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Analysis of Fixed-Bed Column Adsorption of Reactive Yellow 176 onto Surfactant-Modified Zeolite

Ayşegul Faki,[†,‡] Mustafa Turan,*[,‡] Ozgur Ozdemir,[†,‡] and Abdullah Zahid Turan[†,§]

Department of Environmental Engineering and Department of Chemical Engineering, Istanbul Technical University, Maslak 34469, Istanbul, Turkey

Adsorption of Reactive Yellow 176 onto zeolite in a fixed-bed column system was investigated. To increase the adsorption capacity, we modified the surface of natural zeolite with a cationic surfactant (HTAB). The adsorption tests consisted of the modification of zeolite with HTAB followed by the dye removal in the column. The zeolite that was modified at 3 g/L HTAB concentration showed the best performance in adsorbing the yellow dye. The column with a 3 cm diameter and different bed heights of 25, 35, and 50 cm treated 24, 36, and 66 L at the breakthrough point, respectively, for 50 mg/L Reactive Yellow 176 dye solution at a flow rate of 0.050 L/min. The bed depth service time (BDST) model proved to be effective in the comparison of column variables. The minimum bed height, the adsorption rate constant, and the adsorption capacity of the HTAB modified zeolite for yellow dye removal were found to be 12.02 cm, 6.432×10^{-3} L/(mg h), and 12.05 g/L, respectively. Color removal efficiencies of the simulated and real textile wastewaters were evaluated and adsorption capacity in the simulated textile wastewater and the real textile wastewater showed 25 and 62% decrease compared to the yellow dye solution. The column regeneration was also evaluated using a solution consisting of 30 g/L NaCl and 1.5 g/L NaOH with a pH value of 12 at 25 cm bed height with a flow rate of 0.050 L/min at temperatures 30 and 60 °C. Desorption efficiency increased from 23 to 90.6% with the increase in temperature from 30 to 60 °C.

Introduction

The textile industry wastewaters contain colorants originating from printing or dyeing processes. Reactive azo dyes based on the azo chromogen (—N═N—) are presently the most important compounds constituting about 20−40% of the total dyes used for coloring and can not be easily removed by conventional treatment methods because they strongly resist to biodegradation in an aerobic environment.[1−3] Therefore, oxidation and adsorption are two major technologies that are used for wastewater treatment in the textile industry. Among oxidation methods, UV/ozone and UV/H_2O_2 treatments are technologies for decolorizing wastewater.[4,5] Adsorption is one of the most important unit processes in a wastewater treatment plant and the design of the adsorption column usually requires information from pilot-plant experiments.[6−8]

Color removal from textile wastewater is considered as an important application of the adsorption process using low-cost adsorbents such as sepiolite,[9] zeolite,[10] bottom ash,[11] industrial and agricultural waste materials,[12−14] etc., against expensive activated carbon.[15−17] The presence of 4.5 million tons of natural zeolites of high-quality, mainly those of clinoptilolite in Turkey, created an impetus for the utilization of clinoptilolite in wastewater treatment.[18]

Sorptive properties of zeolites have been utilized for a variety of purposes such as adsorption of ammonia by natural zeolite[19−21] and removal of heavy metals[22−24] in batch mode and fixed-bed reactor. Although there are some depletion adsorption studies,[16,25] a few studies have been reported on color removal of textile effluents with modified zeolites in a column reactor. In particular, the extent of the modification process in which hydrophobic materials are converted into total or partial hydrophobic states is important for assessing the compatibility of dye molecules. In this paper, the adsorption of reactive dye onto zeolite that was modified with a cationic surfactant (HTAB) in a fixed-bed column was studied. For this reason, Reactive Yellow 176 dye was chosen as a reactive dye. The effects of HTAB modification and bed height on dye removal and the development of breakthrough curves were investigated. The dynamics of adsorption process was modeled using bed depth service time (BDST) approach. In addition, color removal from simulated and real textile wastewaters were compared and fixed-bed column regeneration was evaluated as a function of temperature.

Experimental Section

Materials and Chemicals. The clinoptilolite sample, hereafter referred as zeolite, used in the experiments was received from Incal Mining company in the Gördes region of Turkey with a sieve size of 0.5−1 mm (35−18 mesh). Chemical and physical properties of the sample were supplied by the producer. Gördes zeolite has the following properties: 1.9−2.2 mequiv/g cation exchange capacity, 0.4 nm pore diameter, 92−96% purity, 40% bed porosity, 2.15 g/cm^3 density, 1.30 g/cm^3 apparent density. Chemical properties of the clinoptilolite sample are summarized in Table 1.

