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Adsorption of Heavy Metals in Wastewater using a Composite Adsorbent derived from Sugarcane Bagasse: Isotherm and Kinetic Studies

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Abstract

This study investigates the adsorption potential of a composite adsorbent of chemically activated cellulose derived from sugarcane bagasse and Chitosan (CHIC) to remove heavy metals from its aqueous solution. The experimental equilibrium data were tested using isotherm models namely, Langmuir, Freundlich and Temkin. The adsorption kinetics and mechanism were also studied using pseudo-first order, pseudo-second order and Elovich to ascertain the behavior of the mechanism. It was found that experimental equilibrium data of Chromium, Copper, Cadmium and Iron followed the Freundlich model indicating multilayer sorption on a heterogenous surface. The higher the K_F greater the adsorption intensity. The higher K_F values exhibit by the adsorption of Fe suggests that Fe has greater adsorption tendency towards the adsorbent. The maximum multilayer sorption capacity at 303 K was estimated to be 1.345 L/g. In addition, the value of *1/n* was below unity indicating that the surface of the adsorbate was heterogeneous, multilayer and the mechanism of adsorption was a chemisorption process. Whereas the adsorption of Lead followed Temkin model. Pseudo-second-order kinetic model provided a better correlation for the experimental data studied for all the metals in comparison to the pseudo-first-order model. The equilibrium data indicated that CHIC can be used as an effective and low-cost adsorbent to remove Metal ions from its solution.

Keywords: Sugarcane Bagasse, Chitosan, Chemisorption, Kinetics, Adsorption Isotherms

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Introduction

Recently, the outpouring of industrial activities has led to excessive rise in the use of heavy metals and certainly resulted in an increased flux of these metal ions in the aquatic environment (Tchounwou, *et al* 2014). A lot of heavy metals are present in industrial runoff but Cu, Cr, Cd, Pb, Hg, Zn, and Ni are the most common heavy metals discharged into water streams from large manufacturing industries (Mahmoud *et al* 2010, Lu *et al* 2009, Singh *et al* 2005 and Anirudhan *et al* 2008). The accumulation of these metal ions is considerably undesirable and are very stable and insistent ecological contaminants since they cannot be degraded or destroyed, and therefore tend to accumulate in the soils, seawater, freshwater and sediments (Kabata-Pendias, 1995). The presence of heavy metals in the aquatic environment is a crucial problem due to their toxicity towards aquatic life, human beings and the environment. Cd, Cr, Cu, Pb and Fe are most widely used heavy metals. These Heavy metals are used in various important industrial applications. There potential sources in industrial effluents include metal cleaning and plating baths, fertilizer, refineries, paints and pigments, municipal and storm water run-off, etc (Anirudhan *et al,* 2008, Zhu *et al,* 2009, Ozer *et al*, 2004, Yao *et al,* 2010). Ingestion and accumulation of metal ions by human beings leads to a lot of health-related issues, such as hepatic and renal damage, central nervous system and possible necrotic changes in the liver and kidney (Hassan *et al*., 2017).

Nevertheless, numerous research works has been directed to develop a simple, cheap and highly operative water purification process that will help in reducing the risk of water borne diseases in most developing countries. Therefore, removal of metal ions from effluents is essential not only to protect the water sources but also for the protection of human health (Liu *et al*, 2018). Heavy metal removal from effluent can be achieved using conventional processes such as (chemical precipitation, coagulation, Ion-exchange etc.) or physiochemical process and adsorption (Ali and Gupta, 2006). Of all the treatment methods mentioned, bio sorption had been reported as an efficient method for the removal of heavy metals from aqueous solution because of their effectiveness even at low concentration, Bio-sorption of heavy metals using adsorbent materials is an example of physiochemical processes (Sud, *et al*, 2008).

Recent studies on bio-sorption have shown that common agricultural wastes can be used as potential bio-sorbents for the removal of heavy metals (Khatoon and Rai, 2016). Agricultural waste materials being economic and ecofriendly due to their unique chemical composition, availability in abundance, renewable by nature, low cost and high efficiency, seem to be feasible option as bio-sorbents for heavy metal removal (Chowdhury *et al,* 2011).

Sugarcane (*Saccharum officinarum*) is a widely cultivated tropical plant species in some part of Nigeria. It is considered one of the underutilized agricultural wastes compared to other numerous biomass-based adsorbent which have received much attention (Ezeonuegbu *et al.,* 2021). In northern part of Nigeria, many farmers cultivate sugarcane as means of livelihood. These sugarcanes are sold to sugar refinery or individuals in communities, markets, villages and to other parts of the country. The bagasse from these canes after chewed or refined are usually thrown away as waste, littering the environment.

