

Response Surface Optimisation of the Adsorption of Cu (II) from Aqueous Solution by Crab Shell Chitosan

*Babatunde E. O¹, Akolo S. A², Ighalo J. O³ & Kovo A. S⁴

^{1,3}Chemical Engineering Department, University of Ilorin, P. M. B. 1515, Ilorin, Kwara state, Nigeria.

²Prudent Energy and Services Limited, Bulk Petroleum and Gas Terminal Oghareki, Oghara, Delta state, Nigeria.

⁴Chemical Engineering Department, Federal University of Technology, P.M.B. 65, Minna, Niger state, Nigeria

* Corresponding author email: babatunde.eo@unilorin.edu.ng, +2348060265818

ABSTRACT

Adsorption of Cu (II) from aqueous solution by crab-shell derived chitosan was evaluated and optimised by response surface methodology alongside comparison with commercial chitosan. The commercial and locally developed chitosan was found effective in removal of copper (II) ion from aqueous solution and the results of the copper ion percentage removal was 99.57% for locally produced chitosan and 99.80% for commercial chitosan at pH of 6.0. Optimum metal uptake (99.57%) was observed at pH 4.75, 120 minutes equilibration time and dosage of 2 g/50ml. The monolayer adsorption capacity of the commercial and locally developed chitosan was 1.44 mg/g and 1.49 mg/g respectively. The isotherms modelling indicated that the Langmuir isotherm was the best fit. The kinetics for the adsorption of copper, onto chitosan was best described by a pseudo-second-order kinetic model. It has been shown that chitosan are excellent precursors for the removal of copper from aqueous solution and consequently for its use in remediating polluted industrial effluents.

Keywords: Adsorption, Chitosan, Crab shells, heavy metals, Optimisation.

1 INTRODUCTION

Environmental pollution by discharge of industrial waste into water streams is a major problem because of the toxic nature of industrial waste. Among various industrial wastes, heavy metals are of great concern because of their bioaccumulation and non-biodegradable nature (Bailey, Olin, Bricka, & Adrian, 1999). Methods of metal ion removal include filtration, chemical precipitation, adsorption, electrode position and membrane systems or even ion exchange process. Among these methods, adsorption is one of the most economically favourable and a technically easy method (Karthikeyan, Rajgopal, & Miranda, 2005). To remove trace levels of heavy metal ions, adsorption by natural occurring materials is one of the most effective and low cost methods (Bailey et al., 1999). Numerous materials have been studied for use as adsorbent for the removal of copper from aqueous solutions. They include fish scales (Das, Bhowal, & Datta, 2016; Eletta & Ighalo, 2019), cabbage leaves (Kamar, Nechifor, Nechifor, Al-Musawi, & Mohammed, 2017), *Terminalia catappa* L. fruit shell (Hevira, Munaf, & Zein, 2015), tea leaves (Ghosh, Das, &

Sinha, 2015), Pine bark (Cutillas-Barreiro et al., 2014) and many others.

Recently many statistical experimental design methods have been utilized in chemical process optimization (Gratuito, Panyathanmaporn, Chumnanklang, Sirinuntawittaya, & Dutta, 2008). Design of experiments is a very useful tool as it provides statistical models, which help in understanding the interactions among the parameters that have been optimized. Response surface methodology (RSM) is one of the experimental designing methods which can surmount the limitations of conventional methods collectively (Olmez, 2009). Response surface methodology is a combination of mathematical and statistical techniques used to determine the optimum operational conditions of the process or to determine a region that satisfies the operating specifications (Alam, Muyibi, & Toramae, 2007). The main advantage of response surface methodology is the reduced number of experimental trials needed to evaluate multiple parameters and their interactions (Karacan, Ozden, & Karacan, 2007). RSM has also been reportedly used in the optimisation of adsorption process (Garg, Kaur, Sud, & Garg, 2009; Ghosh et al., 2015; Kumar & Phanikumar, 2013; Madala, Mudumala, Vudagandla, &

Abburi, 2015; Mandal, Mondal, Mondal, Mukherjee, & Mondal, 2015; Olmez, 2009). In this study, bio sorption of Cu (II) from aqueous solution by crab-shell derived chitosan was evaluated and optimised by response surface methodology alongside comparison with commercial chitosan.

2 METHODOLOGY

2.1 COLLECTION OF SAMPLE

Crab shell was obtained from Lagos lagoon (Nigeria). The crab was washed with tap water to remove possible foreign materials present (dirt and sands). The commercial chitosan was from Sigma-Aldrich in Germany (purity >99%).

