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ADSORPTION STUDIES OF COBALT (II) BY ACTIVATED CARBON PREPARED FROM COCONUT TREE ROOT

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ABSTRACT

Exposure to heavy metals is found to cause stunted growth and development, cancer, organ damage, nervous system damage, irreversible brain damage and at higher dosages, even death for humans (Babel & Kurniawan 2003). Therefore, it has become of paramount importance to eliminate heavy metals from inorganic effluents before being discharged into the environment to replenish the freshwater sources and reduce environmental degradation. In the present study, the adsorption of Co(II) ions from cobalt(II) nitrate hexahydrate solution onto coconut tree root activated carbon (CTRAC) using phosphoric acid has been investigated. The aim of the study is to characterize CTRAC, evaluate its efficiency in Co(II) removal, determine the effective adsorption parameters and find the adsorption kinetic model and isotherm model which best describes the system The central composite design (CCD) under response surface methodology (RSM) by Design Expert Version 11 (Stat-Ease Inc., USA) was employed to evaluate the effective adsorption parameters and derive quadratic relationships between the two responses and the effective parameters. CTRAC was characterized using BET analyzer and particle size analyzer. Lagergren pseudo first order, Ho pseudo second order and Elovich kinetic models were used to model the kinetic data. The equilibrium adsorption data was analyzed to check if it fits the Langmuir or Freundlich isotherm models.

KEYWORDS: *heavy metals, cobalt, adsorption, activated carbon, coconut, isotherm, wastewater*

1. INTRODUCTION

1.1 Importance of Cobalt Removal

One of the contaminants present in the water bodies at astounding levels is cobalt. Cobalt is most commonly found in effluents from the electronic, electroplating and petrochemical industries, mining operations, tanneries, paint industries and nuclear power plants (Demirbas 2003)(Prabakaran & Arivoli 2013). Acute cobalt poisoning in humans via ingestion may lead to diarrhea, heart failure, thyroid and liver damage, bone defects, genetic mutations and possible cancer development. The permissible limits of cobalt in drinking water, irrigation water and for livestock watering are 2µg/L, 0.05mg/L and 1 mg/L respectively (Demirbas 2003). According to statistics, more than 2000 tonnes of cobalt are released annually from mining and mineral processing in the United States, including 480 tonnes of cobalt in coal produced. The total environmental release of cobalt by industrial sources in the United States that was reportable to the Toxics Release Inventory for 2000 was approximately 228,400 kg, out of which water release contributed up to 1633 kg (Kim, Gibb & Howe 2006). The detrimental health effects of cobalt in humans and fauna has called for more efficient and effective cobalt removal techniques over the past decade.

Freshwater shortage is a widespread problem across the world today. About 4 billion people, representing nearly two-thirds of the world population, experience severe water scarcity during at least one month of the year (Mekonnen and Hoekstra, 2016). They lack access to unpolluted water. The growing global consumption of freshwater has generated substantial quantities of contaminated water in its place resulting in a depletion of potable water sources, which is a basic necessity essential for life on earth. Hence, the need for effective wastewater treatment in the present day to replenish the freshwater reserves is greater than ever for the mankind. Heavy metals play a major role in water contamination. They are toxic and pose a threat to human health.

In recent times, adsorption has emerged as the most attractive and favored option for wastewater treatment owing to some of the merits it possesses. However, commercial activated carbon (CAC) remains an expensive material. This has encouraged us to explore new alternative low-cost adsorbents from plants and agricultural wastes, available locally in abundance, that most importantly have cobalt-binding capacities for cobalt removal from wastewater.

2. METHODOLOGY

Adsorption capacity denoted by Qe (mg/g) is influenced by physical and chemical characteristics of the adsorbent (CTRAC) i.e. surface area, pore size, diameter, surface chemistry, pH, by the adsorbate (Co^{2+} ions) i.e. initial concentration of adsorbate in solution, pH, temperature, contact time and also other general parameters i.e. agitation speed and adsorbent dosage. Hence, various studies were conducted to characterize CTRAC and evaluate the effects of the aforementioned parameters on the adsorption capacity and percentage removal in some cases. The methodologies adopted for the studies will be discussed in brief in this chapter.

2.1 Preparation of the adsorbent:

The coconut tree roots collected from around the locality were used in this study. The following procedure was carried out in the preparation of the adsorbent.

1. Coconut tree roots were washed thoroughly with distilled water to remove dust and sand, and the water was discarded.
2. The roots were then put in the dryer at 60 – 800°C to minimize the moisture content.
3. The dried roots were reduced in size (<1cm) before they were ground into powder using a mixer-grinder.
4. The powder was wetted thoroughly with 88% ortho-phosphoric acid (about 100 ml acid for 200g powder).
5. The acid-impregnated powder was then carbonized in a muffle furnace at a steady temperature of 3500°C for 1.5 hours.
6. After carbonization, the CTRAC was first washed with distilled water for two times to remove the free acid followed by 30% solution of sodium bicarbonate ($NaHCO_3$) for neutralizing the pH.
7. Again, the neutralized CTRAC was washed twice with water to remove the free base.
8. The washed CTRAC was then oven-dried at 600°C for 24 hours.
9. The dried CTRAC was further ground and only the material with mean particle size of 80μm was stored in an air-tight container and used.