Kinetic modeling for adsorption processes involves studying the rate of adsorption of a species under particular condition before attaining equilibrium, it involves studying the mechanisms of the adsorption processes (Lima *et al* 2015). At equilibrium, adsorption and desorption processes are balanced. The mechanisms involved in this process is of great importance in designing adsorption system that make use of such adsorbents (Lima *et al* 2015). It is very important to evaluate the adsorption equilibrium and dynamics characteristics by using theoretical models in order to design and control the adsorption process units. Through this study, this "waste" was channeled into the useful purpose of biosorption due to its availability and low cost. In this study, a composite adsorbent was developed for the removal of heavy metals in wastewater using chemically activated cellulose derived from sugarcane bagasse (SCB) and Chitosan. In addition, the kinetics of the adsorption process was examined to understand the biosorption mechanism of the process.

Materials and Methods

Precursor preparation

Sugarcane bagasse (agro-waste) was sourced from a local market in Maiduguri, Borno State (Gamboru Market Maiduguri Metropolitan Council L.G.A) Bagasse was dried in oven at 105°C for 3 h and stored at room temperature in airtight polybag. While chitosan was commercially obtained Ali expresses online shopping mall.

Preparation of adsorbent

Chemically activated cellulose was extracted by sequence of chemical treatments such as alkali treatment, bleaching treatment and acid hydrolysis. The chopped, ground sugarcane Bagasse was subjected to alkali treatment with 4 wt. % NaOH at 80°C for one hour. The insoluble sugarcane Bagasse residue was filtered and washed with distilled water. The alkali treatment was given to obtain a purified cellulose by removing hemicelluloses and lignin. Following the alkali treatment, the bleaching process was carried out with 5wt. % sodium chlorite solution at 80ºC for 2 h. The mixture was allowed to cool and was filtered using distilled water. The bleaching process was repeated four to five times. The acid hydrolysis was conducted by adding 25 g fibers in 500 mL of 60% w/w H_2SO_4 solution at 45ºC under vigorous stirring for 60 min. The hydrolyzed Material was washed by centrifugation at 10,000 rpm for 15 min the supernatant was discarded. The sediment was dispersed in distilled water. The centrifugation step was repeated several times until a constant pH in the range of 7 is reached. The resulting suspension was then sonicated for 10 min in an ice bath. The aqueous suspension produced was stored in a refrigerator at 4^0C to freeze dry for further use. After obtaining the Chemically Activated Cellulose (CAC) the material was hybridized with Chitosan to form a composite material given an acronym called CHIC.

Heavy Metals Adsorption Experiment

The Adsorption Experiments were performed co-currently for all the heavy metals in a series of flasks containing 50 ml solutions of metal ions at desired concentrations and adsorbent dosages. The mixtures were agitated for 120 min at 250 rpm using a shaker mixer Edibon model. The resulting mixtures were filtered, and the concentrations of heavy metals were determined using AAS Atomic Absorption Spectrometer model iCE 3300 Double Beam AA Spectrometer with 100 mm Universal Burner. The effect of adsorbent dosage ranged from 0.1 to 1.2 g on the metal adsorption was studied. The initial concentration used was 50-500 mg/L. The effect of pH on heavy metal adsorption was investigated at pH values from 6 to 8, adjusted either with 1 M HCl or 1 M NaOH using a pH meter, to monitor the change. In addition, the contact time was varied between 20 min and 180 min. The effect of temperature was studied from 25 to 50 ^{0}C. In addition, kinetics experiments were conducted with 0.7 g of adsorbent at 30 ^{0}C temperature with stirring at 250 rpm for 120 min.

The amount of adsorption at equilibrium was obtained using equation (1)

$$q_t = \frac{(C_o - C_e)V}{100w} \qquad (1)$$

Where q_t is metal ion uptake in mg/g at time, t, C_o is the initial concentration at time, t, mg/L, Ce is the concentration at any equilibrium mg/L, V is the volume of solution used (mL), w is the weight of adsorbent (g).

Biosorption isotherms

An isotherm describes the equilibrium relationship between the adsorbate concentration in the liquid phase and that on the adsorbent’s surface at a given condition (Kose *et al*, 2020). It is an invaluable curve describing the phenomenon governing the retention (or release) or mobility of a substance from the aqueous porous media or aquatic environments to a solid-phase at a constant temperature and pH. Isotherms are thermodynamic basic of separation processes and determine the extent to which a material can be adsorbed onto a particular surface (Kose *et al*, 2020). A variety of isotherms have been developed to describe equilibrium relationships. However, no single model is universally applicable, all involve assumptions which may or may not be valid in particular cases. It is therefore important to establish the most appropriate isotherm model for the equilibrium data for evaluating the applicability of the sorption process. In the present study, the Langmuir, Freundlich and Temkin isotherm models were used to describe the equilibrium biosorption data. The Langmuir isotherm is valid for monolayer biosorption onto a completely homogeneous surface with a finite number of binding sites and is given by equation (2) (Kose *et al*, 2020):

$$q_e = \frac{q_m K_L C_e}{1 + K_L C_e} \qquad (2)$$

where q_e (mg g^{-1}) and Ce (mg L^{-1}) are the solid phase concentration and the liquid phase concentration of sorbate at equilibrium respectively, q_m (mg g^{-1}) is the maximum biosorption capacity, and K_L (L mg^{-1}) is the biosorption equilibrium constant better known as the Langmuir constant that quantitatively reflects the affinity between the sorbate and the bio sorbent.