2.2 PREPARATION OF REAGENTS

The major chemicals used during experimental work include Sodium hydroxide (NaOH), sodium hypochlorite (NaClO), copper sulphate pentahydrate ($\text{CuSO}_4 \cdot \text{H}_2\text{O}$) and Hydrochloric acid (HCl) and they were all analytical grade (purity >99%). Sodium Hydroxide, hydrochloric and copper sulphate solution of different concentrations was prepared by dissolving calculated quantity of these chemicals in distilled water. The desired concentration of metal ion was freshly prepared from the stock solution. Copper (II) sulphate pentahydrate ($\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$) was used as the source for copper stock solution. The solution was prepared with deionized water; the copper (II) stock solution (1000 mg/L) was made by dissolving 3.916 g of 99% $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ in 1L deionized water. Samples of different concentrations of copper (II) are prepared from this stock solution by appropriate dilutions.

2.3 PRODUCTION OF CHITOSAN

Isolation of chitosan from crab shell wastes involves four traditional steps; deproteinisation (DP), demineralization (DM), decolourization (DC), and deacetylation (DA). The wet crab was washed and dried followed by grinding and sieving to a particle size of 750 μm , and then placed in a plastic bottle for storage at ambient temperature until used. Deproteinisation (DP) was then carried out on the crab shells. Four hundred grams of crab shell was placed in a solution of 3.5% NaOH (w/v) for 2 h at 65°C, solid: solvent (1:10, w/v), then the solid was separated from the liquid and washed with distilled water until absence of colour in the medium which represents the absence of protein. The next step was to demineralise the shells. The deproteinised shell was placed in 1 N HCl for 30 minutes at room temperature, solid: solvent (1:15, w/v). Subsequently, the liquid was decanted and the solid was washed with

distilled water until neutral pH, the remaining was dried at 50 °C for 12 h and the product was chitin. The chitin was decolourized with 0.315% sodium hypochlorite (NaOCl) (w/v) for 5 minutes at room temperature solid: solvent (1:10, w/v) was poured into the vessel containing the solid and the suspension was agitated until the pigmentation of the solid disappeared. The white solid (chitin) was washed and dried at 50 °C for 12 h in the oven. The deacetylation of chitin was carried out by mixing chitin with 50% NaOH for 30 min at 121°C, solid: solvent (1:10, w/v). The mixture was washed with distilled water several times to remove residual sodium hydroxide, until pH 7 was achieved. The chitosan was dried in an oven at 50 °C for 18 h.

2.4 DESIGN OF EXPERIMENTS

The experimental design for optimization of Cu(II) adsorption was done by applying Response Surface Methodology (RSM), categorical factor of 0 was engaged to optimize the adsorption parameters. The design was composed of three levels (low, medium and high, being coded as (-1, 0 and +1) and a total of 30 runs were carried out to optimize the level of chosen variables. Design Expert (Stat-Ease, Inc., version.7.0.0 Minneapolis, USA) software was used for statistical data analysis. In order to investigate the effect of various independent process parameters such as initial concentration (x_1), pH (x_2), adsorbent dose (x_3) and contact time (x_4) on percentage removal of Cu (II), batch experiments were conducted based on the central composite design (CCD).

2.5 BATCH ADSORPTION STUDIES

Batch adsorption studies were carried out at room temperature using 250 mL conical flasks with 50 mL of the working Cu(II) ion solution of different concentrations ranging from 20 to 30 mg/L on a magnetic stirrer at 300 rpm in view of the results from previous work (Liu & Cheng, 2009). The influence of pH (3.0–6.0) (The pH of each solution was adjusted by adding either 0.1 M of NaOH or HCL solution.), Cu(II) concentration (20-30 mgL^{-1}), contact time (45-120 min), adsorbent dose (1.0 -2.0 g/50 mL) were evaluated during the present study. Samples were collected from the flasks at predetermined time intervals for analysing the residual Cu(II) concentration in the solution. The adsorbate was removed by filtration through Whatmann filter paper. The residual concentration of Cu (II) was determined by atomic absorption spectroscopy (AAS). The experiments were performed in duplicates and the amount of Cu (II) ions adsorbed in milligram per gram was determined by using the following mass balance “Equation (1)”

