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ScienceDirect

Resource-Efficient Technologies 3 (2017) 71–77

www.elsevier.com/locate/reffit

Removal of Crystal Violet dye from aqueous solution using water hyacinth: Equilibrium, kinetics and thermodynamics study

M. Rajeswari Kulkarni *, T. Revanth, Anirudh Acharya, Prasad Bhat

Department of Chemical Engineering, M.S.Ramaiah Institute of Technology, Bangalore 560054, India

Received 20 June 2016; accepted 30 January 2017

Available online 7 March 2017

Abstract

Effluent water from dyeing industries has now for long been a taxing issue. Of the various dyes which are extremely toxic, Crystal Violet which is used in the dyeing industry is known for its mutagenic and mitotic poisoning nature. Water hyacinth (*Eichhornia crassipes*) is a perennial aquatic plant notorious for its rapid invasive growth on the surface of water bodies causing ill-effects on the biodiversity. The potential of powdered roots of water hyacinth was studied for decolorization of Crystal Violet dye. Influence of parameters such as initial pH (2.0–10.0), initial dye concentration (100–500 ppm), biosorbent dosage (0.5–5 g/l), contact time (10–240 min) and temperature (300–323 K) were examined. Maximum removal of dye was observed at pH 7.8. The obtained data were fit into different kinetic models and the biosorption was found to follow pseudo second order kinetic model. The Langmuir monolayer biosorption capacity of water hyacinth was estimated as 322.58 mg/g. The study has demonstrated water hyacinth as a potential low cost biosorbent for effective removal of Crystal Violet dye from aqueous solution.

Keywords: Crystal Violet; Water hyacinth; Dye removal; Isotherm; Thermodynamics; Kinetics

1. Introduction

The rising existence of dyes in the aqueous bodies is one of the most significant environmental issues. The dyes do not undergo natural degradation; hence the persisting color hinders the passage of light into water and spoils the ecosystem [1,2]. Crystal Violet (CV) enters into the aquatic systems from the effluents of textile industry, paint industry and also from medical and biotechnology industry. Crystal Violet is well known for its mutagenic, teratogenic and mitotic poisoning nature. Among the several techniques employed for dye removal, the most feasible technique was found to be the use of biosorbent to adsorb the dye from waste water [3]. Several low cost adsorbents (agricultural, domestic or plant biomass waste) have been used for removal of CV dye such as grapefruit peel [4], rice husk [5], jackfruit leaf powder [6], ginger waste [7], etc. Water hyacinth, a perennial aquatic plant, was studied for its adsorptive capacities in the removal of CV dye. Water hyacinth is infamous for its rapid invasive growth, uncontrolled growth of its weed affects the biodiversity. But, along with the notoriety, the plant is now also at the center of many studies and researches, pertaining to wastewater treatment, for the removal of contaminants such as heavy metals, coloring agents and other organic and carcinogenic compounds, owing to its adsorptive properties. The root powder of this plant was utilized as the biosorbent to decolorize the waste water. The present study is addressing the problem of both the solid and liquid wastes by making use of water hyacinth to remove CV dye and thus finding a feasible solution to the environmental contamination.

2. Materials and methods

2.1. Adsorbate

Crystal Violet dye was purchased from Merck (India) Ltd. Stock solution of CV was prepared by dissolving 0.5 g of accurately weighed dye in 1000 ml of distilled water to obtain 500 ppm dye solution. The solution was then diluted to prepare standard solutions of different concentrations to study the effect of initial dye concentration. The dye concentration was measured in the UV spectrophotometer at the wavelength of 580 nm. The initial pH of dye solution was adjusted by using dilute hydrochloric acid or sodium hydroxide solution.

* Corresponding author. Department of Chemical Engineering, M.S.Ramaiah Institute of Technology, Bangalore 560054, Karnataka, India. Tel.: +91 8023600822; fax: +91 80 2360 3124.

E-mail address: rmkulkarni@msrit.edu (M.R. Kulkarni).

http://dx.doi.org/10.1016/j.reffit.2017.01.009

2.2. Biosorbent preparation

Water hyacinth plants were obtained from Hebbal Lake, Bangalore and were extensively washed with water to remove earthly impurities. The roots were separated from the rest of the plant; the initial moisture content was 88.89%. The roots were sun dried for 5 days to reduce the moisture content to 10%, crushed and then sieved to an average particle size of 100 µm.