The Freundlich isotherm is an empirical equation applicable to non-ideal biosorption on heterogeneous surfaces and is expressed by the following equation (3):

$$q_e = K_F C_e^{1/n} \qquad (3)$$

where q_e is the equilibrium sorbate concentration on the bio sorbent (mg g^{-1}), Ce is the equilibrium sorbate concentration in solution (mg L^{-1}), K_F (mg g^{-1}) (L g^{-1}) 1/n is the Freundlich constant related to sorption capacity and n is the heterogeneity factor.

The Temkin isotherm model assumes that the decline of the heat of sorption as a function of temperature is linear and has the following formulation (equation 4) (Kose *et al*, 2020).:

$$q_e = B_T \ln(K_T C_e) \qquad (4)$$

where qe is the equilibrium adsorbate concentration on the bio sorbent (mg g^{-1}), C_e is the equilibrium adsorbate concentration in solution (mg L^{-1}) and K_T (L g^{-1}) and B_T are the Temkin constants.

Bio-sorption kinetics

The information of the kinetics of any biosorption process is vital since the kinetics defines the uptake rate of sorbate which in turn controls the residence time of the sorbate at the solid–solution interface (Ghosh Suchhand 2011). Therefore, the results obtained from the experiments were used to study the kinetics of metal ions biosorption. The kinetics of the metal ions biosorption onto Composite adsorbent of Chemically Activated Cellulose and Chitosan (CHIC) was analyzed using the pseudo-First-order and pseudo-second-order models. The pseudo-first-order and pseudo-second-order models are frequently used to analyze biosorption data and are expressed as:

$$\ln(q_e - q_t) = ln(q_e) - k_1 t \qquad (5)$$

Where q_t and q_e are the amounts of metal ions adsorbed (mg/g) at time t, and at equilibrium, respectively, k_1 is the rate constant of pseudo-first-order equation (min^{-1})

$$\frac{1}{q_e - q_t} = \frac{1}{q_e} + k_2 t \qquad (6)$$

Where, q_t and q_e are the amounts of metal ions adsorbed (mg/g) at time t, and at equilibrium, respectively, k_2 is the rate constant of pseudo-second-order equation (g/mg min).

Elovich kinetic model was developed by Zeldowitsch (Perez *et al*, 2009) assuming actual solid adsorbent surfaces as energetically heterogeneous and no interactions among the adsorbed species. The linearized form is given as:

$$q_t = \frac{1}{\beta}\ln(\alpha\beta) + \frac{1}{\beta}\ln(t) \qquad (7)$$

Where, α is the initial adsorption rate (mg/min) and ß is related to the extent of surface coverage and the activated energy for chemisorption (g/mg). A plot of q versus ln (t) gives a linear trace with a slope of (1/ß) and an intercept of 1/ß ln (aß), q_t and q_e are the amounts of metal ions adsorbed (mg g^{-1}) at time t, and at equilibrium, respectively.

Results and Discussion

Bio-sorption isotherms

The adsorption data was analyzed by fitting to isotherm models using Langmuir, Freundlich and Temkin. The isotherm experiments were carried out at 303 K with 50 – 500 µg/L concentrations, at solution pH 6.0 and Composite adsorbent of Chemically Activated Cellulose and Chitosan CHIC dosage of 6.0 g/L. The isotherm constants determined are tabulated in Table 1. Fig. 1-5 shows the plots comparing the Langmuir, Freundlich and Temkin isotherm models with the experimental data for the biosorption of the Heavy metals onto Composite adsorbent of Chemically Activated Cellulose and Chitosan CHIC.

Table 1: Isotherm Parameters for the Adsorption of heavy metals onto CHIC at 30°

Models	Chromium	Cadmium	Copper	Lead	Iron
Langmuir					
q_{max} (mg/g)	10.990	10.500	9.172	10.421	6.506
b (L/mg)	0.063	0.029	0.061	0.067	0.071
R_L	0.725	0.749	0.681	0.706	0.861
R^2	0.959	0.914	0.939	0.916	0.579
Freundlich					
K_F (L/g)	1.309	1.248	1.207	0.983	1.345
N	3.187	3.092	3.001	2.312	3.213
1/n	0.314	0.323	0.333	0.433	0.261
R^2	0.990	0.977	0.945	0.944	0.992
Temkin					
K_T (L/mg)	0.309	0.168	0.391	0.714	0.747
b_T (J/mol)	897.000	919.000	120.000	12.000	201.000
R^2	0.915	0.944	0.922	0.961	0.913

