

Optimal Adsorption Parameters of Banana (*Musa paradisiaca*) Stalk based Activated Carbon for removal of Lead (II) from Aqueous Solution

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Abstract— The present study investigated the effect of operating parameters on the adsorption process of lead ion from aqueous solution using Banana Stalk- based Activated Carbon (BSAC). A five factor, five levels Central Composite Design (CCD) was applied to determine the effects of five independent variables (initial metal concentration, contact time, temperature, adsorbent dosage and solution pH) on adsorption capacity of BSAC. Response Surface Methodology (RSM) was employed to optimize the parameters in the experiment. Data analysis showed that all the variables significantly affected the adsorption capacity at $p < 0.05$. The square of the adjusted coefficient of determination for regression model of adsorption capacity is 0.9577. Optimum adsorption capacity of 85.15mg/g was obtained when the initial metal concentration, contact time, temperature, dosage and solution pH were 200g/mL, 140minutes, 50°C, 0.15g and 8.00, respectively. There absolute error between the experimental and the predicted optimum adsorption capacity values was less than 1%.

Index Terms— Adsorption, activated carbon, banana stalk, optimization, response surface methodology,

1 INTRODUCTION

Excessive release of heavy metals into the environment due to massive urbanization and industrialization has posed a great problem worldwide. The industrial effluents which contain different derivatives of heavy metals such as lead, cadmium, zinc, sodium, copper, chromium, and iron are continuously being discharged to the ecosystem causing pollution to the environment and significant toxic impact on living beings [1]. Unlike organic pollutants, the majority of which are susceptible to biological degradation, heavy metals ions do not degrade into harmless end products [2]. Lead is well known highly toxic metal and a cumulative poison. Apart from been toxic, lead is used for cable covering, construction, ammunition, and batteries [3] and its discharge into the environment poses serious threat due to its toxicity to aquatic and terrestrial lives [4, 5]

Quest to manage the environmental impacts of these heavy metals brought about several methods for treating contaminated effluents. These conventional techniques includes chemical precipitation [6], filtration and ion exchange [7], flotation [8], electrolytic recovery, membrane separation [9] and removal by adsorption on minerals [10].

However, most of these conventional methods are expensive and ineffective for low concentration of metal ions concentration particularly in range of 1-100mg/L [11]. They also produce sludge and require the use of high reagent and energy [12]. Studies have revealed adsorption using activated carbon as alternative and effective technique for removal of heavy metals from waste streams. Adsorption which is the process by which the adsorbate adheres or attaches itself to adsorbent is a well-established separation technique to remove dilute pollutants as well as to recover valuable products from aqueous streams [13]. Activated carbons because of their high surface area, microporous character and the chemical nature of their surface have been considered as potential adsorbents for the removal of heavy metals from industrial effluents [14].

Activated Carbon which is widely used in the adsorption process is very expensive. Due to this high cost, locally generated agricultural wastes such as palm shell [15], coconut and seed hull of the palm tree [16], *Eucalyptus camaldulensis* Dehn. bark [17], oil-palm fruit fibre [18], palm shell [19], fluted pumpkin seed shell [20], groundnut shell [21], palmyra palm nut [22], waste biomass [23], watermelon shell and walnut shell [24], peanut shell [25] and olive stone waste [26] have been used to produce activated carbons for various purposes.

Further need for low cost adsorbent as well as reducing environmental menace of agricultural residues brought about the study that explored the use of activated carbon produced from banana (*Musa paradisiaca*) stalk for the removal of lead (II) from its aqueous solution [27]. Ogunleye *et al.* [27], Bello *et al.* [28] and many others listed the factors that influence the adsorption process to include the initial concentration of the adsorbate, pH, temperature, adsorbent dose and time of adsorption. The interactions of these factors are complex and affect the efficiency of any adsorption process. However, a systematic approach to analyze this complex phenomenon in order to establish optimum combination of parameters that

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maximized the efficiency of the process was not reported. Therefore, this research is focused at estimating the optimal adsorption parameters that maximize the lead (II) removal from its aqueous solution using central composite design of experiment.

2.0 MATERIALS AND METHODOLOGY

2.1 Preparation of Adsorbate

Adsorbate containing Pb (II) was prepared from the stock solution of 1000 mgL⁻¹ Pb(NO₃)₂. Reagents used were of analytical grade and deionized water was used in solution preparation. Other concentrations (20 - 100 mg/L) were obtained from this stock solution by serial dilution. The concentration of Pb(II) in adsorbate was analysed by Atomic Absorption Spectrophotometer (model Pye Unicam SP-9 Cambridge, UK.)