2.2 Preparation of the adsorbate:

A 1000mg/L cobalt(II) ion stock solution was prepared by dissolving 4.938g of cobalt nitrate hexahydrate salt, $Co(NO_3)_2.6H_2O$ (analytical grade reagent) in 1000ml of distilled water in a 1000ml standard flask. The various solutions of desired concentrations were prepared from this stock solution by dilution.

2.3 BET surface area analysis and BJH pore size and volume analysis:

Brunauer-Emmett-Teller (BET) and Barrett-Joyner-Halenda (BJH) methods are the most commonly employed methods in the determination of the surface area and pore volume of solid materials respectively. The analyses were carried out in a BET analyzer manufactured by Smart Instruments which complies with ASTM D 4567-03 (2004) and ASTM D 4641-94 (2004) for measuring surface area and pore volume respectively.

The particle size analysis was carried out in a particle size analyzer 1064 manufactured by Cilas Instruments which complies with ISO 13320 standard for measurement accuracy and repeatability. About 3-4 grams of CTRAC was mixed with 10mL of distilled water and the mixture was then kept in the ultrasound bath for 15 minutes. The sonicated sample was added to the analyzer till obscurity reached 6%. The mean diameter of the adsorbent particles was determined from this analysis.

2.4 Batch adsorption studies:

Through the batch studies, the effect of pH (2.0 to 8.0), adsorbent dosage (0.1, 0.15, 0.25, 0.5, 1g CTRAC/100ml), initial concentration (50 to

300mg/L), temperature (20 to 500°C) and agitation speed (100, 150 and 200 rpm) on adsorptive removal of Co(II) ions were studied. The results of each study was plotted against equilibrium adsorption capacity, Qe (mg/L) and/or percentage removal of Co(II). For the studies, 100ml cobalt ion samples of known concentrations were prepared in 250ml conical flasks to which known dosages of adsorbent was added, and then agitated for 24hours in the incubator shaker for equilibration at a known agitation speed. The pH of the solutions were set with the help of the pH meter by adding dilute solutions of HCl and NaOH. The individual parameters were varied in each study while maintaining the other parameters constant. After equilibration, samples were vacuum filtered using the Buchner funnel, flask and aspirator and the concentration of cobalt ions in the filtrates were measured by atomic absorption spectrometer (AAS).

2.5 Preliminary contact time:

The preliminary contact time was found by agitating a 200mL cobalt ion solution of 100mg/L concentration and pH 7 with 1g of CTRAC in a 500mL beaker, at 100rpm and 300°C for 24hours. A 10mL sample of mixture was drawn out of the beaker using a pipette at every predetermined interval (1, 2, 3, 4, 5, 6, 7 and 24hour) and the samples were vacuum filtered and analyzed by AAS. The equilibrium contact time is defined as the time at which the adsorption capacity saturates and stabilizes.

2.6 Response Surface Methodology (RSM) studies:

The response surface methodology (RSM) approach was adopted to evaluate the interactions between the significant adsorption process parameters identified from the batch mode studies, on the two responses, viz, equilibrium adsorption capacity of CTRAC (Qe) and percentage removal of Co(II) ions. RSM is a tremendously helpful tool for this purpose as it helps to minimize the number of experiments, hence saving experimentation time and cost (Asadzadeh,Maleki-Kaklar,Soiltanalinejad & Shabani 2018). The Central Composite Design in Response Surface Methodology provided by the statistical software Design Expert Version 11 (Stat-Ease Inc., USA) was used for the design of experiments and development of quadratic regression models which has the best fit to the experimental data. It is the most preferred design because it has center points, augmented with a group of axial points that allows for estimation of curvature and it can fit a full quadratic model. Analysis of Variance (ANOVA), which is a component of RSM, was then calculated to assess the adequacy of the response models.

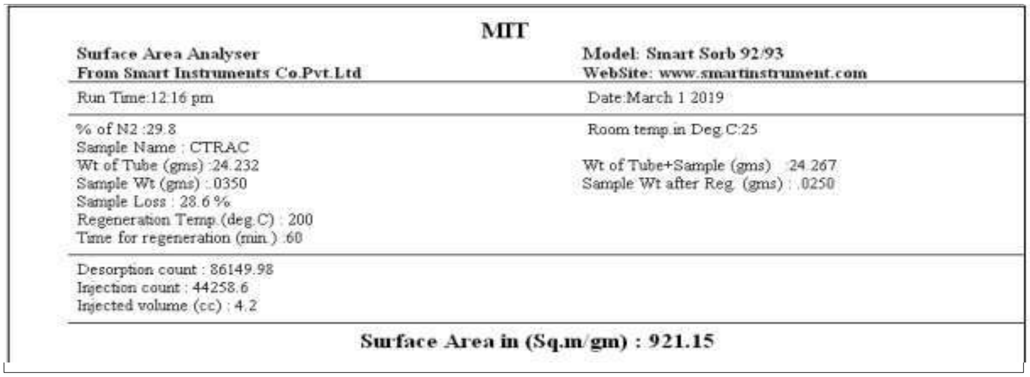
2.7 Kinetic studies:

To investigate the dynamics of the adsorption of Co(II) ions onto CTRAC, the kinetic studies were performed for only concentrations 50 and 100mg/L of cobalt solution. 500mL cobalt ion solutions of pH 7 dosed with 0.5g of CTRAC each, were prepared in 1 litre beakers. They were agitated at 100rpm and 300°C for 6 hours. A 10mL sample of mixture was drawn out of the beakers using a pipette at every pre-determined interval and the samples were vacuum filtered and analyzed by AAS. The corresponding adsorption capacities, Qt (mg/g) at every time interval were calculated. The kinetic data was then fitted to three kinetic models viz, Lagergren pseudo first order, Ho pseudo second order and Elovich models. Pseudo first order and pseudo second order equations were applied assuming that the measured concentrations were equal to the surface concentrations. Rapid Removal of Cobalt Ion from Aqueous Solutions (Ahmadpour *et al* 2009).