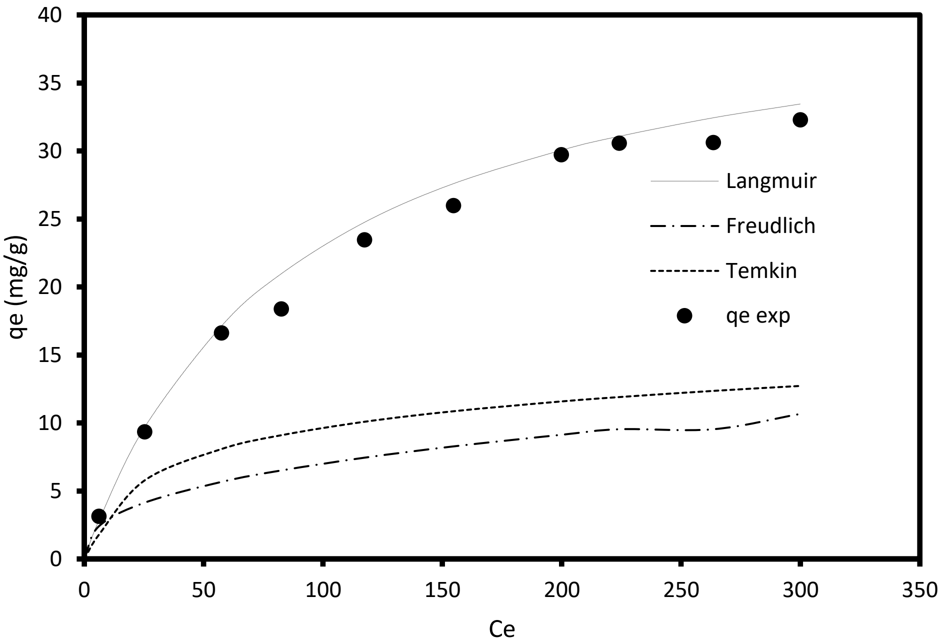

Figure 1: Langmuir, Freundlich and Temkin isotherm for Chromium Adsorption

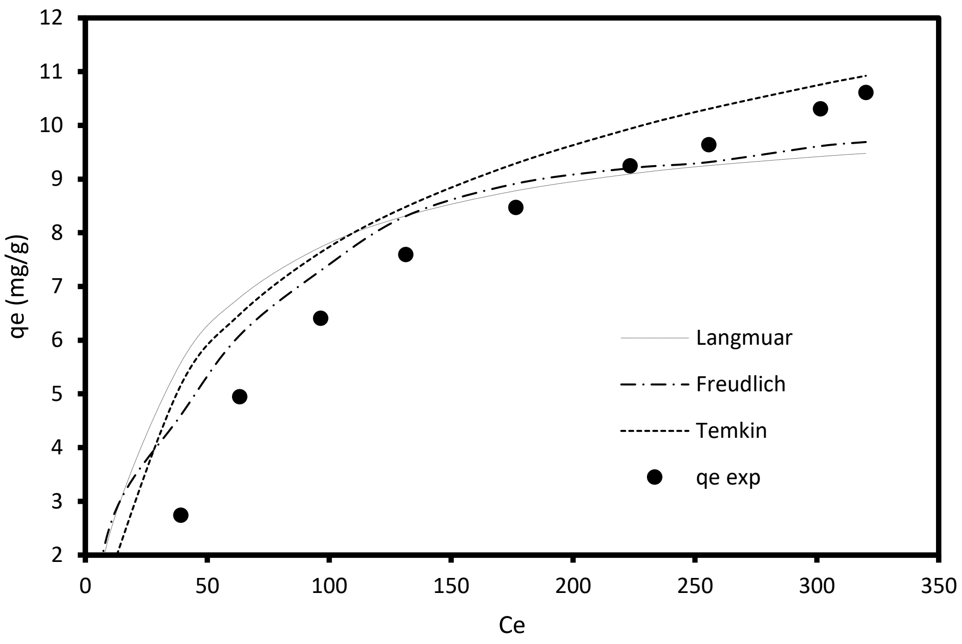

Figure 2: Langmuir, Freundlich and Temkin isotherm for Cadmium Adsorption

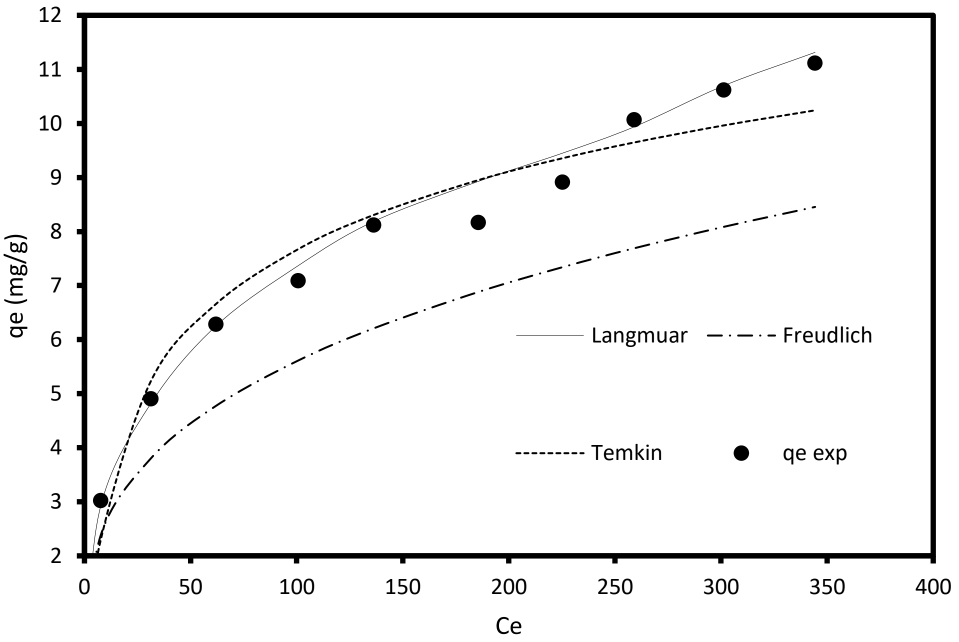

Figure 3: Langmuir, Freundlich and Temkin isotherm for Copper Adsorption

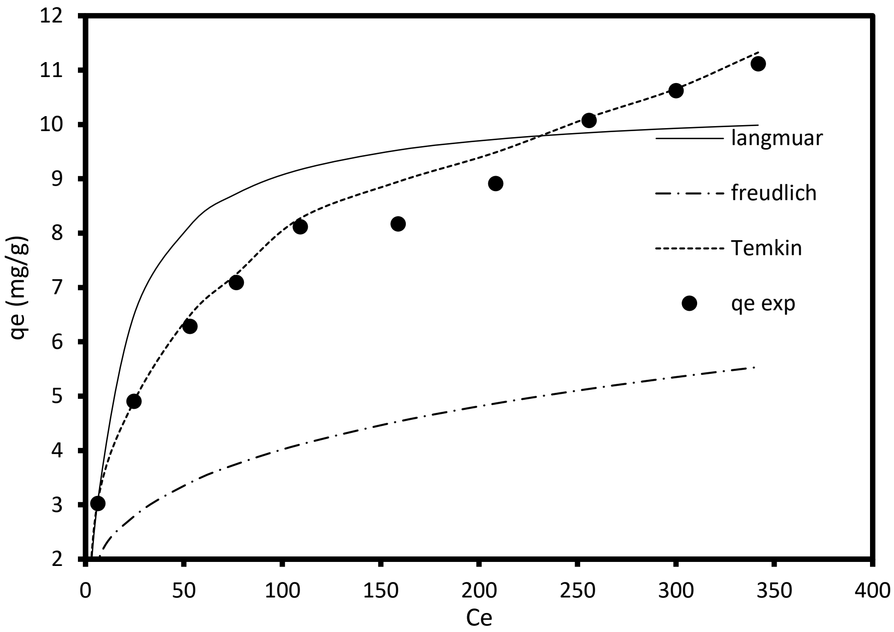

Figure 4: Langmuir, Freundlich and Temkin isotherm for Lead Adsorption

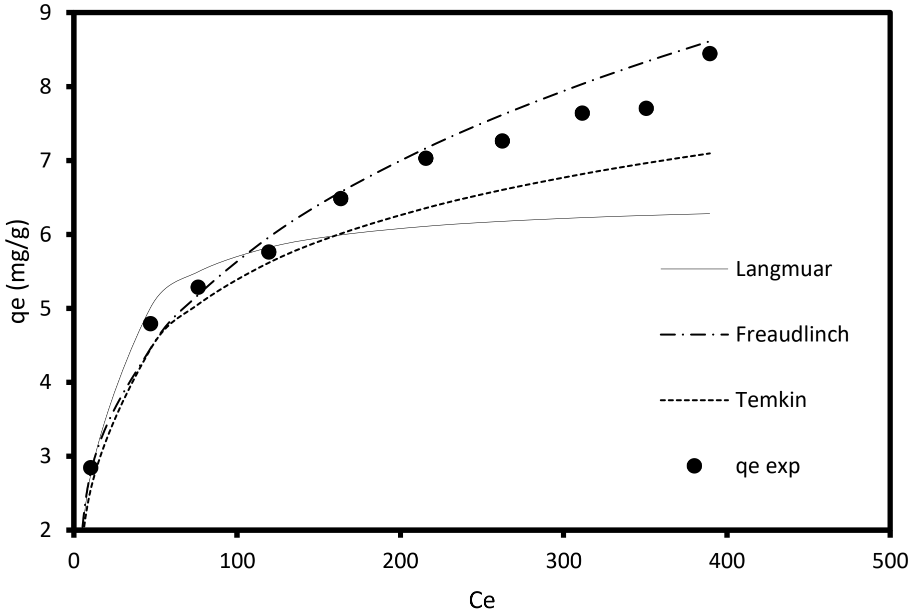

Figure 5: Langmuir, Freundlich and Temkin isotherm for Iron Adsorption

In general, an adsorption isotherm is an important curve describing the phenomenon governing the retention (or release) or mobility of a substance from the aqueous porous media or aquatic environments to a solid-phase at a constant temperature and pH. In this study, three adsorption isotherm models (Langmuir, Freundlich and Temkin) were fitted to experimental equilibrium data for heavy metals adsorption of (Cr, Cd, Cu, Pb and Fe). The results are made known in (Table 1) and the modelled isotherms are plotted in Figure 1-5. The Adsorption equilibrium isotherms were analyzed using the Langmuir, Freundlich and Temkin isotherm model. Adsorption data of Chromium, Copper, Cadmium and Iron were well fitted into Freundlich isotherm model and the adsorption data of Lead was well fitted in Temkin isotherm model Freundlich isotherm model displays an excellent fit to the experimental data of Chromium, Copper, Cadmium and Iron with a coefficient of determination of 0.990, 0.977, 0.945 and 0.992 respectively.

The agreement of the Freundlich model to the equilibrium data could indicate multilayer adsorption by the CHIC surface that could contain a finite number of identical sites. In addition, the value of *1/n* was below unity indicating that the surface of the adsorbate was heterogeneous, multilayer and the mechanism of adsorption was a chemisorption process. The fractional value of *1/n* indicates the surface of adsorbent is of