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Investigation of Nigerian Coconut Shell and Banana Peels for the Removal of Carbon Monoxide (CO) in Indoor Environment

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Abstract In this study, copper chloride modified activated carbon was synthesised by thermal monolayer dispersion (deposition) process. Characterization of the adsorbents were carried out using Fourier Transform Infrared Spectroscopy (FTIR), proximate analysis and ultimate analysis. Furthermore, Response Surface Methodology (RSM) and Artificial Neural Network (ANN) were combined to determine the optimum conditions at which the synthesised adsorbent can remove carbon monoxide from the ambient environment. It cost implication was also determined. This was with a view to examine the Carbon Monoxide removal potential of the synthesised adsorbent. The characterization results showed that the prepared activated carbon are suitable precursor for the impregnation of copper (I) chloride. The RSM showed the optimum condition to be 20g CuCl/CSAC for 10mins with predicted CO adsorption of 77.01% with R^2 value of 0.9843 and 15g of CuCl/BPAC for 10mins with predicted CO adsorption of 69.71% with R^2 value of 0.9759. The ANN results were 25g CuCl/CSAC for 10mins with predicted CO adsorption of 77.15% with R^2 value of 1 and 20g of CuCl/BPAC for 10mins with predicted CO adsorption of 69.17% with R^2 value of 1. The ANN model indicates a better accuracy over RSM.

Keywords: *adsorption, carbon monoxide, RSM and ANN*

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1. Introduction

Exposure to air pollution leads to detrimental effects on human health, including increased risk of respiratory disease, cardiovascular disease, cancer, and death [1]. Despite the increased information about the related hazards of air pollution, it is always considered just an outdoor problem, in the general conviction that the boundaries of the indoor room and in particular, one's house, provide protection. Ambient air pollutant concentrations and sources differ greatly across the globe among which are unfinished solid fuel combustion for domestic cooking and heating in rural households in developing nations which has a serious effect on safety and the biggest effect regarding humanity [2]. Also, cleaning chemicals, manufactured goods, furnishings, building equipment, insufficient air circulation as well as faulty air conditioning system in advanced Western countries can degenerate the quality of indoor air, therefore leading to sick building syndrome, elevated incidence of sensitivities, and air route diseases [3,4].

Carbon monoxide (CO) is one of the indoor air pollutants that require removal attention as proposed in this study. Carbon monoxide is a tasteless, odourless, colourless and non-irritating pollutants in gaseous form [5] that can be released from natural or anthropogenic sources into the ambient environment. Indoor concentrations are influenced by and comparatively parallel in the direction of outdoor carbon monoxide concentrations [6] when the ratios of indoor to outdoor concentrations are about one (unity) with no CO emitting sources in the ambient environment [7]. In ambient air at home, exposure to elevated levels of CO is uncommon and restricted to specific circumstances such as being near to CO emissions sources [8].

Based on the exposed person's health and physiological status, the concentration of pollutants and exposure time, CO exposure can result in multiple health challenges influencing the cardiovascular system, central nervous systems, and blood [7,9]. Some of the significant CO exposure effects are the formation of carboxyhemoglobin (COHb) with haemoglobin molecules in the blood, decreasing oxygen release and transportation; thereby resulting in death [10]. One of the methods employed for the removal of carbon monoxide in indoor environment is adsorption technology.

Adsorption technology especially the use of activated carbons is considered to be sustainable, environmentally

friendly, simple, economical and efficient which makes it a superior and the most commonly used technique in adsorption compared to other methods [11]. They also possess a rapid adsorption capabilities and large internal surface area with high porosity [12,13]. The choice of adsorbents is the key to determine separation efficiency for adsorption-based CO separation [14]. Porous materials including activated carbon [15,16] zeolites [17,18], and metal-organic frameworks [19,20] have been found to be capable of adsorbing carbon monoxide. Nonetheless, these materials cannot separate CO selectively from mixture of gases because of the reduced adsorption ability for CO. For Olefin/paraffin separation [21,22] and CO separation [23,24,25,26,27], adsorbents with copper (I) π-complexation have been given considerable attention industrially for the separation of CO from mixture of gases but its application in the environmental control of CO has not been explored which this research aim to achieve. The advantage of these adsorbents is that the π-complexation bonds formed on the adsorbents between CO and Cu (I) ions are stronger than those formed by van der Waals forces alone to give higher adsorption ability for carbon monoxide [28]. Furthermore, desorption is easy by employing simple engineering techniques like increasing the temperature or lowering the pressure [29].

