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Ultrasound facilitates and improves removal of Cd(II) from aqueous solution by the discarded tire rubber

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Abstract

Some of the heavy metal ions such as cadmium are toxic and represent as hazardous pollutants due to their persistence in the environment. In this study the ground discarded tire rubber was used for the sorption of cadmium from aqueous solution. The batch sorption tests were conducted to investigate the sorption of Cd(II) by discarded tire rubber in the presence and absence of ultrasound. To assess the capability of sorbent, research parameters such as ultrasonic waves, solution temperature, particle size of ground tire and others were investigated. The experimental data were fitted in Langmuir model better than Freundlich one. Therefore, the former model was applied to the sorption equilibrium in order to determine the maximum metal sorption capacity in the presence and absence of ultrasound. The Langmuir constants were also obtained from the isotherms under different conditions. In the presence of ultrasound the tire rubber was a more efficient sorbent for this pollutant than its absence. According to the results, the internal porous and film diffusions were both effective in the sorption process. The porous and film diffusion coefficients of the ground tire rubber were, respectively, about 1.8 and 2.7 times more in the presence of ultrasound than its absence. The effect of ultrasound on the sorption process could be explained by the thermal and non-thermal properties of ultrasonic field.

Keywords: Ultrasound; Discarded tire rubber; Cadmium(II); Sorption; Langmuir model

1. Introduction

Toxic metals are often discharged into the environment from a number of industrial processes. Cadmium is widely used in industries in operations such as cadmium plating, and the manufacture of alkaline batteries, copper alloys, paints and plastics [1]. This metal is a non-essential and non-beneficial element for plants and animals. Its toxic effects are well documented and diseases such as renal damage, anemia and itai-itai are associated with excess cadmium [2,3]. The drinking water guideline value recommended for this element by World Health Organization (WHO) and American Water Works Association (AWWA) is 0.005 mg cadmium per liter [4]. Various methods exist for the removal of cadmium ions from solution, such as filtration, chemical precipitation, ion exchange, sorption by activated carbon and others. From the viewpoint of economics, these methods are not generally acceptable and different groups have recently focused the research on the use of low cost sorbents such as bagasse sugar [5], hematite [6], perlite [7], starch xanthate [8], sawdust of pinus sylvestris [9] and discarded automobile tires [10]. In this study, finely-ground discarded tire rubber which caused many public health and environment problems [11] has been used as an interesting and cheap medium for the sorption of cadmium from aqueous solution. This was done in the presence and absence of treatment with ultrasound (a variation of pressure or density with frequencies above the human hearing threshold ≈18 kHz). Ultrasound through its mechanical waves, is known to have an effect on the sorption process. Ultrasonic waves strongly affect mass transfer between two phases. It is well understood that ultrasonic waves have a greater efficiency for interface mixing than conventional agitation [12,13]. This behavior could be the reason for the enhancement of the sorption kinetic process [14–17,19].

2. Materials and methods

2.1. Materials

The finely-ground discarded tire rubber with an average particle size of 0.4 mm was prepared from Yazd Tire Company in

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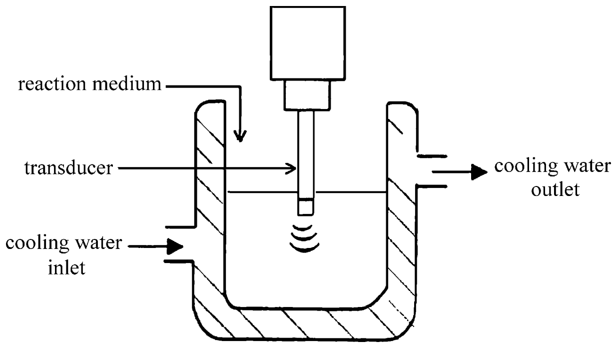

Fig. 1. Scheme of the experimental set-up for the sorption under ultrasonic field.

Iran. Cadmium chloride was from Riedel. A stock solution of cadmium chloride with a concentration of 1000 ppm was prepared in de-ionized distilled water. This solution was diluted as required to obtain the standard solutions.

2.2. Apparatus

The ultrasonic irradiation was carried out with equipment operating at 20 kHz (Misonix-XL2020). Ultrasonic waves were emitted from a titanium horn with a diameter of 1.2 cm. The cylindrical sonochemical reactor (volume = 100 ml) was thermostated by a water jacket (Fig. 1). Ultrasonic energy dissipated in the reactor was set generally at 30.0 W and monitored colorimetrically.

