Response Surface Modelling and Optimization of Lead Adsorption from Wastewater Using Rice Husk Activated Carbon

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ORIGINAL RESEARCH

Abstract- Nigeria is renowned for its vast production of paddy rice, resulting in a significant volume of rice husk generation. Consequently, the conversion of these quantities of rice husk into beneficial applications is imperative to mitigate environmental pollution. The rice husk, procured from local millers in Zaria market, Nigeria, was subjected to thermal and chemical methods to produce activated carbon. The carbonization process involved heating at three different temperatures (300, 350 and 400 ℃) and subsequent mixing with 1M H3PO4 at a 1:2 ratio. Batch adsorption experiments were conducted, varying dosages of rice husk activated carbon (1 - 5 g), lead initial concentrations (10 - 60 mg/l), and carbonization temperatures (300 - 400 ℃). The Response Surface Methodology was utilized to model the adsorption capacities and removal efficiencies obtained. At carbonization temperature of 350 ℃, initial lead concentration of 60 mg/l, and adsorbent dosage of 3 g, the optimum removal efficiency and adsorption capacity 100% and 1.690 mg/g, respectively were observed. The veracity of the model equations was confirmed through the verification of the optimum adsorption conditions, with recorded percentage errors of 0.253% and 17.988%, for removal efficiency and adsorption capacity, respectively. The study's findings showed that rice husk activated carbon was highly effective in removing lead from wastewater. Furthermore, the model equations demonstrated reliability in forecasting the responses, and the optimum conditions were deemed valid.

Keywords- Adsorption; lead; pollution; removal efficiency; rice husk

1 Introduction

Nigeria is recognized for its capacity to produce substantial quantities of paddy rice, as estimated to be 8.17 million tonnes in 2020 by the World Data Atlas (2020). The processing of extensive amounts of paddy rice typically generates plentiful amounts of rice husk, which is the shell acquired after extracting rice grains from paddy rice (Mistry, 2010; Adamu and Adie, 2020). Reports suggest that approximately 20% of paddy rice is composed of rice husk (Mitra et al., 2019), implying that an increase in paddy rice production in the country would result in a proportionate increase in rice husk formation (Babaso and Sharanagouda, 2017; Adamu et al., 2021). Consequently, it is essential to pay attention to the generated rice husk, which is considered a potential effective adsorbent, as it is solid waste (Wang and Lin, 2008). In other words, its modification to a more beneficial application is necessary to control the environmental pollution that could result from its generation and subsequent release into the environment (Bari et al., 2022; Alam et al., 2020). Nevertheless, regular activated carbon is recognized for being costly and challenging to regenerate (Sa'ad, 2020; Mohammad et al., 2014). Thus, it is imperative to take into account agricultural by-products like rice husk, which are easily accessible in the environment, for making of activated carbon (Youssef, 2014; Montalvo-Anvia, 2022) using them in removing heavy metals and other physicochemical contaminants from wastewater (Ansari & Mohammad-Khah, 2009)

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The benefits of this strategy are manifold: it lessens environmental contamination, transforms solid waste into wealth, and eliminates pollutants from wastewater. Activated carbon remains a suitable material for removing many pollutants from water and wastewater, including organic pollutants. The functioning of activated carbon in the treatment of sewage is reliant upon the substances to be absorbed and the characteristics of the activated carbon used (Idris et al., 2011). Similarly, heavy metals are not needed by the human body, even in small amounts. The human body has no mechanism to degrade and render them harmless (Hanum et al., 2017; Daouda et al., 2022), making their removal essential to protect against their detrimental effects. Moreover, heavy metals are recognized for causing a range of health problems, though some heavy metals, such as zinc, copper, and iron, are essential for consistent bodily functions in small amounts (El Said et al., 2018). However, the heavy metals that pose the greatest risk to human health are actually lead, cadmium and mercury. Lead can cause high blood pressure, kidney failure, cancer, and lung failure (Saeed et al., 2021; Niu et al., 2014), which underscores the need to remove lead from wastewater to save human lives from the effects of chronic diseases.