3. RESULTS AND DISCUSSIONS

3.1 Characterization

3.1.1 BET surface area analysis and BJH pore size and volume analysis: The specific surface area and specific pore volume obtained of the adsorbent particles was 921.15sq.m/g and 0.4622cc/g respectively.



MIT

Surface Area Analyser
From Smart Instruments Co.Pvt.Ltd

Model: Smart Sorb 92/93
WebSite: www.smartinstrument.com

Run Time:12:16 pm
Date:March 1 2019

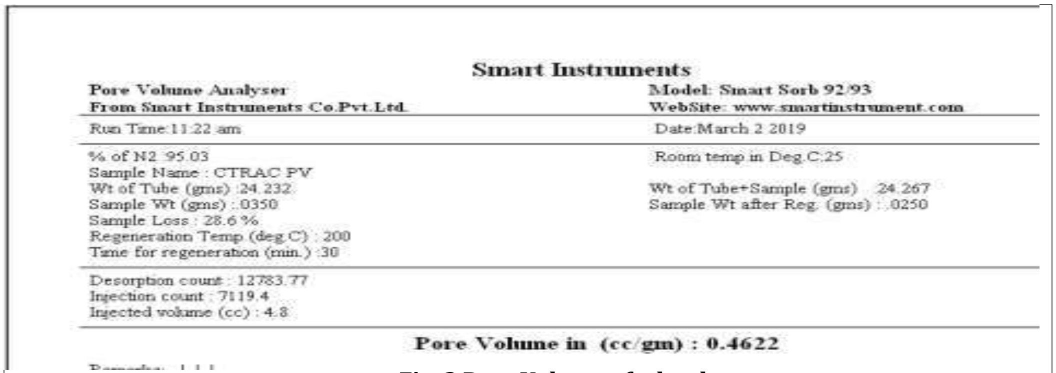
% of N2 :29.8
Sample Name : CTRAC
Wt of Tube (gms) :24.232
Sample Wt (gms) :.0350
Sample Loss : 28.6 %
Regeneration Temp.(deg.C) : 200
Time for regeneration (min.) :60

Room temp.in Deg.C:25
Wt of Tube+Sample (gms) : 24.267
Sample Wt after Reg. (gms) : .0250

Desorption count : 86149.98
Injection count : 44258.6
Injected volume (cc) : 4.2

Surface Area in (Sq.m/gm) : 921.15

Fig. 1 Surface Area of adsorbent



Smart Instruments

Pore Volume Analyser
From Smart Instruments Co.Pvt.Ltd.

Model: Smart Sorb 92/93
WebSite: www.smartinstrument.com

Run Time:11:22 am
Date:March 2 2019

% of N2 :95.03
Sample Name : CTRAC PV
Wt of Tube (gms) :24.232
Sample Wt (gms) :.0350
Sample Loss : 28.6 %
Regeneration Temp.(deg.C) : 200
Time for regeneration (min.) :30

Room temp.in Deg.C:25
Wt of Tube+Sample (gms) : 24.267
Sample Wt after Reg. (gms) : .0250

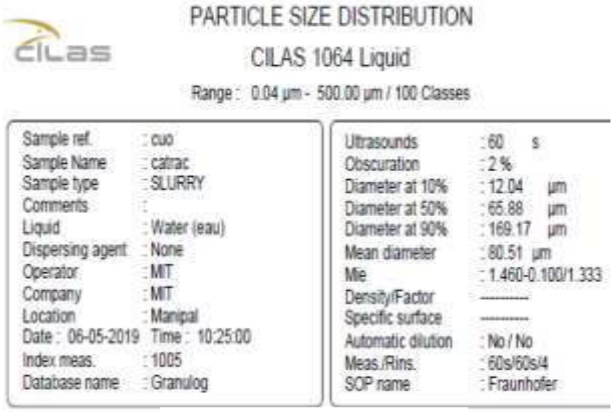
Desorption count : 12783.77
Injection count : 7119.4
Injected volume (cc) : 4.8

Pore Volume in (cc/gm) : 0.4622

Fig. 2 Pore Volume of adsorbent

3.1.2 Particle size analysis:

The mean diameter of the adsorbent particles was obtained as 80.51µm.