2.2 Adsorbent Preparation and Characterization

Banana Stalks (BS) were washed thoroughly and then dried at 120 °C in an oven for 24 hours to constant weight. The dried samples were cut into small pieces, grinded and sieved into desire mesh size of 300 -425µm. Dried BS of 100g was pyrolysed in the Gollenkamp Muffle furnace (model Tactical 308) at 600°C for 1hour. The char produced was cooled to room temperature and treated with phosphoric acid (H₃PO₄) at a ratio 1:1 (w/v). The mixture was dehydrated in an oven for 12 hours at 105°C and then carbonized in the absence of air at 800°C for 2 hours. The carbonized sample was cooled, filtered and mixed with 0.1M HCl for 1 hour on magnetic stirrer. The sample was finally washed with hot de-ionized water until the pH of the washed solution reached 7.0 and then stored as BSAC. Surface characteristics of the BSAC were carried out using ASTM [29] methods while Fourier Transform Infrared (FTIR) spectroscopic analysis was performed on the raw and BSAC using (FTIR - 2000, Perkin Elmer) and spectra were measured from 4000 to 400 cm⁻¹

2.3 Batch Adsorption Equilibrium Experiment

Batch equilibrium tests were carried out on the adsorption of Pb(II) on BSAC. The adsorption experiments were carried out in 250ml conical flasks with stopper on a mechanical shaker equipped with a thermostatic water bath operating at 120 rpm. The effect of initial metal ion concentration (50, 100,150,200 and 250mg/L), contact time (15, 30, 60, 120 and 180 minutes), temperature (25, 30, 40 and 50°C), solution pH (2, 4, 6, 8 and 10) and adsorbent dose (0.05, 0.1, 0.15, 0.20, 0.25 and 0.30g/100ml of Pb(II) solution) were investigated. During the experiment, the combination of parameter considered were varied according to the experimental design. The pH of the solution was adjusted to the desire pH by addition of 0.1M HCl or 0.1M NaOH and monitored using pH meter. Sample solutions were withdrawn and filtered using Whatman filter paper at time interval to determine residual concentrations. The concentrations of Pb(II) solution before and after adsorption were determined using Atomic Absorption Spectrophotometer (Model Pye Unicam SP-9 Cambridge, UK.) . The linear Beer-Lambert relationship between absorbance and concentration with the calibration curve was established by plotting

the graph of absorbance versus concentration of the Pb(II) solution.

The adsorbed phase concentration (q_t, in mg/g) at time (t) was calculated using equation (1)

$$q_t = \frac{C_0 - C_t}{m} \quad (1)$$

Where, C₀ and C_t are the initial and the final lead concentration (mg/L), respectively; V is the adsorbate volume (L) and m is the mass of adsorbent used (g).

2.5 Experimental Design and Data Analysis

Design Expert software version 6.0.8 (STAT-EASE Inc., Minneapolis, USA) was used to design the experiments using Central Composite Design (CCD) with five factors and five levels in the Response Surface Methodology (RSM).The dependent variable selected for this study was the adsorption capacity of BSAC, expressed in mg/g, and the independent variables chosen were the temperature, adsorbent dose, contact time, initial concentration of lead (II) and solution pH. Regression analysis of the experimental data to fit the response equation in terms of the factors was carried out and the quality of fit of the model was expressed by the correlation coefficient (R-squared) and Analysis of Variance (ANOVA). A second order polynomial equation was proposed to fit the experimental data as given in equation (2):

$$Y = a_0 + a_1A + a_2B + a_3C + a_4D + a_5E + a_{11}A^2 + a_{22}B^2 + a_{33}C^2 + a_{44}D^2 + a_{55}E^2 + a_{12}AB + a_{13}AC + a_{14}AD + a_{15}AE + a_{23}BC + a_{24}BD + a_{25}BE + a_{34}CD + a_{35}CE + a_{45}DE \quad (2)$$

where Y is the predicted response for Adsorption capacity of BSAC for Pb(II), a₀ is the value of the fitted response at the centre point of the design, a_i, a_{ii}, a_{ij} being the linear, quadratic, and cross product terms, respectively.

A statistical optimization of the model was conducted using the RSM. The CCD was used to determine the main and interaction effects of all the process parameters. The ranges of all the factors studied are as given in Table 1. The actual values of the process variables and their ranges were selected based on the preliminary experiments. The optimum values of all the variables were obtained by solving the regression equations and by analyzing the contour and 3D surface plots.

