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Removal of nickel by activated carbon from sewage sludge

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ABSTRACT

Activated carbons have been prepared from sewage sludge of the municipal wastewater treatment plant using chemical activation method. Porous structure of activated carbon was characterized by nitrogen adsorption and scanning electron microscopy. And activated carbon was also characterized by its surface area and porosity. Then it was used as an adsorbent for the removal of nickel ions from aqueous solution. The effects of parameters such as contact time and initial nickel ion concentration were investigated. The adsorption kinetics of nickel ions in aqueous solution onto activated carbon was investigated through experimental data. The results showed that the adsorption processes were perfectly fitted to the pseudo-second order model with very high regression coefficients. It may be evaluated as an environmentally friendly and extra economic treatment of nickel ions in aqueous solution.

KEYWORDS

Activated carbon; Porous materials; Sewage sludge; Nickel ions.

INTRODUCTION

The ground and surface waters pollution by chemical contaminants is a worldwide problem. Heavy metal contamination of water sources is hazardous to plants, animals and microorganism and can be carcinogenic to mankind[1]. On the other hand, metals are playing important roles in most industries. Copper for instance is used in engine moving parts, brake linings, metal plating, fungicides, insecticides et al.[2]. In order to remove undesired heavy metals, chemical separation, membrane processes, electro chemical treatment, electro-deposition and adsorption have been used[3].

Activated carbon is the most widely used adsorbent due to its effectiveness and versatility[4], but it is relatively expensive[5]. So many investigations have made efforts in low cost alternatives to activated carbon from waste, such as corncob, peanut shells and waste fiberboard[6,7].

The sewage sludge from municipal wastewater treatment plant is an inevitable by-product during wastewater purification. Most disposal methods, such as sea dumping, landfill, individual combustion and farmland utilization, have some limitations, and lots of sewage sludge is not disposed properly, causing serious waste and pollution. Thus, it is significant to search for innovative approaches to using sewage sludge[8]. In recent years, some researchers have focused on converting sewage sludge into activated carbon based on its high content of organic components[9,10]. This would not only solve the disposal problem of sewage sludge but also turn solid waste into useful material in producing adsorbent for wastewater treatment. Several studies have demonstrated the feasibility of this approach including chemical and physical activation[11,12].

In this work, activated carbon from sewage sludge of the municipal wastewater treatment plant was prepared by chemical activation method. Then, the pore structure characteristics and adsorption kinetic of the activated carbon were investigated.

MATERIALS AND METHODS

Preparation of the adsorbents

The sewage sludge of the municipal wastewater treatment plant was obtained from the municipal wastewater treatment plant of Shaoxing City in Zhejiang Province of P.R. China. It contained around 33% inorganic matter mainly in the form of metal oxidation and salt, and 63% of organic matter mainly in the form of death biosolid, and about 4% water content. The content of Cu, Cr, Pb, As and Cd in the sewage sludge of the municipal wastewater treatment plant was 221mg/kg, 165 mg/kg, 57 mg/kg, 3.6mg/kg and 2.58 mg/kg respectively. The raw sewage sludge was dried at 105 ℃ for 8 h, to achieve constant weight, then comminuted and sieved into a uniform size of 80 mesh. The 50 g of dehydrated sewage sludge was soaked stilly with 100mL 10% HCl solution in 250 mL Erlenmeyer flasks for 24 h at room temperature. Then, it was soaked again stilly with 100mL 25% $ZnCl_2$ solution in 250 mL Erlenmeyer flasks for 24 h at room temperature. Then, it was dried again at 105 ℃ for 8 h to constant weight and was carbonized at 600 ℃ in a muffle furnace for 50 min. The product of 80 mesh activated carbon was thus obtained and stored for later adsorption experiments.

Adsorption experiments

Adsorption experiments were conducted in a set of 250 mL Erlenmeyer flasks containing 0.10g of activated carbon and 100 mL of nickel ion solutions with various initial concentrations (20mg/L, 30mg/L, 40mg/L and 50mg/L). The initial pH was adjusted to 5.0 with 1 mol/L HCl. The flasks were placed in a shaker at a constant temperature 293K and 200 rpm. The samples were filtered and the residual concentration of nickel ion was analyzed by atomic absorption spectrophotometry (AAS).

Analytical methods

The textural characteristics of activated carbon including surface area, pore volume, pore size distribution were determined using standard N_2-adsorption techniques. The surface physical morphology of activated carbon was observed by a scanning electron microscope.

The amount of adsorbed nickel ion q_t (mg/g) at different time, was calculated as follows:

$$q_t = \frac{(C_0 - C_t) \times V}{m} \quad (1)$$

where C_0 and C_t (mg/L) are the initial and equilibrium liquid-phase concentrations of nickel ion respectively. V (L) is the solution volume and m (g) is the mass of adsorbent used.