Furthermore, the modelling and optimization of processes play a pivotal role in enhancing outputs without the involvement of additional resources (Khan et al., 2020). This is because, when it comes to experimental adsorption of lead from wastewater, it demands some series of tests that are frequently exhausting and time-consuming. Consequently, there arises a pressing need to employ Response Surface Modelling (RSM) to economize time, curtail experimental count, reduce expenses, and minimize laboratory workload (Sivaprakasam and Venugopal, 2019). Hence, the fundamental objective of this study is to model and optimize the adsorption of lead from wastewater using activated carbon produced from rice husk, utilizing RSM.

2 Materials And Methods

2.1 Materials

The laboratory equipment utilized in this study includes a magnetic stirrer identified as model 79-1, an electric furnace manufactured by Nabertherm with a temperature range of 30 to 3000°C, a centrifuge machine of the Gallenramp Junoir variety, an electronic weighing balance produced by Mettler and referenced as P160N, a pH meter created by Hanna instrument, and an atomic absorption spectrophotometer, specifically the AA6800 model manufactured by Shimadzu. The experimental mechanism also utilized a 250ml conical flask, measuring cylinders of both 100 and 1000 ml capacity, a 25 ml pipette, a 20 ml syringe, and solution that consisted of sodium hydroxide (NaOH) with a concentration of 0.1M, distilled water, de-ionized water, hydrochloric acid (HCl) solution of 0.1M, lead trioxonitrate (V) ($Pb(NO_3)_2$), and 1M tetraoxophosphate (V) acid (H_3PO_4).

2.2 Methods

2.2.1. Collection of Rice Husk

The rice husk was procured from indigenous millers situated at the Zaria city market, which is located in the Zaria Local Government Area of Kaduna State, Nigeria.

2.2.2 Production of activated carbon from rice husk

The rice husk was subjected to a thorough washing process using tap water and subsequently distilled water. The prescribed procedure in (Adamu and Adie, 2020b) was followed, which involved drying the substance in an oven at 100 °C for five hours. The carbonation of the dried rice husk was performed at 300, 350, and 400°C, using an electric furnace. The carbonized rice husks were then combined with 1M H_3PO_4 in a ratio of 1:2 (1g of rice husk to 2ml of H_3PO_4). After a careful rinsing with distilled water to achieve a pH of 7, the prepared activated carbons were positioned in an oven at 80 °C for an hour. The samples were thereafter stored in an airtight container.

2.2.3 Preparation of Lead (Pb) solution

A 100 mg/l concentration lead solution was produced by dissolving 0.1599 g of $Pb(NO_3)_2$ in a 1000 ml volumetric flask with 10 ml of 0.1M HNO_3. This was followed by the addition of de-ionized water until the 1000 ml mark was reached. Three solutions with lead concentrations of 10, 35, and 60 mg/l were obtained by adding 90, 65, and 40 ml of de-ionized water to the 10, 35, and 60 ml Pb solutions, respectively, from the original 100 mg/l Pb solution.

2.2.4 Design of Experiments

The experimental design was facilitated by the utilization of the design expert tool, with careful consideration given to the input variables of Carbonization temperature, °C (A), initial Pb concentration, mg/l (B), and rice husk activated carbon dosage, g (C). Meanwhile, the output variables of removal efficiency, % (K_1) and adsorption capacity, mg/g (K_2) were outlined in Table 1.

Table 1. Input variables and outputs (responses)

Input variables	Lower value	Upper value	Responses
A (°C)	300	400	K_1 (%) and
B (mg/l)	10	60	K_2 (mg/g)
C (g)	1	5	

One gram of activated carbon, made from rice husks and carbonized at 400 °C, was utilized to conduct a batch adsorption experiment. The initial concentration of Pb was set at 60 mg/L in accordance with the design matrix outlined in Table 2. The mixture was agitated at the speed of 150 rpm for an hour at room temperature. Following this, the concentration of Pb in the effluent was determined using AAS. The batch adsorption experiment was conducted using the same process for all adsorption settings as outlined in Table 2. The determination of removal efficiency (K_1) and adsorption at equilibrium (K_2) was executed by applying equations (1) and (2), respectively, utilizing computational techniques.

$$K_1 = \left(\frac{B_i - B_e}{B_i}\right) \times 100 \quad (1)$$

$$K_2 = \frac{(B_i - B_e) \times V}{C} \quad (2)$$

Where B_i and B_e are the primary and final Pb concentrations, C is the rice husk activated carbon dosage and V is the Pb solution volume (100ml).

