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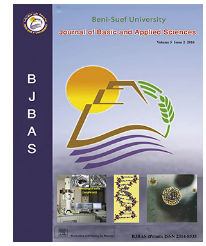

Full Length Article

Evaluation of optimum adsorption conditions for Ni (II) and Cd (II) removal from aqueous solution by modified plantain peels (MPP)

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ABSTRACT

The most ideal conditions for the adsorption of Ni (II) and Cd (II) ions onto modified plantain peel (MPP) from aqueous solution were investigated. The effects of three adsorption variables (pH, MPP dose and initial adsorbate concentration) were studied using central composite design (CCD), a subset of response surface methodology (RSM). Quadratic models were developed for both Ni (II) and Cd (II) percentage removals. The prime adsorption conditions obtained were pH of 4.36, MPP dose of 0.82 g and initial concentration of 120 mg/L with desirability of 1.00 which gave good monolayer adsorption capacities of 77.52 and 70.92 mg/g for Ni (II) and Cd (II) respectively. The adsorption data were modelled using Langmuir and Freundlich adsorption isotherms; the equilibrium adsorption of both Ni (II) and Cd (II) on MPP obeyed Langmuir model, and pseudo-second-order kinetics was the order that best described the two adsorption processes.

1. Introduction

Air, food, soil and water were narrated to be the media where heavy metals such as copper, cadmium, nickel, lead, and zinc are introduced into the environment (Garba et al., 2015c; Sadaf et al., 2015). These heavy metals are reported to be hazardous resulting in damage to ecosystems as well as human health (Ozdes et al., 2009; Tuzen et al., 2009) especially if their concentration is more than the accepted limit (Alslaibi et al., 2013). Their main sources include wastewater discharged from hospitals (Verlicchi et al., 2010), different industries such as Cd–Ni battery, metal plating and alloy manufacturing (Khavidaki and Aghaie, 2013; Kobya et al., 2005; Krishnan et al., 2011; Kula et al., 2008). Presence of these metals in waste stream and ground water is a very serious environmental concern since these metal ions are toxic to various life forms; therefore, removing them as well as controlling their levels in waste waters is very crucial (Serencam et al., 2008).

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Chemical precipitation, ion exchange, electrodialysis, solvent extraction, coagulation, evaporation and adsorption are among the most prevalent technologies for the removal of metal ions from aqueous solutions (Garba and Afidah, 2014; Garba et al., 2014, 2015b; Mohammadi et al., 2015; Mohan et al., 2008; Mondal et al., 2015), with adsorption being the most widely used method for removing contaminants from wastewater (Farghali et al., 2013; Garba et al., 2015a). Sorption methods are considered flexible and easy to operate with much less sludge disposal problems (Cao et al., 2014; Mohammadi et al., 2015).

Various adsorbents were narrated in the literature for the removal of heavy metal ions; however, new adsorbents with local availability, high adsorption capacity as well as economic suitability are still needed. This prompted many researchers into investigating cheaper substitutes such as zeolites, silica gel, chitosan, clay materials and agricultural wastes (Mekatel et al., 2015; Shirzad-Siboni et al., 2015; Tsai et al., 1998). Response surface methodology (RSM) is a mathematical model that was reported to be a very useful tool in optimizing the preparation conditions of activated carbons (Garba and Afidah, 2015), but not much was reported on its application in optimizing adsorption process parameters.

Therefore, the innovative aspect of this research is to optimize the paramount parameters for an effective adsorption of Ni (II) and Cd (II) from an aqueous solution using CCD. CCD was chosen to evaluate the interaction of the most crucial adsorption parameters such as pH, MPP dose as well as initial concentrations.

2. Materials and methods

2.1. Reagents

All the chemicals used in this work were of analytical reagent grade purchased from Sigma-Aldrich and Merck (Darmstadt, Germany); they were used without any further purification. All the glassware used was washed and rinsed several times. Nickel and cadmium solutions and standards were prepared by using analytical grade nickel chloride ($NiCl_2{\cdot}6H_2O$) and cadmium chloride ($CdCl_2$) with distilled water. The solutions of Ni (II) and Cd (II) were prepared from stock solutions containing 1000 mg/L of Ni (II) and Cd(II), respectively.

2.2. Preparation of adsorbent material

Plantain peels used in this study were collected from local food sellers, restaurants and eateries around Samaru and Sabon Gari Local Government of Kaduna state, Nigeria. They were washed and sun dried for 7 days. The dried plantain peels were then crushed into smaller particles in a mortar and sieved with 150 μm sieve until a reasonable quantity of that particle size is obtained, followed by repeated washing to eliminate dust and other impurities. It was then dried in an oven at 25 °C for about 48 h after which it was stored in sterilized closed glass bottles prior to use as an adsorbent. The powdered plantain peels were then modified by immersing in 5% solution of NaOH and autoclaved at 121 °C for 15 min at 10 psi. After keeping at 25 °C for 48 h, it was filtered and washed many times with distilled water until clear water with neutral pH was obtained (Ashrafi et al., 2014). Then, the modified plantain peel (MPP) was dried at 25 °C for 48 h. The MPP was applied for all the adsorption experiments.

2.3. Metal ions adsorption experiments

In order to study and evaluate the significance of variables on the percentage removal of Ni (II) and Cd (II), the adsorption experiments were carried out using a batch procedure by shaking 100 mL of the metal ions solutions in a 250 mL Erlenmeyer flask according to the pH, MPP dose and initial concentration as shown in Table 1. The coded points and their corresponding values are presented in Table 2. During the adsorption process, the flasks were agitated on a mechanical shaker at 150 rpm. The aqueous samples were analysed using an inductively coupled plasma-atomic emission spectrometer. The adsorption efficiencies were evaluated using the following equation:

$$\text{Adsorption efficiency (\%)} = \frac{C_o - C_e}{C_o} \times 100 \quad (1)$$

where C_o and C_e are the liquid-phase concentrations at initial and equilibrium states (mg/L), respectively.

The equilibrium amounts q_e (mg/g) adsorbed per unit mass of adsorbent were evaluated using Equation (2):

$$q_e = \frac{(C_o - C_e)V}{W} \quad (2)$$

where q_e (mg/g) is the equilibrium amount of the metal ions adsorbed per unit mass of MPP; V (L) is the volume of the solution and W (g) is the mass of MPP used.

The kinetic tests were identical to those of equilibrium. The aqueous samples were taken at preset time intervals and the metal ions concentrations were measured. The amount adsorbed at time t, q_t (mg/g) was calculated using Equation (3):

$$q_t = \frac{(C_o - C_t)V}{W} \quad (3)$$

where C_o and C_t (mg/L) are the liquid-phase concentration at the initial and any time t, respectively.

2.4. Adsorption isotherms and kinetic models

2.4.1. Adsorption isotherm

The equilibrium characteristics of this adsorption study were described through Langmuir (Lang) and Freundlich (Freund). Lang model presumes monolayer adsorption onto a surface containing finite number of adsorption sites (Langmuir, 1916). Its linear form is given as:

$$\frac{C_e}{q_e} = \frac{1}{K_L \cdot Q_a^0} + \frac{C_e}{Q_a^0} \quad (4)$$

Q_a^0(mg/g) and K_L (L/mg) are Lang constants related to adsorption capacity and rate of adsorption, respectively.

The essential characteristics of Lang model can be described by dimensionless separation factor, R_L, given as: