; fixed adsorbent dose; 303 K temperature and then become almost constant after 120 minutes. Studies showed that equilibrium was

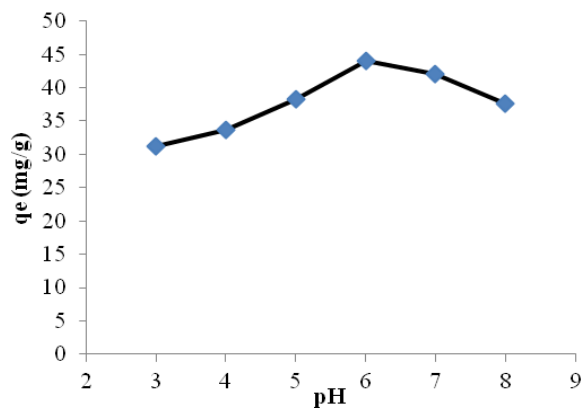
attained at 120 min & was taken for the later experiments to make certain that equilibrium is well attained.

3.2.5 Effect of temperature

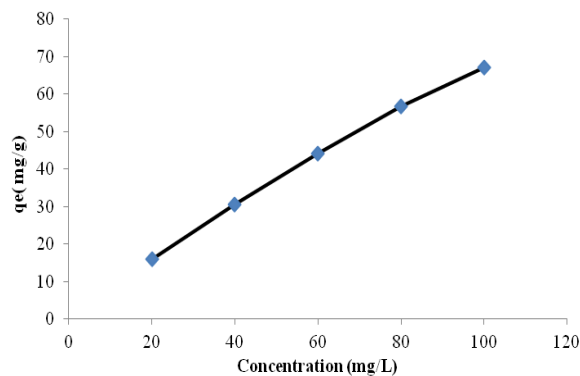
The lead ions adsorption by PCFP was performed within the temperature range of 297 K to 333 K with other

optimized adsorption conditions i.e, pH = 6; initial concentration = 60 ppm; adsorbent dose = 20 mg/L; contact time = 120 minutes. The lead ions adsorption increased with increase in temperature which might be attributed to increase in the movability of metal ions & interaction of ions in solutions with the adsorption sites of adsorbent.

(a)



(b)



(c)

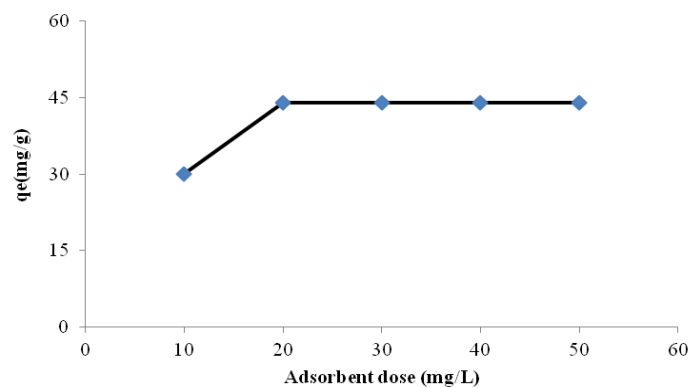


Figure 3. Effect of pH, initial lead ions adsorption, and adsorbent dose on adsorption of lead onto PCFP

3.3 Adsorption isotherms

In the current study, different isotherms were applied to analyze the experimental data & calculated results are summarized in Table 1.

$$C_e/q_e = 1/(q_{max}K_L) + C_e/q_{max} \quad (2)$$

Where C_e = Equilibrium concentration (g/L), q_e = Amount of adsorbate at equilibrium (mg/g), q_{max} = Adsorption capability (mg/g), K_L = Constant (L/mg). The value of q_{max} & K_L is calculated from the Langmuir linear plot C_e versus C_e/q_e (Figure 4(a)). In present work,

$$R_L = 1/(1 + K_L C_0) \quad (3)$$

Where K_L = Constant (L/mg) and C_0 = Initial concentration of Pb(II) (g/L). When the value of the R_L is 0, isotherm will be irreversible, for $R_L > 1$ will be unfavorable, $R_L = 1$ will be linear and for $0 < R_L < 1$ will be favorable. The R_L value calculated by equation (3), R_L were found

$$\ln q_e = \ln K + 1/n \ln C_e \quad (4)$$

Where q_e = Amount of Pb(II) adsorbed (mg/g), C_e = Equilibrium concentration (g/L), K = Freundlich constant. The value of n & K was calculated from the linear Freundlich plot of $\ln C_e$ and $\ln q_e$ (Figure 4 (b)). The value of n obtained from slope

$$q_e = B \ln A + B \ln C_e \quad (5)$$

Where q_e = Amount of Pb(II) adsorbed(mg/g), C_e = Equilibrium concentration (g/L), A & B are constants.