heterogeneous type with an exponential distribution of energy sites (Onwu and Ogah, 2010). The value of 1/n less than 1 (Table 1) is indicative of favorable adsorption (Vaishnav *et al*, 2012). A smaller value of 1*/n* indicates better adsorption mechanism and formation of relatively stronger bond between adsorbate and adsorbent. The magnitude of *n* gives a measure of favorability of adsorption. The values of *n* between 1 and 10 (i.e.,1/n less than 1) represents a favorable sorption. For the present study the value of *n* also presented the same trend representing a beneficial sorption for all the metals. The values of K_F were found to be 1.345 L/g implying that there was high uptake of the metal ions unto the CHIC surface. The higher the value of K_F the greater the adsorption intensity (Zhang *et al*, 2012). The higher K_F values exhibit by the adsorption of Fe suggests that Fe has greater adsorption tendency towards the adsorbent than Cr, Cd, Cu and Pb (Xiong *et al*, 2010).

However, the Temkin model also fitted well to the equilibrium data of Lead with a coefficient of determination of 0.961 respectively. Temkin isotherm model considers the effects of indirect adsorbate/adsorbate interactions on the adsorption process; it is also assumed that the heat of adsorption of all molecules in the layer decreases linearly as a result of increase surface coverage. The Temkin isotherm model assumes that the adsorption heat of all molecules decreases linearly with the increase in coverage of the adsorbent surface, and that adsorption is characterized by a uniform distribution of binding energies, up to a maximum binding energy (Subbaiah *et al.,* 2009). If heat of sorption value is less than 1.0 kcal/mol, then physical adsorption is occurring. And when the value is between 20-50 kcal/mol, then chemical adsorption occurs. If heat of sorption value is in-between (1 - 20 kcal/mol), then both physical and chemical adsorptions are involved in the adsorption. From Temkin isotherm the value of the adsorption binding energy from Table 1. The estimated value binding energy for the present study was found to be in the range 0.292 Kcal/mol for Lead with this finding the binding energy is physical adsorption for Lead.

