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Comparison the removal of reactive red 195 dye using powder and ash of barberry stem as a low cost adsorbent from aqueous solutions: Isotherm and kinetic study

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ABSTRACT

Dyes are used in various sectors, such as the textile, leather, paper, and plastic industries, and a significant part of this dye enters the environment via wastewaters. The present research was a laboratory-scale study with the aim of investigating the effective parameters in the dye-removal process, including pH (3−11), contact time (5–120 min), dye concentration (10–50 mg/l), adsorbent dose (1–4 g/l), and temperature (15–35 °C). The maximum adsorption capacity was observed at pH = 3, contact time = 10 min, initial dye concentration = 50 mg/l, adsorbent dose = 1 g/l, and temperature = 15 °C. With these parameters, the maximum adsorption capacities for barberry stem powder and ash were 27.2 mg/g and 8.8 mg/g, respectively. The results of examining the adsorption isotherms showed that the barberry powder followed from both the Langmuir (0.94) and Freundlich (0.94) isotherms, while barberry stem ash followed from the Freundlich (0.85) isotherm. Kinetic adsorption studies showed that the dye adsorption on both adsorbents followed a pseudo-second-order kinetics. The results showed that the barberry stem powder and ash had desirable capacity in reactive red 195 (RR195) dye from aqueous solutions and textile wastewaters.

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1. Introduction

Many wastewaters from housing, agriculture, and industrial resources enter the environment annually, containing high concentrations of organic and non-organic chemical materials, such as hydrocarbon solvents, cyanide, heavy metals, insecticides, and dyes [1]. Dyes are the most dangerous chemical compounds found in industrial wastewaters [1]; they are used in many different sectors, such as the food and pharmacy, textile, plastic carpet weaving, cosmetics, leather, and paper industries. However, in terms of dye production, the most significant industries are generally the textile and dyeing industries [2–4]. Currently, about 700,000 tons and 10,000 types of dyes and pigments are produced all over the world annually, and a significant proportion of these products enters the environment through wastewater [5]. Among these dyes, reactive dyes are more problematic in comparison with the other types of dyes, and they must be omitted from wastewater [6,7].

Reactive dyes represent an important part of commercial artificial dyes; they have covalent bonds among their groups and textile tissue surfaces, mainly due to their high connection ability. These compounds are also recognizable by people in very low values and concentrations, so the dyes are aesthetically unpleasant [6,7]. Moreover, these compounds are toxic, resulting in skin and eye irritation and skin sensitivity [8]. In addition, many of them are mutagenic and carcinogenic [9]. Another problem related to dyes is the reduction in aqueous photosynthesis. Therefore, dyes prevent sun light and influence plant growth, resulting in the eutrophication phenomenon [10].

Various physical, chemical, and biological techniques are used to remove dyes, including the following: coagulation and flocculation, adsorption, membrane filtration, electrochemical techniques, nanotechnology and ozonation [11,12]. Among these techniques, although the advanced oxidation approaches, such as ozonation, photon processing, and photocatalytic methods exhibit high efficiency in dye removal,

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they are not often used because of their high price [13]. Using popular techniques, such as coagulation and flocculation, is problematic for dye removal because of their high solubility in aqueous environments [14]. However, the adsorption technique is an efficient approach to removing dye; the advantages of this technique include its low design cost, simple utilization, and lack of sensitivity to toxic compounds. Based on previous studies, adsorption by active carbon is one of the popular techniques for water and wastewater treatment [15]. However, its application also has disadvantages, such as its revival complexity, high cost, and need for expertise. In this regard, employing cheap adsorbents with high efficiency has been suggested [16,17]. Using agriculture wastes can change garbage into useful materials and facilitate their removal [18].

Many bioadsorbents, such as palm ash [19], papaya seeds [20], wheat husks [21], rice husks [22], coconut shells [23], and coffee shells [24] have been examined in terms of their capacity to remove dyeing materials. Other advantages of bioadsorbents are their low cost, accessibility, reusability, lack of production of chemical sludge, high efficiency, and affordability for high volumes of wastewater containing low concentrations of pollutants, as well as the ability to use the extra sludge obtained from water treatment plants [25]. The aim of this study is to use the powder and ash of barberry plant stems for removal of reactive red 195 (RR195) dye from aqueous solutions. The effects of various parameters such as contact time, the amount of bioadsorbent, initial concentration, temperature and pH were studied on bioadsorbent. Then, adsorption method was used to remove RR195 from water and wastewater and obtained experimental data were fitted with common different adsorption isotherm models. Finally, the kinetics of adsorption was studied.

