Research Article

Modeling and Optimization for Production of Rice Husk Activated Carbon and Adsorption of Phenol

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Modeling of adsorption process establishes mathematical relationship between the interacting process variables and process optimization is important in determining the values of factors for which the response is at maximum. In this paper, response surface methodology was employed for the modeling and optimization of adsorption of phenol onto rice husk activated carbon. Among the action variables considered are activated carbon pretreatment temperature, adsorbent dosage, and initial concentration of phenol, while the response variables are removal efficiency and adsorption capacity. Regression analysis was used to analyze the models developed. The outcome of this research showed that 99.79% and 99.81% of the variations in removal efficiency and adsorption capacity, respectively, are attributed to the three process variables considered, that is, pretreatment temperature, adsorbent dosage, and initial phenol concentration. Therefore, the models can be used to predict the interaction of the process variables. Optimization tests showed that the optimum operating conditions for the adsorption process occurred at initial solute concentration of 40.61 mg/L, pretreatment temperature of 441.46°C, adsorbent dosage 4 g, adsorption capacity of 0.9595 mg/g, and removal efficiency of 97.16%. These optimum operating conditions were experimentally validated.

1. Introduction

The increase in industrial, agricultural, and domestic activities has led to the discharge of large amounts of wastewater containing toxic pollutants. The growing awareness of the adverse effects of the presence of these water pollutants has led to increased strict regulation of water pollution, hence making the treatment of wastewater generated from industrial activities a high priority [1]. Phenols are among the most common water pollutants that can cause hazards including health hazard which may lead to death. Amongst hydrocarbons present in refinery wastewater, phenol is one of the main dissolved components and it is also one of the difficult hydrocarbons to degrade biologically [2, 3]. Consequently, pollution control and management have evolved many technologies for the treatment of wastewater [4, 5]. These technologies and methodologies which differ in their performance and effectiveness include coagulation, filtration,

ion exchange, sedimentation, solvent extraction, adsorption, electrodialysis, chemical oxidation, disinfection, chemical precipitation, and membrane separation [6, 7]. Among the various available technologies for water pollution control, adsorption process is considered relatively better because of its convenience, ease in operation and simplicity of design [8–10]. The process can remove different types of pollutants due to the availability of wide range of adsorbents especially activated carbon which make it to have a wider applicability in water pollution control [7, 11–13]. Rice husk is an agricultural waste that is readily available as a by-product of rice processing but requires pretreatment to produce activated carbon for better performance as an adsorbent.

Response Surface Methodology (RSM) had been known as a collection of mathematical and statistical techniques for modeling and analyzing problems in which a response of interest is influenced by several variables. Basically, it had been used in multivariate experimental design, statistical

modeling and process optimization [14, 15]. Thus process optimization was observed to be important in determining the values of factors for which the response is at maximum. The application of statistical experimental design techniques in adsorption process was found to result in reduced process variability combined with the requirement of less resources (time, reagents and experimental work) [16, 17]. It had been reported that RSM has several classes of designs, among which are; central composite design, box-behnken design and three-level factorial design being the most widely used and the experimental data required are dependent on the chosen design [18, 19]. There is little or no information on the optimization of carbonization temperature for the production of rice husk activated carbon for phenol adsorption using response surface methodology. In addition, the usual approach to modeling and optimization has been on either the process variable for the production of activated carbon or that of the batch adsorption process. This paper, however, highlights a novel approach involving the simultaneous modeling and optimization of process variables for the production of rice husk activated carbon and batch adsorption of phenol using response surface methodology.

2. Methods

2.1. Production of Activated Carbon. The natural precursor used in the preparation of adsorbent was rice husk which was collected from National Cereal Research Institute, Badeggi. When collected from NCRI Rice Mill, the rice husk was washed with distilled water to remove dirt and surface impurity, then oven-dried at 100°C for 24 h in accordance with the procedure of Kudaybergenov et al. [20]. In the thermal pretreatment, rice husk was placed on a ceramic flat surface, charged into a furnace and heated to a temperature of 300°C at a heating rate of 20–25°C/min and residence time of 1 h. The charred residue was collected and cooled at room temperature. The procedure above was repeated for 400°C and 500°C. The thermal pretreated rice husks were labeled RH300, RH400 and RH500. In the chemical pretreatment, each of the carbonized rice husk (charred residue) was activated with 1 M H_3PO_4 for 3 h at impregnation ratio of 2:1 (volume mL of acid/mass g of rice husk) and later oven-dried overnight at 200°C to ensure proper drying [21, 22]. The material was then removed from the oven, cooled for 2 h and then washed with distilled water to bring the pH to 7.0 and again oven-dried overnight at 100°C [21].