With the growing rate of CO emissions coupled with its detrimental effects, it becomes a requirement to remove CO from the indoor environment. This research involves the preparation of activated carbon from low-cost materials (coconut shell, and banana peels) modified with copper (I) ion. Characterization of the samples was carried out using Fourier Transform Infrared Spectroscopy (FTIR), proximate analysis and ultimate analysis. Then adsorption of CO in the indoor environment was monitored using an analyser. Also, Optimization was done using Response Surface Methodology (RSM) and Artificial Neural Networks (ANN). The cost implication of the prepared adsorbent was also determined.

2. Materials and Methods

2.1. Collection of Raw Material

Carbonaceous precursor used for activated carbon preparation were coconut shells and banana peel collected from the premises of Odo Ogbe Market, Ile-Ife Osun State. Before use, it was gently washed with tap water followed by distilled water to remove the attached dirt and impurities on the surface of the precursor and then sundried.

2.2. Preparation of Activated Carbon

Preparation of the activated carbon was carried out using the method reported by Guo *et al* [30] for the coconut shell and Viena *et al*. [31] for the banana peel. The coconut shells were dried at 110°C in a hot air oven for 48 hours and the banana peels were dried for 24 hours in the same oven at 105°C. To reach a particle size of 2 mm, the dried samples were ground, crushed, and sieved with a mechanical sieve. The sieved coconut shell was carbonized in a muffle furnace at 600°C for 2 hours while that of banana peels was carbonized under the same condition at 400°C for 1 hour. The carbonized sample was then activated thermally with wet steam for 30mins to produce the activated carbon. The method reported by Gao *et al* [32] was used for impregnating CuCl into the activated carbon earlier prepared via thermal monolayer dispersion (deposition) process. The activated carbon was mixed and grinded thoroughly with copper (II) chloride. The mixture was placed in a muffle furnace for activation at 543K for 8 hours to obtain the copper (I) based adsorbents.

2.3. Characterization of Activated Carbon

2.3.1. Proximate Analysis and Ultimate Analysis

The proximate analysis was conducted according to the American Society for Testing and Material ASTM D121 [33] and the result are expressed in term of ash contents (residues of inorganic matter that remains after pyrolysis), moisture contents, volatile matter (comprising of vapours and gases evolved during combustion), and fixed carbon content (containing the non-volatile fraction). Proximate analysis was carried out in three replicates. Also, elemental analysis was carried out to determine the percentage of C (Carbon), H (Hydrogen), O_2 (Oxygen), N (Nitrogen) and S (Sulphur) present in Coconut Shell (CS), Banana Peels (BP), Coconut Shell Activated Carbon (CSAC) and Banana Peel Activated Carbon (BPAC).

2.3.2. Fourier Transform Infrared Spectroscopy

About 1mg of activated carbon samples were ground and milled with 100mg potassium bromide to give fine powder which was compressed into thin pellet and scanned using Shimadzu 8400 spectrophotometer. The reading of the spectral were taken in the range 4000 to 400cm^{-1} to determine the functional groups present in the activated carbon which are important for the adsorption process.

2.4. Experimental Design and Statistical Analysis

2.4.1. Response Surface Methodology

RSM of Design expert software version 11 (Stat-Ease Inc., Minneapolis, USA) was used in this study. Historical data experimental design was employed in modelling and optimizing percentage quantity of carbon monoxide adsorbed. The dependent variable selected for this study was quantity of carbon monoxide adsorbed expressed in percentage and the independent variable chosen was quantity of adsorbent used (varied from 5g to 25g) and the residence time (varied from 2mins to 10mins). Regression analysis of the experimental data set to fit the response equation in terms of the factors were carried out and the quality of the fit of the model was expressed by the correlation coefficient (R^2) and Analysis of Variance (ANOVA). A statistical optimization of the model was carried out using RSM.