3.0 RESULTS AND DISCUSSION

3.1 Characterization of BSAC

The FTIR spectroscopic characteristics for the Raw Banana Stalk (RBS) and BSAC are as shown in Figure 1a and 1b, respectively while the FTIR analysis indicating bands and peaks with their corresponding ascribed functional groups are on Table 2. There is a shift in bands, change in wave numbers, and absorbance difference between the RBS and BSAC samples, which indicate that chemical transformation took place during chemical treatment and carbonization. The combined

Table1: Levels for parameters used in the adsorption

Parameters	Range of levels				
	-α	-1	0	+1	+α
A: Initial concentration (mg/l)	50	100	150	200	250
B: Contact time (minutes)	20	60	100	140	180
C: Temperature (°C)	25	30	40	50	60
D: Adsorbent dosage (g/100ml)	0.1	0.15	0.2	0.25	0.3
E: Solution pH	2	4	6	8	10

effects of chemical activation and carbonization on the RBS to produce BSAC resulted in enhancement and disappearance of some of the functional groups as well as shifting and lowering of wavelength numbers. The results of the surface characterization, which gave the quantification of the surface acidic and basic groups of the adsorbent, are presented in Table 3. Oxygen functional groups with various acidic groups (carbonyl, lactonic and phenolic) are found to be higher than the basic group This is an indication of the dominance of acidic groups. The presence of the surface functional groups depicts the metal binding capacity of the adsorbent.

Table 2: FTIR Spectra Characteristics

RBS			BSAC	
IR Spectra Peak (cm ⁻¹)	Functional groups	IR Spectra Peak (cm ⁻¹)	Functional groups	
3889.63	Bonded O-H group	3843.30	O-H group	
3639		3797.60		
3302.82	O-H group of carboxylic acid	3390.74, 3290.42, 3154	O-H group of carboxylic acid	
2918	Aliphatic C-H group	2822.50	Aliphatic C-H group	
2323.47		2383.53		
1636.16	Carbonyl stretching with aromatic Ring	1621	C=O stretching	
1594.01	Amide group	1058	C=O=C stretching for ether or hydroxyl group	
1316	Nitrate (NO ₂) symmetric stretching	980	β-glycolic linkages	
1252.96				
1028	Si - O - Si asymmetric stretching	472-438	C=C stretching (lignin) and C-N stretching	
661-523.76	C-S stretching			

BSAC	Surface Chemistry
Carboxylic (meq. g-1)	0.2152
Lactonic (meq. g-1)	0.2445
Phenolic (meq. g-1)	0.2816
Acidic (meq. g-1)	0.7413
Basic (meq. g-1)	0.1842
pH _{PZC}	4.25

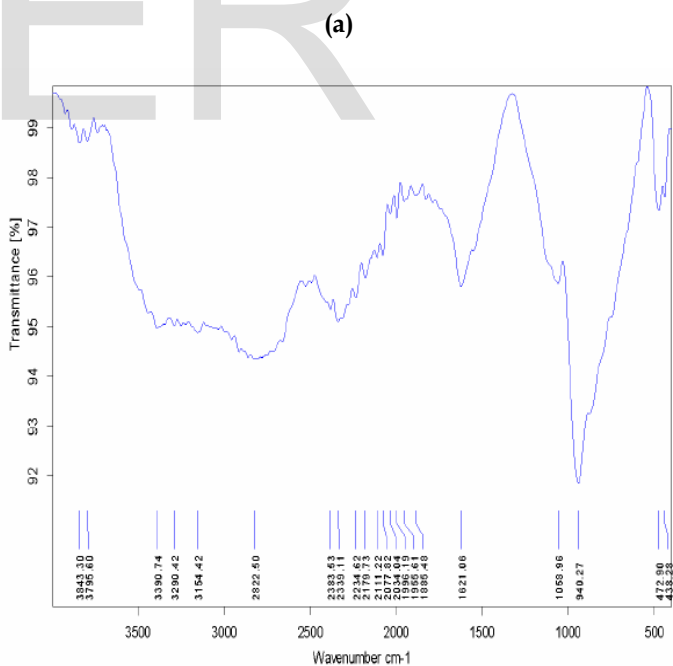
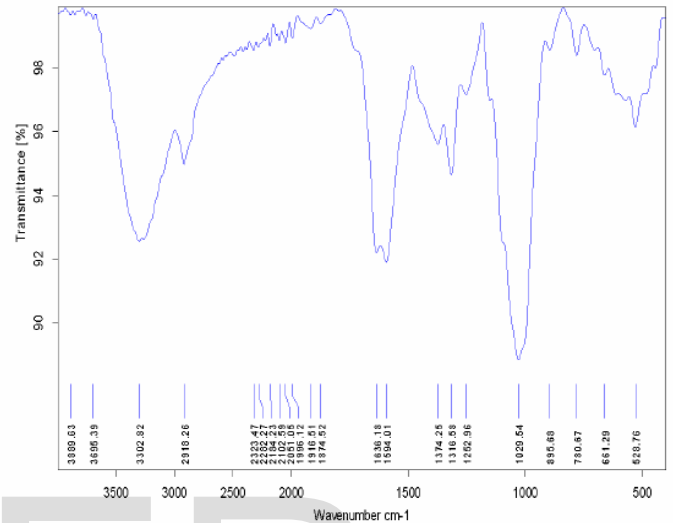