$$(B = RT/b_T) \quad (6)$$

Where R = Ideal gas constant (8.314 J/mol/K), T = Temperature (K) and b_T = Temkin isotherm constant. The value of A and B can be determined by linear Temkin plot of q_e versus $\ln C_e$ Langmuir model,

3.3.1 The Langmuir isotherm

Linear form of Langmuir isotherm can be represented as follows:

Langmuir maximum adsorption capacity (q_{max}) and equilibrium constant were 121.95 mg/g & 0.0371 l/mg respectively (Table 1). Dimensionless separation constant (R_L) is used to determine the favorability of the isotherm. Equilibrium parameter can be represented as follows:

to be less than 1 and greater than 0 for Pb(II) ions.

3.3.2 Freundlich isotherm

Linear form of Freundlich model can be represented as follows:

was 1.397 which is more than unity and indicated the favourable normal adsorption.

3.3.3 Temkin isotherm

Linear form of Temkin isotherm can be represented as follows:

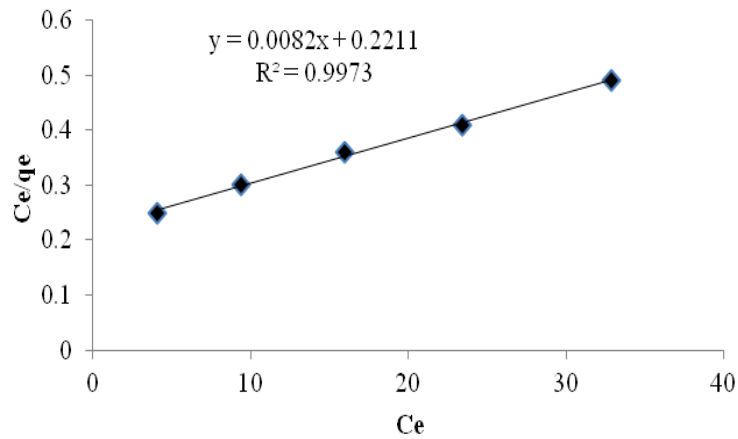
B can be determined by using following equation:

Freundlich model and Temkin models are summarized in (Table 1). The value of heat of adsorption was 24.626KJ/mol which was less than 40 kJ/mol and indicated the physical adsorption.

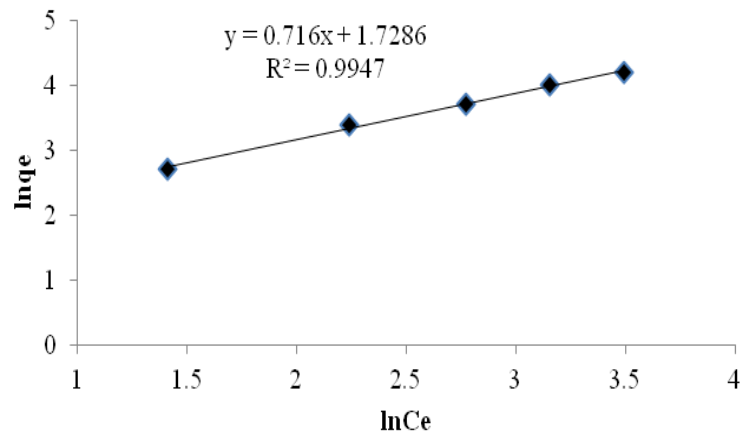
For lead ions adsorption from water sample Langmuir model was found to be best fitted model rather than Freundlich and Temkin model (Figure 4) as

the Langmuir regression correlation coefficient is more close to unity as compared to those observed in Freundlich and Temkin model.

(a)



(b)



(c)

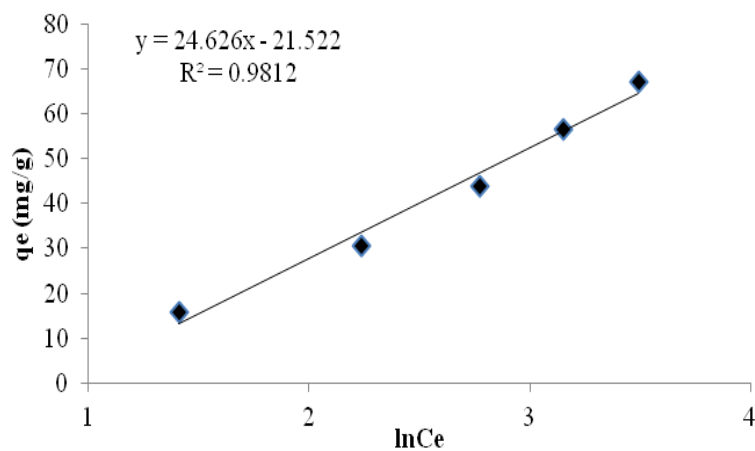


Figure 4. (a) Langmuir isotherm model (b) Freundlich isotherm model (c) Temkin isotherm model for lead ions adsorption onto *Pavo Cristatus* feather powder