2.3. Analysis

The cadmium concentration in the solution was determined by spectrophotometry, using a Shimadzu AA-670 atomic absorption spectrophotometer.

2.4. Procedure

Batch experiments were conducted by adding 1.0 g of ground tire to 60 ml of cadmium aqueous solution of the desired concentrations at different temperatures, with constant stirring. Equilibrium was reached after 2 h. In order to determine the sorption isotherm of Cd(II) on the powdered tires in an ultrasonic field, the ultrasonic waves were applied continuously on the system from the beginning. Equilibrium was reached after 30 min. The ion concentration retained in the sorbent phase (mg g^{-1}) was calculated by using Eq. (1):

$$q_e = \frac{(C_o - C_e)}{W} V \quad (1)$$

where C_o and C_e are the initial and equilibrium concentrations of metal ion (mg l^{-1}), V is the volume (l), and W is the weight of the sorbent (g) in the mixture.

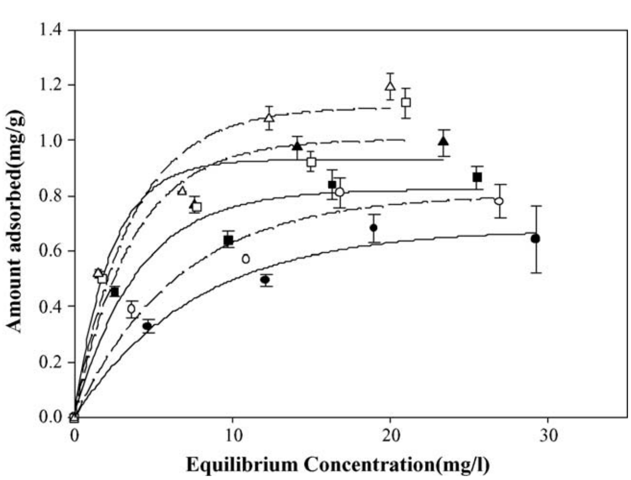

Fig. 2. Sorption isotherms of Cd(II) on the powder tire in the presence and absence of ultrasound: (●) stirring (30 °C); (■) stirring (40 °C); (▲) stirring (50 °C); (○) irradiation (30 °C); (□) irradiation (40 °C); (△) irradiation (50 °C).

3. Results and discussion

3.1. Sorption isotherms

Fig. 2 shows the sorption of Cd(II) on the powdered rubber at different temperatures in the presence and absence of ultrasound. The sorption capacity of metal ion was found to be greater in the presence of ultrasound than with simply stirring as a classical method. In both cases, the isotherms exhibited a Langmuir shape. In stirring, the optimum contact time was 2 h and for sonication it was 30 min. This behavior could be explained by the acoustic cavitation (formation, growth and collapse of cavity) which was produced during the sonication. As the bubble collapses, a localized high pressure and temperature are produced in the fluid [18]. In addition, the asymmetric collapse of bubbles in a heterogeneous system produces micro-jets with high velocity on the surface of the sorbent. This action leads to destroying and tearing off the sorbent which may expose new sites and increase the "internal sorption capacity (ISC)" of the powdered tire and also enhancing mass transfer into the pores. These effects can be reasons for increasing the sorption capacity in the presence of ultrasound.

The experimental data were found to fit the Langmuir model better than Freundlich model. The linear form of Langmuir model is represented by Eq. (2):

$$\frac{C_e}{q_e} = \left(\frac{1}{Q_o b}\right) + \left(\frac{1}{Q_o}\right) C_e \quad (2)$$

where q_e is the concentration of the sorbed solute per unit weight of sorbent at equilibrium (mg g^{-1}), C_e is the equilibrium concentration of the pollutant in the mixture (mg l^{-1}) and Q_o corresponds to complete coverage of available sorption sites. The factor b is related to the free energy ($b \propto e^{-\Delta G/RT}$) and the intensity of sorption. A linear plot of (C_e/q_e) versus C_e was employed to find the values of Q_o and b from the slope and the intercept of the line (Fig. 3). Table 1 gives these values with good correlation coefficients.

3.2. Effect of temperature

Fig. 4 shows the effect of temperature in the presence and absence of ultrasound. The sorption capacity of rubber increased with increasing temperature in both cases.