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

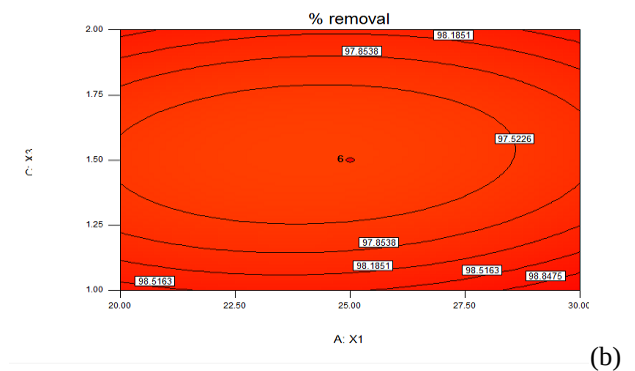
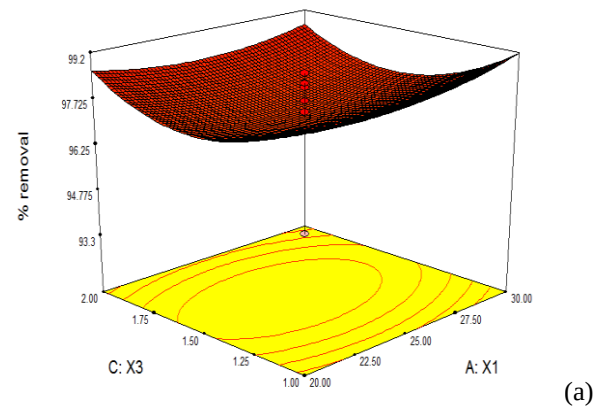
Where C_o and C_e are Cu (II) concentrations (mg/L) before and after adsorption respectively, V is the volume of adsorbate in litre and m is the weight of the adsorbent in grams. The percentage removal of Cu (II) ions was calculated from the following “Equation (2)”

$$(\%) \text{ Removal} = \frac{(C_o - C_e)}{C_o} \times 100 \quad (2)$$

3 RESULTS AND DISCUSSION

3.1 RESPONSE SURFACE PLOTS OF ADSORPTION FACTORS

The ultimate objective of the design used in this study was to find out the significant effects of the process parameters viz., initial concentration, pH, adsorbent dose and contact time on the removal efficiency of Cu (II). The response surface and contour plots were used to investigate the effect of all the factors on the responses. The 3D response surface plots are useful in investigating both the main and interaction effects of the factors. These figures also show the estimated Y parameter as a function of the normalized factor variables, the height of the surface represents the value of Y . A steep slope or curvature in a factor shows that the response is sensitive to that factor. A relatively flat line shows insensitivity to change in that particular factor great influence on the removal of Cu(II), initial metal concentration has less effect on the responses compared to other factors.



Figures 1(a-b): Interaction between adsorbent dose (x3) and initial concentration (x1) on Cu (II) removal, a-response plot, b-contour plot

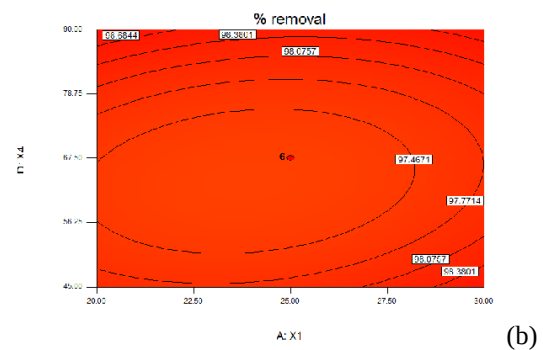
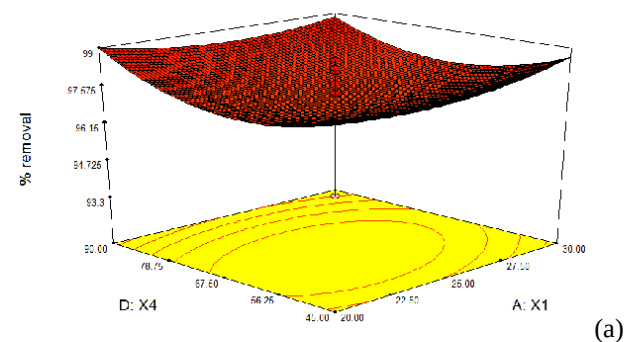
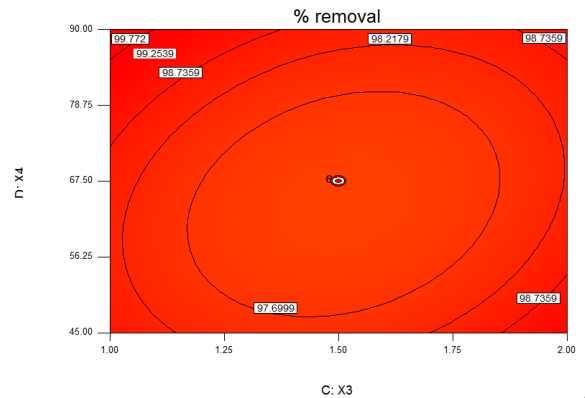
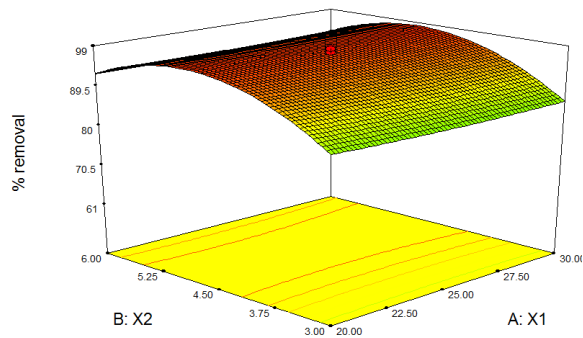
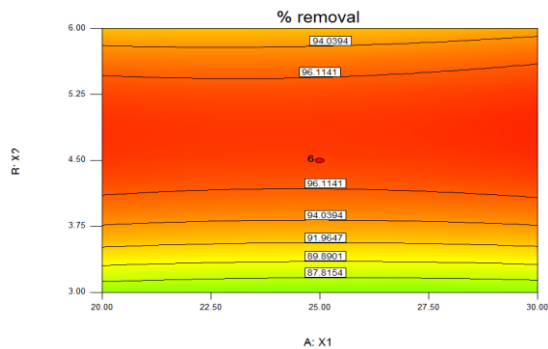