Figure 1: FTIR spectra for (a) RBS and (b) BSAC

Table 3: Surface Characteristics of BSAC

3.2 Adsorption of Pb(II) onto BSAC

The matrix of the various adsorption parameters of Pb(II) adsorption to the BSAC with respect to the adsorption capacity are presented in Table 4. At each pair of experimental runs, run number 1 and 7; 2 and 20; 3 and 15; 4 and 8; 5 and 10 had the same process conditions with different initial Pb(II) concentration; results shows that adsorption capacity (mg/g) of BSAC for Pb(II) removal increased with increased initial Pb(II) concentration. This observation is due to the fact that adsorbent have limited number of active sites and will continue to adsorb adsorbate until a certain concentration is reached when the active sites become saturated [30]. Effect of different solution pH were investigated at the same process condition of initial concentration, contact time, temperature and adsorbent dose as shown on runs 17, 18 and 36. As pH decreased from 10 to 6 to 2, the adsorption capacity decreased from 73.68 to 43.24 to 16.53. This observation is consistent with previous of the surface characteristics (Table 3) of the BSAC that is more acidic in nature and hence it ability to absorb more in a basic medium. Similarly, run numbers 15 and 19; 20 and 29 had the same process operating condition with different temperature; finding shows that increase in temperature led to increased adsorption. This was mainly due to increased surface activity, confirming that adsorption Pb(II) onto BSAC was endothermic [27]. A rise in temperature usually accelerates and increases mass transfer. It was also observed that adsorption capacity of BSAC increased with increasing contact time while other conditions were kept constant. However, at lower pH value of 4 ($pH_{PZC} = 4.25$) with other constant conditions, adsorption capacity of BSAC increased from 19.92 to 28.50 mg/g by changing adsorbent dose from 0.15 to 0.25g/100ml (Runs 33 and 37). This result was reversed at higher pH value as can be seen on the pairs of runs 7 and 9; 1 and 26, where the adsorption capacity reduced with increasing dose. This observation is largely due to the acidic surface characteristic of the BSAC.

3.3 Second Order Polynomial Regression Model and Statistical Analysis

The regression coefficients, standard error of coefficients, and p-values for the significant factors in the estimation of the BSAC adsorption capacity in terms of initial concentration (A), contact time (B), temperature (C), adsorbent dose (D) and solution pH (E) are listed in Table 5. As a replica of equation (2) by substituting the coefficient with the corresponding values on Table 5 for the significant terms at $p < 0.05$, equation (3) was obtained.

$$Y = 43.37 + 8.91A + 8.35B + 2.46C + 2.12D + 10.75E - 2.68A^2 + 3.76AB + 1.43AC + 1.43AD + 3.67AE - 3.08BD + 3.67BE - 2.68DE \quad (3)$$

Equation (3) was used to evaluate the influence of process variables on the adsorption capacity (mg/g) of BSAC for Pb(II). Analysis of variance method was employed to further estimate the significance and accuracy of the model. The corresponding results are presented in Table 6 where the model showed vary high F value (74.16) and a very low probability value (p -value model = 0.001) for the system investigated. **Table 4: Central Composite design Experimental Runs with corresponding Response**