2. Material and methods

2.1. Materials

This research was conducted in the batch mode at a laboratory scale in the Environmental Health Engineering Department, Faculty of Health, Birjand University of Medical Sciences in 2017. The dyeing materials used in this research (RR195) were kindly provided by the Iran Alvan Sabet Co. This dye is a reactive, water-soluble dye, with a molecular formula and a molecular weight of 983.5; its chemical structure is shown in Fig. 1 [6]. An ultraviolet-visible (UV–vis) spectrophotometer with a wavelength of 540 nm was used to measure the dye concentrations. In this research, barberry stems from Birjand gardens were used as the studied adsorbents.

2.2. Preparation of the adsorbents

Barberry stems were collected from Birjand gardens as a natural adsorbent, and their preparation phase was carried out in the laboratory. First, the barberry was washed well in water (105 °C for 4 h) and then dried; after peeling off the stem, it was completely milled. Then, a standard sieve (35 mesh) was used for adsorbent granulation. Following this, parts of the barberry stem were burnt in a furnace at 550 °C for 1 h to prepare the needed ash, and then, it was contained pure of humidity that was used as adsorbent. Scanning electron microscope (SEM) images were used to determine the structural characteristics of the manufactured adsorbents (powder and ash from barberry stems).

2.3. Adsorption study

To examine the dye-removal efficiency of the studied adsorbents, a dye with 1000 mg/l concentration was prepared, and the mentioned dye solutions were prepared for the experiments by diluting this solution. The parameters of pH (3–11), contact time (5–120 min), dye concentration (10–50 mg/l), adsorbent dose (1–4 g/l), and temperature (15–35 °C) were studied to examine the factors affecting the adsorption. The pH was adjusted with HCl and NaOH (1 N) using a 765 Caliamatic pH-meter (Knick). During the experiment, the solutions were poured into 250-ml flasks and placed on an Orbital shaker (model KS260C) with a mixing rate of 250 rpm. They were then passed through Whatman filter paper, and the dye concentration was measured using a spectrophotometer. It should be noted that the incubator shaker device (COMBI-SHAKER, model NB-101MT) was used to test the effect of temperature on the dye adsorption process. Finally, Eq. (1) was used to determine the adsorption capacity value (amounts of the adsorbed dye from the solution per unit of adsorbent weight):

$$q_e = \frac{(C_0 - C_e)}{m} V \tag{1}$$

In this equation, q_e is the dye adsorption capacity (mg/l), C_0 is the initial dye concentration (mg/l), Ce is the residual dye concentration (mg/l), m is the adsorbent dose (g), and V is the sample volume (l) [12].

$$\frac{C_e}{q_e} = \frac{1}{K_a Q_m} + \frac{1}{Q_m} \times C_e \tag{2}$$

The Langmuir and Freundlich adsorption models were used to examine adsorption isotherm. The linear equation of the Langmuir isotherm is given in Eq. (2). In this equation, Ce is the liquid phase equilibrium concentration (mg/l), q_e is the adsorption capacity of the adsorbent (mg/g), q_m is the maximum adsorption capacity of the adsorbent (mg/g), and K_a is the adsorption equilibrium constant (l/mg) that is related to the apparent energy of adsorption [26]:

The Freundlich adsorption isotherm equation is given in Eq. (3):

$$\ln q_e = \ln K_F + \frac{1}{n_F} \ln C_e \tag{3}$$

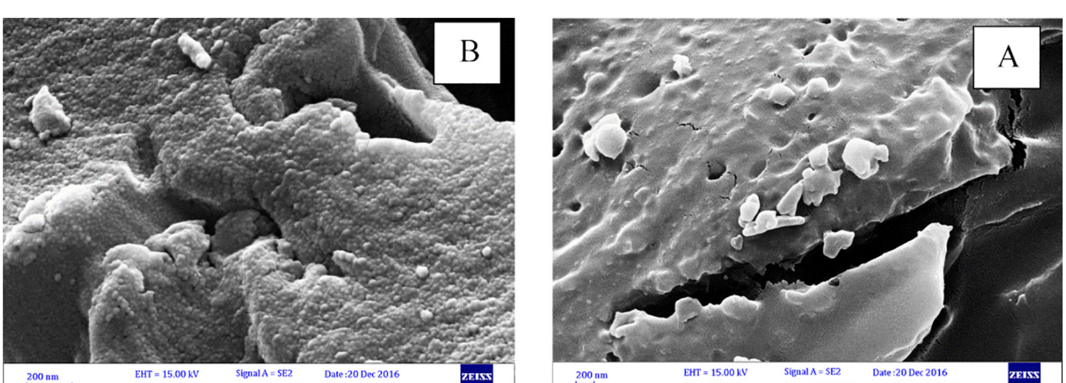

Fig. 1. SEM images of (a) Barberry Stem powder and (b) Barberry Stem ash before adsorbent process.

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