The reactive dye, Everzol Yellow 3RS/HC (C.I. Reactive Yellow 176), which contains anionic sulfonate groups, was purchased from the Everlight Chemical Ind. Corp., Taiwan. A quaternary amine, hexadecyltrimethylammonium bromide (HTAB, $C_{19}H_{42}BrN$) having 99% purity was purchased from Sigma-Aldrich Co. to be used in the modification of the surface of zeolite in column mode.[7] The equilibrium concentration of Reactive Yellow 176 was determined at $\lambda_{max} = 400$ nm using a visible spectrophotometer (WTW Photolab). The calibration

* To whom correspondence should be addressed. E-mail: mturan@ins.itu.edu.tr.

† E-mail addresses: aysegul_faki@hotmail.com; ozguro@kaski.gov.tr, azturan@hotmail.com.

‡ Department of Environmental Engineering.

§ Department of Chemical Engineering.

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Table 1. Chemical Composition of Gördes Clinoptilolite

constituent	zeolite (% by wt)
SiO_2	70.5
CaO	2.9
K_2O	1.75
SO_3	0.01
AI_2O_3	13.5
MgO	1.2
TiO_2	0.05
P_2O_5	0.05
Fe_2O_3	1.10
Na_2O	0.04
LOI[a]	4.55

[a] Loss on ignition.

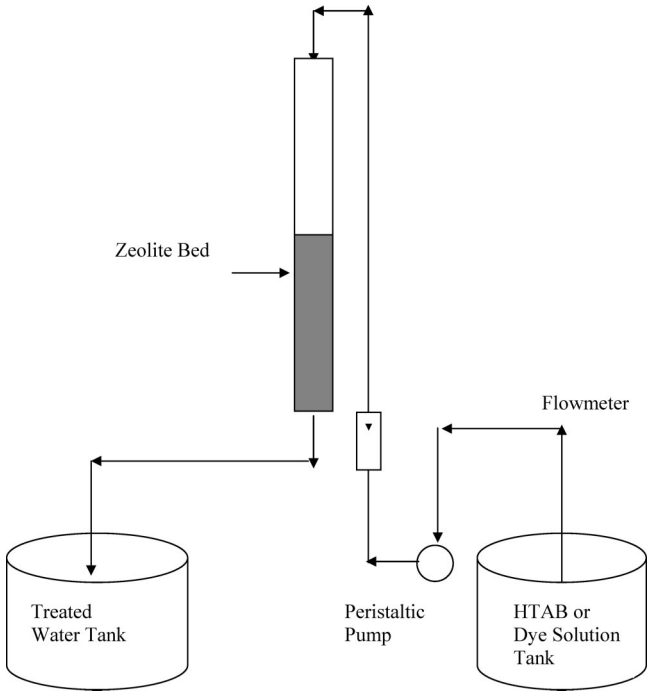

Figure 1. Schematic flowsheet of fixed-bed column setup.

curve at respective wavelengths was established as a function of dye concentration. The reproducibility of the data varied in the range of ±1.5%. The analysis for the cationic surfactant (HTAB) was performed by a two phase titration technique originally applied to anionic surfactants using dimidium bromide and disulfine blue as indicators. This technique is based on the formation of a complex structure between an anionic surfactant (sodium dodecylsulfate) and the cationic reagent (HTAB). The complex is soluble in chloroform and changes from blue to pink in the presence of indicators.[26,27]

Column Studies. The laboratory scale experimental setup consists of a zeolite fixed-bed column, HTAB solution and dye solution tanks, a peristaltic pump, a flowmeter, valves and a treated water tank (Figure 1). The cylindrical plexiglas column has a diameter of 3 cm and a height of 100 cm. The particle size of clinoptilolite is 0.5−1 mm (35−18 mesh) with bed heights of 25, 35, and 50 cm (fixed-bed volumes of 175, 245, and 350 cm^3) and filling weights of 150, 210, and 300 g, respectively. A sample of 15 g of HTAB was dissolved in a known volume of distilled water to obtain the desired concentration of HTAB solution. The reactive dye weighing 0.5 g was mixed with 10 L of water to make up a solution of 50 mg/L dye. The samples were taken in 2 h periods and analyzed using a visible spectrophotometer (WTW Photolab).

Experiments were performed to determine the optimum HTAB concentration for preparing modified zeolite and subsequent removal of Reactive Yellow 176 dye by modified zeolite in the column system. The system consists of a fixed-bed column to the top of which HTAB or dye solution is pumped from a tank. At the first stage of the experiments, HTAB solution was fed to zeolite column at a flow rate of 0.025 L/min (2.12 $m^3/(m^2h)$) using a peristaltic pump (Seko PR1). At the second stage, yellow dye solution (50 mg/L) was fed to the column in the down-flow mode with a volumetric flow rate of 0.050 L/min (4.24 $m^3/(m^2h)$) and optimum HTAB concentration for zeolite was examined at 2, 3, 4, and 5 g/L HTAB concentrations, respectively. Samples were collected against time for HTAB and dye solutions at certain intervals and analyzed for residual concentration in the effluents. Amounts of the adsorbed dye were calculated from the difference between influent and effluent concentrations.