3.4 Kinetics of adsorption

The kinetics of the adsorption can be explained by the following kinetic models.

$$\ln(q_e - q_t) = \ln(q_e) - k_1 t \quad (7)$$

Where q_e & q_t represent amount of adsorbate (mg/g) at equilibrium & at any time t , respectively & k_1 is first order rate constant.

$$t/q_t = 1 / k_2 q_e^2 + t/q_e \quad (8)$$

Where q_e and q_t represent amount of adsorbate (mg/g) at equilibrium & at any time t , respectively & k_2 is second order rate constant.

The value of q_e and k_1 were calculated from the plots of $\ln(q_e - q_t)$ versus t for the pseudo-first-order model. Similarly, the value of k_2 and q_e were determined from the plots of t/q_t versus t for pseudo-second-order kinetics respectively (Figure 5).

The calculated kinetic constants & correlation coefficients for pseudo-first-order model & pseudo-second-order-model

$$K_c = C_{AC}/C_e \quad (9)$$

$$\Delta G^o = -RT \ln K_c \quad (10)$$

Where K_c = Equilibrium constant, C_{AC} = Equilibrium amount of Pb(II) ions (mg/L) and C_e = Equilibrium amount of Pb(II) ions

$$\ln K_c = -\Delta H^o/RT + \Delta S^o/R \quad (11)$$

$$\ln K_c = -\Delta H^o/2.303RT + \Delta S^o/R \quad (12)$$

The ΔH^o and ΔS^o were obtained from the linear plot of $\ln K_c$ versus $1/T$ (Figure 5).

3.4.1 Pseudo-first-order kinetic model

The linear form of the pseudo-first-order model can be expressed as follows:

3.4.2 Pseudo-second-order kinetic model

The linear form of the pseudo-second-order kinetic model can be expressed as follows:

showed that pseudo second order kinetics was best fitted model & the calculated q_e value was in reasonable agreement with the experimental q_e value by applying pseudo-second-order model (Table 1).

3.5 Thermodynamics studies

The thermodynamic parameters helps in the evaluation of spontaneous nature and heat change associated with the adsorption. The thermodynamic factors such as Gibbs free energy, entropy (ΔS^o) & enthalpy (ΔH^o) were calculated according to the following equation:

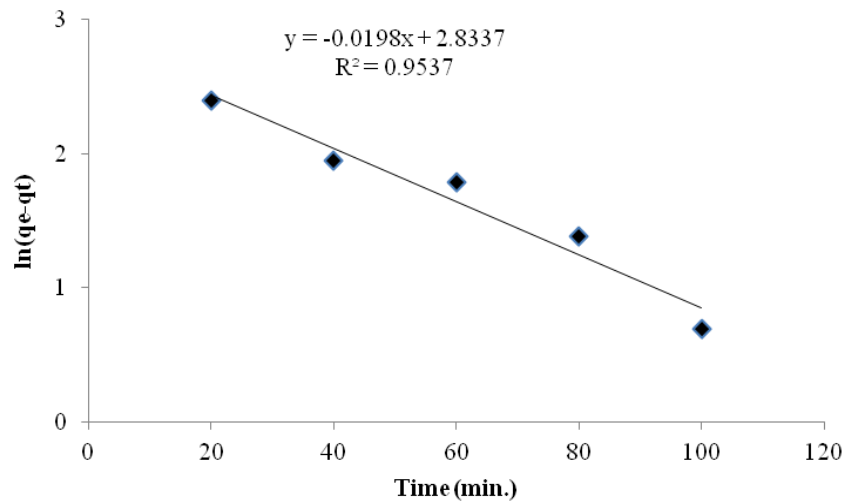
(mg/L). The ΔH^o and ΔS^o were determined from the following relation:

The Gibb's free energy value represents that the process is spontaneous and feasible (Table 1). In present work,