The matrix of design is revealed in Table 2, which encompasses the randomized carbonization temperature (A) as Input 1, initial Pb concentration (B) as Input 2 and rice activated carbon dosage (C) as Input 3. Additionally, the Table presents the responses (outputs), namely the removal efficiency and adsorption capacity, which were documented under the randomized settings of the input parameters.

Table 2: Design matrix for the input variables and outputs

Std	Run	Input 1	Input 2	Input 3	Response 1 (K_1)	Response 2 (K_2)
		A (°C)	B (mg/l)	C (g)	K_1 (%)	K_2 (mg/g)
4	1	400	60	1	99.956	5.9974
3	2	300	60	1	97.389	1.1687
20	3	350	35	3	99.369	1.1593
8	4	400	60	5	99.113	1.1989
17	5	350	35	3	99.369	1.1593
2	6	400	10	1	98.770	0.9877
15	7	350	35	3	99.369	1.1593
18	8	350	35	3	99.369	1.1593
9	9	300	35	3	95.941	1.1193
6	10	400	10	5	99.781	0.1996
10	11	400	35	3	99.684	1.163
14	12	350	35	5	99.339	0.6954
13	13	350	35	1	99.818	3.4936
16	14	350	35	3	99.369	1.1593
7	15	300	60	5	97.389	1.1687
1	16	300	10	1	88.649	0.8865
5	17	300	10	5	86.492	0.173
11	18	350	10	3	98.207	0.3274
12	19	350	60	3	99.613	1.9923
19	20	350	35	3	99.369	1.1593

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3 Results and Discussion

3.1 Generation of Model Equations

The statistical summary of the model is presented in Table 3. The commendable R^2 value of 0.9504, an adjusted R^2 value of 0.9058, and a predicted R^2 value of 0.5511, making the quadratic model's R^2 values impressive. Furthermore, it is noteworthy that the model has a low standard deviation of 1.13 and is devoid of any aliasing issues, thus being recommended by the software. It is imperative to highlight that the selection of the quadratic equation is based on the criterion of high R^2 value and low standard deviation, signifying that 90.58% of the variations in the removal efficiency can be attributed to the carbonization temperature, initial Pb concentration, and rice husk activated carbon dosage. Additionally, a study conducted by (Mohammad et al., 2014b) revealed that 99.79% of the variation in phenol removal efficiency on rice husk activated carbon can be attributed to the carbonization temperature, initial concentration, and adsorbent dosage.

Table 3. Summary of removal efficiency statistics (K1)

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	
Linear	2.54	0.5989	0.5237	0.1806	211.01	
2FI	2.15	0.7671	0.6597	-0.6754	431.45	
Quadratic	1.13	0.9504	0.9058	0.5511	115.59	Suggested
Cubic	0.41	0.9961	0.9876	-3.8158	1240.18	Aliased

In Table 4, the adsorption capacity's summary statistics are provided. The quadratic equation illustrated a satisfactory R^2 score of 0.9559, an adjusted R^2 of 0.9163, and a projected R^2 of 0.2433. Additionally, this model exhibited a standard deviation of 0.24 and was not found to be aliased, making it the preferred equation among the others tested. These findings indicate that approximately 91.63% of the changes in adsorption capacity can be attributed to variations in carbonization temperature, initial Pb concentration, and rice husk activated carbon dosage. Another investigation by Sujatha and Sivarethinamohan (2021) similarly found that the quadratic equation was suitable for modelling the adsorption of lead onto activated carbon produced from De oiled suya.

Table 4. Summary of adsorption capacity statistics (K2)

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	
Linear	0.37	0.8210	0.7874	0.6370	4.56	
2FI	0.32	0.8917	0.8417	0.2746	9.11	
Quadratic	0.24	0.9559	0.9163	0.2433	9.50	Suggested
Cubic	0.059	0.9983	0.9948	-1.0327	25.53	Aliased

The model equations in (1) and (2) were generated through design expert to depict respectively, the removal efficiency (K_1) and adsorption capacity (K_2). The equations encompass the independent variables, namely the carbonization temperature (A), initial Pb concentration (B), and rice activated carbon dosage (C), while the respective removal efficiency (K_1) and adsorption capacity (K_2) are the responses.

$$K1 = -50.03853 + 0.70757A + 0.83576B - 1.03083C - 0.0018321AB + 0.00390375AC + 0.0027525BC - 0.000843818A^2 - 0.00161927B^2 - 0.085886C^2 \quad (1)$$

$$K2 = 6.24010 + 0.031558A + 0.018209B - 0.10083C + 0.000140982AB - 0.00196874AC + 0.00405783BC - 0.0000381222A^2 - 0.000705280B^2 + 0.054168C^2 \quad (2)$$

3.2 Statistical Analysis

The analysis of variance for the removal efficiency (K_1) is presented in Table 5. It has been unveiled that the removal efficiency demonstrated an F-value of 21.31 with a resultant P-value of less than 0.0001, which denotes that the model was statistically noteworthy at the 95% confidence level. Additionally, the model terms that exhibited significance were A, B, AB and A^2, as they recorded P-values of less than 0.05. On the other hand, the terms that were deemed insignificant were C, AC, BC, B^2 and C^2. Also, the model term that exhibited more impact on the removal efficiency was B with an F-value of 81.46, and the impact of the model terms on the removal efficiency followed the order: A>B>AB>A^2.

Table 5. Analysis of variance for removal efficiency (K1)

Source	Sum of Squares	df	Mean square	F value	P-value	Comment
Model	244.76	9	27.20	21.31	< 0.0001	Significant
A	103.95	1	103.95	81.46	< 0.0001	Significant
B	49.99	1	49.99	39.17	< 0.0001	Significant
C	0.28	1	0.28	0.22	0.6502	
AB	41.96	1	41.96	32.88	0.0002	Significant
AC	1.22	1	1.22	0.96	0.3514	
BC	0.15	1	0.15	0.12	0.7375	
A^2	12.24	1	12.24	9.59	0.0113	Significant
B^2	2.82	1	2.82	2.21	0.1682	
C^2	0.32	1	0.32	0.25	0.6250	
Residual	12.76	10	1.28			

The analysis of variance of adsorption capacity (K_2) is captured in Table 6. The model for adsorption capacity exhibited F-value of 24.11 with P-value of <0.0001, implying a statistically significant model at 95% confidence level. The model determined that the impactful factors included A, B, C, AC, BC, and B^2, but AB, A^2, and C^2 were insignificant. The adsorption capacity was most impacted by B with an F-value of 104.10 amongst the model terms. Furthermore, the effect of model terms on response was in the order of B>C> B^2>A>BC>AC.

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Table 6. Analysis of variance of adsorption capacity (K2)

Source	Sum of squares	Df	Mean square	F value	P-value	Comment
Model	12.00	9	1.33	24.11	< 0.0001	Significant
A	0.38	1	0.38	6.88	0.0255	Significant
B	5.76	1	5.76	104.10	< 0.0001	Significant
C	4.17	1	4.17	75.36	< 0.0001	Significant
AB	0.25	1	0.25	4.49	0.0601	
AC	0.31	1	0.31	5.60	0.0395	Significant
BC	0.33	1	0.33	5.95	0.0349	Significant
A^2	0.025	1	0.025	0.45	0.5169	
B^2	0.53	1	0.53	9.66	0.0111	Significant
C^2	0.13	1	0.13	2.33	0.1576	
Residual	0.55	10	0.055			

Similarly, the model equations for the removal efficiency (K_1) and adsorption capacity (K_2) are portrayed in equations (3) and (4) after removal of the insignificant model terms.

$$K1 = 50.03853 + 0.70757A + 0.83576B - 0.0018321AB - 0.000843818A^2 \quad (3)$$

$$K2 = -6.24010 + 0.031558A + 0.018209B - 0.10083C - 0.00196874AC + 0.00405783BC - 0.000705280B^2 \quad (4)$$

In a conducted investigation by (Ibrahim, 2010 26), it was observed that the model terms of the initial cadmium concentration and rice husk adsorbent dosage were statistically significant at a 95% confidence level. In a similar vein, (Mohammad, 2015) discovered that the model terms of the initial phenol concentration, carbonization temperature, and rice husk adsorbent dosage were statistically significant at a 95% confidence level.