PARTICLE SIZE DISTRIBUTION
CILAS 1064 Liquid
Range : 0.04 µm - 500.00 µm / 100 Classes

Sample ref. : cuo
Sample Name : catrac
Sample type : SLURRY
Comments :
Liquid : Water (eau)
Dispersing agent : None
Operator : MIT
Company : MIT
Location : Manipal
Date : 06-05-2019 Time : 10:25:00
Index meas. : 1005
Database name : Granulog

Ultrasounds : 60 s
Obscuration : 2 %
Diameter at 10% : 12.04 µm
Diameter at 50% : 65.88 µm
Diameter at 90% : 169.17 µm
Mean diameter : 80.51 µm
Mie : 1.460-0.100/1.333
Density/Factor ----------
Specific surface ----------
Automatic dilution : No / No
Meas./Rins. : 60s/60s/4
SOP name : Fraunhofer

Fig 3. Particle size

3.2 Batch Mode Adsorption Studies:

3.2.1 Effect of pH:

The percentage removal of Co(II) increased with increasing pH as shown in Figure 9. The lowest percentage removal observed was 17.28% at pH 2.0. There was a rapid increase in removal from pH 2.0 to 3.0. At lower pH values such as 2.0, the adsorption of Co(II) ions was low because the binding sites were positively charged by the H^+ ions and the electrostatic repulsion between the positively charged Co^{2+} and positively charged binding sites inhibited the binding of Co(II) ions onto the adsorbent surface. The H+ ions also competed with Co^{2+} ions for the negatively charged adsorption sites, hence the low uptake of Co(II) at low pH values (Swelam *et al* 2016). As pH increased, there were fewer H+ ions present in the solution and as a result, more negatively charged binding sites were available for adsorption and this lead to an appreciable increase in the uptake of Co^{2+} due to electrostatic attractions between them (Stevens & Batlokwa 2017). This explains the steady increase in removal from pH 3.0. The highest percentage removal observed was 45.57% at pH 7.0. Therefore, the optimum pH for Co(II) removal is 7.0.

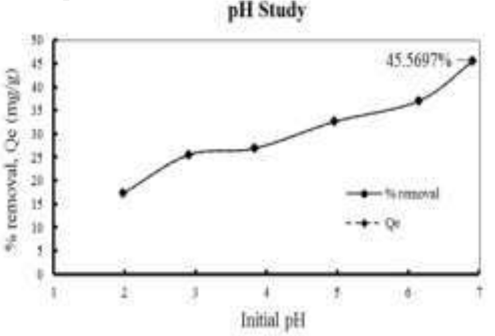


Fig. 4 Effect of pH on adsorption capacity of CTRAC and percentage removal of Co(II) ions (100ml sample, 100mg/L of Co(II), 0.1g CTRAC/100ml, 30°C, 150rpm, 24hours)

3.2.2 Effect of adsorbent dosage:

The adsorbent dosage is another important parameter during adsorption studies as it determines the capacity of the adsorbent to adsorb metal ion for a given concentration of the solution. Figure 10 shows that with an increase in adsorbent dosage from 0.1 to 1 g/100ml, the percentage removal of Co(II) increased from 29.91 to 89.50% whereas the adsorption capacity decreased from 29.91 to 8.95mg/g. The increase in percentage removal can be attributed to increased adsorbent surface area and availability of more binding sites. The observed decrease in adsorption capacity may be attributed to overlapping of adsorption sites due to aggregation of adsorbent particles, leading to reduction in surface area available to Co(II) and a consequent increase in diffusion path length (Musapatika, Onyango & Aoyi 2010)(Musapatika *et al* 2012). It can be observed that there was not a significant increase in percentage removal from 82.36 to 89.50% despite of a two-fold increase in the dosage of CTRAC from 0.5 to 1g/100ml. Therefore, the most economical adsorbent dosage is 0.5g/100ml.

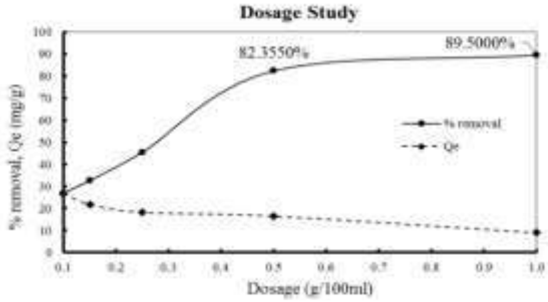


Fig. 5 Dosage Study

3.2.3 Effect of initial concentration of Co(II) ions:

At high initial concentration values, the ratio of Co(II) ions in the solution to the available binding sites was greater, meaning more ions were present in the solution than adsorbed, hence the lower percentage removal values. Whereas, at low initial concentration values, this ratio was smaller, hence higher the percentage removal of Co(II) ions. The increase in adsorption capacity at higher initial concentrations could be due to the stronger driving force of the concentration gradient which enabled more interaction of the Co(II) ions with the adsorbent's binding sites (Ajenifuja, Ajao & Ajayi 2017).

