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PLANTAIN STALK POWDER AS A NOVEL ECO – FRIENDLY ADSORBENT FOR REMOVAL OF COPPER (II) IONS FROM AQUEOUS SOLUTIONS

Victor E. Ebiekpe[1] and Precious C. Chinonyere[1]
[1]Department of Pure & Applied Chemistry, Veritas University, Abuja – Nigeria

KeyWords
Adsorption, Agricultural-waste, Aqueous solutions, Isotherm, Langmuir model, Plantain stalk powder, R^2 Value

ABSTRACT

The removal of Cu^{2+} ions from aqueous solutions using plantain stalk powder (an agricultural waste) as a novel adsorbent was investigated using batch method. Factors influencing copper adsorption such as initial copper ion concentration (1.0 – 6.0 mg/l), pH (3 - 10) and contact time (1 – 5 hrs) at constant temperature 30^{o} C (303 K) were investigated. The adsorption process was relatively fast and equilibrium was established within 2 hrs. Maximum adsorption of 89.9% for Cu^{2+} ions was found to occur at around pH 5. The equilibrium data obtained were analyzed using different adsorption isotherm models. The result was best described by the Langmuir model with R^2 value of 0.98. The maximum adsorption capacity for the adsorption process calculated from the Langmuir isotherm was found to be 250 mg/g. The high value of the adsorption capacity indicated that plantain stalk powder can be used as an excellent alternative for the removal of Cu^{2+} ions from waste-water.

Introduction

Advances in science and technology have brought tremendous progress in many spheres of development but in the process, also contributed to degradation of environment due to very little attention paid to the treatment of industrial effluents[15]. The discharge of non-biodegradable heavy metals into water bodies is hazardous because the consumption of polluted water causes various health problems. Therefore it is important to apply an efficient method for heavy metal reduction to a very low concentration before discharge[2].Conventional methods for the removal of heavy metals include precipitation, coagulation/flocculation, ion exchange, electro-dialysis, solvent extraction etc. However, these methods are often prohibitively costly, non renewable; having inadequate efficiencies at low metal concentration.These constrains have caused the search for alternative method that would be environmental friendly and efficient for metal removal. Such a possibility offers a method that uses adsorbent fromvarious biological materials of little or no-cost[18].In recent years, attention has been directed towards the use of agricultural waste and by-products for the removal of heavy metals from industrial effluents. The adsorptions of these heavy metals from aqueous solutions using various agricultural waste products have been extensively studied for their technical visibility as adsorbents[1, 3, 5-10,14, 21]. Adsorption of heavy metals by these materials might be attributed to their protein, carbohydrates and phenolic compounds which have metal binding functional groups[22].

Plantain one of the common names for herbaceous plants of the genus *Musa*, the other being "banana" is the tenth most important staple that feeds the world[16]. They are a major food staple in East Africa, West and Central Africa (Cameroon), Central America, the Caribbean Islands and northern, coastal parts of South America[19]. Plantains fruit all year round which makes the crop a reliable all-season staple food, particularly in developing countries with inadequate food storage, preservation and transportation technologies. Although they appear to be trees, *Musa* species are technically perennial herbaceous plants because their hard, fibrous “trunks” are actually pseudo-stems composed of overlapping bases of the large, spirally arranged leaves, typically 8–20 per plant. The primary stem bears a single large terminal inflorescence, a spike with pistillate (female) flowers below and staminate (male) flowers above. This develops into a bunch of plantain, consisting of 4–6 clusters of8–10 plantains each, spiralling around the central peduncle (stalk). The peduncle is the stalk that supports the inflorescence and attaches it to the rhizome. Plantains are high in carbohydrates, fibre, potassium, magnesium, phosphorus, and several vitamins. Fruits, leaves, and stems have numerous traditional medicinal uses; including treating dysentery, diarrhoea, and digestive disorders. Lixivium from plantain stalk is used to control powdery mildew[11]. The aim of the present study is to investigate the feasibility of using plantain stalk powder as an alternative adsorbent for the maximum removal of copper ions from aqueous solutions.

Materials and Methods

Materials: Copper sulphate ($CuSO_4.5H_2O$) was used for the preparation of the stock solution of Cu^{2+}in distilled water. For the pH adjustment throughout the experiment, 0.1M hydrochloric acid (HCl) and 0.1M sodium hydroxide (NaOH) were used as necessary.All chemicals used in the present study were of analytical grade. Atomic Adsorption Spectrophotometer (AAS) model HGA 850, USA, was used to determine the concentration of Cu^{2+} ions.

Preparation of plantain stalk powder: Plantain stalk used for this study were remove manually from a fresh plantain bunch inflorescent obtained from a local market around Veritas University in Obehie, Abia State – Nigeria. The plantain stalk was washed several times with distilled water to remove dirt and sand debris. The plantain stalk was cut into small pieces and dried in an oven at 60^o C for 24 hours. The dried stalk were grounded to fine powder, sieved with 120µm (micrometer) mesh and preserved in a sample bottle for use as adsorbent.