3.3 Comparison of the Experimental (Actual) and Predicted Values

Table 7 presents an array of input variables that have been randomized, including the experimental removal efficiency (Ex. K_1), predicted removal efficiency (Pr. K_1) and their corresponding residuals (errors). The data denotes that Run 1 had an adsorption test conducted with a carbonization temperature (A) of 400 °C, an initial Pb concentration (B) of 60 mg/l, and a rice husk activated carbon dosage (C) of 1 g. The equivalent removal efficiency and adsorption capacity during the run were 99.956% and 5.9974 mg/g, respectively. Experimental adsorption capacity (Ex. K_2), predicted adsorption capacity (Pr. K_2) and their respective errors are also presented in the table. Moreover, the table has the mean absolute errors (MAEs) for removal efficiency and adsorption capacity.

Table 7. Actual-predicted values and errors

	Input variables			Response 1			Response 2		
Run	A (°C)	B (mg/l)	C (g)	Ex. K_1 (%)	Pr. K_1 (%)	Error	Ex. K_2 (mg/g)	Pr. K_2 (mg/g)	Error
1	400	60	1	99.956	98.930	1.026	5.9974	5.1039	0.8935
2	300	60	1	97.389	97.850	0.461	1.1687	1.6323	0.4636
3	350	35	3	99.369	99.590	0.221	1.1593	1.1972	0.0379
4	400	60	5	99.113	99.660	0.547	1.1989	1.4191	0.2202
5	350	35	3	99.369	99.590	0.221	1.1593	1.1972	0.0379
6	400	10	1	98.770	99.320	0.550	0.9877	1.1853	0.1976
7	350	35	3	99.369	99.590	0.221	1.1593	1.1972	0.0379
8	350	35	3	99.369	99.590	0.221	1.1593	1.1972	0.0379
9	300	35	3	95.941	94.260	1.681	1.1193	0.8958	0.2235
10	400	10	5	99.781	99.490	0.291	0.1996	0.1451	0.0545
11	400	35	3	99.684	100.700	1.016	1.1630	1.3231	0.1601
12	350	35	5	99.339	99.080	0.259	0.6954	0.7788	0.0834
13	350	35	1	99.818	99.410	0.408	3.4936	2.8292	0.6644
14	350	35	3	99.369	99.590	0.221	1.1593	1.1972	0.0379
15	300	60	5	97.389	97.010	0.379	1.1687	1.0018	0.1669
16	300	10	1	88.649	89.070	0.421	0.8865	0.7634	0.1231
17	300	10	5	86.492	87.680	1.188	0.173	0.2080	0.0350
18	350	10	3	98.207	96.340	1.867	0.3274	0.3606	0.0332
19	350	60	3	99.613	100.810	1.197	1.9923	1.6487	0.3436
20	350	35	3	99.369	99.590	0.221	1.1593	1.1972	0.0379
MAE						**0.6309**			**0.1945**

A comparison between actual and predicted values for both adsorption capacity and removal efficiency is demonstrated in Table 7. The experimental and predicted values exhibit a noteworthy level of agreement according to the data presented in the table. Calculated values of 0.6309 and 0.1945 were derived as MAEs for predicting removal efficiency and adsorption capacity, respectively. These values indicate that the model can be deemed as valid. It is worth mentioning that the precision of the created model is directly related to the size of the MAE. In other terms, the nearer the MAE comes to zero, the more precise the model produced is at predicting the responses.

3.4 Combined effects of the input factors on the outputs

Figures 1 and 2 demonstrate the combined impacts of the carbonization temperature and initial Pb concentration on the removal efficiency and adsorption capacity, respectively. Figure 1 demonstrates a notable influence of both variables on the removal efficiency. Due to the fact that both variables increase, the efficiency of removal increases accordingly. Moreover, the joint effects were more pronounced at higher values of the two input variables. As per Figure 2, it is clear that the initial Pb concentration has a greater impact on the adsorption capacity than the carbonization temperatures, although an increase in both variables yields to an ascending adsorption capacity. The findings of previous studies Mohammad (2015); Adamu and Adie (2020a); Adamu et al. (2021) and Sujatha and Sivarethinamohan (2021) agreed with these observations.

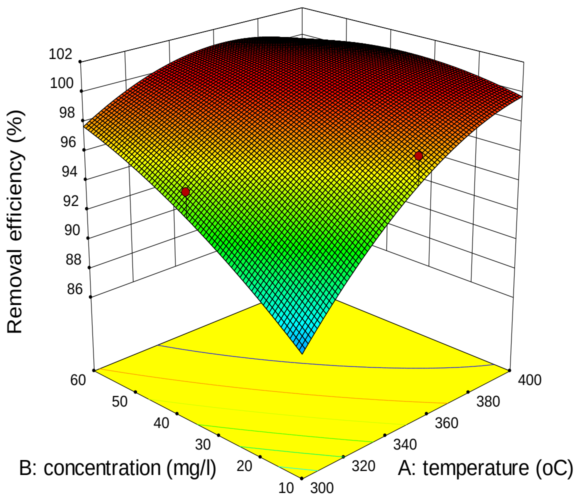

Fig. 1: combined effects of A and B on K1

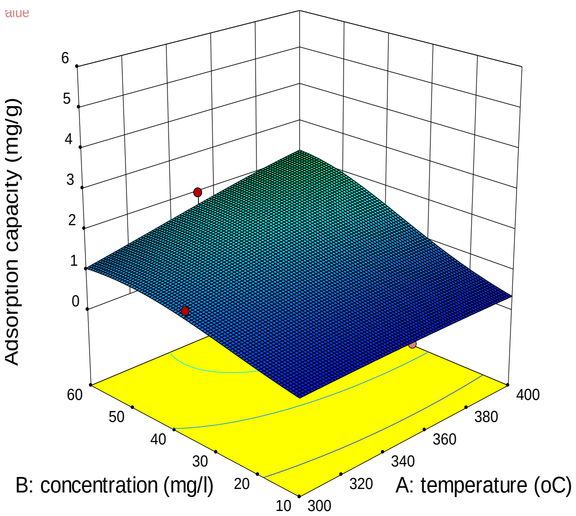

Fig. 2: combined effects of A and B on K2

The related impacts of the adsorbent dosage and carbonization temperature on the effectiveness of removal and adsorption ability are exhibited in Figures 3 and 4, respectively. The results presented in Figure 3 suggest that the effectiveness of Pb removal improved when both the dosage and carbonization temperature were increased, but the temperature had a more significant effect.