Run	Factors at both Actual and Coded Levels										Response	
	A: Initial Concentration (mg/L)		B: Contact Time (Minutes)		C: Temperature (°C)		D: Adsorbent dose (g/100ml)		E: Solution pH		Adsorption Capacity (mg/g)	
	Actual	Coded	Actual	Coded	Actual	Coded	Actual	Coded	Actual	Coded		
1	200	1	140	1	50	1	0.15	-1	8	1	86.26	
2	100	-1	60	-1	50	1	0.15	-1	8	1	29.45	
3	200	1	60	-1	50	1	0.25	1	8	1	56.34	
4	200	1	140	1	30	-1	0.15	-1	4	-1	35.86	
5	100	-1	140	1	50	1	0.25	1	4	-1	30.16	
6	150	0	100	0	40	0	0.30	2	6	0	49.96	
7	100	-1	140	1	50	1	0.15	-1	8	1	50.95	
8	100	-1	140	1	30	-1	0.15	-1	4	-1	26.90	
9	100	-1	140	1	50	1	0.25	1	8	1	39.24	
10	200	1	140	1	50	1	0.25	1	4	-1	50.31	
11	200	1	140	1	30	-1	0.15	-1	8	1	79.56	
12	200	1	140	1	30	-1	0.25	1	4	-1	38.92	
13	150	0	100	0	40	0	0.10	-2	6	0	37.32	
14	200	1	60	-1	30	-1	0.25	1	4	-1	32.91	
15	100	-1	60	-1	50	1	0.25	1	8	1	37.08	
16	100	-1	140	1	30	-1	0.15	-1	8	1	48.38	
17	150	0	100	0	40	0	0.20	0	10	2	73.68	
18	150	0	100	0	40	0	0.20	0	6	0	43.24	
19	100	-1	60	-1	30	-1	0.25	1	8	1	33.03	
20	200	1	60	-1	50	1	0.15	-1	8	1	43.74	
21	250	2	100	0	40	0	0.20	0	6	0	52.94	
22	100	-1	60	-1	30	-1	0.15	-1	4	-1	19.87	
23	200	1	60	-1	30	-1	0.25	1	8	1	45.65	
24	100	-1	60	-1	30	-1	0.25	1	4	-1	26.04	
25	150	0	20	-2	40	0	0.20	0	6	0	21.75	
26	200	1	140	1	50	1	0.25	1	8	1	78.23	
27	100	-1	60	-1	30	-1	0.15	-1	8	1	29.83	
28	200	1	140	1	50	1	0.15	-1	4	-1	42.41	
29	200	1	60	-1	30	-1	0.15	-1	8	1	36.90	
30	200	1	60	-1	50	1	0.25	1	4	-1	42.44	
31	150	0	100	0	20	-2	0.20	0	6	0	36.05	
32	50	-2	100	0	40	0	0.20	0	6	0	12.39	
33	100	-1	60	-1	50	1	0.25	1	4	-1	28.50	
34	100	-1	140	1	30	-1	0.25	1	4	-1	27.75	
35	200	1	60	-1	50	1	0.15	-1	4	-1	23.92	
36	150	0	100	0	40	0	0.20	0	2	-2	16.53	
37	100	-1	60	-1	50	1	0.15	-1	4	-1	19.92	
38	150	0	180	2	40	0	0.20	0	6	0	62.63	
39	100	-1	140	1	50	1	0.15	-1	4	-1	27.88	
40	200	1	140	1	30	-1	0.25	1	8	1	75.86	
41	100	-1	140	1	30	-1	0.25	1	8	1	38.30	

F and p values of the lack of fit for the models were 8.72 and 0.1745, respectively, which indicates that the lack of fit of the model is not significant. Hence, the experimental data fitted well in Equation (3) for the adsorption of Pb(II) onto BSAC. The Lack of Fit is designed to determine whether the selected model is adequate to describe the observed data, or whether a more complicated model should be used.

The Predicted R^2 of 0.9385 is correspondently in reasonable agreement with the Adjusted R^2 of 0.9577. Adequate Precision measures the signal to noise ratio. A ratio > 4

is desirable. The ratio of 33.741 in this study indicates an adequate signal. This model can be used to navigate the design space. The coefficient of variation (CV) as the ratio of the standard error of estimate to the mean value of the observed response is a measure of reproducibility of the model, generally a model can be considered reasonably reproducible if its CV is not greater than 10 per cent. Hence, the low variation coefficient value (CV = 6.21%) obtained indicates a high precision and reliability of the experiments.

Table 5: Coefficients of Models of Adsorption of Pb(II) onto BSAC

Factors	Coefficient of Estimate	DF	Standard Error	p-Value
a ₀	43.37	1	0.87	0.0001*
a ₁	8.91	1	0.58	0.0001*
a ₂	8.35	1	0.58	0.0001*
a ₃	2.46	1	0.58	0.0002*
a ₄	2.12	1	0.58	0.0010*
a ₅	10.75	1	0.58	0.0001*
a ₁₂	3.76	1	0.65	0.0001*
a ₁₃	1.43	1	0.65	0.0365*
a ₁₄	1.43	1	0.65	0.0358*
a ₁₅	3.67	1	0.65	0.0001*
a ₂₄	-3.08	1	0.65	0.0001*
a ₂₅	3.67	1	0.65	0.0001*
a ₄₅	-1.95	1	0.65	0.0056*
a ₁₁	-2.68	1	0.71	0.0007*

Table 6: ANOVA for Response Equation of Adsorptive Capacity of BSAC

Source	Sum of Square	DF	Mean Square	F-Value	p-value
Model	13071.45	13	1005.50	74.16	0.0001*
Residual	393.20	29	13.56		
Lack of Fit	123.50	22	5.60	8.72	0.1745
Pure Error	0.00	7	0.00		
Total	13464.64	42			

* Significant at p < 0.05; R² = 0.9708; Adjusted R² = 0.9577; Predicted R² = 0.9385; Adequate Precision = 33.741