Figure 2(a-b): Interaction between contact time (x4) and initial concentration (x1) on Cu (II) removal, a-response plot, b-contour plot.



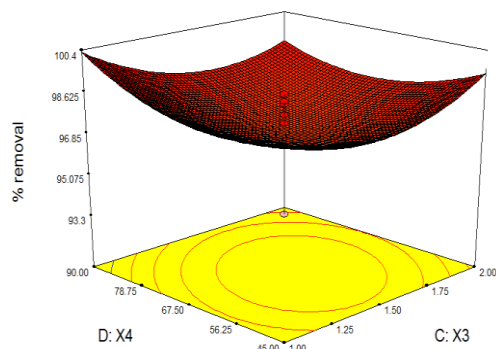
(a)

Figure 4(a-b): Interaction between contact time (x4) and adsorbent dose (x3) on Cu (II) removal, a-response plot, b-contour plot.

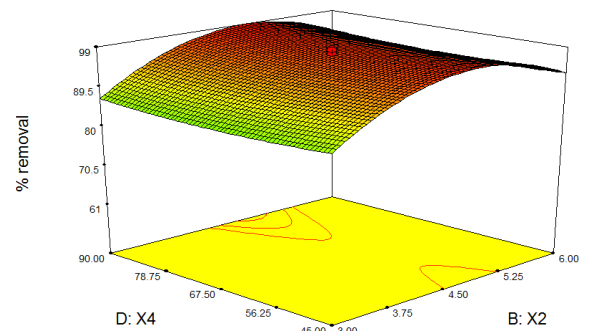


(b)

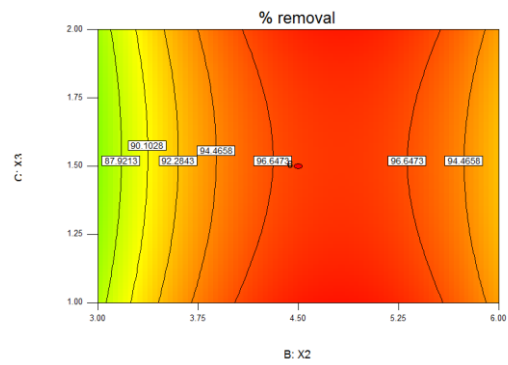
Figure 3(a-b): Interaction between pH (x2) and initial concentration (x1) on Cu (II) removal, a-response plot, b-contour plot



(a)



(a)



(b)

Figure 5(a-b): Interaction between contact time (x4) and pH (x3) on Cu (II) removal, a-response plot, b-contour plot.