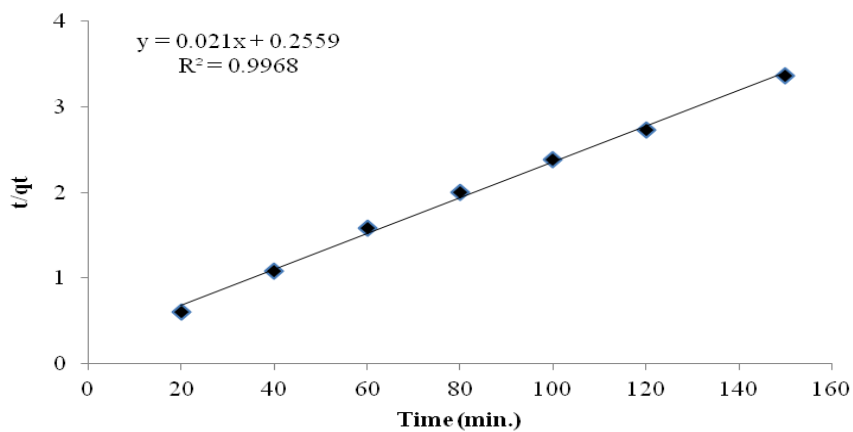
with increase in temperature, ΔG° value became more negative indicating the increase in spontaneity of Pb(II) adsorption

on PCFP surface. The positive value of ΔH° and ΔS° confirmed the endothermic process and there was increase in randomness.

(a)



(b)



(c)

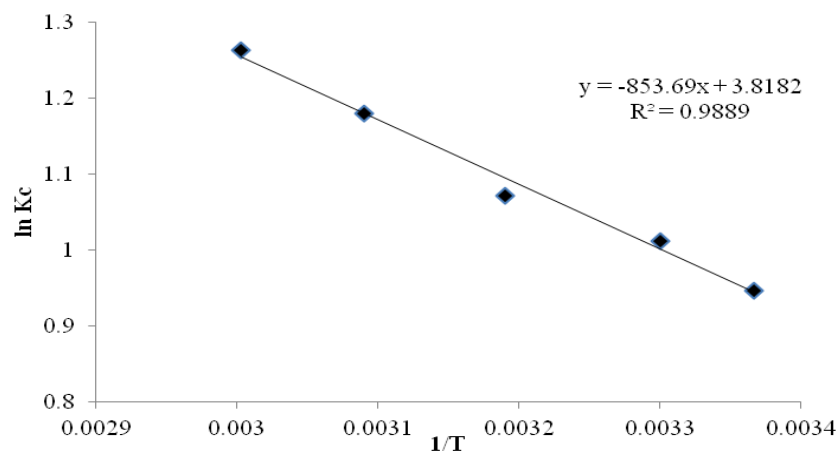


Figure 5. (a) Pseudo-first order kinetic and (b) pseudo-second order kinetic model (c) thermodynamic behavior for adsorption of lead ions onto *Pavo Cristatus* feather powder

Table 1. Parameters of Isotherm models, adsorption kinetics and thermodynamics study

Isotherm models								
Langmuir			Freundlich			Temkin		
q_{max} (mg/g)	K_L (l/g)	R^2	n	K	R^2	B	A	R^2
121.95	0.037	0.997	1.397	5.633	0.995	24.626	0.417	0.981

Kinetics						
Pseudo first order kinetics			Pseudo second order kinetics			
q_e (mg/g)	k_1 (min^{-1})	R^2	q_e (mg/g)	k_2 (g/mg/min)	R^2	$q_e, exp.$ (mg/g)
16.99	0.0198	0.953	47.61	0.0017	0.996	44

Thermodynamic parameters							
					ΔG° (kJ/mol)	ΔH° (kJ/ mol)	ΔS° (kJ/ mol/K)
297K	303K	313K	323K	333K			
-2.11	-2.30	-2.61	-2.92	-3.23	7.09	0.031	

3.6 Comparison of Pavo Cristatus feather with other adsorbents

A comparative study of adsorptive performance of the adsorbent used in present study, i.e PFCP and other naturally occurring adsorbents already reported in literature was carried out. On analysis, it

was noticed that the maximum capacity (q_{max}) of PFCP i.e 121.95mg/g is superior to almost all previous report. This comparison also indicated highest adsorption efficiency of the PFCP for removal of Pb(II) ions from aqueous medium (Table 2) makes it very good candidate for water treatment .

Table 2. Comparison of *Pavo Cristatus* feather and other adsorbents for adsorption of lead ions from water/wastewater samples.