3.4 Process Optimization

In order to acquire a maximum response value of the adsorption capacity of BSAC, the numerical optimization

function was used to optimize the process parameters. The response function was the adsorption capacity (mg/g) as a function of the factors. A desirability index of 0.985 was obtained at A = 10 ml and E = 0.15 g. The effect of independent variables on the response is shown in Figures 3-12. The effects of initial concentration (C = 50°C), temperature (T = 30°C), pH (pH = 6), and contact time (t = 120 min) are shown in Figures 3, 4, 5, and 6, respectively. Similar figures for the effect of contact time with each of temperature, adsorbent dose and pH when other factors are kept at optimum values are as shown on Figures 7, 8 and 9, respectively. Figures 10 and 11 depict the effects of temperature with each of adsorbent dose and pH, respectively. Finally, Figure 12 depicts the effect of adsorbent dose and pH on the adsorption capacity of BSAC.

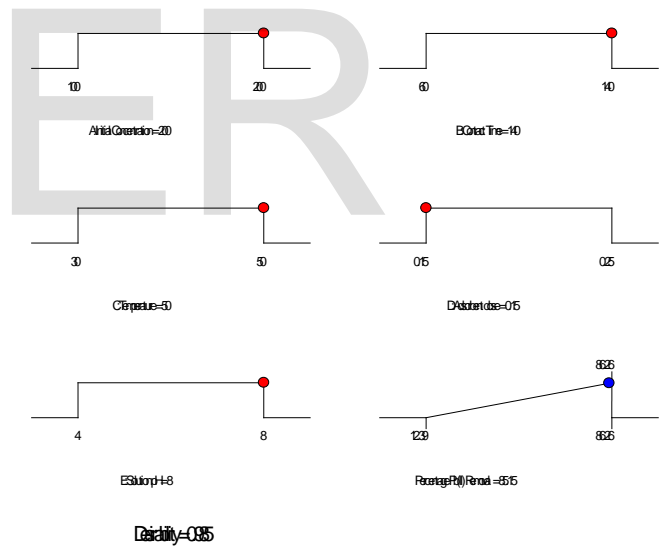


Figure 2: Ramps showing the optimized process conditions for adsorption capacity.

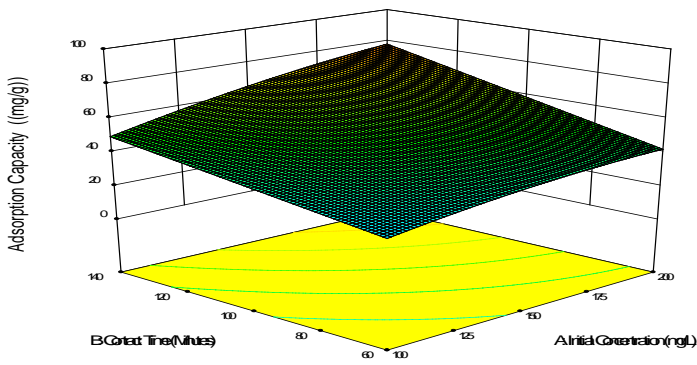


Figure 3: Effects of Initial Concentration and Contact Time on Adsorption Capacity of BSAC (at C = 50°C, D = 0.15 g/100ml and E= 8)

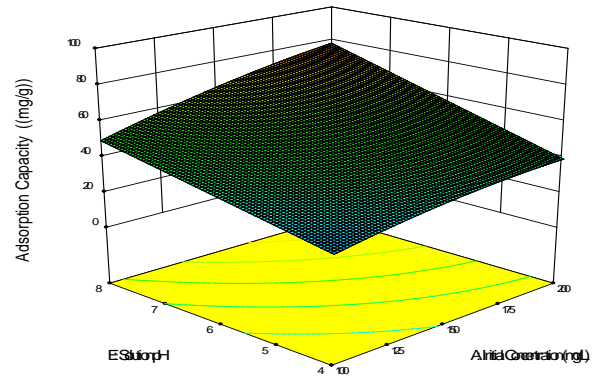


Figure 6: Effects of Initial Concentration and Solution pH on Adsorption Capacity of BSAC (at B= 140 minutes , C = 50°C and D = 0.15 g/100ml)

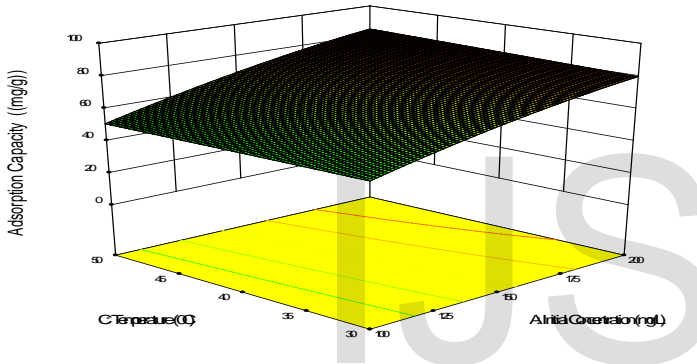


Figure 4: Effects of Initial Concentration and Temperature on Adsorption Capacity of BSAC (at B = 140 minutes, D = 0.15 g/100ml and E= 8)