Biosorption kinetics

In order to investigate the mechanism of adsorption and its potential rate-controlling steps that include mass transport and chemical reaction processes, kinetic models are exploited to test the experimental data. In this study, the experimental equilibrium data of the adsorption of Heavy metals (Cr, Cd, Cu, Pb and Fe) onto Composite adsorbent of Chemically Activated Cellulose and Chitosan CHIC at initial concentrations of 50 – 500 mg/L was examined at different time intervals at 30°C. The experimental data were analyzed by the pseudo-first-order, pseudo-second-order kinetic model and Elovich model. Table 2 (a-e) present the results of fitting experimental data with pseudo-first-order, pseudo-second-order model and Elovich model using correlation coefficient (R^2). The results suggest that pseudo-first-order kinetic model fitted well to the corresponding data of Cd, Pb and Fe while pseudo Second-order model fitted well to the corresponding data of Cu and Cr respectively. The theoretical $q_{e\ cal}$ values are closer to the experimental $q_{e\ exp}$ values reinforcing the applicability of this model, the equilibrium plots of the analysis are shown in Fig. 6 (a-e) and all the R^2 values are shown in Table 2 (a-e), confirming the applicability of models. The qe_{exp}, $qe_{cal,}$ K_1 and K_2 values were calculated from slope and intercept of the plots, respectively and are listed in Table 2. Further the kinetic data was fitted to the Elovich equation. The Elovich equation assumes that the solid surface-active sites are heterogeneous in nature and therefore, exhibit different activation energies for chemisorption (Perez *et al*, 2009). The Elovich plot (qt vs. ln t) are shown in Fig. 2 (a-e). The values of the coefficients α and β are listed in Table 2 (a-e).

Table 2 (a): Kinetic Models Constants Parameters for Chromium adsorption on CHIC

		Pseudo First-Order			**Pseudo Second-Order**			**Elovich**		
C_o (mg/L)	**$q_{e\ exp}$ *(mg/g)***	**K_1 (1/h)**	**$q_{e\ cal}$ (mg/g)**	**R^2**	**K_2 *(g/mg.min)***	**$q_{e\ cal}$ (mg/g)**	**R^2**	**β *(mg/g)***	**α (mg/min)**	**R^2**
50.000	3.140	0.030	1.660	0.659	0.017	4.778	0.984	0.768	0.658	0.879
100.000	5.340	0.014	2.300	0.140	0.007	8.382	0.969	1.536	0.179	0.879
150.000	6.610	0.131	7.320	0.956	0.004	10.846	0.939	2.248	0.071	0.877
200.000	8.390	0.058	17.370	0.940	0.007	12.642	0.989	2.938	0.050	0.879
250.000	9.470	0.069	3.310	0.878	0.001	16.722	0.877	3.505	0.036	0.877
300.000	10.380	0.047	10.350	0.915	0.008	15.385	0.992	4.243	0.023	0.875
350.000	10.730	0.047	10.350	0.915	0.002	15.576	0.936	4.530	0.019	0.866
400.000	12.560	0.043	11.890	0.913	0.017	11.628	0.992	5.351	0.016	0.858
450.000	13.320	0.046	13.070	0.913	0.003	16.234	0.958	5.848	0.014	0.865
500.000	14.280	0.048	14.390	0.915	0.002	19.841	0.909	6.689	0.010	0.879

Table 2 (b): Kinetic Models Constants Parameters for Cadmium adsorption on CHIC

		Pseudo First-Order			**Pseudo Second-Order**			**Elovich**		
C_o (mg/L)	**$q_{e\ exp}$ (mg/g)**	**K_1 (1/h)**	**$q_{e\ cal}$ (mg/g)**	**R^2**	**K_2 (g/mg.min)**	**$q_{e\ cal}$ (mg/g)**	**R^2**	**β (mg/g)**	**α (mg/min)**	**R^2**
50.000	2.745	0.051	3.004	0.970	0.008	4.880	0.952	0.944	0.191	0.969
100.000	4.947	0.048	5.402	0.963	0.002	9.017	0.839	1.886	0.000	0.969
150.000	6.409	0.056	6.446	0.943	0.002	12.642	0.876	2.831	0.030	0.969
200.000	7.594	0.050	16.479	0.949	0.004	13.055	0.955	3.775	0.018	0.969
250.000	8.470	0.038	5.393	0.904	0.002	15.479	0.941	4.719	0.013	0.969
300.000	9.248	0.041	9.892	0.907	0.003	16.103	0.958	5.179	3.577	0.963
350.000	9.642	0.044	8.050	0.901	0.006	13.245	0.956	5.089	0.011	0.913
400.000	10.307	0.039	12.441	0.906	0.001	17.986	0.849	5.945	0.009	0.922
450.000	10.611	0.038	13.803	0.905	0.008	10.753	0.984	6.638	0.008	0.919
500.000	10.849	0.049	12.308	0.873	0.007	9.940	0.978	7.376	0.007	0.919

Table 2 (c): Kinetic Models Constants Parameters for Copper adsorption on CHIC

C_o *(mg/L)*	$q_{e\,exp}$ *(mg/g)*	*Pseudo First-Order*			*Pseudo Second-Order*			*Elovich*		
		K_1 *(1/h)*	$q_{e\,cal}$ *(mg/g)*	R^2	K_2 *(g/ mg.min)*	$q_{e\,cal}$ *(mg/g)*	R^2	β *(mg/g)*	α *(mg/min)*	R^2
50.000	3.024	0.032	1.659	0.579	0.015	4.737	0.983	0.726	0.751	0.952
100.000	4.904	0.073	3.725	0.679	0.006	7.874	0.962	1.452	0.157	0.952
150.000	6.285	0.025	2.324	0.335	0.003	10.661	0.926	2.178	3.301	0.952
200.000	7.094	0.019	3.161	0.094	0.002	12.516	0.899	2.904	0.031	0.952
250.000	8.119	0.007	1.083	0.015	0.003	11.274	0.948	3.630	0.014	0.952
300.000	8.171	0.016	1.856	0.160	0.005	11.723	0.966	4.241	0.011	0.946
350.000	8.913	0.128	15.149	0.947	0.008	13.661	0.974	4.991	0.009	0.946
400.000	10.071	0.108	14.237	0.960	0.002	16.474	0.941	5.645	0.008	0.945
450.000	10.619	0.099	14.664	0.957	-0.138	15.723	0.985	6.086	0.008	0.933
500.000	11.119	0.099	16.292	0.957	0.001	20.746	0.882	6.762	0.007	0.933