Adsorbent	Preparation method	q_{max} (mg/g)	Other target metal ions	Temp. (K)	pH	Reg. coeff. (R^2)	Isotherms/ kinetics	Ref.
Rice husk	commercially available	1.41	NA	NA	4-5	0.832	Langmuir	Raikar et al., 2015
Alluvial soil	commercially available	1.567	NA	313	6	0.918	Langmuir	Das et al., 2014
Orange and banana peel	Commercially available	7.75 and 7.97	NA	NA	5.5	0.963 and 0.969	Langmuir	Annadurai et al., 2002
Pomegranate peel	commercially available	13.87	NA	NA	5.6-7.6	0.999	Langmuir/ Pseudosecond- order	El-Ashtoukhy et al., 2008
Ficus carica leaves	commercially available	37.74	Cd	293	5	0.999	Langmuir/ Pseudosecond- order	Farhan et al., 2013
Diceriocaryum eriocarpum	commercially available	41.49	NA	298	NA	0.966	Langmuir	Edokpayi et al., 2015
Sago waste	Commercially available	46.6	Cu	NA	4.5	0.98	Langmuir/ Pseudosecond- order	Quek et al., 1998
Dried water hyacinth	leaves and stem	66.6 and 90.5	NA	298	5	0.999 and 0.999	Langmuir/ Pseudosecond- order	El-Wakil et al., 2014
Sphagnum moss peat	peat 1, peat 2, peat 3	87.22, 92.77 and 80.61	NA	NA	6	NA	Langmuir	Bulgariu et al., 2009
Manganoxide minerals	commercially available	98	Cd	318	NA	0.999	Langmuir/ Pseudosecond- order	Sonmezay et al., 2012
Pomegranate biomass	Commercially available	111.5	NA	NA	4.5	0.963	Langmuir	Alam et al., 2012
Orange barks	commercially available	112.4	NA	298	3-4.6	0.950	Langmuir	Azouaoua et al., 2013
<i>Pavo Cristatus</i> feather	commercially available	121.95	NA	310	6	0.997	Langmuir/ Pseudosecond- order	This study

(NA-Not available)

3.7 Statistical analysis

RSM is a statistical and mathematical tool for maximizing the responses by optimizing the operational variables (Saini et al., 2019; Kaur et al., 2019). BBD was applied to study the lead ions adsorption onto PCFP. Design Expert® software was used to design the experiments and regression model. Solution pH, initial concentration, contact time & temperature were selected as independent input variables (Table 3). Coded & actual terms for the selected input

variables factors are shown in table3. Table 4 shows the experimental and predicted values of lead ions uptake onto *Pavo Cristatus* feather powder. The % removal of 67.14 for lead ions was noted at central points of all factors viz., pH 6, initial concentration 60 ppm, contact time 70 min and temperature 40 °C .The optimal parameters for maximum % removal of Pb(II) (81.4712 %) were obtained at pH 6.31, initial concentration of 43.79 mg/L, contact time 119.51 minutes & temperature 59.67 °C.

Table 3. Actual and coded values of different process parameters of lead ions

Factors	Low(-1)	Mid(0)	High(+1)
pH (A)	3	6	9
initial ion concentration (B)	20	60	100
contact time (C)	20	70	120
Temperature (D)	20	40	60

3.7.1 Adequacy of the model

Design expert software confirmed that the quadratic model was a significant model for PCFP. The analysis of variance (ANOVA) was applied to validate the relevancy of the model (Table 5). The R² value for lead ions was 0.993, respectively. The quadratic model was a significant

model for lead ions adsorption from water by PCFP. Quadratic model could not explain 0.6805% of variations for lead ions. The predicted R² (0.9608) are in good accord with the adjusted R² (0.986) for Pb(II) ions. Adequate precision ratio greater than 4 is required for adequate signal. Table 5 showed that the signal to noise ratio is 45.959 for Pb(II) ions.

Table 4. Experimental and predicted values of lead ions uptake onto *Pavo Cristatus* feather powder

Run	A	B	C	D	Experimental % removal	Predicted % removal
1	0	0	0	0	67.16	67.16
2	0	-1	-1	0	44.50	45.85
3	0	-1	1	0	75.67	75.30
4	1	1	0	0	45.00	43.68
5	1	0	1	0	62.16	63.97
6	-1	0	0	-1	42.80	43.70
7	1	0	0	1	58.60	58.54
8	1	0	0	-1	41.16	40.40
9	0	0	-1	1	58.60	57.55
10	0	1	1	0	64.00	63.49
11	0	0	-1	-1	44.33	44.66
12	0	1	0	1	65.20	66.00

