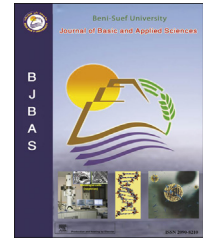


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Potential of a low-cost bentonite for heavy metal abstraction from binary component system

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ABSTRACT

A low-cost and easily obtainable Nigerian bentonite (UAB) was utilized for the removal of heavy metals (Nickel and Manganese) from a binary system. The bentonite was used without chemical modification in order to keep the process cost low. A Fourier transform infrared spectrum was utilized to determine the surface functional groups responsible for adsorption. Scanning electron microscopy revealed a porous surface of UAB. Batch adsorption methodology was applied to study the effect of pH, initial metal ion concentration, adsorbent dose, adsorbent particle size, ligands (citric acid and EDTA), contact time and temperature on the adsorption process. The isotherm data were analyzed using the Langmuir, Freundlich, Temkin and Scatchard isotherm. Scatchard plot analysis revealed the heterogeneous nature of UAB. Kinetic parameters were tested using the pseudo-first order, pseudo-second order, intraparticle and film diffusion models. The presence of film diffusion mechanism was found to play a major role in the adsorption process. Thermodynamic studies revealed an endothermic, spontaneous and physical adsorption process. Importantly, over 90% of both metal ions were desorbed from the bentonite in desorption studies. The results indicated the potential of UAB as a low-cost and eco-friendly adsorbent for the removal of Ni(II) and Mn(II) ions from aqua media.

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1. Introduction

The pollution of water with toxic substances is a major problem because it affects the environmental quality as well as plants, animals and human health. Heavy metals are one of the toxic substances and are hazardous even at very low concentrations (Liu et al., 2008). Heavy metals are harmful because they are non-biodegradable, bio-accumulate in the

food chain and are persistent in nature (Ceribasis and Yetis, 2001). Manganese for instance is toxic mainly because of its organoleptic properties (Taffarel and Rubio, 2009). Nickel which is used to produce ferrous steel cutlery and mainly obtained from Ni/Fe storage batteries is responsible for gastrointestinal irritation and lung cancer in humans when present above the threshold limit (Greenwood and Earnshaw, 1993). As a result of the toxic effect of these heavy metals, the need for their removal from industrial wastewaters is very

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important. This led to the use of many techniques for their removal from wastewaters by many researchers such as solvent extraction, ion exchange, chemical precipitation, membrane separation, reverse osmosis, electrolysis and adsorption (Tewari et al., 2005). These techniques are expensive, complicated; time consuming and sometimes ineffective in the lowering of concentration ranges (Schiewer and Patil, 2008).

The adsorption technique has been found to be superior to the other techniques for removal of heavy metals, in terms of cost, flexibility, simplicity of design, ease of operation, insensitivity to toxic pollutants and better removal efficiency (Amer et al., 2010; Mohan et al., 2008). Also, it does not result in the formation of harmful substances like most of the other techniques. Activated carbon has been found to be the most effective adsorbent for the removal of metals from solution due to its high adsorption capacity. However, it is expensive and this limits its wide spread use in most industries and developing nations. As a result, many researchers have studied the use of several low-cost adsorbents for the removal of metal ions from solution, so as to minimize the problem of high cost involved in the use of activated carbon. Some of the low-cost adsorbents that have been utilized include agricultural waste and biomass materials, clays, zeolites, siliceous materials, fly ash and bentonite (Bhattacharyya et al., 2008; Dawodu et al., 2012a; Vaghetti et al., 2008). This study is an extension in the same direction in utilizing a commonly available adsorbent, namely, bentonite for the removal of heavy metals from solution. Bentonite was chosen because it is present in an abundant amount in Afuze, Owan east local government area, Edo state, Nigeria and can be utilized as a cheap alternative adsorbent. Bentonite has also been reported to have a high adsorption capacity for heavy metals due to its high specific surface area, small particle size, high porosity and high cation exchange capacity (Doulia et al., 2009).