Table 2 (d): Kinetic Models Constants Parameters for Lead adsorption on CHIC

C_o **(mg/L)**	$q_{e\,exp}$ **(mg/g)**	**Pseudo First-Order**			**Pseudo Second-Order**			**Elovich**		
		K_1 **(1/h)**	$q_{e\,cal}$ **(mg/g)**	R^2	K_2 ***(g/mg.min)***	$q_{e\,cal}$ **(mg/g)**	R^2	β ***(mg/g)***	α **(mg/min)**	R^2
50.000	3.024	0.048	3.022	0.969	0.008	4.880	0.952	0.989	0.177	0.938
100.000	4.904	0.039	5.592	0.964	0.002	9.017	0.839	1.979	0.057	0.938
150.000	6.285	0.062	6.282	0.948	0.002	12.642	0.876	2.969	0.026	0.938
200.000	7.094	0.049	16.325	0.951	0.004	13.054	0.955	3.959	0.017	0.938
250.000	8.119	0.043	8.702	0.905	0.002	15.479	0.941	4.949	0.011	0.938
300.000	8.171	0.012	20.023	0.866	0.003	16.103	0.958	5.416	0.009	0.908
350.000	8.913	0.051	10.188	0.919	0.006	13.245	0.956	5.670	0.000	0.851
400.000	10.071	0.061	11.414	0.928	0.001	17.986	0.849	6.507	0.006	0.854
450.000	10.619	0.097	14.480	0.957	0.732	1.107	0.984	6.823	0.005	0.821
500.000	11.119	0.097	16.088	0.957	0.007	9.940	0.978	7.558	0.005	0.819

Table 2 (e): Kinetic Models Constants Parameters for iron adsorption on CHIC

		Pseudo First-Order			*Pseudo Second-Order*			*Elovich*		
C_o *(mg/L)*	$q_{e\,exp}$ *(mg/g)*	K_1 *(1/h)*	$q_{e\,cal}$ *(mg/g)*	R^2	K_2 *(g/mg. min)*	$q_{e\,cal}$ *(mg/g)*	R^2	*β (mg/g)*	*α (mg/min)*	R^2
50.000	2.843	0.077	3.175	0.966	0.013	4.354	0.973	0.663	0.746	0.931
100.000	4.791	0.103	6.865	0.929	0.005	7.062	0.932	1.326	4.181	0.931
150.000	5.286	0.131	7.323	0.956	0.003	10.224	0.916	1.989	0.076	0.931
200.000	5.760	0.073	20.468	0.916	0.002	13.245	0.896	2.652	0.049	0.931
250.000	6.482	0.058	8.201	0.925	0.001	16.207	0.874	3.315	0.035	0.931
300.000	7.030	0.052	9.299	0.920	0.001	18.868	0.787	3.978	0.022	0.931
350.000	7.262	0.049	10.232	0.918	0.001	21.368	0.712	4.641	0.000	0.931
400.000	7.640	0.017	19.460	0.880	0.001	20.921	0.737	5.304	0.011	0.931
450.000	7.704	0.089	13.819	0.952	0.002	18.587	0.868	5.967	0.008	0.931
500.000	8.443	0.089	15.356	0.952	0.001	20.367	0.878	6.630	3.267	0.931

Conclusion

In this study, a composite adsorbent Composite adsorbent of Chemically Activated Cellulose and Chitosan (CHIC) was tested and evaluated as a possible adsorbent for removal of Heavy metals in wastewater using batch sorption technique. Experimental equilibrium data of Chromium, Copper, Cadmium and Iron followed the Freundlich model, while the Adsorption of Lead followed the xTemkin model. The fit with the Freundlich model, indicating multilayer sorption on a heterogeneous surface. The higher the K_F value the greater the adsorption intensity. The higher K_F values exhibited by the adsorption of Fe suggests that Fe has greater adsorption tendency towards the adsorbent. The maximum multilayer sorption capacity at 303K was estimated to be 1.345 L/g. In addition, the value of *1/n* was below unity indicating that the surface of the adsorbate was heterogeneous, multilayer and the mechanism of adsorption was a chemisorption process. The adsorption kinetics of Chromium, Copper followed pseudo-second-order kinetic model and the adsorption kinetics Cadmium, Lead and Iron followed pseudo-First-order kinetic model. The theoretical $q_{e\ cal}$ values are closer to the experimental $q_{e\ exp}$ values emphasizing the applicability of the models.

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