2.2. Preliminary Batch Experiment. In the preliminary Batch Adsorption experiment, 2 g of the pretreated adsorbent was added to 100 mL of standard solution of phenol with initial concentration of 10, 30, and 50 mg/L in 250 mL conical flask. The mixture in the flask was placed on magnetic stirrer at 150 rpm [23, 24] for 90 min at ambient temperature. Using a 5 mL syringe, samples were withdrawn at predetermined time interval (90 min) and centrifuged at 3000 rpm for 20 min. The supernatant solution was collected from the centrifuge by decantation and filtered using a micro filter attached to a 5 mL syringe. The procedure above was repeated for 3 and

4 g of pretreated adsorbents. The analysis of phenol in each sample filtrate was carried out using UV spectrophotometer set at wave length of 270 nm.

2.3. Determination of Adsorption Capacities and Removal Efficiency. Adsorption capacity q_e at equilibrium was determined using the equation [25, 26]:

$$q_e = \frac{(C_o - C_t)V}{m} \quad (1)$$

Adsorption removal efficiency was determined using the equation [27–29]:

$$RE = \frac{(C_o - C_e)}{C_o} \times 100, \quad (2)$$

where q_e = adsorption capacity at equilibrium (mg/g), C_o = initial concentration of solute (mg/L), C_e = equilibrium concentration of solute (mg/L), V = volume of solution (L), m = mass of activated carbon used (g), and RE = removal efficiency (%).

2.4. Modeling and Optimization

2.4.1. Experimental Design. The Central Composite Design (CCD) was applied in this work to study the interaction of variables involved in the preparation of rice husk activated carbon as well as batch adsorption process of phenol using the activated carbon prepared. The CCD is widely used for modeling and optimization and it requires only a minimum number of experiments. Generally, the CCD consists of three kinds of runs; they are factorial runs (2^n), axial runs ($2n$) and center runs (n_c) [30, 31]. This design consist of a 2^n factorial (coded to the usual ± 1 notation) augmented by $2n$ axial points ($\pm\alpha, 0, 0$), ($0, \pm\alpha, 0$), ($0, 0, \pm\alpha$), and n_c center points ($0, 0, 0$) [1, 32], where α is the distance of the axial point from the center [33]. The center points are used to determine the experimental error and reproducibility of the data [34, 35] and the axial points are chosen such that they allow rotatability which ensures that the variance of the model prediction is constant at all points equidistant from the design center [36]. Therefore, according to Abbas [37] and Arulkumar et al., [38], the number of experimental runs required is given by the equation:

$$N = 2^n + 2n + n_c, \quad (3)$$

where N = total number of experimental runs, n = number of independent variables (factors), and n_c = number of center points.

Three variables were considered in this study, they are (i) pretreatment temperature “A”, a rice husk activated carbon production variable, (ii) initial phenol concentration “B”, a batch adsorption process variable, and (iii) adsorbent dosage “C”, a batch adsorption process variable.

For three variables, the number of center run was six, therefore number of experimental run required was computed as:

$$N = 2^3 + 2n + n_c = 2^3 + 2(3) + 6 = 8 + 6 + 6 = 20. \quad (4)$$

TABLE 1: Design matrix for the factors and respective response from experiment.

Run	Type	Coded factors			Uncoded factors			Responses	
		A (°C)	B (mg/L)	C (g)	A (°C)	B (mg/L)	C (g)	Y ₁ (%)	Y ₂ (mg/g)
1	Factorial	-1	1	-1	300	50	2	88.32	2.21
2	Factorial	1	1	1	500	50	4	94.70	1.18
3	Factorial	1	1	-1	500	50	2	95.72	2.39
4	Axial	1	0	0	500	30	3	93.86	0.94
5	Center	0	0	0	400	30	3	90.47	0.91
6	Axial	-1	0	0	300	30	3	82.57	0.83
7	Center	0	0	0	400	30	3	90.47	0.91
8	Factorial	-1	1	1	300	50	4	94.17	1.18
9	Axial	0	1	0	400	50	3	93.47	1.56
10	Center	0	0	0	400	30	3	90.47	0.91
11	Axial	0	-1	0	400	10	3	75.79	0.25
12	Axial	0	0	1	400	30	4	93.68	0.70
13	Factorial	-1	-1	-1	300	10	2	56.49	0.28
14	Factorial	1	-1	-1	500	10	2	78.25	0.39
15	Center	0	0	0	400	30	3	90.47	0.91
16	Factorial	-1	-1	1	300	10	4	71.93	0.18
17	Center	0	0	0	400	30	3	90.47	0.91
18	Center	0	0	0	400	30	3	90.47	0.91
19	Axial	0	0	-1	400	30	2	88.42	1.33
20	Factorial	1	-1	1	500	10	4	85.79	0.21

This implied that 20 experimental runs consisting of 8 factorial runs, 6 axial runs and 6 center runs were required. The two response variables considered in the study were: (i) removal efficiency (Y_1) and (ii) adsorption capacity (Y_2).

2.4.2. Regression Model. Each response was used to develop an empirical model that correlate the response to the three factors that is, rice husk activated carbon preparation variable (A) and batch adsorption process variables (B , C), using second-order polynomial equation [39–41]:

$$Y = b_0 + \sum_{i=1}^n b_i X_i + \sum_{i=1}^n b_{ii} X_i^2 + \sum_{i=1}^{n-1} \sum_{j=i+1}^n b_{ij} X_i X_j, \quad (5)$$

where Y is the predicted response, b_0 is the constant coefficient, b_i is the linear coefficient, b_{ij} is the interaction coefficient, b_{ii} is the quadratic coefficient, and X_i , X_j are the coded values for the factors.

2.4.3. Statistical and Graphical Analysis. Significance of the model equations and their terms were evaluated using statistical tools such as coefficient of determination (R -squared), Fisher value (F -value), probability (P value), and residual [42–44]. Graphs were employed to analyze the combined effect of factors on responses using 3D plots and to also analyze the predicted versus actual value plots of the response variables.

2.4.4. Optimization. Optimization technique was employed to determine the optimum operating conditions for the

process variables under consideration. To achieve this, goals were set with constraints. For each of the factors, goal was set “in range” with constraints 300–500, 10–50, and 2–4 of lower-upper level for factors A , B , and C , respectively. For the response surface, the goal for Y_2 was also set “in range” with constraint 0.18–2.393 as lower-upper levels, while the goal for Y_1 was set “maximize” at 100. Therefore removal efficiency becomes the objective function or performance index.

2.4.5. Model Validation. Model validation was carried out by conducting batch experiment under optimum operating conditions. In order to evaluate the validity of the model, experimental values obtained were compared with the model predicted values.

2.4.6. Software Application. Design Expert Software (version 8) was used for the design of the experiment, regression, statistical analysis, optimization, and graphical analysis.

3. Results and Discussion

3.1. Responses Obtained from the Experiment. Table 1 shows the design matrix consisting of types of run, coded and actual factors as randomized by the software, and respective response obtained from the experiment. From the results, it could be observed that the highest removal efficiency (Y_1) of 95.72% was obtained and this was followed by the removal efficiency of 94.17%. In terms of adsorption capacity (Y_2), the highest value of 2.39 mg/g was obtained and this was followed by adsorption capacity of 2.21 mg/g. In comparison, recent studies by Kalderis et al., [13], Kermani et al., [45], Mahvi et

TABLE 2: Regression statistics for removal efficiency (model for response Y_1).

Source	Standard deviation	R^2	Adjusted R^2	Predicted R^2	Comment
Linear	5.02	0.7729	0.7303	0.5487	
2FI	4.29	0.8653	0.8031	0.1189	
Quadratic	0.61	0.9979	0.9960	0.9826	Suggested
Cubic	0.056	1.0000	1.0000	0.9871	Aliased

TABLE 3: Regression statistics for adsorption capacity (model for response Y_2).

Source	Standard Deviation	R^2	Adjusted R^2	Predicted R^2	Comment
Linear	0.19	0.9173	0.9018	0.8114	
2FI	0.073	0.9897	0.9850	0.9442	
Quadratic	0.036	0.9981	0.9963	0.9819	Suggested
Cubic	3.00E - 03	1.0000	1.0000	0.9902	Aliased

al., [46], and Daffalla et al., [47] on adsorption of phenol onto rice husk activated carbon shows that adsorption capacities of 27.58 mg/g, 0.886 mg/g, 0.95–1 mg/g, and 0.98–46.19 mg/g were obtained, respectively. The differences in adsorption capacities could be as a result of the influence of the processes employed in the production of the activated carbon which was reported to have significant influence on its performance in adsorption process [48].

3.2. Development of Model Equations. Correlation between the response surface and factors were developed using CCD of the Design Expert software. According to sequential model sum of squares, the models were selected based on the highest order polynomials where the additional terms were significant and the models were not aliased [49, 50]. Correlation coefficient and standard deviation were used to evaluate the fitness of the models developed. The closer the R^2 value is to unity and the smaller the standard deviation, the better the model in predicting the response [51].

Table 2 shows that the quadratic model has relatively small standard deviation of 0.61 and relatively high R^2 value of 0.9979 with predicted R^2 (0.9960) in reasonable agreement with adjusted R^2 (0.9826). It was also observed on the table that the quadratic model for response Y_1 was not aliased. This implies that the quadratic model can be employed to describe the relationship between response Y_1 and the interacting variables. Table 3 also shows that the quadratic model has relatively small standard deviation of 0.036 and relatively high R^2 value of 0.9981 with predicted R^2 (0.9819) in reasonable agreement with adjusted R^2 (0.9963). It was also observed on the same table that the quadratic model for response Y_2 was not aliased. This implies that the quadratic model can be employed to describe the relationship between response Y_2 and the interacting variables.

The R^2 values of 0.9979 and 0.9981 implied that 99.79% and 99.81% of the variation in removal efficiency and

adsorption capacity respectively can be attributed to the three factors (A -pretreatment temperature; B -initial phenol concentration; C -adsorbent dosage) considered. Therefore, the quadratic models were selected as suggested by the software and the response surface model equations in their actual values are

$$\begin{aligned}
 Y_1 = & -0.000217641A^2 - 0.014404B^2 + 0.65959C^2 \\
 & - 0.00173025AB - 0.018465AC - 0.1137BC \\
 & + 0.33625A + 2.38714B + 10.1384C - 51.11583, \\
 Y_2 = & -0.00000184545A^2 + 0.0000113636B^2 \\
 & + 0.11355C^2 + 0.0000030625AB \\
 & - 0.00031625AC - 0.012256BC + 0.00278124A \\
 & + 0.070862B - 0.50129C - 0.12217.
 \end{aligned} \tag{6}$$

3.3. Statistical Analysis. The model equations selected were further evaluated using ANOVA component of the software. Table 4 shows that response surface quadratic model for removal efficiency has F -value of 529.68 indicating that the model is significant. For the model terms, P value less than 0.05 implies that model term is significant [52–55] and largest F -value signifies the model term having the most significant effect on the response [50, 56]. In this case, the significant model terms are A , B , C , AB , AC , BC , A^2 , and B^2 while C^2 is the insignificant model term. The model term having the most significant effect on the response is B with F -value of 2589.51 and the effect is in the order $B > A > C > AB > B^2 > BC > AC > A^2$. Table 5 shows that response surface quadratic model for adsorption capacity has F -value of 570.02 indicating that the model is significant. In this case, the significant model terms are A , B , C , AC , BC , and C^2 while AB , A^2 , and B^2 are insignificant model terms. The model term having the most significant effect on the response is B with F -value of 3947.85 and the effect is in the order $B > C > BC > C^2 > A > AC$.

Therefore, removing the insignificant model terms, the quadratic models for the responses become:

$$\begin{aligned}
 Y_1 = & -0.000217641A^2 - 0.014404B^2 - 0.00173025AB \\
 & - 0.018465AC - 0.1137BC + 0.33625A \\
 & + 2.38714B + 10.1384C - 51.11583, \\
 Y_2 = & 0.11355C^2 - 0.00031625AC - 0.012256BC \\
 & + 0.00278124A + 0.070862B - 0.50129C \\
 & - 0.12217.
 \end{aligned} \tag{7}$$

The residual of the response surface models presented in Tables 5 and 6 shows that the highest-lowest error (residual) for response Y_1 is 1.02–0.03% and that of Y_2 is 0.07–0.00027 mg/g. This also signifies the quality of the models in terms of predicting the responses.