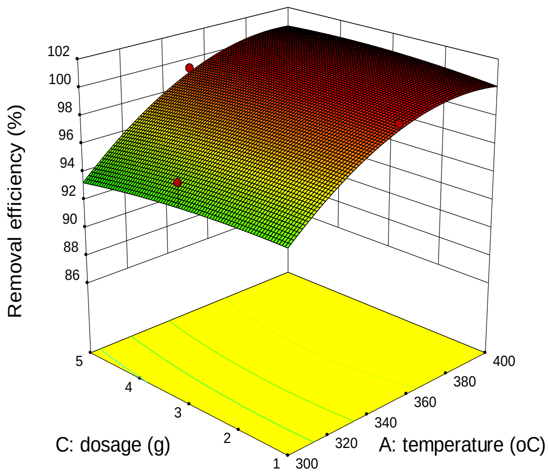

Fig. 3: combined effects of A and C on K1

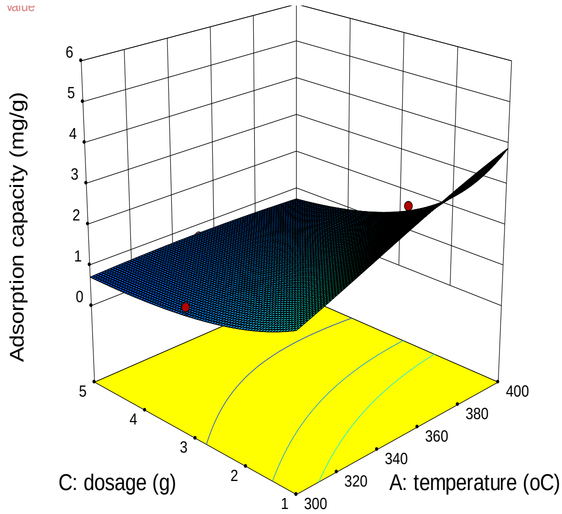

Fig. 4: combined effects of A and C on K2

Figure 4 depicts that the adsorbent dose and carbonization temperature had a collective impact on the adsorption capacity. It is noticeable that a boost in the dosage brought about a decrease in the adsorption capacity, as attested by Ataguba and Brink (2022). In contrast, a rise in the carbonization temperature produced a larger adsorption capacity as a consequence of the generation of additional pores. These findings are consistent with the conclusions reached in previous research studies by Mohammad (2015) and Adamu et al. (2021).

The concomitant influence of the dose and original Pb concentration on the removal efficacy and adsorption capability is defined in Figures 5 and 6, respectively. Moreover, Figure 5 demonstrates that a rise in both adsorbent dosage and initial Pb concentration caused an escalation in the removal efficiency. However, but the original Pb concentration had more influence than adsorbent dosage on the removal efficiency as depicted in the Figure.

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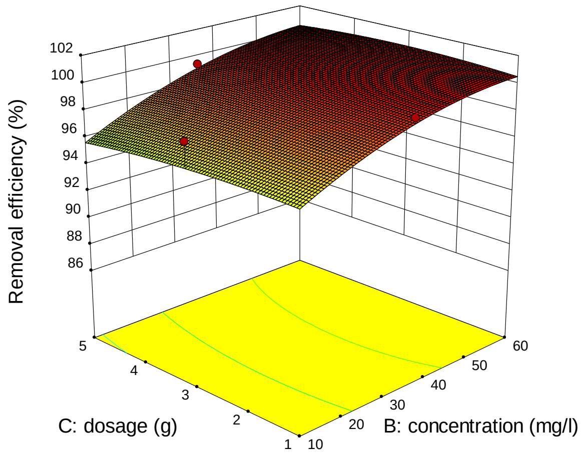

Fig. 5: combined effects of B and C on K1

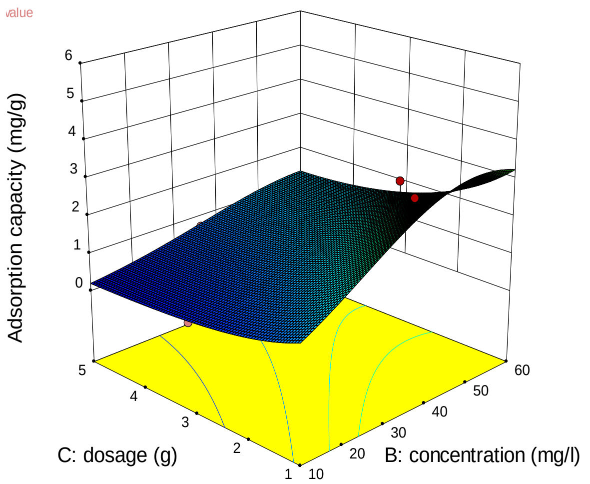

Fig. 6: combined effects of B and C on K2

Likewise, Figure 6 exhibits that both the adsorbent dose and initial Pb concentration had a conjoined influence on the adsorption capacity. Nevertheless, while the escalation in adsorbent dose resulted in a decrement of adsorption capacity, the escalation in the initial Pb concentration steered to an intensification of the adsorption capacity, which could be credited to the enhancement in the driving force that prevails the Pb transport resistance from the bulk solution to rice husk activated carbon. Furthermore, the conclusions witnessed in Figure 6 were also noted in the revelations of Adamu et al. (2021); Mohammad, 2015; Dauda et al. (2015) and Adamu et al. (2018).