Statistical analyses of data

All experiments were repeated in duplicate and the data of results were the mean and the standard deviation (SD). The value of the SD was calculated by Excel Software. All error estimates given in the text and error bars in figures are standard deviation of means (mean±SD). All statistical significance was noted at α=0.05 unless otherwise noted.

RESULTS AND DISCUSSION

The textural characteristics of activated carbon

The textural characteristics of activated carbon are obtained from the standard N_2-adsorption techniques. The adsorption and desorption isotherms of the activated carbon are shown in Figure 1. It can be seen that the isotherms were reversible, indicated simultaneous presence of micropores and mesopores. The specific surface area and pore structure of the activated carbons are measured. The BET surface area of activated carbon is 432.45 m^2/g, the total pore volume is 0.43 cm^3/g and the Nominal pore size is 0.53 nm. It shows that activated carbon has a large specific surface area typical for commercial activated carbons[13]. In addition, the content of Cu, Cr, Pb, As and Cd in activated carbon was 462mg/kg, 512 mg/kg, 130 mg/kg, 8.2mg/kg and 6.13 mg/kg respectively. The chemical activation of the sewage sludge of the municipal wastewater plant before the pyrolysis resulted in an increase of the adsorption capacity[14].

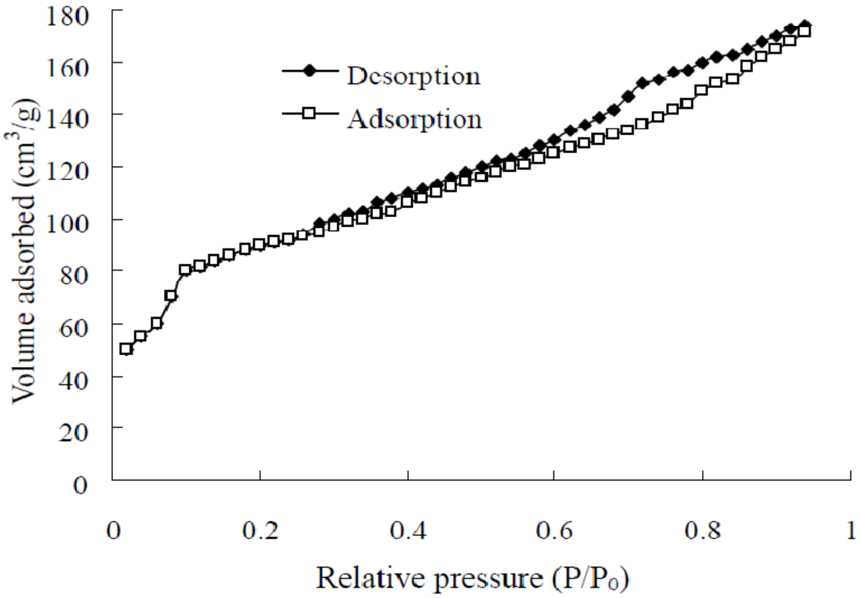


Figure 1: N_2 adsorption-desorption isotherms of activated carbon

The surface of the activated carbon is observed using scanning electron microscopy. Figure 2 shows the TEM image of activated carbon. Through this image irregular and porous structures can be observed, indicating that activated carbon presents an adequate morphology for dye adsorption.

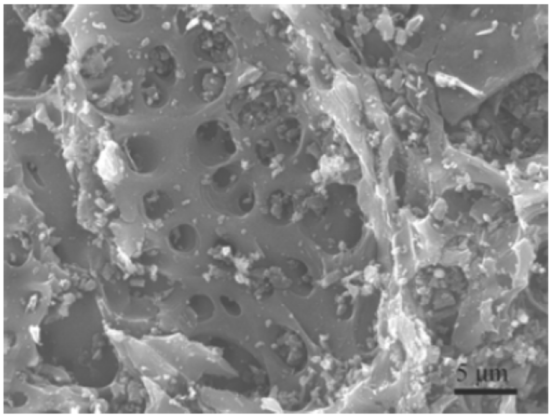


Figure 2: SEM image of activated carbon

Effect of contact time

The influence of contact time on the removal of nickel ions in aqueous solution by activated carbon is shown in Figure 3. It can be concluded that the adsorption process is very rapid. The adsorption rate of nickel ions increases sharply at short contact time and slowed gradually as equilibrium was approached. It may be due to the availability of initial large number of vacant surface active sites for adsorption and adsorption rate is very fast. As equilibrium was approached, the filling of vacant sites becomes difficult due to repulsive forces between nickel ions adsorbed on solid surface and nickel ions from solution[15].