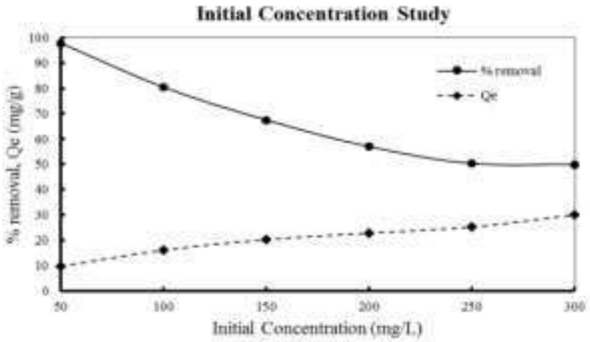


Fig. 6 Initial Concentration study

3.2.4 Effect of temperature:

The effect of temperature on the adsorption capacity and percentage removal of Co(II) ions is shown in Figure 12. It was observed that there was a gradual decline in the adsorption capacity and percentage removal of Co(II) from 15.96 to 14.12mg/g and 79.78 to 70.61% respectively with an increase in temperature over the range 20 to 50°C. This decrease suggests that the adsorption of Co(II) ions onto CTRAC was an exothermic process. (Navid Nourbakhsh *et al* 2018) (Shuhua *et al* 2015) attributed the decrease to increased tendency of desorption of aqueous metal ions from the adsorbent surface.

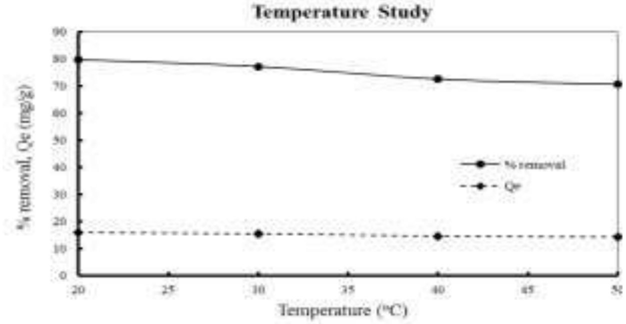


Fig. 7 Temperature

3.2.5 Preliminary contact time:

Optimal contact time is an important parameter for economical operation of a wastewater treatment system and is useful in scaling up of treatment operations (Mahapatra, Ramteke & Paliwal 2015). The contact time required by a 100mg/L solution dosed with 0.5g CTRAC/100ml to attain equilibrium was 6 hours. The rate of adsorption was initially rapid with 90% of the adsorption completed in the first hour as there was presence of a large number of vacant binding sites in the beginning. Adsorption then slowed down after the first hour as most of the binding sites were already occupied and further binding of Co(II) ions to the remaining sites became difficult due to repulsive force between adsorbed ions on the adsorbent surface and ions present in solution (Shuhua *et al* 2015). Then, adsorption reached equilibrium as the adsorption on CTRAC reached saturation at the value 16.65mg/g.

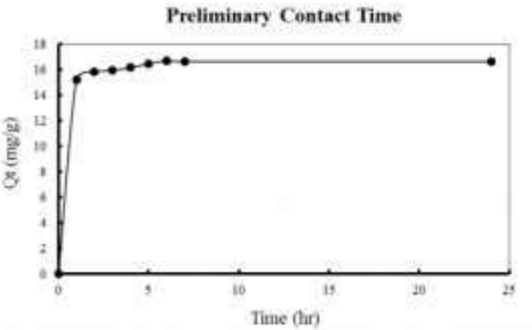
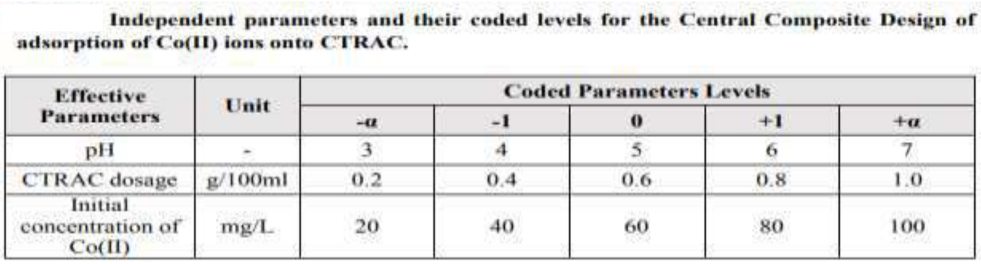