This paper reports the use of a natural Nigerian bentonite for the simultaneous adsorption of Ni(II) and Mn(II) ions from aqueous solution as a low cost adsorbent. The bentonite was used without chemical modification or treatment in order to keep the process cost low. The effect of pH, initial metal ion concentration, contact time, adsorbent dose, particle size, temperature and ligand were determined. Equilibrium, kinetic and thermodynamic parameters were also evaluated to help provide a comprehensive explanation of the sorption process.

2. Experimental

2.1. Preparation of adsorbent

The bentonite was obtained from Afuze, in Owan east local government area, Edo state, Nigeria. It was then dissolved in excess distilled water in a pretreated plastic container, stirred to ensure uniform dissolution and then sieved through a 500 μm mesh, in order to get rid of plant materials and unwanted particles. The suspension was allowed to settle for 24 h and then excess water was decanted. The bentonite residue was sundried for several days and then dried in an

oven at 105 °C for 4 h, to get rid of water present. The dried bentonite was then pulverized and passed through mesh sieves of sizes 100–500 μm , to obtain the unmodified Afuze bentonite (UAB). The prepared adsorbent was then preserved in an air-tight polythene bag until use.

2.2. Adsorbent characterization

The elemental composition of UAB was determined after digestion of the sample with nitric acid and by the use of the Atomic Absorption Spectrophotometer (AAS) (Buck scientific model 210VGP) as described (Papafiliopaki et al., 2008). Cation exchange capacity (CEC) of UAB was determined by the ammonium acetate method (Rhoades, 1982). The pH point of zero charge (pHpzc) was carried out as described (Onyango et al., 2004), while the slurry pH of UAB was obtained by soaking 1g of the adsorbent in 50 ml of distilled water, then stirred for 24 h and filtered, after which the final pH was determined by the use of a pH meter. A Fourier Transform Infrared (FTIR) spectrum of UAB was determined by the Fourier Transform Infrared spectrophotometer (Shimadzu FTIR 8400s). The BET surface area and pore property of UAB was determined via nitrogen adsorption-desorption isotherms by the use of a micromeritics ASAP 2010 model analyzer. The Scanning Electron microscope (SEM) (Hitachi S4800 model) was used to access the morphology of the adsorbent. X-ray diffraction (XRD) analysis was determined using a model MD 10 Randicon diffractometer operating at 25kv and 20 mA. The scanning regions of the diffraction were 16–72° on the 2 θ angle.

2.3. Preparation of binary solution

All the reagents used in this study were of analytical grade obtained from Sigma Aldrich and were used without further purification. A binary stock solution containing 1000 mg/L of Ni(II) and Mn(II) ions was prepared by dissolving appropriate amounts of NiSO₄·6H₂O and MnSO₄·H₂O in 1 L double distilled water. The stock solution was used to prepare dilute solutions of different working concentrations (100–500 mg/L). The pH of the solution was altered to values ranging from 2.0 to 8.0 by the drop wise addition of 0.1M NaOH or 0.1M HCl when required.

2.4. Batch adsorption

The adsorption of Ni(II) and Mn(II) ions unto UAB was studied by the use of batch adsorption procedure. The effects of various operating parameters on adsorption were determined. Each experiment was performed in duplicate and the mean value was computed to ensure quality assurance. At the end of a given contact time for each experiment, the solution mixture was filtered using whatmann No.1 filter paper and the residual Ni(II) and Mn(II) ion concentration in the filtrate was determined using the AAS. The batch experiments were performed under optimum experimental condition as described: The effect of pH was determined at pH values of 2–8 by adding 0.1 g of UAB to 50 ml of solution, at a solution concentration 100 mg/L, contact time 180min, adsorbent particle size 100 μm and at room temperature of 300 K. Initial metal ion

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