2.4.2. Artificial Neural Networks

In ANN modelling, MATLAB software was used for training and validation of neural network models. Levenberg-Marquardt back propagation algorithm (LMP) were used for the ANN design. The architecture of ANN

used was 25-10-25, with 25 corresponding to input values, 10 corresponding to hidden layer neurons and 25 to the output layers. MATLAB 2019 was used for testing, training and validation of the network model for carbon monoxide adsorption. The neural network after successful training was used to predict carbon monoxide adsorption.

2.5. Adsorption Measurement

In this study, adsorption test was carried out in an environmental chamber (box-like) assumed as the indoor environment. The adsorbate, CO was sourced from a portable Tiger generator. Two experimental treatments were applied which are copper chloride-modified coconut shell activated carbon and copper chloride-modified banana peel activated carbon. The adsorption study was carried out in three replicates with the quantity of the adsorbents ranging from 5g to 25g and the residence time the adsorbent spent with the adsorbate in the environmental chamber varied between 2mins and 10mins.

The experiment started with the introduction of carbon monoxide from the generator into the environmental chamber for 6mins after which the concentration of carbon monoxide inside the chamber was determined and recorded after 3mins as the initial carbon monoxide concentration. After the initial CO concentration as been determined, 5g of the adsorbents was introduced into the environmental chamber and sealed with duct tape to prevent the leakage of carbon monoxide from the box. After 2mins of adsorbate contact with the adsorbent, the analyser was attached to the chamber for 3mins to check for reduction in concentration of carbon monoxide after which the analyser was removed and the chamber was sealed again to stay for 4mins. The analyser was attached again for 3mins to determine the carbon monoxide concentration and removed. The chamber was sealed to stay for the next 6mins and carbon monoxide concentration was determined using the analyser like earlier. The process continues for 8mins and 10mins. After the 10mins, the adsorbents were removed from the environmental chamber and the whole procedure repeated over again until three replicate readings were obtained for 5g followed by 10g, 15g, 20g, and 25g at a residence time of 2mins, 4mins, 6mins, 8mins, and 10mins. Optimization was carried out using Response Surface Methodology and Artificial Neural Networks. Data obtained before and after carbon monoxide adsorption were used to determine the percentage adsorption which was calculated based on Equation 1.

$$Percentage\ Adsorption\ (\%) = \left(\frac{C_o - C_t}{C_o}\right) \times 100 \qquad (1)$$

Where: C_o = carbon monoxide concentration before adsorption (ppm)
C_t = carbon monoxide concentration after adsorption (ppm)

3. Results and Discussion

3.1. Proximate and Ultimate Analysis

The proximate analysis result as presented in Table 1 shows the ash content for CS to be 0.6% and that for CSAC was 1.7%. Also, the ash content for BP was 4.7% and that for BPAC was 4.1%. Percentage ash contents obtained were within the ranges described by Jabit [34], that the ash content is usually in the range of 2 to 10%. Further, high content of ash decreases the mechanical strength of activated carbons and affect its adsorptive ability. Moisture content was found to be 4.2% for CS but 3.2% for CSAC signifying a reduction in moisture contents. Similarly, this was observed with BP for which the moisture content was 9.5% but reduces to 5.9% for BPAC. Aziza *et al*. [35] reported that, the moisture content is related to the porosity of activated carbon as high moisture content reduce expansion of pore size for the uptake of the adsorbate. The Volatile matter content was 78.02% for CS but 16.01% for CSAC. Similarly, for BP was 77.24% while that for BPAC was 13.28%. From these results, the activated carbon samples have a lower volatile matter compared with the non-activated samples. Volatile matter results from organic matter decomposition releasing volatiles and leading to micropore development [36]. Also, according to Olowoyo and orere [37], low volatile matter enhances high porosity and high carbon of adsorbent which this study agrees with. Carbon content which is the residual amount of carbon present was 17.12% for CS, 79.09% for CSAC, 8.45% for BP and 76.72% for BPAC. As reported by Malik *et al*. [36], most activated carbon has a carbon content within the ranges of 50 to 90% which was within the range obtained in this study.