13	0	-1	0	-1	55.15	53.90
14	0	0	0	0	67.16	67.16
15	0	-1	0	1	65.70	65.13
16	0	0	1	-1	62.45	63.08
17	-1	-1	0	0	46.20	47.10
18	0	0	1	1	81.30	80.55
19	1	0	-1	0	36.70	37.096
20	-1	0	0	1	54.33	55.92
21	-1	0	1	0	58.99	58.13
22	-1	1	0	0	48.00	47.67
23	-1	0	-1	0	45.85	43.59
24	1	-1	0	0	50.50	50.41
25	0	0	0	0	67.16	67.16
26	0	1	-1	0	50.30	51.51
27	0	0	0	0	67.16	67.16
28	0	1	0	-1	46.76	46.88
29	0	0	0	0	67.16	67.16

Table 5. Analysis of variance table and statistics of lead ions adsorption

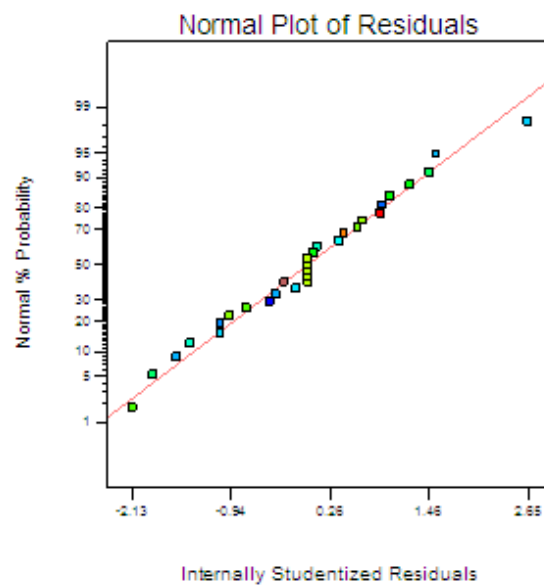
Variance table					
Source	Sum of squares	df	Mean Square	F value	p-value Prob > F
Model	3532.463	14	252.3188	145.9403	< 0.0001
A	0.350208	1	0.350208	0.202559	0.6596
B	28.39763	1	28.39763	16.42509	0.0012
C	1287.334	1	1287.334	744.589	< 0.0001
D	691.2972	1	691.2972	399.8437	< 0.0001
AB	13.3225	1	13.3225	7.705684	0.0149
AC	37.9456	1	37.9456	21.94759	0.0004
AD	8.732025	1	8.732025	5.050571	0.0413
BC	76.30023	1	76.30023	44.13177	< 0.0001
BD	15.56303	1	15.56303	9.001596	0.0095
CD	5.2441	1	5.2441	3.033168	0.1035
A ²	1296.447	1	1296.447	749.8601	< 0.0001
B ²	218.2995	1	218.2995	126.2636	< 0.0001
C ²	34.83766	1	34.83766	20.14997	0.0005
D ²	73.93988	1	73.93988	42.76655	< 0.0001

Model summary statistics of lead ions adsorption			
Std. Dev.	1.314883	R-Squared	0.993195
Mean	56.55345	Adj R-Squared	0.986389
C.V. %	2.325028	Pred R-Squared	0.960800
PRESS	139.42	Adeq Precision	45.95964

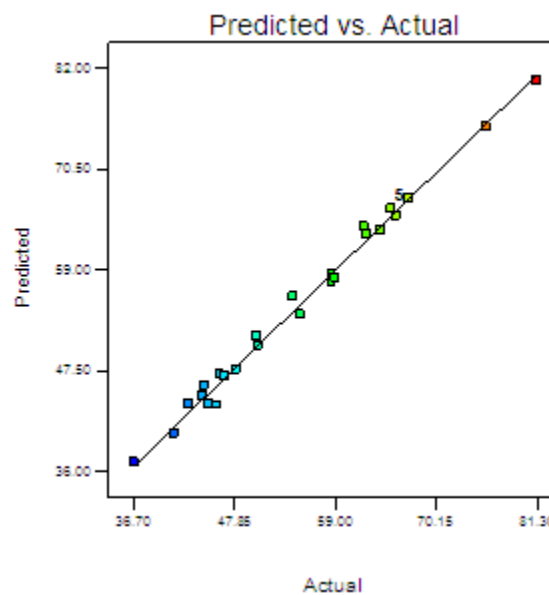
The final quadratic equation in terms of coded variables is given below:

$$\% \text{ removal (Pb)} = 67.16 - 0.1708A - 1.5383B + 10.3575C + 7.59D - 1.825AB + 3.08AC + 1.4775AD - 4.3675BC + 1.9725BD + 1.145CD - 14.1375A^2 - 5.80125B^2 - 2.3175C^2 - 3.37625D^2 \quad (13)$$