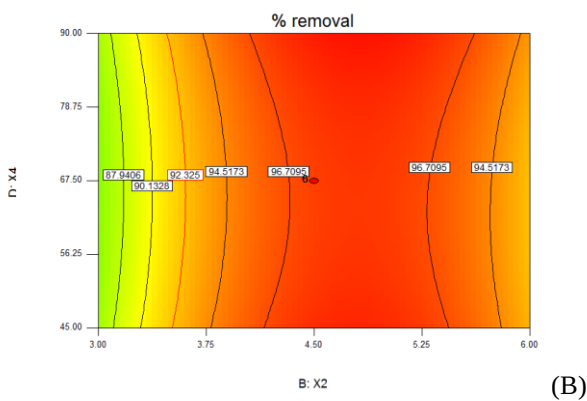
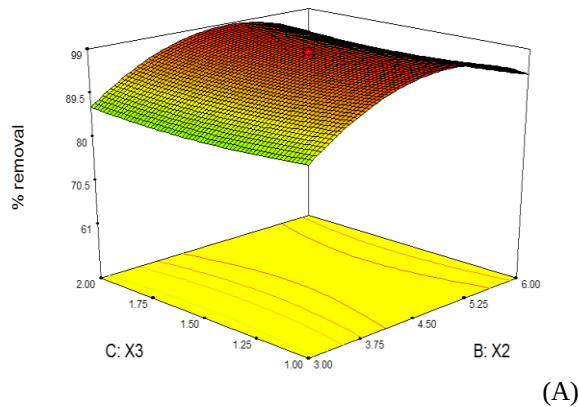


Figure 6(A-B): Interaction between pH (x2) and adsorbent dose (x3) on Cu (II) removal, a-response plot, b-contour plot.

The response and contour plots in figures 1 to 6 elucidate the relationship between the factors and how they affect the removal of copper from aqueous solutions. Figures 1 reveals that copper removal increases with increasing adsorbent dose and initial copper concentration does not have any effect on this trend. Figures 2 also reveal that copper removal increases with increasing time and initial copper concentration does not have any effect on this trend. Figure 3 reveals that copper uptake is optimum at about pH 4.75. The relationship of pH and metal uptake is not affected by initial copper concentration. Figures 4 reveals that metal uptake is maximum at the highest values of equilibration time and adsorbent dosage respectively. Figure 5 and 6 reveals that contact time and adsorbent dosage does not have any effect on the relationship between pH and metal uptake respectively. It can be surmised that metal uptake was maximum (99%) at

pH 4.75, 120 minutes equilibration time and dosage of 2 g/50ml.

3.2 EFFECT OF CONTACT TIME ON ADSORPTION OF COPPER ION

The relationship between contact time and the percentage removal of copper ion from solution using commercial and locally produced chitosan (pH = 6, Mass of chitosan = 1 g, initial concentration = 30 mg/L, and Agitation Speed 300 rpm) are shown in figure 7.

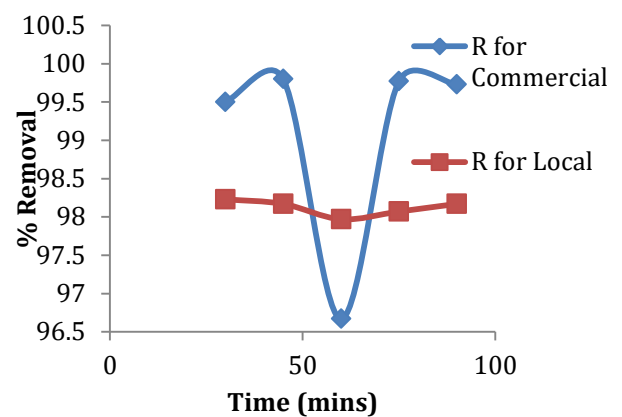


Figure 7: Effect of contact time on both commercial and locally developed chitosan

The contact time represents the time necessary for the adsorption process to reach equilibrium. For each sample the adsorption capacity was studied as a function of time. During short contact times, adsorption was fast due to the availability of plenty of active sites on the adsorbent surface. As the active sites were occupied, adsorption slowed down and finally an equilibrium stage was reached. The adsorption reached equilibrium at short contact time which was due to the availability of active sites on the adsorbent surface which was indicated by the fiber metric image measurements and pore histogram in figures 8 (a-b) and 9 (a-b). As the active sites were occupied, adsorption slowed down and finally an equilibrium stage was reached. It is evident that percentage metal ion removal reached equilibrium at within 40 minutes for Cu (II) for both commercial and locally produced chitosan from crab shell after which further increase in time did not bring about any further improvement.