Fig. 8 Preliminary

3.3 Response Surface Methodology (RSM) studies

3.3.1 Experiment design:

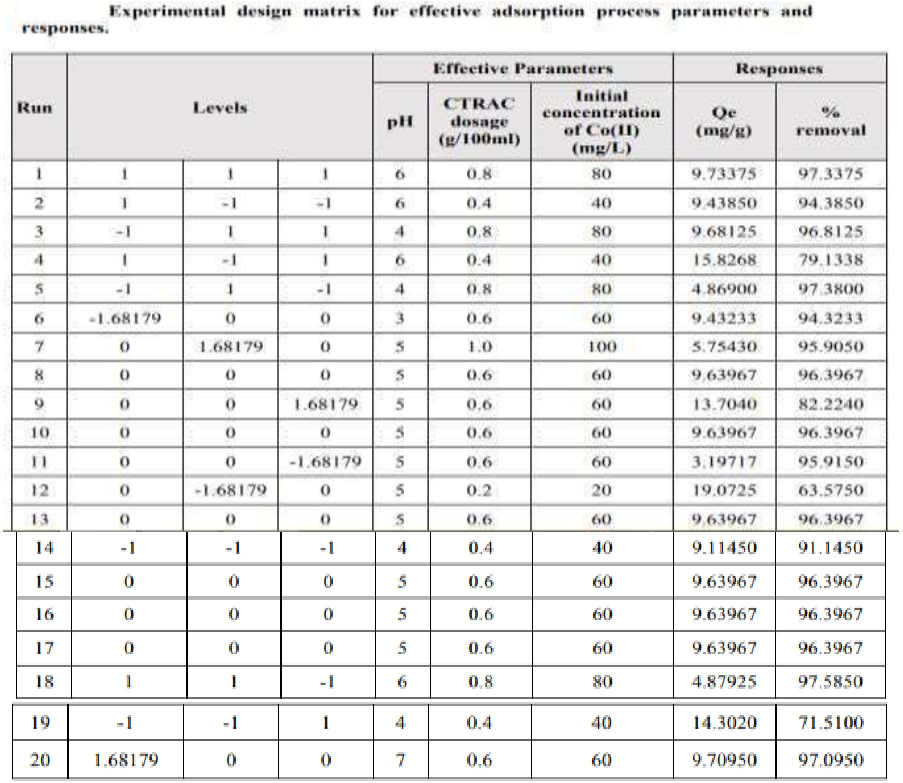
The table of experiments was designed with the following three effective adsorption process parameters that were observed to have prominent effects on adsorption capacity and percentage removal, during the batch mode studies earlier on, namely pH (3-7), CTRAC dosage (0.2-1.0g/100ml) and initial concentration of Co(II) ions (20-100mg/L). Each of these parameters are set to 5 levels: plus and minus alpha (axial points), plus and minus 1 (factorial points) and centre point. Alpha refers to the distance of the axial points from the centre point and it makes the design rotatable (Garba & Rahim 2014). Coded levels plus and minus 1 denotes high and low values respectively of the individual parameters. The coded levels and the corresponding parameter values are shown in Table 4. A total of 20 runs were generated consisting of 8 factorial points, 6 axial points and 6 centre points. The centre point (0,0,0) was replicated 6 times to determine the experimental error and the reproducibility of the data (Garba & Rahim 2014). For this case, value of alpha was computed by the software as 1.682. The runs and their respective results are given in Table 5 below. The adsorptive capacity of CTRAC, Qe and percentage removal of Co(II) ions were found to range from 3.20 to 15.83mg/g and 63.58 to 97.59% respectively.



Independent parameters and their coded levels for the Central Composite Design of adsorption of Co(II) ions onto CTRAC.

Effective Parameters	Unit	Coded Parameters Levels				
		$-\alpha$	-1	0	+1	$+\alpha$
pH	-	3	4	5	6	7
CTRAC dosage	g/100ml	0.2	0.4	0.6	0.8	1.0
Initial concentration of Co(II)	mg/L	20	40	60	80	100

Fig. 9



Experimental design matrix for effective adsorption process parameters and responses.

Run	Levels			Effective Parameters			Responses	
				pH	CTRAC dosage (g/100ml)	Initial concentration of Co(II) (mg/L)	Qe (mg/g)	% removal
1	1	1	1	6	0.8	80	9.73375	97.3375
2	1	-1	-1	6	0.4	40	9.43850	94.3850
3	-1	1	1	4	0.8	80	9.68125	96.8125
4	1	-1	1	6	0.4	40	15.8268	79.1338
5	-1	1	-1	4	0.8	80	4.86900	97.3800
6	-1.68179	0	0	3	0.6	60	9.43233	94.3233
7	0	1.68179	0	5	1.0	100	5.75430	95.9050
8	0	0	0	5	0.6	60	9.63967	96.3967
9	0	0	1.68179	5	0.6	60	13.7040	82.2240
10	0	0	0	5	0.6	60	9.63967	96.3967
11	0	0	-1.68179	5	0.6	60	3.19717	95.9150
12	0	-1.68179	0	5	0.2	20	19.0725	63.5750
13	0	0	0	5	0.6	60	9.63967	96.3967
14	-1	-1	-1	4	0.4	40	9.11450	91.1450
15	0	0	0	5	0.6	60	9.63967	96.3967
16	0	0	0	5	0.6	60	9.63967	96.3967
17	0	0	0	5	0.6	60	9.63967	96.3967
18	1	1	-1	6	0.8	80	4.87925	97.5850
19	-1	-1	1	4	0.4	40	14.3020	71.5100
20	1.68179	0	0	7	0.6	60	9.70950	97.0950

Fig. 10

3.3.2 Regression model equation:

In RSM, regression model equations were developed to predict the two responses as a function of the independent effective adsorption process parameters and their interactions.

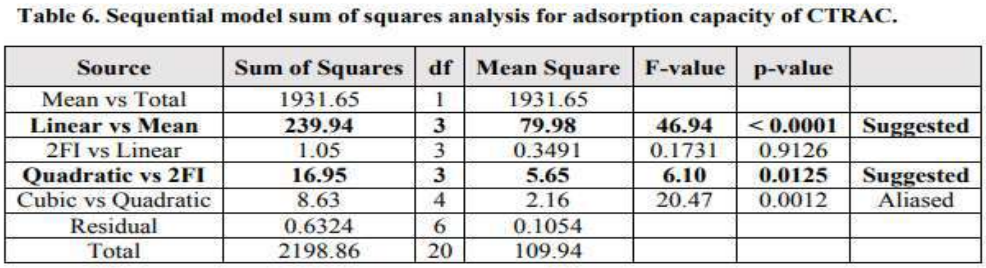


Table 6. Sequential model sum of squares analysis for adsorption capacity of CTRAC.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Mean vs Total	1931.65	1	1931.65			
Linear vs Mean	**239.94**	**3**	**79.98**	**46.94**	**< 0.0001**	**Suggested**
2FI vs Linear	1.05	3	0.3491	0.1731	0.9126	
Quadratic vs 2FI	**16.95**	**3**	**5.65**	**6.10**	**0.0125**	**Suggested**
Cubic vs Quadratic	8.63	4	2.16	20.47	0.0012	Aliased
Residual	0.6324	6	0.1054			
Total	2198.86	20	109.94			