TABLE 4: ANOVA table for removal efficiency (model for response Y_1).

Source	Sum of squares	df	Mean square	<i>F</i> -value	<i>P</i> value	Comment
Model	1773.14	9	197.02	529.63	<0.0001	Significant
<i>A</i>	300.64	1	300.64	808.29	<0.0001	Significant
<i>B</i>	963.17	1	963.17	2589.51	<0.0001	Significant
<i>C</i>	109.47	1	109.47	294.33	<0.0001	Significant
<i>AB</i>	95.8	1	95.8	257.56	<0.0001	Significant
<i>AC</i>	27.28	1	27.28	73.33	<0.0001	Significant
<i>BC</i>	41.13	1	41.13	110.59	<0.0001	Significant
A^2	13.07	1	13.07	35.02	0.0001	Significant
B^2	91.28	1	91.28	245.42	<0.0001	Significant
C^2	1.2	1	1.2	3.22	0.1031	
Residual	3.72	10	0.37			

TABLE 5: ANOVA table for adsorption capacity (model for response Y_2).

Source	Sum of squares $\times 10^{-2}$	df	Mean square $\times 10^{-2}$	<i>F</i> -value	<i>P</i> value	Comment
Model	674	9	75	570.02	<0.0001	Significant
<i>A</i>	2	1	2	15.28	0.0029	Significant
<i>B</i>	518	1	518	3947.56	<0.0001	Significant
<i>C</i>	99	1	99	751.81	<0.0001	Significant
<i>AB</i>	0.03	1	0.03	0.23	0.6429	
<i>AC</i>	0.8	1	0.8	6.09	0.0332	Significant
<i>BC</i>	48	1	48	366.07	<0.0001	Significant
A^2	0.094	1	0.094	0.71	0.4181	
B^2	0.0057	1	0.0057	0.043	0.8394	
C^2	3.5	1	3.5	27	0.0004	Significant
Residual	1.3	10	0.13			

TABLE 6: Actual-predicted values and residual.

Run	Response Y_1 (%)			Response Y_2 (mg/g)		
	Actual	Predicted	Residual	Actual	Predicted	Residual
1	88.32	88.06	0.25	2.21	2.20	0.0082
2	94.70	94.19	0.51	1.18	1.18	0.001
3	95.72	95.8	0.083	2.39	2.36	0.028
4	93.86	93.74	0.12	0.94	0.93	0.0093
5	90.47	90.44	0.03	0.91	0.90	0.0016
6	82.57	82.78	0.21	0.83	0.84	0.014
7	90.47	90.44	0.03	0.91	0.90	0.0016
8	94.17	93.84	0.34	1.18	1.14	0.033
9	93.47	94.49	1.02	1.56	1.63	0.07
10	90.47	90.44	0.03	0.91	0.90	0.0016
11	75.79	74.86	0.93	0.25	0.19	0.065
12	93.68	94.41	0.72	0.70	0.70	0.00027
13	56.49	56.98	0.49	0.28	0.28	0.00021
14	78.25	78.56	0.31	0.39	0.42	0.31
15	90.47	90.44	0.03	0.91	0.90	0.0016
16	71.93	71.82	0.11	0.18	0.21	0.027
17	90.47	90.44	0.03	0.91	0.90	0.0016
18	90.47	90.44	0.03	0.91	0.90	0.0016
19	88.42	87.79	0.63	1.33	1.33	0.0051
20	85.79	86.02	0.23	0.21	0.22	0.0069

FIGURE 1: Actual-predicted plot for response Y_1 .

The plots of actual versus predicted values of response Y_1 and Y_2 in Figures 1 and 2, respectively, show very minimal divergence of points from the diagonal indicating that these response surface model equations can be used to adequately represent the interaction of the three factors.

3.4. Combined Effect of Factors on Response

3.4.1. Combined Effect of Temperature and Initial Concentration at Constant Adsorbent Dosage. Figure 3 shows the combined effect of temperature and initial concentration on removal efficiency. It was observed that the two factors have significant combined effect on removal efficiency and increase in any of the factors reasonably increases the removal efficiency. The combined effect was observed to be greater at higher values of the two factors. The combined effect of temperature and initial concentration on adsorption capacity is as shown in Figure 4. The figure shows that the combined effect is almost completely as a result of the singular effect of initial concentration with temperature having very small effect. It was also observed that adsorption capacity is significantly increased with increase in initial concentration whereas increase in temperature results in relatively very small increase in adsorption capacity.

