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Use of BDST and an ANN model for prediction of dye adsorption efficiency of *Eucalyptus camaldulensis* barks in fixed-bed system

Behzat Balci [a], Olcayto Keskinkan [a,*], Mutlu Avci [b]

[a] Department of Environmental Engineering, Faculty of Engineering and Architecture, Cukurova University, 01330 Balcalı/Adana, Turkey

[b] Department of Computer Engineering, Faculty of Engineering and Architecture, Cukurova University, 01330 Balcalı/Adana, Turkey

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ABSTRACT

In this study, the Bohart and Adams' model taking into account bed depth, and influent dye concentration was studied to exhibit adsorption process of textile dyes (Basic Blue 41 – BB41 and Reactive Black 5 – RB5) in glass columns using tree barks (*Eucalyptus camaldulensis*). Adsorption capacity coefficient values are determined using the Bohart and Adams' bed depth service model. The model indicated that adsorption properties of *E. camaldulensis* barks conform for tertiary treatment for textile BB41 and RB5 containing wastewaters. An artificial neural network (ANN) based model for determining dye adsorption capability of bed system is also developed. The breakthrough curves of adsorption are also exhibited by this model. Results showed that ANN model could describe present system. Results showed that with the increases of bed height, and the decreases of influent dye concentrations, the breakthrough time was delayed.

1. Introduction

Artificial neural networks (ANNs) have become widely used in various research areas where the available information is experimental. ANNs introduce an easy mathematical function approximation for any linear and nonlinear systems. Topology of the neural networks consists of input layer, hidden layers and output layer. The neural network training method develops the input–output relation for the modeled system utilizing data sets (Sato, Sha, & Palosaari, 1999). Various researchers used the ANN for exhibit the performance of adsorption systems successfully (Brasquet & Le Cloirec, 1999; Du, Yuan, Zhao, & Li, 2007; Kumar & Porkodi, 2009; Robinson, Chandran, & Nigam, 2002; Yetilmezsoy & Demirel, 2008).

On the other hand, dye contamination in aqueous wastewater from industries is a serious problem because dyes are not biodegradable and tend to suppress photosynthetic activity in aquatic habitats by preventing the sunlight penetration. Dyes have also toxicological characteristics which are the main issues for environmentalists and have been the subject of growing attention for some years. Removal of textile dyes from wastewaters is one of the major problems in wastewater treatment technology. Traditional treatment methods such as ion exchange, chemical precipitation, and membrane separation are often ineffective and very expensive when they are used for the removal of dyes.

Currently, the most widely used and effective physical method for the treatment of colored wastewater is adsorption. The most convenient method for designing adsorption systems is the use of adsorption isotherms. The theoretical adsorption capacity of the adsorbent for a particular contaminant can be determined by calculating its adsorption isotherm (Tchobanoglous, 2003). The performance of a given adsorption system can be demonstrated through the use of adsorption isotherms. The degree to which adsorption will occur and the resulting equilibrium relationships are correlated according to the empirical relationship of Freundlich and the theoretically derived Langmuir relationship (Eckenfelder, 1989). In most wastewater flowing systems, since the contact time is not sufficiently long for the attainment of equilibrium, the data obtained under batch conditions are generally not adequate. Hence, it is required to perform equilibrium studies by using columns (Zhou, Zhang, Zhou, & Guo, 2004).

Activated carbon is the most popular and widely used adsorbent. In most industries, activated carbon columns are employed for the treatment of toxic, non-biodegradable wastewaters and as a tertiary treatment following biological oxidation (Eckenfelder, 1989). However, it is expensive because of the chemicals required for its regeneration after pollutant removal; the higher the quality, the greater the cost. Some natural materials not only have excellent adsorbability of dyes, but also have biocompatibility,

Abbreviations: BB41, C.I. Basic Blue 41; RB5, C.I. Reactive Black 5; ANN, artificial neural network; BDST, bed depth service time model; MLP, multilayer perceptron.

* Corresponding author. Fax: +90 3223386126.
E-mail address: olcayto@cu.edu.tr (O. Keskinkan).

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Nomenclature

w/w	percent on dry weight bases, g/g
A	absorbency, nm
V_b	volume of water treated at breakthrough, L
T_b	time required for the effluent to reach the breakthrough concentration, h
D	bed depth, cm
N_0	average adsorption capacity per volume of bed, mg dye/L solution
C_0	column influent dye concentration or initial dye concentration, mg/L
C_b	allowable effluent dye concentration at breakthrough point, mg/L
C_t	effluent concentration at time t, min
υ	linear flow rate through the bed, cm/h
K	rate constant of adsorption, L/mg h
w_{ji}	the weight of input *i* to neuron *j*,
x_{pi}	input *i*, that is, output *i* from the previous layer for input pattern *p*
b_j	the threshold value
V	volume of water, L (As an input of the system for ANN)
h_i	bed depth, cm ((As an input of the system for ANN)
h	normalized bed depth, cm (As an input of the system for ANN)
C_i	influent dye concentration, mg/L (As an input of the system for ANN)
C	normalized effluent dye concentration, mg/L (As an input of the system for ANN)
X	the input matrix for the neural network
y	dye concentration of the treated water (As an output of the system for ANN)
W_1	weight of the first layer of the neural network
W_2	weight of the second layer of the neural network
b_1	bias values of the first layers of the neural network
b_2	bias values of the second layers of the neural network
$Q_{0.1}$	breakthrough capacity (at 10% or $C_t/C_0 = 0.1$)