Fig. 11

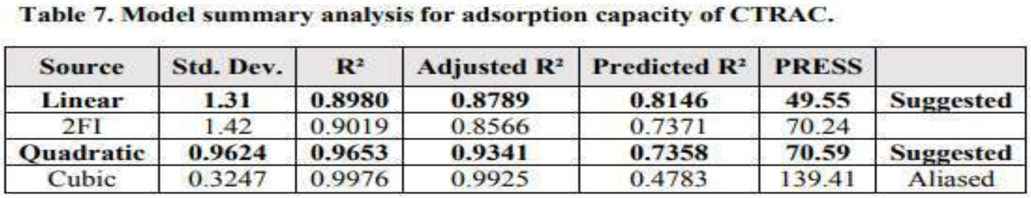
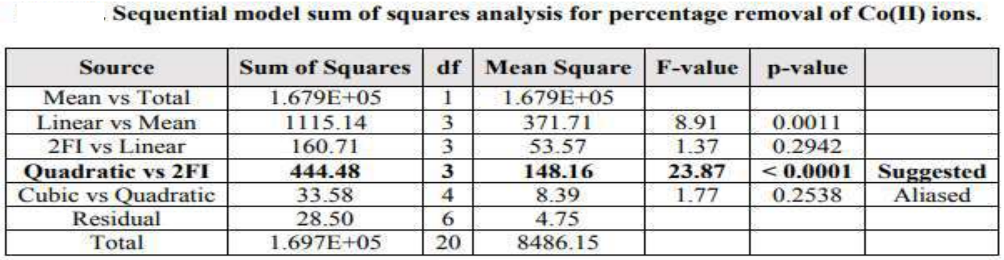


Table 7. Model summary analysis for adsorption capacity of CTRAC.

Source	Std. Dev.	R²	Adjusted R²	Predicted R²	PRESS	
Linear	**1.31**	**0.8980**	**0.8789**	**0.8146**	**49.55**	**Suggested**
2FI	1.42	0.9019	0.8566	0.7371	70.24	
Quadratic	**0.9624**	**0.9653**	**0.9341**	**0.7358**	**70.59**	**Suggested**
Cubic	0.3247	0.9976	0.9925	0.4783	139.41	Aliased

Fig. 12



. Sequential model sum of squares analysis for percentage removal of Co(II) ions.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Mean vs Total	1.679E+05	1	1.679E+05			
Linear vs Mean	1115.14	3	371.71	8.91	0.0011	
2FI vs Linear	160.71	3	53.57	1.37	0.2942	
Quadratic vs 2FI	**444.48**	**3**	**148.16**	**23.87**	**< 0.0001**	**Suggested**
Cubic vs Quadratic	33.58	4	8.39	1.77	0.2538	Aliased
Residual	28.50	6	4.75			
Total	1.697E+05	20	8486.15			

Fig. 13

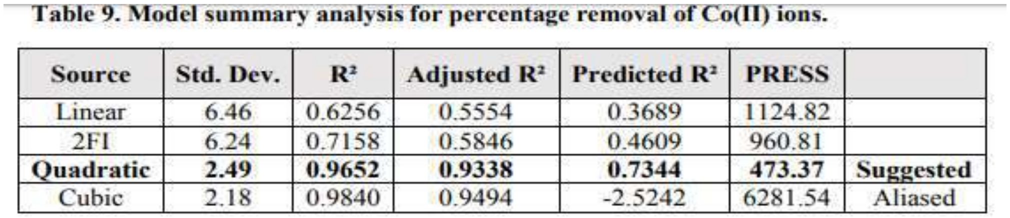


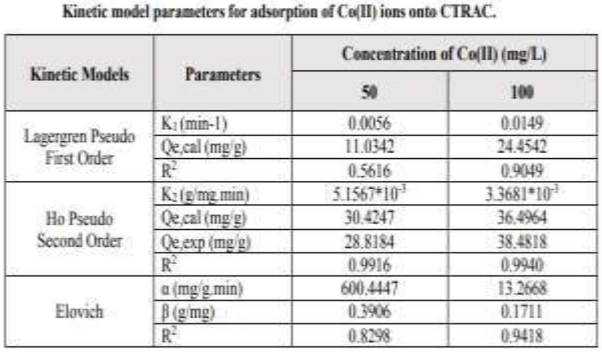
Table 9. Model summary analysis for percentage removal of Co(II) ions.