The ultimate analysis result as presented in Table 1, shows that CS has a carbon percentage of 49.67%, hydrogen of 5.24%, nitrogen of 0.69%, sulphur of 0.12% and oxygen of 44.28% and that of BP has a carbon percentage of 40.64%, hydrogen of 5.56%, nitrogen of 1.28%, sulphur of 0.13% and oxygen of 52.39%. CSAC has a carbon percentage of 72.22%, hydrogen of 1.95%, nitrogen of 0.80%, sulphur of 1.38% and oxygen of 23.65% and that of BPAC has a carbon percentage of 62.79%, hydrogen of 3.51%, nitrogen of 1,5%, sulphur of 10.61% and oxygen of 21.59%. As reported by Kumar and Jena [38], high carbon content results from increased aromaticity during activation. Also, low percentage of hydrogen, nitrogen, sulphur, and oxygen results from the decomposition of coconut shell and banana peels during pyrolysis and activation. Volatile compounds containing mainly hydrogen, oxygen, sulphur, and nitrogen leave the carbonaceous product during heating to give carbon-rich activated carbon.

3.2. Analysis of Functional Groups by FTIR

The structural configuration was determined by FTIR to check the presence and change in functional group characteristics in the activated carbon and the modified activated carbon. The spectra for CSAC and CuCl/CSAC are presented in Figure 1. Also, the spectra for BPAC and CuCl /BPAC are presented in Figure 2.

For CSAC, bands at wavelength 3446.91cm^{-1} and 3053.42cm^{-1} was that of OH group of carboxylic acid. 2935.76cm^{-1} 2360.95cm^{-1} is for aliphatic C-H group. Peak at 1697.41cm^{-1} represent the C-O stretching of carbonyl group. Bands at wavelength 1338.64-1089.82cm^{-1} represent CO and OH groups from carboxylate and alcohol. For

CuCl/CSAC, bands at 3444.98cm^{-1}, 3346.61cm^{-1} and 3078.49cm^{-1} represent the OH group of carboxylic acid. Band at 2364.81cm^{-1} represent aliphatic C-H group. Bands at 1178.55cm^{-1} and 1145.75cm^{-1} is for C-O stretch. For BPAC, band at wavelength 3408.33-3271.38 cm^{-1} represent the OH stretching vibration. The band at wavelength 2962.76cm^{-1}, 2611.70cm^{-1}, and 2362.88cm^{-1} represent the aliphatic C-H groups. Bands at 1593.2cm^{-1} shows presence of C=C groups and the bands at 1047.38cm^{-1} show presence of C-O groups. Band at 835.31cm^{-1} is that of amine group. For CuCl/BPAC, 3444.98-3360.11cm^{-1} represent the presence of OH group. The absorption peak at 2928.04-2860.53cm^{-1}, 2362.88cm^{-1} is that of CH stretching vibration. There is a shift in bands, change in wave numbers, and absorbance difference between the CSAC and CuCl/CSAC samples and also between BPAC and CuCl/BPAC samples. This is an indication that chemical transformation took place during physical activation and chemical modification of the samples which resulted in disappearance and enhancement of some functional groups as well as shifting and lowering of wavelength numbers. Oxygen functional groups with various acidic groups such as carboxylic acid, lactones and phenol enhances the metal binding ability of the activated-carbon.

Table 1. Proximate and Ultimate Analysis Results for the Raw and Activated samples

Parameters	RCS	RBS	CSAC	BPAC
Proximate				
Moisture Content	4.23(±0.062)	9.56(±0.22)	3.20(±0.64)	5.90(±0.26)
Volatile Moisture	78.01(±0.075)	77.24(±0.28)	16.01(±0.52)	13.28(±0.30)
Ash Content	0.63(±0.046)	4.75(±0.17)	1.70(±0.30)	4.10(±0.26)
Fixed Carbon	17.12(±0.092)	8.45(±0.32)	79.09(±0.18)	76.72(±0.41)
Ultimate (%)				
Carbon	49.67(±1.85)	40.64(±0.31)	72.22(±0.31)	62.79(±0.19)
Hydrogen	5.24(±0.31)	5.56(±0.29)	1.95(±0.23)	3.51(±0.14)
Nitrogen	0.69(±0.06)	1.28(±0.03)	0.80(±0.1)	1.50(±0.17)
Sulphur	0.12(±0.03)	0.13(±0.03)	1.38(±0.03)	10.61(±0.17)
Oxygen	44.28(±1.60)	52.39(±0.11)	23.65(±0.22)	21.59(±0.31)

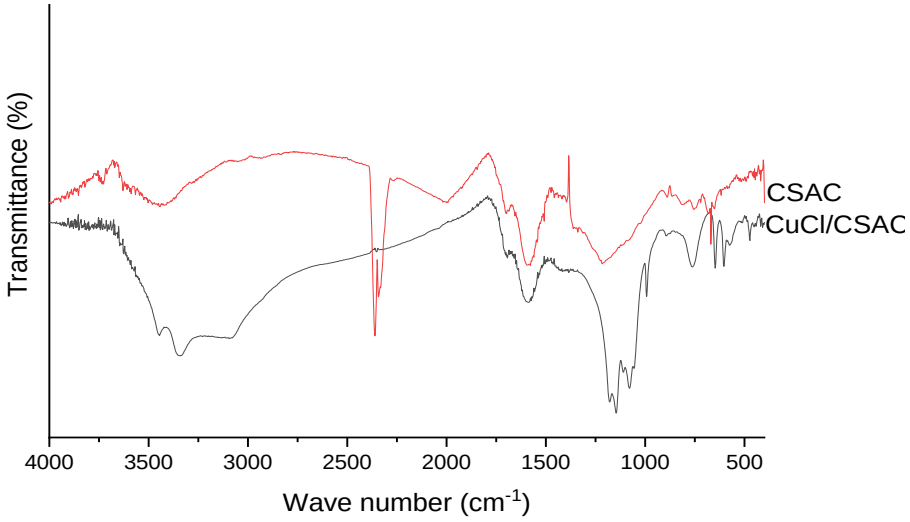

Figure 1. FTIR spectra for CSAC and CuCl/CSAC

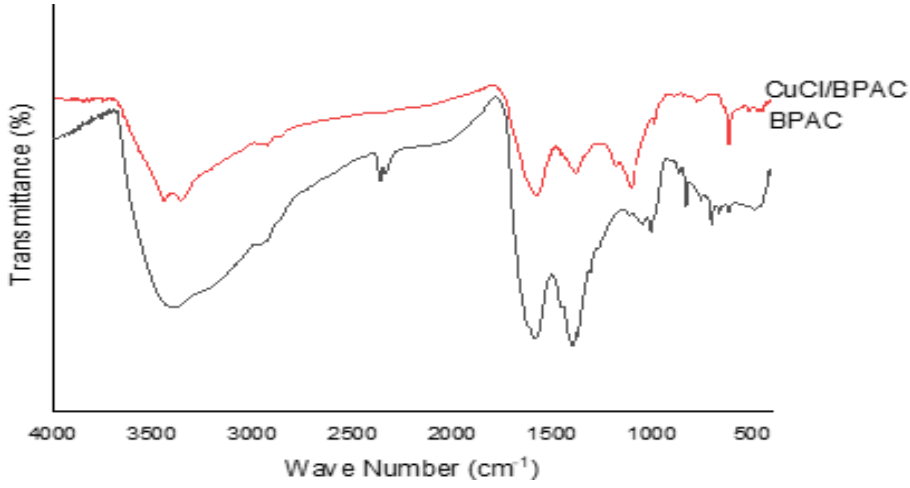

Figure 2. FTIR spectra for BPAC and CuCl/BPAC

3.3. Modelling and Optimization Using Design Expert

Design expert using historical data in Response Surface Methodology was used to determine the effect of quantity of adsorbent and time on carbon monoxide adsorption. The historical data RSM design and the response for this study using CuCl/CSAC and CuCl/BPAC are presented in Table 2. Polynomial regression analysis was performed on the response presented in Table 2 for CuCl/CSAC and CuCl/BPAC to determine the model term coefficients. The coefficient of the model terms is as shown on Table 4. The Predicted response for carbon monoxide adsorption is expressed by Equation 2 and 3 for CuCl/CSAC and CuCl/BPAC respectively. The equations were solved using the Design expert software package in order to obtain optimal values for each of the independent factors employed in the modelling and optimization of CO adsorption.