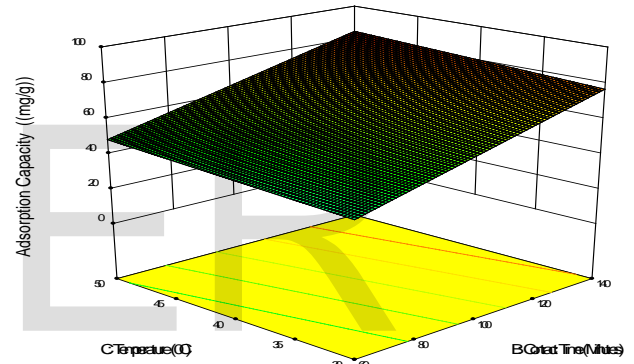


Figure 7: Effects of Contact Time and Temperature on Adsorption Capacity of BSAC (at A= 200 mg/L, D = 0.15 g/100ml and E= 8)

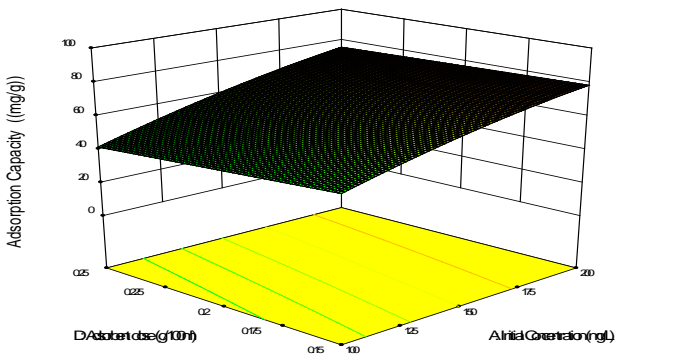


Figure 5: Effects of Initial Concentration and Adsorbent Dose on Adsorption Capacity of BSAC (at B = 140 minutes , C = 50°C and E= 8)

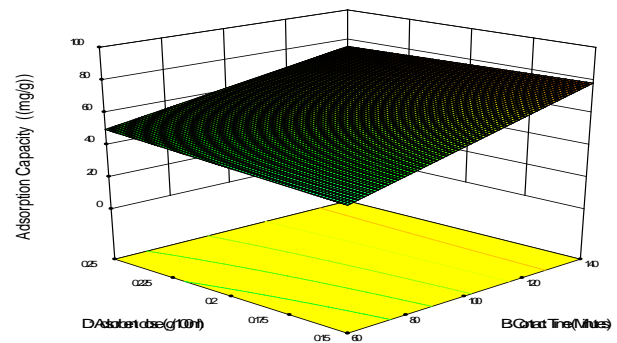


Figure 8: Effects of Contact Time and Adsorbent Dose on Adsorption Capacity of BSAC (at A= 200 mg/L, C= 50 °C and E= 8)

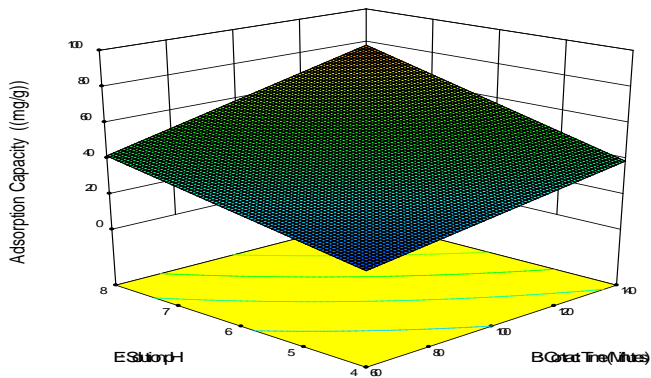


Figure 9: Effects of Contact Time and Solution pH on Adsorption Capacity of BSAC (at A= 200 mg/L, C=50°C and D = 0.15 g/100ml)

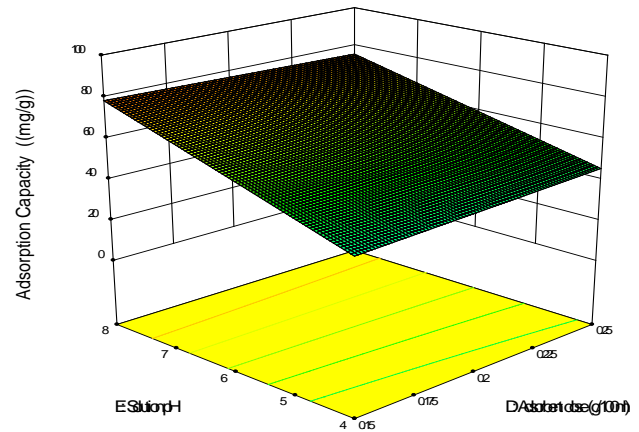


Figure 12: Effects of Adsorbent Dose and Solution pH on Adsorption Capacity of BSAC (at A= 200 mg/L, B= 140 minutes and C= 50°C)