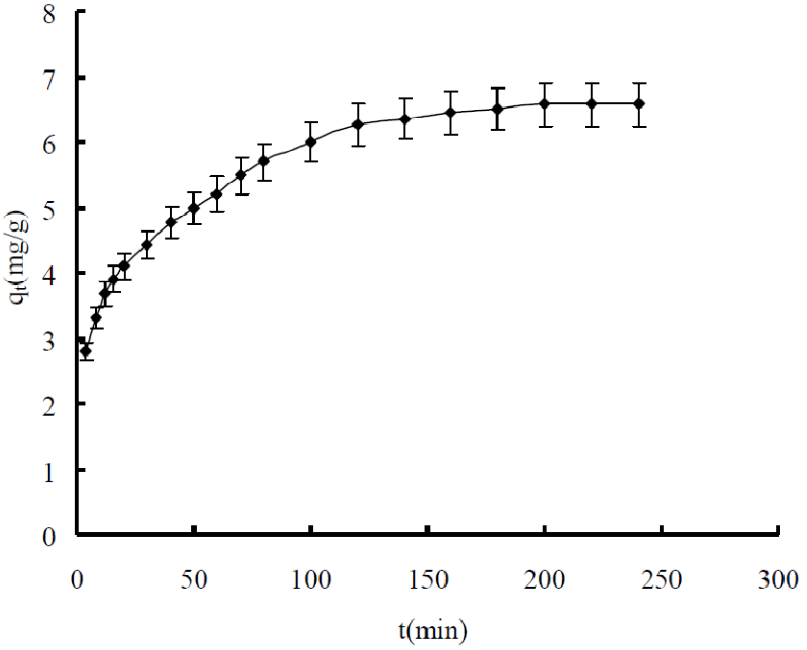


Figure 3: Effect of contact time on adsorption of nickel ions in aqueous solution onto activated carbon. Experimental conditions: 0.10 g of activated carbon, 20mg/L of initial nickel ions concentration, 293 K, 200 rpm and pH 5.0

Adsorption kinetics

In order to investigate the adsorption kinetic mechanism of nickel ions in aqueous solution onto activated carbon, three models (the pseudo-first-order model, the pseudo-second-order model and the intraparticle diffusion model) were used in this study.

The linear pseudo-first-order model of Lagergren is given as follows[16]:

$$\ln(q_e - q_t) = \ln q_e - k_1 \times t \qquad \textbf{(2)}$$

Where q_e and q_t are the amounts of nickel ions absorbed onto the adsorbent (mg/g) at equilibrium and at t respectively. k_1 is the rate constant of first-order adsorption (min^{-1}).

The pseudo-second-order kinetic model developed by Ho and McKay[17] is based on the experimental information of solid-phase sorption. The linear pseudo-second-order model can be expressed as follows:

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \qquad \textbf{(3)}$$

Where k_2 is the rate constant of second-order adsorption (g· mg^{-1}· min^{-1}).

According to Hamdaoui[16], any kinetic approach of the intraparticle diffusion may be deduced successively from works of Weber et al.[17] and Boyd et al.[18]. As proved recently[19], in order to appreciate the role of the intraparticle diffusion in the adsorption process, the following kinetic expression is used:

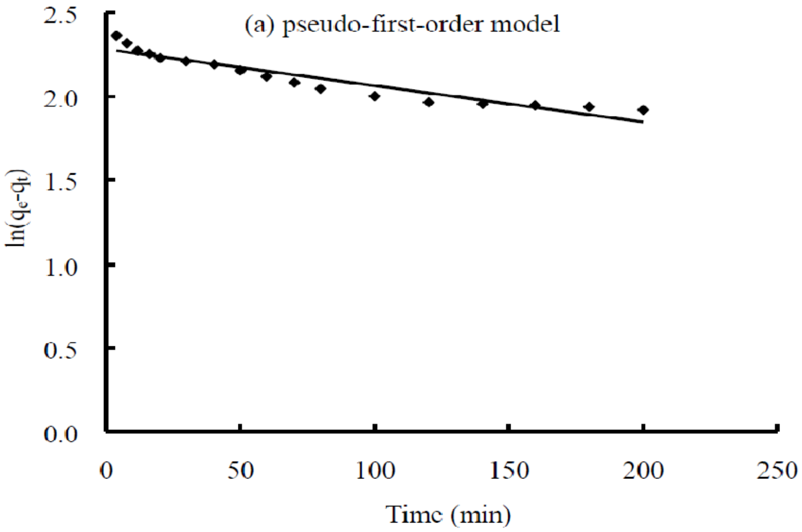
$$q_t = k_i t^{\frac{1}{2}} \qquad \textbf{(4)}$$

Or

$$q_t = k_i t^{\frac{1}{2}} + C_{st} \qquad \textbf{(5)}$$

Where k_i and C_{st} are the constant of intraparticle diffusion rate. It can be obtained from the slope of the straight line of q_t versus $t^{\frac{1}{2}}$

The adsorption kinetic models were shown in Figure 4.