$$Y = 40.97 + 9.01A + 22.08B + 7.64AB + 0.4043A^2 - 5.76B^2 \quad (2)$$

$$Y = 39.05 - 6.01A + 22.67B + 3.66AB - 7.26A^2 - 3.08B^2 \quad (3)$$

Analysis of Variance was employed to further estimate the significance and accuracy of the model as presented in Table 3 for CuCl/CSAC and CuCl/BPAC respectively. The low p-value <0.0001 and the large model F-value 49.62 for CuCl/CSAC suggest a statistically significant regression model. Similarly, P-value <0.0001 and large model F-value 39.28 for CuCl/BPAC also suggest that the regression model is significant. P-value < 0.05 indicate the significance of the model terms at 95% confidence level. From the ANOVA, it can be observed that four (4) of the five (5) model terms (A, B, AB, B^2) are significant for CuCl/CSAC. For CuCl/BPAC three (3) of the five (5) model terms (A, B, A^2) are significant. The significant model terms have synergistic effect on the regression model while the insignificant terms have antagonistic effect. Therefore, the significant terms positively contribute to the model equation.

3.4. Modelling and Optimization Using Artificial Neural Networks

The experimental data and the ANN response for CuCl/CSAC and CuCl/BPAC are presented in Table 2. The correlation coefficient (R) obtained for ANN was 1 for both CuCl/CSAC and CuCl/BPAC. This value of R (1) shows a strong agreement between the experimental and predicted CO adsorbed by ANN. The R^2 value of 1 indicate a good fit of the model. The predicted optimal condition for carbon monoxide adsorption as presented in Table 2 were 25g CuCl/CSAC for 10mins with predicted CO adsorption of 77.15% and 20g of CuCl/BPAC for 10mins with predicted CO adsorption of 69.17%.

Table 2. Comparison of Actual and predicted CO adsorption using RSM and ANN

		RSM				ANN			
Quantity	Time	Actual CuCl/CSAC (%)	Predicted CuCl/CSAC (%)	Actual CuCl/BPAC (%)	Predicted CuCl/BPAC (%)	Actual CuCl/CSAC (%)	Predicted CuCl/CSAC (%)	Actual CuCl/BPAC (%)	Predicted CuCl/BPAC (%)
5	2	11.92	12.17	7.64	3.68	11.9235298	11.92353	7.641469	7.641469
10	2	13.61	12.55	3.25	10.30	13.6112233	13.61122	3.248897	3.248897
15	2	16.22	13.13	11.77	13.29	16.2168528	16.21685	11.77215	11.77215
20	2	6.14	13.91	12.28	12.65	6.14062046	6.14062	12.28282	12.28282
25	2	17.66	14.90	12.80	8.39	17.6620404	17.66204	12.79687	12.79687
5	4	18.97	23.70	22.23	15.50	18.9678172	18.96782	22.2288	22.2288
10	4	33.03	26.00	14.98	23.04	33.0327946	33.03279	14.9835	14.9835
15	4	34.82	28.49	29.11	26.94	34.8230176	34.82302	29.11259	29.11259
20	4	25.18	31.18	26.41	27.22	25.1766654	25.17667	26.40987	26.40987
25	4	35.22	34.08	25.17	23.87	35.2179118	35.21791	25.16987	25.16987
5	6	28.34	32.36	32.81	25.78	28.3402739	28.34027	32.81301	32.81301
10	6	41.71	36.57	22.48	34.23	41.7076925	41.70769	22.47902	22.47902
15	6	38.17	40.97	44.68	39.05	38.1742739	38.17427	44.67605	44.67605
20	6	36.98	45.58	42.05	40.24	36.9779852	36.97799	42.05052	42.05052
25	6	55.96	50.38	34.52	37.80	55.9634103	55.96341	34.51948	34.51948
5	8	35.17	38.14	35.79	34.51	35.1719031	35.1719	35.79223	35.79223
10	8	48.66	44.26	40.04	43.88	48.6555003	48.6555	40.03537	40.03537
15	8	53.32	50.57	52.49	49.61	53.3195021	53.3195	52.49493	52.49493
20	8	51.02	57.09	56.53	51.72	51.0181180	51.01812	56.53435	56.53435
25	8	68.19	63.81	44.44	50.19	68.1944208	68.19442	44.44309	44.44309
5	10	39.82	41.05	37.42	41.71	39.8164054	39.81641	37.42366	37.42366
10	10	54.38	49.07	47.76	51.98	54.3755857	54.37559	47.75908	47.75908
15	10	58.30	57.30	65.93	58.63	58.2987552	58.29876	65.92752	65.92752
20	10	57.38	65.72	69.17	61.65	57.3818084	57.38181	69.1685	69.1685
25	10	77.15	74.35	55.13	61.04	77.1514953	77.1515	55.12878	55.12878