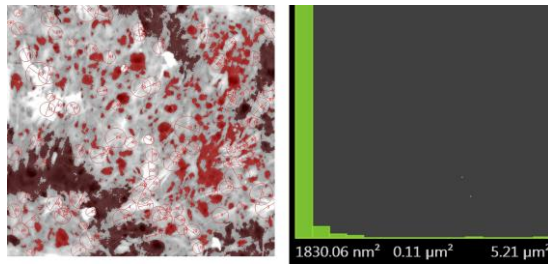


Figure 8 (a-b): Fibermetric Image and Pore Histogram of local developed chitosan

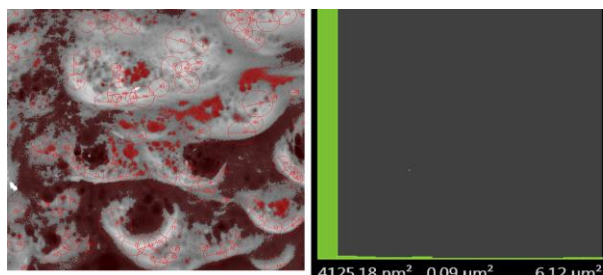


Figure 9 (a-b): Fibermetric Image and Pore Histogram of commercial chitosan

3.3 EQUILIBRIUM ISOTHERM MODELLING

Equilibrium isotherm are essential for describing the mechanism of adsorption, the equilibrium data of Cu^{2+} ion were subjected to five different adsorption isotherm models: Langmuir, Elovich, Temkin Freundlich and Dubinin-Radushkevich. The model constants are summarized in Table 1.

TABLE 1: Equilibrium isotherms parameters for Cu^{2+} adsorption on chitosan

Parameters	Locally developed chitosan	Commercial chitosan
Langmuir		
a(mg/g)	1.4435	1.4900
b (L/mg)	92.491	3728.56
R	0.000361	0.0000
R^2	0.9999	0.9999
Freundlich		
1/n	0.008	0.003
K_F	1.45	1.48
R^2	0.998	0.985
Temkin		
A_T (L/g)	4.297	4.41
$b_T (\times 10^3)$	99.58	500.52

B	0.02488	0.00495
R^2	0.810	0.983
Elovich		
Q_m (mg/g)	0.0301	0.00502
K_F (L/mg)	0.0000	0.0000
R^2	0.9006	0.9915
Dubinin-Radushkevich		
K_{ad} (mol ² /kJ ²)	2.290×10^{-9}	-
E (kJ/mol)	0.59	-
R^2	0.9901	-

The Langmuir and Freundlich isotherm models predict the adsorption data better than Elovich and Temkin because high correlation coefficients ($R^2 > 0.99$) were obtained at a higher confidence level. The Freundlich constants K_F and $1/n$ for Cu^{2+} were found to be 1.49 mg/g and 0.003 for commercial chitosan and 1.45 mg/g and 0.008 for locally developed chitosan respectively. The values of $1/n$ are between 0 than 1 for both the adsorbents, which indicate normal adsorption. The low $1/n$ suggested that any large change in the initial concentration Cu^{2+} ions would not result in a change in the amount of Cu^{2+} adsorbed by the chitosan. According to the values of the correlation coefficient (R^2), the best-fit isotherm model was the Langmuir isotherm model follow by the Freundlich model. The Elovich modelling of the experimental data also indicate chemisorption took place. High correlation coefficients were observed when the data were fitted to this model especially for the commercial chitosan and this also suggested that the adsorption of Cu^{2+} occurred by chemisorption. The Temkin model had the lowest value of correlation coefficient, which suggested that this model was not the best description of Cu^{2+} ion adsorption onto locally developed and commercial chitosan. However, the model did indicate that Cu^{2+} is an exothermic process, since $B > 0$ for both commercial and locally developed adsorbents. The numerical value of mean free energy E calculated from Dubinin–Radushkevich (D-R) isotherm model was 0.59 kJ/mol. If the value of E lies between 8 – 16 kJ/mol, the process is said to follow chemical ion exchange while $E < 8$ kJ/mol then the process follows physical adsorption (Horsfall, Spiff, & Ai, 2004). In the current study the biosorption process of Cu (II) onto locally developed chitosan follows physical adsorption.

3.4 ADSORPTION KINETICS

The data on the dependence of adsorption capacity on time were used for kinetic analysis. The results of the fitted data show that pseudo-second order kinetics model yielded linear plots compared to the pseudo-first-order reaction model, which is significantly scattered (non-linear).