2.3. Biosorption experiments

The effects of initial pH (2.0–10.0), contact time (10–240 min), biosorbent dosage (0.5–5 g/l), initial dye concentration (100–500 ppm) and temperature (300–323 K) on biosorption of CV were examined in a batch system. One hundred milliliters of dye solution was in contact with water hyacinth root powder in an incubator orbital shaker. After biosorption, the samples were filtered and residual dye concentration was analyzed. All the biosorption experiments were performed in duplicate and deviations were within 5%; average values were used in the result analysis. Dye uptake and percentage removal were calculated by using Eq. (1) and Eq. (2).

$$q = \frac{v(c_i - c_f)}{m} \tag{1}$$

$$\%\, CV\ removal = \frac{(c_i - c_f)}{c_i} \times 100 \tag{2}$$

where q is the dye uptake (mg/g), V is volume of dye solution (l), C_i is the initial concentration of Crystal Violet in the solution (ppm), C_f is the final concentration of Crystal Violet in the solution (ppm) and m is the amount of water hyacinth root powder (g).

2.4. Surface characterization

2.4.1. FTIR analysis

Fourier transform-infrared spectrometer (Bruker alpha) was used in the range of 4000–500 cm^{-1} to determine the functional groups present on the surface of the biosorbent. The spectra obtained are shown in Fig. 1(a) and (b). The presence of peak at 533.41 cm^{-1} indicates the probability of an alkyl halide C—Br stretching with a strong absorption band. Peak at 1004.05 cm^{-1} indicates a strong bending of a = C—H bond. After biosorption, peaks at 1583.02 cm^{-1} indicates probable C=C stretching and peaks at 1360.33 cm^{-1} and 1170 cm^{-1} can be attributed to stretching of C=H and C—N groups. A decrease in the frequency at 1002.56 cm^{-1} from 1004.05 cm^{-1} and a peak at 534.81 cm^{-1} indicates a role of C—Br and C—H bond in the biosorption of the dye onto biosorbent.

2.4.2. SEM analysis

SEM imaging of the biosorbent surface was carried out before and after biosorption of CV, using scanning electron microscope (JEOL, Japan) with 30 kV and at 10,000 times of magnification. The images are presented in Fig. 2(a) and (b) respectively. In Fig. 2(a), the surface was relatively free of any kind of aggregations. Fig. 2(b) shows image of the surface after biosorption of CV, with aggregations on the surface, possibly be

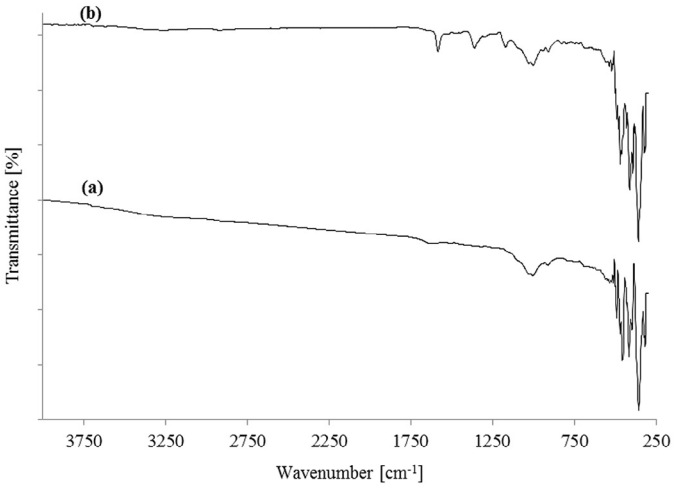

Fig. 1. FTIR of biosorbent (a) before biosorption and (b) after biosorption of CV.

the particles of the dyes adsorbed onto the surface at the pores and the pore walls. The surfaces of CV-loaded water hyacinth root powder was appeared to be rough and wrinkled by the dye molecules, indicating involvement of ion exchange in the dye removal.

3. Results and discussion

3.1. Effect of pH on biosorption of CV

The effect of initial pH on dye removal was investigated at different initial CV concentrations (100–500 ppm) by maintaining a fixed contact time of 120 min, ambient temperature of 27 °C and biosorbent dosage of 1 g/l. The percentage removal was observed to increase sharply with an increase in pH from 2.0 to 4.0. The removal was found to be high thereafter but with a constant trend until pH 10.0. The variation has been depicted in Fig. 3. The maximum removal was observed at pH 7.8. Low biosorption of CV at lower pH is due to the high concentration of H^+ ions which result in repulsion and hence cause the reduced biosorption at lower pH [4,8]. As the pH increases, more negatively charged surfaces are available resulting in decrease in repulsion between the positively charged dye molecule and the biosorbent [5,9].

3.2. Effect of contact time on biosorption of CV

The study on the effect of contact time provides useful information on time taken to attain equilibrium. Time taken to achieve equilibrium depends on the rate of mass transfer, which, in turn, depends on the conditions provided for the contact between the solid and the liquid phase [10]. The effect of contact time (10–240 min) on the removal of CV dye was studied for an initial dye concentration of 500 ppm, ambient temperature of 27 °C, biosorbent dosage of 1 g/l and pH 7.8. It can be observed from Fig. 4 that the initial rate of CV biosorption is rapid within 40 min of contact time due to high concentration gradient and the availability of large surface area for biosorption. The rate slows down after 40 min due to the