Table 3. ANOVA for Response Surface Quadratic Model using CuCl/BPAC

	CuCl/BPAC			CuCl/CSAC		
Source	Sum of Squares	F-value	p-value	Sum of Squares	F-value	p-value
Model	7230.79	39.28	< 0.0001 significant	7621.55	49.62	< 0.0001 significant
A-Quantity	451.55	12.26	0.0024	1014.76	33.04	< 0.0001
B-Time	6423.57	174.46	< 0.0001	6095.86	198.45	< 0.0001
AB	83.62	2.27	0.1483	365.21	11.89	0.0027
A^2	230.43	6.26	0.0217	0.7152	0.0233	0.8803
B^2	41.63	1.13	0.3010	145.00	4.72	0.0427
Residual	699.57			583.64		
Lack of fit	19			19		
Coefficient of determination	R^2	Adjusted R^2	Predicted R^2	R^2	Adjusted R^2	Predicted R^2
Values	0.9118	0.8886	0.8402	0.9289	0.9102	0.8871
Pure error	0			0		
Cor Total	7930.36			8205.19		
Std. Dev.	6.07			5.54		
Mean	33.88			38.29		
C.V. %	17.91			14.47		

p-value <0.0001 suggest a statistically significant regression model.

Table 4. Coefficient of Models of Adsorption of carbon monoxide

Factor	Coefficient of Estimate for CuCl/CSAC	Coefficient of Estimate for CuCl/BPAC	DF	Standard Error for CuCl/CSAC	Standard Error for CuCl/BPAC
Intercept	40.97	39.05	1	2.18	2.38
A-Quantity	9.01	6.01	1	1.57	1.72
B-Time	22.08	22.67	1	1.57	1.72
AB	7.64	3.66	1	2.22	2.43
A^2	0.4043	-7.26	1	2.65	2.90
B^2	-5.76	-3.08	1	2.65	2.90

Adequate precision ratio which is a measure of signal-to-noise ratio and a ratio value greater than 4 is desirable. The adequate precision ratio of 22.9032 for CuCl/CSAC and 19.5003 for CuCl/BPAC indicates adequate signal. The regression model fitting was regulated by the coefficients of determination (R^2) which gave a high value of 0.9289 for CuCl/CSAC and 0.9118 for CuCl/BPAC from the ANOVA results. A reasonable agreement of the R^2 with the Adjusted R^2, is of great importance. The Adjusted R^2 obtained were 0.9102 for CuCl/CSAC and 0.8886 for CuCl/BPAC. The proximity of the R^2 and Adjusted R^2 value to 1.0 indicates that a high correlation exists between experimental and predicted values of carbon monoxide adsorbed.

Furthermore, the optimal conditions for the process were statistically predicted for as 21.48g of CuCl/CSAC for 8.14mins with a predicted CO adsorption of 59.78%. Similarly, for CuCl/BPAC, a quantity of 23.87g for 3.82mins with a predicted CO adsorption of 23.64%