biodegradability, and nontoxicity. To replace activated carbon with cheaper alternatives such as natural materials mentioned above, and to utilize various waste products, many novel materials have been tested such as micro-organisms (Aksu, 2001; Aksu & Tezer, 2000; Basibuyuk & Forster, 2003; Hu, 1992; Mohan et al., 2002), tree fern (Ho, Chiang, & Hsueh, 2005), banana pith (Namasivayam & Kanchana, 1992; Namasivayam, Prabha, & Kumutha, 1998), neem sawdust (Khattri & Singh, 2000), peat (Poots, McKay, & Healy, 1978), agricultural waste residues (Robinson et al., 2002), recycled alum sludge (Chu, 2001), Fuller's Earth (Atun, Hisarlı, Sheldrick, & Muhler, 2003), lignite (Allen & Brown, 1995), perlite (Dogan, Mahir, & Onganer, 2000), apple pomace and wheat straw (Robinson et al., 2002), bottom ash and de-oiled soy (Gupta, Mittal, Krishnan, & Mittal, 2006; Low, Lee, & Tan, 1995), carbon slurry waste (Jain, Gupta, & Suhas, 2003), bamboo dust, coconut shell, groundnut shell and rice husk (Kanan & Sundaram, 2001), coir pith (Namasivayam et al., 2001), orange peel (Namasivayam, Muniasamy, Gayathri, Rani, & Ranganathan, 1996), Indian rosewood sawdust (Garg, Amita, Kumar, & Gupta, 2004), chitosan and chitin (Juang, Tseng, Wu, & Lin, 1996), biogas residual slurry (Namasivayam & Yamuna, 1992), activated carbon prepared from plum kernels (Wu, Tseng, & Juang, 1999), fly ash (Wang, Boyjoo, & Choueib, 2005), kaolinite (Ghosh & Bhattacharyya, 2002), calcinated alumite (Ozacar & Sengil, 2002), cement kiln dust (Nassar, Daifullah, Magdy, & Ebrahiem, 2002) and aquatic plants including *Spirodela polyrrhiza* (Waranusantigul, Pokethitiyook, Kruatrachue, & Upatham, 2003), *Hydrilla verticillata* (Low, Lee, & Heng, 1993), *Eichornia crassipes* (Low et al., 1995) and *Ceratophyllum demersum* and *Myriophyllum spicatum* (Keskinkan, 2006). Although the contribution of natural adsorbents to wastewater treatment is already known there is little literature information on the dye adsorption capacities of *Eucalyptus* tree barks (Mohan, Rao, Prasad, & Karthikeyan, 2002) in a batch and fixed-bed system. Moreover, there are no literatures concerning biosorption of BB41 and RB5 onto barks of *Eucalyptus camaldulensis*. The determination of the dye adsorption capability of *E. camaldulensis* barks may contribute to system design approaches to adsorption systems for dye-containing wastewaters. Data from any dye adsorption studies can also be incorporated into full-scale field applications through the determination of the adsorption characteristics of *E. camaldulensis* barks. In this study, important parameters to design a column packed with *E. camaldulensis* barks such as column bed height and initial concentration of dye solution have been investigated. The breakthrough curves for the adsorption of dyes were analyzed using BDST. Adsorption potential of dyes (BB41 and RB5) towards *E. camaldulensis* barks at different dye concentrations was also exhibited by using an artificial neural network.

2. Experimental methods

2.1. Adsorbent

In the south region of Turkey, *E. camaldulensis* is a common species. It is native to Australia. Large evergreen tree *E. camaldulensis* has 24–40 m high and its stout trunk is often short and crooked, to 2 m in diameter and crown open, widely spreading irregular. Their barks are smooth, white, gray, or buff (Little, 1983). According to Yadav, Sharma, and Kothari (2002), chemical composition of *Eucalyptus* barks is generally organic and percents on dry weight bases (w/w) of composition of barks are 37.4 cellulose, 19.2 hemicellulose, 5.5 free sugars, 62.2 total carbohydrates, 28.0 lignin, 4.9 ash, 1.1 total nitrogen, 15.5 water extractables, 7.2 alcohol extractables, 93.2 total organic matter.

Since the *E. camaldulensis* barks free of cost from any processing industries only the transport cost is involved for the tertiary wastewater treatment.

The barks of *E. camaldulensis*, were collected from Balcalı campus of the University of Çukurova (Adana, Turkey). All experiments were undertaken using the barks in continuous flow fixed-bed system. Upon collection, barks were washed with hot distilled water (60 ± 2 °C) and dried at room temperature before application.

2.2. Adsorbate

The dyestuffs, BB41 and RB5 were obtained from a local textile mill. The structures of the dyes used are as shown in Fig. 1. Because of their persistence to waste water treatment, certain researchers have focused on azo dyes. Therefore, BB41 and RB5 were selected as a model compound for estimating the adsorption capacity of the plants used in the present study. Stock solutions of BB41 and RB5 were prepared using distilled water.

2.3. Analytical method

The dye concentrations in influents and effluents were determined by using a UV–visible recording spectrophotometer