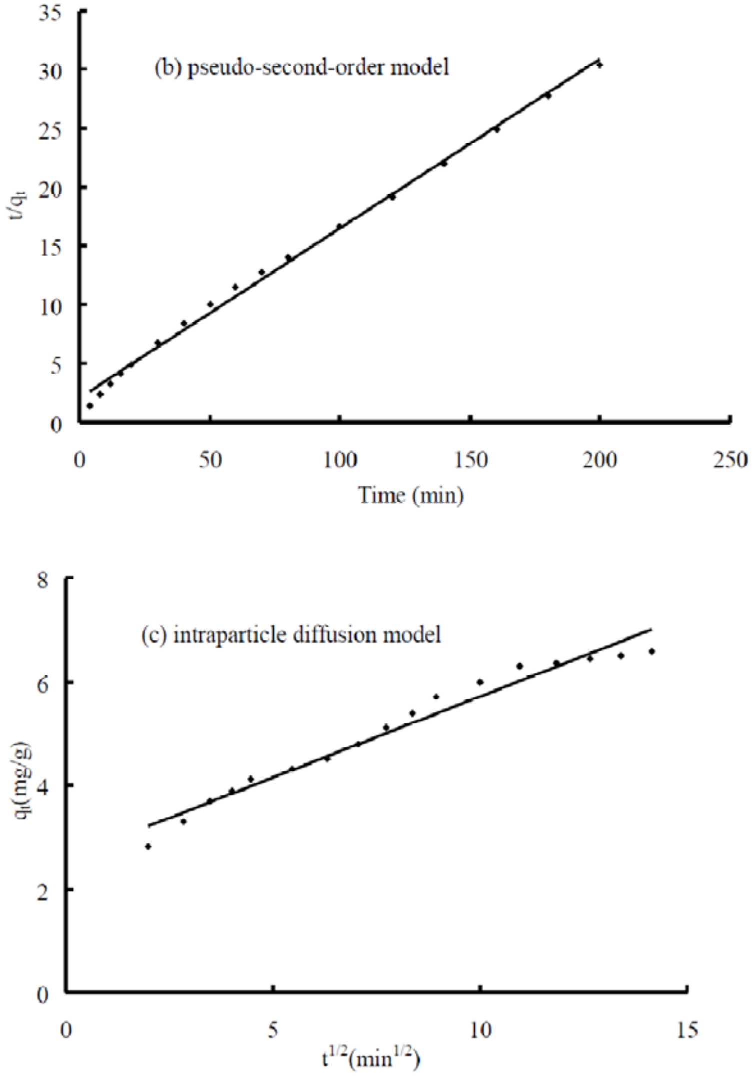


Figure 4: (a) pseudo-first-order model for adsorption of nickel ions in aqueous solution onto activated carbon at 3293 K, (b) pseudo-second-order model for adsorption of nickel ions in aqueous solution onto activated carbon at 293 K, (c) intraparticle diffusion model for adsorption of nickel ion onto activated carbon at 293K. Experimental conditions: 0.10 g of activated carbon, 20mg/L of initial nickel ions concentration, 200 rpm and pH 5.0

All kinetic data for the adsorption of nickel ions in aqueous solution onto activated carbon could be derived from this line. The validity of the exploited models is verified by the correlation coefficient (R^2). R^2 values of the pseudo-first-order model, the pseudo-second-order model and the intraparticle diffusion model for adsorption of nickel ions in aqueous solution onto activated carbon were 0.9003, 0.9961 and 0.9665 respectively. Comparison of the R^2 values for different models suggests that the pseudo-second-order kinetic model fits best since its highest value. The pseudo-second-order kinetic model implies that the predominant process here is chemical adsorption, which involves a sharing of electrons between the adsorbate and the surface of the adsorbent[20,21].

CONCLUSIONS

The activated carbon was obtained from wheat straw lignin with H_3PO_4 activation. Then, the pore structure characteristics and adsorption nickel ions in aqueous solution capacity of the activated carbon were investigated. The activated carbon contains irregular and porous structures and a large specific surface area. The adsorption of nickel ions in aqueous solution onto activated carbon is fast and the adsorption kinetics can be best described by the pseudo-second order model. The predominant process here is chemical adsorption, which involves a sharing of electrons between the adsorbate and the surface of the adsorbent.

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