3.5 Optimization and validation of the optimum adsorption conditions of Lead

The present investigation has proficiently optimized the settings for adsorption in regards to removal efficiency (K_1) and adsorption capability (K_2). The experimental findings propose that the prime conditions for achieving the optimum removal efficiency and adsorption capacity of 100.00% and 1.690 mg/g, in that order, are carbonization temperature (A) at 350.00 °C, initial Pb concentration (B) at 60 mg/l, and rice husk activated carbon dosage (C) at 3.00 g, as given in Table 8. Furthermore, Table 8 illustrates the validation of the optimized conditions and the errors encountered during optimization.

Additionally, Table 8 presents a comparison between the theoretical and experimental values of the optimal adsorption conditions achieved. The table indicates that the hypothetical and experimental adsorption capacity and removal efficiency are in agreement. Similarly, the recorded percentage errors for the adsorption capacity plus removal efficiency were respectively, 17.988% and 0.253%. It suggests that the models and optimal conditions produced were to some extent, dependable and accurate, in predicting the responses. Likewise, the research conducted by Mohammad et al. (2014b) confirmed the achievement of the optimal condition for the adsorption of phenol onto rice shell activated carbon at a carbonization temperature of 441.46 °C, given an initial phenol concentration of 40.61mg/l plus a dosage of 4 g. As a result, the adsorption capacity and removal efficiency were respectively, optimised as 0.9595 mg/g and 97.16%.

Furthermore, work was conducted by Olalekan et al. (2019) on optimizing the adsorption of lead onto rice husk supported zerovalent iron nanoparticles using RSM. The study achieved an optimized lead removal percentage of 98.74% by implementing the optimal adsorption conditions of 60.12 minutes for contact time, 4.01 for pH, and 0.5 g for dosage. Additionally, the absorption of chromium (VI) in the chitosan-resole aerogel was optimized by Flores-Gomez et al. (2023) using RSM and resulted in a 94.4% removal level at a primary concentration of 31 mg/L and a time of 3.02 hours. Nonetheless, the improved extraction efficiency was determined to be noticeably lower than that of the current study. Furthermore, Adamu et al. (2023) documented optimal removal effectiveness and adsorption capability for lead (Pb) adsorption, onto activated carbon prepared from sugarcane bagasse, achieving 100% and 2.50 mg/g, respectively. These results were obtained at the optimum adsorption settings of 300 °C for carbonization temperature, 25 mg/l for initial cadmium concentration, and 1.0 gram for dosages.

Similarly, Montalvo-Anvia et al. (2022) modified rice husk chemically and removed cadmium (Cd) from wastewater. The study achieved 92.65% removal of Cd from the wastewater. Moreover, Sivaprakasam and Venugopal (2019) reported the removal of lead from synthetic wastewater onto activated carbon produced from Diplocyclos Paltamus. The study achieved optimum conditions of: 30 mg/L, 100 mins, 50 °C and 6 for initial Pb concentration, contact time, process temperature and pH, correspondingly, with relative removal efficiency of 84.05%.

Table 8. Optimization and validation of the optimum operating conditions

				Theoretical		Experimental		% Error	
T (°C)	w (g)	C_o (mg/l)	Ce (mg/l)	qe (mg/g)	R.E. (%)	qe (mg/g)	R.E. (%)	Qe	R.E.
350	3.00	60	0.1519	1.690	100.00	1.994	99.747	17.988	0.253

4 Conclusion

The adsorption of lead from wastewater using activated carbon derived from rice husk was successfully optimized utilizing Response Surface Methodology (RSM). The prime conditions for lead removal from wastewater were established to be a carbonization temperature of 350 °C, a primary lead concentration of 60 mg/l, and a dosage of 3 g, resulting in an ultimate removal efficiency of 100% and an adsorption capacity of 1.690 mg/g. The validation of these optimal adsorption conditions yielded percentage errors of 0.253% and 17.988% for removal effectiveness and adsorption ability, respectively. Additionally, the average absolute errors (MAEs) for the removal efficacy and absorption capability were determined to be 0.6309 and 0.1945, respectively. Thus, the activated carbon derived from rice husk showcased relatively good adsorption properties for lead removal from wastewater, and the models developed exhibited a high level of accuracy in predicting the efficiency of removal and the capacity of adsorption.

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