(a)



(b)



(c)

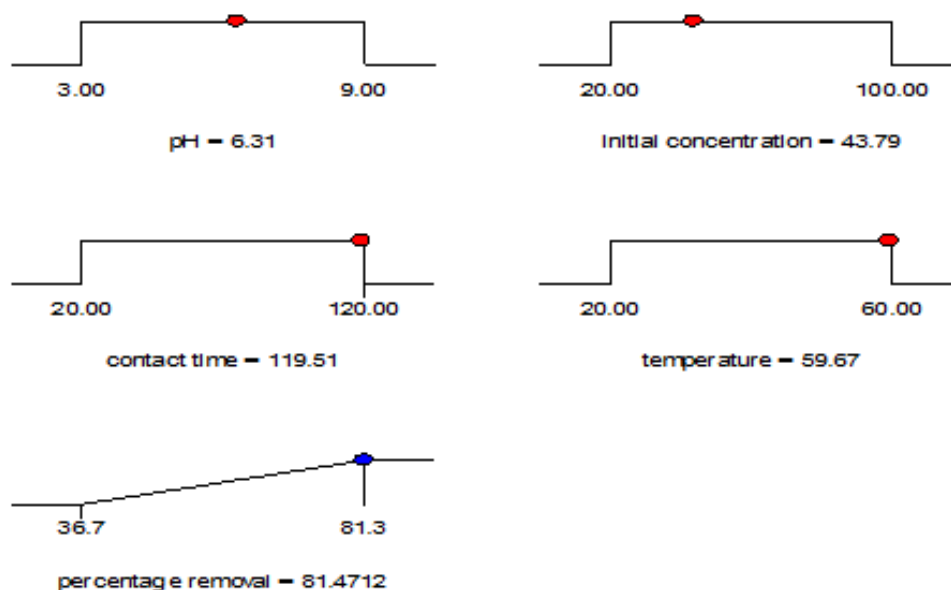


Figure 6. (a) Normal plot of residuals and (b) Predicted vs actual plot (c) desirability ramps of lead ions adsorption onto *Pavo Cristatus* feather powder

3.7.2 Interactive effects of different parameters on percentage removal

Figure 6 (a&b) represents the normal plot of residuals and the plot between experimental & predicted % removal value of lead ions adsorption onto PCFP. The suitability of the model was indicated by the data points spread near the straight line. Data points around the line in Figure 6 confirm that the predictions are close to the observed values.

The contour plots and three dimensional (3-d) plots shows the interactions between the two independent variables & their influence on the response. The 3-d plots of % removal of lead ions versus initial concentration, temperature, contact time and pH are given in Figure 7 (a-f) for PCFP.

Figure 7 (a-f) represents the relationship between percentage removal and independent variables. The simultaneous effect of two variables (pH/contact time, pH/initial concentration,

pH /temperature, initial concentration/temperature, initial concentration/contact time & contact time/temperature on percentage removal at fixed adsorbent dose is shown in Figure 7. The shape of the curves in Figure 7(a) to (f) indicates good interaction of the variables at fixed adsorbent dose of 20mg/L. Desirability function was applied in numerical optimization to find out optimum conditions for maximum removal of Pb(II) while taking care of all variables at fixed adsorbent dose of 20 mg/L. The desirability function is a technique for the simultaneous determination of optimal settings of input factors that can determine optimal performance levels for one or more responses. Desirable values for input variables and response can be selected from the given input optimizations. The input factors were given specific values from the given input optimizations. The optimal parameters for maximum % removal of Pb(II) (81.47 %) were obtained at pH 6.31, initial lead ion concentration of 43.79 mg/L, contact time 119.51 minutes & temperature 59.67 °C (Figure 6).