Table 2. Kinetic parameters for Cu²⁺ adsorption on chitosan

Parameters	Locally developed chitosan	Commercial chitosan
Pseudo first order		
q _e cal (mg/g)	1.042	1.096
q _e exp (mg/g)	1.4735	1.4965
k ₁ (min ⁻¹)	0.085	0.104
R ²	0.0323	0.4965
Pseudo second order		
q _e cal. (mg/g)	1.4728	1.4993
q _e exp (mg/g)	1.4735	1.4965
k ₂ (g/mgmin)	66.02	10.35
R ²	0.999	0.999

Also the theoretical (calculated) value of q_e of, pseudo-second-order reaction model, are closer to the experimental value of q_e for instance, the calculated value of Cu²⁺ onto local chitosan was 1.4728 mgg⁻¹ which is in closed agreement with the experimental value of 1.4935 mgg⁻¹ compared to Cu²⁺ of pseudo-first-order reaction model, with calculated valued of 0.1042 mgg⁻¹ which differ greatly from the experimental value of 1.4735 mgg⁻¹. Also the calculated value of Cu²⁺ onto commercial chitosan was 1.4993 mgg⁻¹ which is in closed agreement with the experimental value of 1.4965 mgg⁻¹ compared to Cu²⁺ of pseudo-first-order reaction model, with calculated valued of 1.096 mgg⁻¹ which differ greatly from the experimental value of 1.4735 mgg⁻¹ these fact suggest that the adsorption of Cu²⁺ by commercial and locally produced chitosan from crab shells follows the pseudo-second-order reaction model which rely on the assumption that chemisorption is the rate-limiting step. In chemisorption the heavy metals stick to the adsorbent surface by forming a chemical usually covalent bond and tend to find sites that maximize their coordination with the surface (Yusuff, Popoola & Babatunde, 2019).

5 CONCLUSION

A detailed batch experimental study was carried out for the removal of copper (II) from aqueous solution using commercial and locally developed chitosan. The commercial and locally developed chitosan was found effective in removal of copper (II) ion from aqueous solution and the results of the copper ion percentage removal was 99.57% for locally produced chitosan and 99.80 for commercial chitosan at pH of 6.0. Optimum metal uptake (99.57%) was observed at pH 4.75, 120 minutes equilibration time and dosage of 2g/50ml. The results obtained from isotherms adsorption studies of Cu (II) ions by being analysed in five adsorption models, namely, Langmuir, Freundlich, Elovich, Temkin and

Dubinnin-Radushkevich. The isotherms equation indicated to be best fitted to the Langmuir isotherm equation under the concentration range studied. The kinetics for the adsorption of copper, onto chitosan was best described by a pseudo-second-order kinetic model.

ACKNOWLEDGEMENT

The authors would like to acknowledge the Department of Chemical Engineering, Federal University of Technology Minna, Nigeria for their immense support during execution of the work.

Abbreviations

C₀ initial concentration of metal ion in the liquid phase (mg/L)

C_e equilibrium concentration of metal ion in the liquid phase (mg/L)

K₁ rate constant of pseudo-first order adsorption (min⁻¹)

k₂ rate constant of pseudo-second order adsorption (g·mg⁻¹·min⁻¹)

K_F Freundlich isotherm constant is in (mg/g)

b Langmuir isotherm constant (L/mg)

m amount of chitosan membrane (g)

n number of experimental data

q adsorption amount (mg/g)

q_e adsorption amount at equilibrium (pseudo-second order equation constant) (mg/g)

a maximum adsorption capacity (Langmuir isotherm constant) (mg/g)

q_t adsorption amount at time t (mg/g)

t time (min)

V volume of the solution (L)

K_E is the Elovich equilibrium constant (L/mg)

K is the Dubinin-Radushkevich constant (kJ²/mol)

REFERENCES

- Alam, M. Z., Muyibi, S. A., & Toramae, J. (2007). Statistical optimization of adsorption processes for removal of 2,4-dichlorophenol by activated carbon derived from oil palm empty fruit bunches. *Journal of Environmental Science and Health, Part B*, 19, 674–677.
- Bailey, S. E., Olin, T. J., Bricka, R. M., & Adrian, D. D. (1999). A Review Of Potentially Low-Cost Sorbents For Heavy Metals. *Journal of Water. Resources*, 33(11), 2469–2479.
- Cutillas-Barreiro, L., Ansias-Manso, L., Fernandez-Calvino, D., Arias-Estevéz, M., Novoa-Munoz, J. C., Fernandez-Sanjurjo, M. J., Núñez-Delgado, A. (2014). Pine bark as bio-adsorbent for Cd, Cu,