3.4.2. Combined Effect of Temperature and Adsorbent Dosage at Constant Initial Concentration. Figure 5 shows that temperature and adsorbent dosage have relatively small combined effect on removal efficiency. It was observed that the effect of temperature is relatively higher than that of adsorbent dosage and increase in any of the two factors increases the removal efficiency. Figure 6 shows the combined effect of temperature and adsorbent dosage on adsorption capacity. It was observed that adsorbent dosage greatly controls the combined effect of the two factors with temperature having

FIGURE 2: Actual-predicted plot for response Y_2 . FIGURE 3: Combined effect of factors A-B on response Y_1 .

very little effect. It was also observed that increasing the adsorbent dosage decreases the adsorption capacity.

3.4.3. Combined Effect of Initial Concentration and Adsorbent Dosage at Constant Temperature. Figure 7 shows that initial concentration and adsorbent dosage have significant combined effect on removal efficiency with initial concentration

FIGURE 4: Combined effect of factors A-B on response Y_2 .

exhibiting the greatest effect though adsorbent dosage shows reasonable effect too. The combined effect was observed to be greater at higher values of the two factors. It was also observed that increasing any of the factors increases the removal efficiency. Figure 8 shows that the two factors have significant combined effect on adsorption capacity. It was observed that, at higher initial concentration, increase in adsorbent dosage greatly decreases the adsorption capacity than at lower initial concentrations. Increase in initial concentration was also observed to increase the adsorption capacity but with much effect at lower adsorbent dosage.

3.5. Optimization. Optimization of the two responses under the same condition is difficult because the interest regions of factors are different. When Y_1 increases, Y_2 decreases and vice versa. Therefore the function of desirability was applied and the operating condition with the highest desirability was considered as selected by the software. Hence, the optimum operating conditions for the production of rice husk activated carbon and batch adsorption of phenol using the rice husk activated carbon are as follows.

Factors

A-temperature of pretreatment = 441.46°C ,

B-initial phenol concentration = 40.61 mg/L,

C-activated carbon dosage = 4 g.

FIGURE 5: Combined effect of factors A-C on response Y_1 . FIGURE 6: Combined effect of factors A-C on response Y_2 .

TABLE 7: Model validation.

Tp (°C)	m (g)	C_o (mg/L)	Experimental		Theoretical		Percentage error	
			q_e (mg/g)	RE (%)	q_e (mg/g)	RE (%)	q_e	RE
441.46	4	40.61	0.969	95.464	0.960	97.160	1.000	1.777

FIGURE 7: Combined effect of factors B-C on response Y_1 . FIGURE 8: Combined effect of factors B-C on response Y_2 .

Response

Y_1 -removal efficiency = 97.1608%,

Y_2 -adsorption capacity = 0.9595 mg/g.

3.6. Model Validation. Table 7 compares the results of experimental values with predicted values under optimum operating condition. It can be seen from the table that the percentage error of experimental against predicted value for adsorption capacity and removal efficiency are 1% and 1.777%, respectively. Therefore, this shows that the models and optimum operating condition developed for the factors are valid and applicable in predicting the response variables.

4. Conclusions

The quadratic models developed have R^2 values of 0.9979 and 0.9981 for removal efficiency and adsorption capacity, respectively. Therefore, 99.79% and 99.81% of the variations in removal efficiency and adsorption capacity, respectively, are attributed to the three process variables considered and the models can be used to predict the interaction of the process variables. Modeling revealed that, aside singular

effect, interaction of factors also significantly affects the adsorption capacity and removal efficiency. The single effect of the three process variables on adsorption capacity is in the order: initial solute concentration > adsorbent dosage > pretreatment temperature, while that of removal efficiency is in the order: initial solute concentration > pretreatment temperature > adsorbent dosage. Optimization revealed that the optimum operating condition for the adsorption process is initial solute concentration 40.61 mg/L; pretreatment temperature 441.46°C; adsorbent dosage 4 g; adsorption capacity 0.9595 mg/g; removal efficiency 97.16%.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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