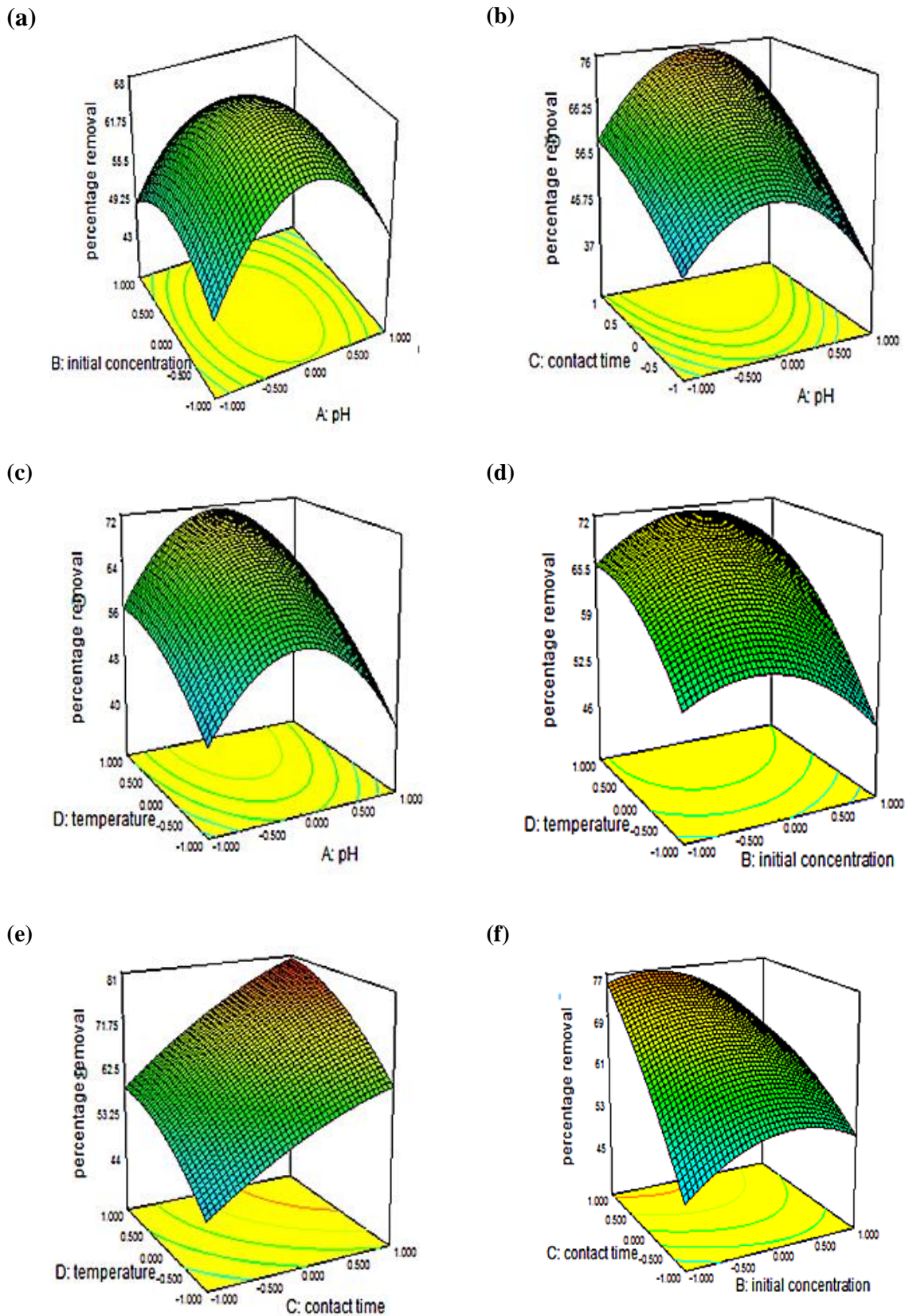


Figure 7. Response surface plots showing the effect of independent input variables on lead ions adsorption onto *Pavo Cristatus* feather powder.

4. CONCLUSIONS

The SEM and the EDX, BET and FTIR studies confirmed the chemical adsorption of lead ions onto PCPF due to the formation of new chemical bond between metal ions and carboxylate group generated by the loss of proton on the surface. The results of batch studies showed that lead removal rely on the temperature, initial concentration of Pb(II), pH & contact time. Optimal values obtained from batch studies for lead adsorption onto PCPF were pH 6; adsorbent dose 20 mg/L; temperature 303 K and contact time 120 minutes. Adsorption isotherms and kinetic studies showed that lead ions adsorption onto *Pavo Cristatus* feather followed the Langmuir model indicating monolayer adsorption. Langmuir maximum removal efficiency was 121.95 mg/g. BBD was applied to study the interactive effects of parameters on removal percentage and to optimize various parameters for Pb(II) adsorption onto PCFP from solution. The predicted and experimental values of removal percentage obtained at various conditions confirmed good agreement with reasonably little error. The optimal parameters for maximum % removal of lead (81.4712) were obtained at initial lead (II) ion concentration of 43.79 mg/L, pH 6.31, contact time 119.51 minutes and temperature 59.67 °C. The results indicate that *Pavo Cristatus* feather shows good adsorption behavior for lead and can be used as a viable and economic adsorbent.

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6. CONFLICT OF INTEREST

The authors declare that they do not have any conflict of interest.

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