3.5. Performance Evaluation of the Predictive Capability of RSM and ANN Models

The prediction and estimation abilities of both RSM and ANN were critically examined in order to determine the efficacy of the models and also to determine the model with best fit. Coefficients of determination (R^2) and the predicted quantity of CO adsorbed were employed to compare the RSM and ANN result. The R^2 value for RSM (0.9289) for CuCl/CSAC, 0.9118 for CuCl/BPAC are lower than the values of R^2 for ANN (1 for CuCl/CSAC and 1 for CuCl/BPAC). It is thus obvious that R^2 values for ANN is closer to 1 (unity) than the corresponding values for RSM. Also, the most desirable RSM predicted quantity of CO adsorption value was 59.78% for CuCl/CSAC but 23.64% for CuCl/BPAC. Similarly, that of ANN was 77.15% for CuCl/CSAC but 69.17% for CuCl/BPAC. Based on these indicators, ANN gives higher accuracy and efficiency than the RSM for CO adsorption using copper (I) ion modified activated carbon. The predicted optimal conditions were validated in the laboratory by carrying out three independent experiments in replicates under the conditions predicted and the average carbon monoxide adsorption was computed for each process as presented in Table 4 for CuCl/CSAC and CuCl/BPAC respectively.

It can be observed from Table 5 that the validation results for ANN was 76.81% CuCl/CSAC and 68.64% CuCl/BPAC while that of RSM was 44.28% for CuCl/CSAC and 19.99% for CuCl/BPAC. The validation result for ANN was closer compared to that of RSM. Both the ANN and RSM models have the ability to predict the experimental data. However, the predictive capability of ANN model was higher than that of RSM

Table 5. Model Predicted and Validation Results for ANN and RSM

Adsorbents	Quantity (grams)	Time (mins)	Initial CO concentration	Final CO concentration	Quantity adsorbed	Average
ANN						
	25		458	105	77.07	
CuCl/CSAC		10	470	102	78.30	76.81
			445	111	75.06	
	20		368	125	66.03	
CuCl/BPAC RSM		10	395	111	71.90	68.64
			375	120	68.00	
	21.48		401	245	38.90	
CuCl/CSAC		8.14	455	251	44.84	44.28
			395	201	49.11	
	23.87		468	385	17.74	
CuCl/BPAC		3.82	366	290	20.76	19.99
			340	267	21.47	

3.6. Cost Estimation of the Produced Activated Carbon

The cost of production of the activated carbon was considered since production cost of adsorbent has been the major challenge against its full adoption. Cost analysis involved in the production of the activated carbon was done using the Nigerian currency (₦).

1. Cost of raw materials (CRM) = ₦ 0.00 (the raw materials used are waste agricultural material)
2. Cost of washing raw materials (CWRM) = ₦ 1000 (distilled water was used)
3. Cost of drying, carbonization and activation (CDCA)= ₦ 4000
4. Cost of chemical for impregnation (CCI) = ₦ 8,500 (copper (II) chloride)
5. Cost of analysis (CA) = ₦ 30,000 (proximate, ultimate, FTIR analysis)

Net cost = CRM + CWRM + CDCA + CCI + CA = ₦ 43,500.

4. Conclusion and Recommendation

4.1. Conclusion

In this study, carbon monoxide removal in indoor environment using CuCl/activated carbon was investigated. Production and characterization of the adsorbents and their subsequent use for CO adsorption were carried out. The effects of quantity and time on CO adsorption were also evaluated using Response Surface Methodology (RSM) and Artificial Neural Networks (ANN). Cost implication of the prepared adsorbents were assessed.

The results of this research revealed that CuCl/CSAC and CuCl/BPAC are veritable adsorbents for the removal of carbon monoxide in the indoor environment. The proximate and ultimate analysis revealed that the activated carbon produced from coconut shell and banana peels have a high carbon content which is a desirable characteristic. A fixed carbon content of 79.09% for CSAC and 76.72% for BPAC were within the ranges of 50 to 90% reported in literature. Also, the presence of oxygen functional groups as shown by the FTIR results enhances the metal binding ability of the activated carbon. For the Optimization study, ANN model was found to be more accurate based on the coefficient of determination and the predicted CO adsorption than RSM. The study concluded that Nigerian coconut shell and banana peels are potential activated carbon precursors for the removal of carbon monoxide from indoor environment.

4.2. Recommendation

It is recommended that; further research can be carried out by combining the two raw materials used as support for copper (I) chloride to enhance the removal of carbon monoxide from indoor environment.

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