Experimental procedure Batch adsorption experiments were carried to study the effect of contact time, effect of initial metal ion concentration and the effect of pH on the adsorption of Cu^{2+} ions by plantain stalk powder. Adsorption studies were carried by treating 20ml of each metal ion solution and 0.3g of the adsorbent. At the end of each experiment, the content of each tube was filtered and the concentration of the metal ions in each filtrate was determined using Atomic Adsorption Spectrophotometer (AAS).

Variation of contact time: The adsorption of the metal ions on plantain stalk powder was studied at various time intervals (1 to 5 hours). The metal ions solutions were measured into five labeled sample containers each containing 0.3g of the adsorbent. The mixture was uniformly agitated for one (1) hour. The experimental setup was thereafter repeated for various time intervals of 2, 3, 4 and 5 hours. At the end of each contact time, the content of each sample tube was filteredand the concentration of the metal ion in the filtrates was determined using Atomic Adsorption Spectrophotometer (AAS).The equilibrium time for the adsorption of Cu^{2+} ion onto the adsorbent was noted. The amountof metal ions adsorbed at time t, q_t (mg/g) and the adsorption efficiency (%) of Cu^{2+}were calculated using equation 1 and 2 respectively:

$$q_t = [(C_o - C_t)V]/W \quad (1)$$
$$q_t =[(C_o - C_t)/C_o)]x100 \quad (2)$$

where C_o (mg/l) is the initial concentration of the Cu^{2+} ions and C_t (mg/l) is the concentration of the copper ion at any time, t, V (ml) is the volume of the solution and W (g) is the mass of dry adsorbent used.

Variation of initial metal ion concentration: Batch adsorption was carried out using initial metal ion concentrations of 1.0, 2.0, 4.0 and 6.0mg/l each for the aqueous solutions of Cu^{2+} ions. 0.3g of adsorbent was weighed into each of the four labeled sample containers and 20ml of 1.0mg/l solution of each metal was measured into the containers. The adsorption mixtures were uniformly and continuously agitated for equilibrium time of two (2) hours. After which the content of each sample container was filtered. The concentration of the metal ion in the filtrates was determined using Atomic Adsorption Spectrophotometer (AAS). The amount of metal ions adsorbed at equilibrium time of 2 hours, q_e (mg/g) and the adsorption efficiency (%) of Cu^{2+} were calculated using equation (3) and (4) respectively.

$$q_e = [(C_o - C_e) V]/W \quad (3)$$
$$q_e =[(C_o - C_e)/C_o]x100 \quad (4)$$

whereC_e (mg/l) is the concentration of the copper ion at equilibrium time, t.

Variation of pH: The metal ions solutions of different pH (3 - 10) values were measured into five labeled sample containers containing0.3g of the adsorbent. The adsorption mixtures were uniformly and continuously agitatedfor equilibrium time of two (2) hours. After which the content of each sample container was filtered and the concentration of the metal ions in the filtrates was determined using Atomic Adsorption Spectrophotometer (AAS). The amount of metal ions adsorbed at different pH values within the equilibrium time of 2 hours, q_e (mg/g) and the adsorption efficiency (%) of Cu^{2+} were calculated using equation 3 and 4 respectively.

Results and Discussion

Characterization of the adsorbent: Some physico-chemical characteristics of the plantain stalk powder were investigated and compared with those of the commercial activated carbon (CAC). The physico-chemical characteristics determined were moisture content and pH value (Table 1). The result showed that the pH value and the moisture content obtained from plantain stalk powder were within the limit of the reference activated carbon.

Effect of Contact Time: The effect of contact time on the extent of adsorption of Cu^{2+} ions was studied and the result obtained is depicted in FIG 1. From the result, the percent removal of Cu^{2+} ions was found to be high after the first 1 hour and then increases slowly until it reaches saturation level after 2hours indicating equilibrium point.The initial faster rate may be due to availability of the free sites on the adsorbents. As these were progressively filled, the more difficult the sorption becomes.

Effect of Initial Cu^{2+} ion Concentration on the Adsorption: The effect of initial concentration on the percent removal of Cu^{2+} ion by the adsorbentis presentedin FIG. 2. The result showed that percentage removal decreased with increase in metal ion concentration. The plausible reason for this might beattributed to the fact that at lower initial metal ion concentrations, sufficient adsorptionsites are available for the adsorption of the heavy metal ions[17].

Effect of pH on Cu^{2+} Adsorption: The pH is an important parameter in adsorption process because it affects the surface charge of the adsorbent and the degree of ionization. FIG. 3 shows that maximum percentage of Cu^{2+} adsorbed on plantain stalk powder were observed at pH 5.3. An increase in the adsorption occurred in the pH range of 3 to 5 and slightly decreased at higher pH values.