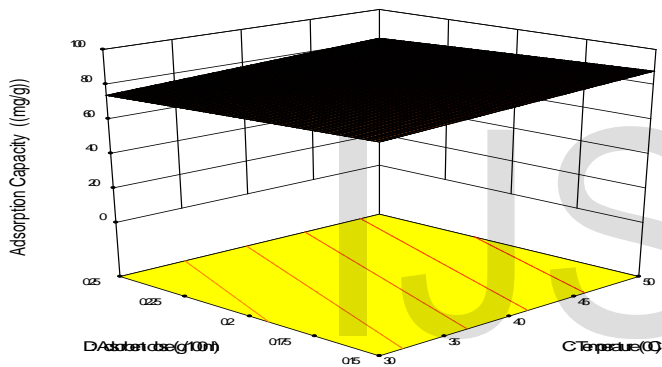


Figure 10: Effects of Temperature and Adsorbent Dose on Adsorption Capacity of BSAC (at A= 200 mg/L, B= 140 minutes and E= 8)

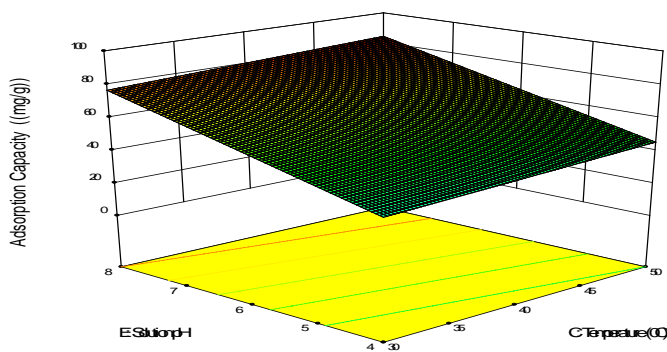


Figure 11: Effects of Temperature and Solution pH on Adsorption Capacity of BSAC (at A= 200 mg/L, B= 140 minutes and D = 0.15 g/100ml)

3.5. The Validation of the Optimal Conditions

To test if the predicted optimal condition values were in line with the corresponding experimental results, additional experiments for determining adsorption capacity were performed under the optimized conditions. Considering various initial concentration of Pb(II) may be used, values such as 100, 150 and 250mg/L were imposed as constraints while other optimal conditions that would ensure maximum adsorption capacity were sought and experimented in triplicate and the average values compared with the predicted maximum value of adsorption capacity as shown on Table 7. The absolute relative error between the predicted and average experimented maximum adsorption capacity were all less than 1%. This result shows that the model developed can be used to adequately predict the adsorption of the Pb(II) onto BSAC

Table 7: Validation of the Optimal Parameters of BSAC Adsorption Capacity

Optimized Adsorption Factors					Predicted Adsorption Capacity (mg/g)	Experimented Adsorption Capacity (mg/g)	Average Experimented Adsorption Capacity (mg/g)	Absolute Relative Errors (%)
A (mg/L)	B (Min.)	C (°C)	D (g/100ml)	E	Y_{pred}	Y_{Exp}	Y_{Ave}	
100	140	50	0.15	8	52.49	52.60	52.77	0.53
						52.80		
						52.90		
150	140	50	0.15	8	71.50	72.00	71.74	0.34
						71.80		
						71.42		
250	138	47	0.20	7.7	87.97	87.60	87.80	0.19
						88.10		
						87.70		

4.0 CONCLUSION

This study demonstrated efficacy of central composite design in estimating the influence of interaction of adsorption variables on the adsorption capacity of BSAC. The variables of initial concentration, contact time, temperature, adsorbent dose and pH had a strong influence on the adsorption of Pb(II) using BSAC as adsorbent. The adsorption capacity of BSAC was influenced positively by concentration, contact time, temperature, adsorbent dose and pH. Also, it was influenced positively by interactions of initial concentration and contact time; initial concentration and temperature; initial concentration and adsorbent dose; initial concentration and pH; contact time and pH but negatively by interaction of contact time and adsorbent dose; adsorbent dose and pH. The obtained reduced second-order polynomial quadratic regression model for the responses of adsorption capacity of BSAC was significant. Finally, the maximum adsorption capacity of BSAC predicted by the model was in agreement with the experimental values.

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