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	
Linear	6.46	0.6256	0.5554	0.3689	1124.82	
2FI	6.24	0.7158	0.5846	0.4609	960.81	
Quadratic	**2.49**	**0.9652**	**0.9338**	**0.7344**	**473.37**	**Suggested**
Cubic	2.18	0.9840	0.9494	-2.5242	6281.54	Aliased

Fig.14

The most suitable regression model was determined based on the sequential model sum of square and model summary analyses of the various models as shown in the tables above. The highest order polynomial where the additional terms are significant, where the model is not aliased and has the highest adjusted R^2 and predicted R^2 is selected (Garba & Rahim 2014). R^2 is the correlation coefficient which indicates the extent of agreement between the predicted and experimental data. Therefore, the quadratic regression models were selected for both adsorption capacity and percentage removal.

3.4 Kinetic Studies:



Kinetic model parameters for adsorption of Co(II) ions onto CTRAC.

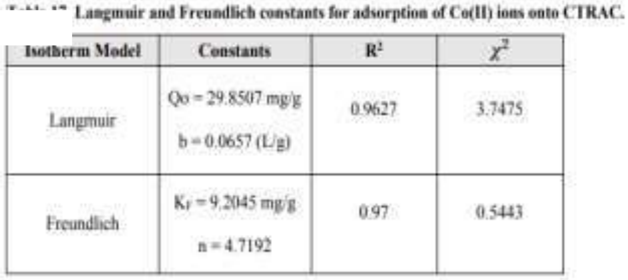
Kinetic Models	Parameters	Concentration of Co(II) (mg/L)	
		50	100
Lagergren Pseudo First Order	K_1 (min-1)	0.0056	0.0149
	Qe,cal (mg/g)	11.0342	24.4542
	R^2	0.5616	0.9049
Ho Pseudo Second Order	K_2 (g/mg.min)	$5.1567*10^{-3}$	$3.3681*10^{-3}$
	Qe,cal (mg/g)	30.4247	36.4964
	Qe,exp (mg/g)	28.8184	38.4818
	R^2	0.9916	0.9940
Elovich	α (mg/g.min)	600.4447	13.2668
	β (g/mg)	0.3906	0.1711
	R^2	0.8298	0.9418

Fig. 15

From the analysis of the results obtained, Ho pseudo second order model (0.9916 and 0.9940) showed the highest R^2 values when compared with Lagergren pseudo first order model (0.5616 and 0.9049) and Elovich model (0.8298 and 0.9418).

Therefore, it was concluded that the Ho pseudo second order model provided the best representation of the dynamics of the adsorption of Co(II) ions from the solution onto CTRAC, especially for higher initial concentrations.

3.5 Adsorption isotherm studies:



Langmuir and Freundlich constants for adsorption of Co(II) ions onto CTRAC.

Isotherm Model	Constants	R^2	χ^2
Langmuir	Q_0 = 29.8507 mg/g b = 0.0657 (L/g)	0.9627	3.7475
Freundlich	K_f = 9.2045 mg/g n = 4.7192	0.97	0.5443

Fig. 16

According to the Chi-squared error values, it is apparent that the experimental data of the adsorption of Co(II) ions onto CTRAC was better fitted by Freundlich isotherm, since Freundlich isotherm had a smaller error value of only 0.5443.

Therefore from the adsorption isotherm studies, it can be concluded that CTRAC is a promising adsorbent for Co(II) ions and the applicability of Freundlich isotherm showed that the adsorption of Co(II) ions onto CTRAC involved multilayer adsorption onto energetically heterogeneous surfaces.

4. CONCLUSION AND FUTURE SCOPE

4.1 Conclusion:

This work demonstrated the ability of activated carbon prepared from coconut tree roots to adsorb Co(II) ions from aqueous solutions. From the batch mode adsorption studies conducted, the adsorption capacity of CTRAC was found to have increased with increase in pH, decrease in CTRAC dosage, increase in initial concentration of Co(II) ions, decrease in temperature and the percentage removal of Co(II) ions was found to have increased with increase in pH, increase in CTRAC dosage, decrease in initial concentration of Co(II) ions, decrease in temperature.

Out of the five adsorption parameters considered for batch mode studies, three parameters (pH, CTRAC dosage and initial concentration of Co(II) ions) were identified to have effect on the adsorption capacity of CTRAC and percentage removal of Co(II) ions. Quadratic models developed for adsorption capacity of CTRAC and percentage removal of Co(II) ions had high R^2 values of 0.9653 and 0.9652 respectively and were also proved as significant and adequate in predicting the responses. The adsorption of Co(II) ions onto CTRAC was found to obey Ho pseudo second order kinetic model indicating that the adsorption was of chemisorption type. The results of adsorption isotherm studies revealed that the equilibrium data was better represented by Freundlich isotherm model than Langmuir isotherm model. Therefore, it can be concluded that CTRAC has the potential to serve as an efficient, cost-effective alternative to expensive commercial activated carbon for removal of cobalt ions from wastewater.

4.2 Future Scope:

Separation and regeneration. 2. Competitive adsorption from a mixture of different types of aqueous metal ion species onto activated carbon 3. Desorption studies to ascertain the mechanism of adsorption and recovery of the adsorbate and adsorbent.

4.3 Efficient Disposal of Heavy-Metal Laden Adsorbent:

The disposal of the adsorbent loaded with heavy metal must be evaluated so as to ensure environmentally safe conditions. The following disposal methods may be considered: Burning of the adsorbent after drying and using the heat for steam generation Using it for composite materials Composting process of biodegradable waste Regeneration by treatment with acid or organic solvent solution.

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