- Ni, Pb and Zn: Batch-type and stirred flow chamber experiments. *Journal of environmental management*, 144, 258-264.
- Das, A., Bhowal, A., & Datta, S. (2016). Biomass characterisation and adsorption mechanism of Cu (II) biosorption onto fish (*Catla catla*) scales. *International Journal of Environmental Engineering*, 8(1), 81-94.
- Eletta, A. A. O., & Ighalo, J. O. (2019). A Review of fish scales as a Source of Biosorbent for the Removal of Pollutants from Industrial Effluents. *Journal of Research Information in Civil Engineering*, 16(1), 2479-2510.
doi:10.13140/RG.2.2.20511.61604
- Garg, U. K., Kaur, M., Sud, D., & Garg, V. (2009). Removal of hexavalent chromium from aqueous solution by adsorption on treated sugarcane bagasse using response surface methodological approach. *Desalination*, 249(2), 475-479.
- Ghosh, A., Das, P., & Sinha, K. (2015). Modeling of biosorption of Cu (II) by alkali-modified spent tea leaves using response surface methodology (RSM) and artificial neural network (ANN). *Applied Water Science*, 5(2), 191-199.
- Gratuito, M. K. B., Panyathanmaporn, T., Chumnanklang, R. A., Sirinuntawittaya, N., & Dutta, A. (2008). Production of activated carbon from coconut shell: Optimization using response surface methodology. *Bioresources Technology*, 99, 4887-4895.
- Hevira, L., Munaf, E., & Zein, R. (2015). The use of *Terminalia catappa* L. fruit shell as biosorbent for the removal of Pb(II), Cd(II) and Cu(II) ion in liquid waste. *Journal of Chemical and Pharmaceutical Research*, 7(10), 78-89.
- Horsfall, M. J., Spiff, A. I., & Ai, A. A. (2004). Studies on the influence of mercaptoacetic acid (MAA) modification of cassava (*manihot sculenta* cranz) waste from biomass on the adsorption of Cu²⁺ and Cd²⁺ from aqueous solution. *Bulletin of the Korean chemical society*, 25(7), 969-976.
- Kamar, F. H., Nechifor, A. C., Nechifor, G., Al-Musawi, T. J., & Mohammed, A. H. (2017). Aqueous Phase Biosorption of Pb (II), Cu (II), and Cd (II) onto Cabbage Leaves Powder. *International Journal of Chemical Reactor Engineering*, 15(2).
- Karacan, F., Ozden, U., & Karacan, S. (2007). Optimization of manufacturing conditions for activated carbon from Turkish lignite by chemical activation using response surface methodology. *Applied Thermal Engineering*, 27, 1212-1218.
- Karthikeyan, T., Rajgopal, S., & Miranda, L. R. (2005). Chromium (VI) adsorption from aqueous solution by Hevea brasiliensis sawdust activated carbon. *Journal of Hazardous Material*, 124(3), 192-199.
- Kumar, M. S., & Phanikumar, B. (2013). Response surface modelling of Cr⁶⁺ adsorption from aqueous solution by neem bark powder: Box- Behnken experimental approach. *Environmental Science and Pollution Research*, 20(3), 1327-1343.
- Liu, X. L., & Cheng, Z. H. (2009). Removal of copper by a modified chitosan adsorptive membrane. *Frontiers of Chemical Engineering China*, 3, 102-106.
- Madala, S., Mudumala, V. N. R., Vudagandla, S., & Abburi, K. (2015). Modified leaf biomass for Pb (II) removal from aqueous solution: Application of response surface methodology. *Ecological Engineering*, 83, 218-226.
- Mandal, N., Mondal, S., Mondal, A., Mukherjee, K., & Mondal, B. (2015). Response surface modeling of Cu(II) removal from wastewater using fish scale-derived hydroxyapatite: application of Box- Behnken experimental design. *Desalination and Water Treatment*, 1-14.
- Olmez, T. (2009). The optimization of Cr (VI) reduction and removal by electrocoagulation using response surface methodology. *Journal of Hazardous Material*, 162, 1371-1378.
- Yusuff, A.S., Popoola, L.T. & Babatunde, E.O. (2019): Adsorption of cadmium ion from aqueous solutions by copper-based metal organic framework: equilibrium modeling and kinetic studies. *Applied Water Science* 9: 106.
Retrieved from
<http://link.springer.com/article/10.1007/s13201-019-0991-z>



3rd International Engineering Conference (IEC 2019)
Federal University of Technology, Minna, Nigeria