Analysis of Adsorption Isotherms: The equilibrium data for Cu^{2+} removal were tested for fit. From the result obtained (FIG. 4 and Table 2), the experimental data were best described by the Langmuir isotherm model (Equation 5) with regression coefficient (R^2) of

0.98.R^2 is regarded as a measure of the goodness-of-fit of experimental data on the isotherm models. The constant q_m (mg/g) is a measure of maximum adsorption capacity of the adsorbent and K_a (l/mg) is a constant related to energy of adsorption. This indicates that the adsorption of Cu^{2+}takes place as monolayer adsorption on the adsorbent surface, homogenous in adsorption affinity and with constant adsorption energy.The essential characteristics of the Langmuir isotherm can be expressed in terms of a dimensionless constant separator factorR_L, calculated using equation (6):

$$1/q_e = (1/k_a q_m).1/C_e + 1/q_m \quad (5)$$

$$R_L = 1/(1+K_a C_o) \quad (6)$$

The value of R_L indicates the shape of the isotherm to be either unfavourable (R_L>1), linear (R_L = 1), favourable (0 < R_L< 1), or irreversible (R_L = 0). The values of R_L obtained from the present study as presented in Table 3 is in the range (0 <R_L< 1), which is an indication of the favourable adsorption of the Cu^{2+} on the adsorbents[6].

Conclusions

The use of plantain stalk (an agricultural waste) powder as an adsorbent seems to be an effective, economical and promising alternative over conventional methods for the removal of heavy metal ions from aqueous solutions.

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TABLE 1 Physiochemical parameters of plantain stalk powder

Physiochemical parameters	Values
% moisture content	2.4
pH	7.2

TABLE 2 Isotherm parameters for the adsorption of Cu^{2+} by plantain stalk powder

Langmuir isotherm		
R^2	q_m (mg/g)	K_a (l/mg)
0.984	250	0.308

TABLE 3 R_L values at different initial Cu^{2+} ions concentration

Initial Cu^{2+} concentration, C_o (mg/l)	R_L value
1.0	0.76
2.0	0.62
4.0	0.45
5.0	0.35

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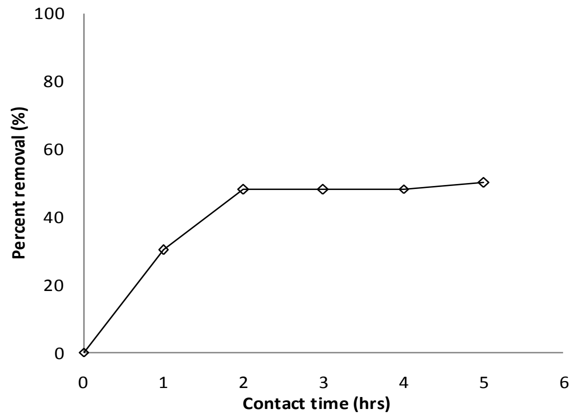

FIG. 1 Effect of contact time on percent removal of Cu^{2+} ions by plantain stalk powder at 30^{o}C

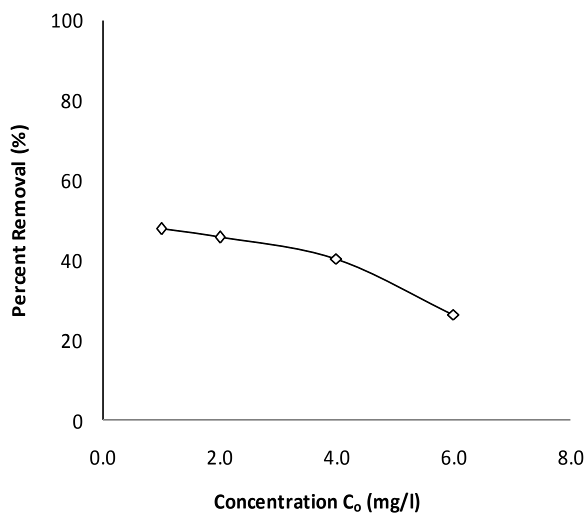

FIG. 2 Effect of initial metal ion concentration on percent removal of Cu^{2+} ions by plantain stalk powder at 30^{o} C

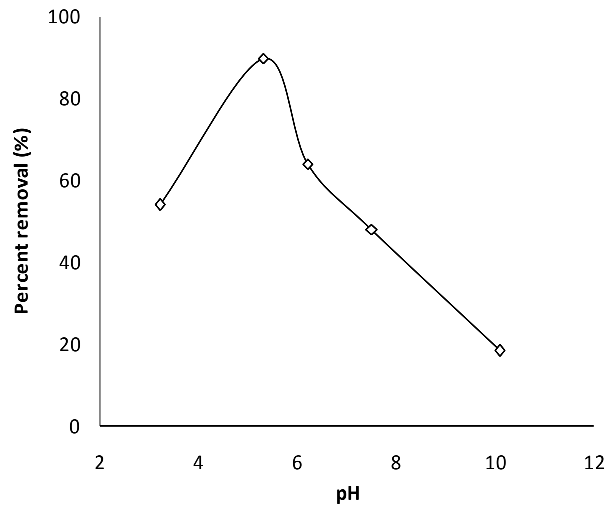

FIG. 3 Effect of pH on percent removal of Cu^{2+} ions by