Results and Discussion

Adsorption Column Design Parameters. Adsorption performance of the modified zeolite bed can be evaluated while bed volumes (BV) at breakthrough point ($C/C_0 = 0.1$) is maximum. The breakthrough curves were constructed by plotting the normalized effluent concentration (C/C_0) versus time (t) and/or bed volumes (BV). The bed volumes, BV, and the empty bed contact time, EBCT, at the fixed-bed column are defined, respectively, as follows

$$\mathrm{BV} = V_F/V_R = Q_t/V_R \quad (1)$$

$$\mathrm{EBCT} = V_R/Q \quad (2)$$

where V_F is the total volume of wastewater treated during the adsorption process at time t (L), V_R is the fixed-bed volume of zeolite (L), C_0 is the influent concentration (mg/L), C is the effluent concentration at time t (mg/L), Q is the feed flow rate in the fixed bed (L/min), and t is the service time (min).

The formation and the movement of the adsorption zone can be evaluated numerically.[28,29] The time required for the adsorption zone to become established and move completely out of the bed at exhaust time is

$$t_{Exh} = V_{Exh}/Q = \mathrm{BV}_{Exh}\mathrm{EBCT} \quad (3)$$

The rate at which the adsorption zone (U_z) is moving up or down through the bed is

$$U_z = h_z/t_z = h/(t_{Exh} - t_f) \quad (4)$$

From eq 4, the height of the adsorption zone (h_z) is obtained

$$h_z = h(t_z)/(t_{Exh} - t_f) \quad (5)$$

where V_{Exh} is the total volume of wastewater treated in the zeolite column at exhaust time (L), h_z is the height of adsorption zone (cm); h is the total bed height (cm); and t_f is the time required for the adsorption zone to initially form (min). The t_f value can be found as follows

$$t_f = (1 - F)t_z \quad (6)$$

At breakthrough, the fraction (F) of zeolite present in the adsorption zone still possessing the ability to remove yellow dye is

$$F = S_z/S_{max} = \int_{V_b}^{V_{Ehx}} (C_0 -)dV/C_0(V_E - V_b) \quad (7)$$

where V_b is the total volume of the wastewater treated to the breakthrough point (L), S_z is the amount of solute that has been

removed by the adsorption zone from breakthrough to exhaustion; and S_{max} is the amount of solute removed by the adsorption zone when completely exhausted. The percentage of the total column saturated at breakthrough point is

$$\% \text{ saturation} = (h + (F-1)h_z) \times 100/h \quad (8)$$

Bed Depth Service Time (BDST) Model. The objective of fixed-bed operations is to reduce the concentration in the effluent so that it does not exceed a specific breakthrough concentration (C_b). The original work on the BDST model was carried out by Bohart and Adams[30] who proposed a relationship between bed depth, Z, and the time taken for breakthrough to occur. The service time, t, is related to the process conditions and operating parameters

$$\ln(C_0/C_b - 1) = \ln(e^{K_{ad}N_0Z/V} - 1) - k_{ad}C_0t \quad (9)$$

Hutchins[29] proposed a linear relationship between the bed depth and service time

$$t = N_0Z/C_0V - (1/k_{ad}C_0)\ln(C_0/C_b - 1) \quad (10)$$

where C_b is the solute concentration at breakthrough point (mg/L), k_{ad} is the adsorption rate constant (L/(mg h)), N_0 is the adsorption capacity (mg of solute/L of adsorbent), Z is the bed depth of column (cm), V is the linear flow velocity of feed to bed (cm/h), and t is the service time of column (h).

The critical bed depth, Z_0, is the minimum column height necessary to produce an effluent concentration C_b. By letting $t = 0$, Z_0 is obtained from eq 10

$$Z_0 = (V/k_{ad}N_0)\ln(C_0/C_b - 1) \quad (11)$$

Equation 10 enables the service time, t, of an adsorption bed to be determined by a specified bed depth, Z, of adsorbent. t and Z are correlated with the process parameters and the influent concentration of solute, solution flow-rate and the adsorption capacity.[32] Equation 10 can be expressed in the following form:

$$t = mZ + n \quad (12)$$

where

$$m = \text{slope} = N_0/C_0V \quad (13)$$

$$n = \text{intercept} = -(1/k_{ad}C_0)\ln(C_0/C_b - 1) \quad (14)$$

Behavior of Adsorption Column Based on Bed Modification. Because the reactive dyes have negative sulfonate groups, they are repelled by the negatively charged zeolite surface, which causes relatively low adsorption capacity.[33] To increase the adsorption capacity, we modified the surface of natural zeolite with a cationic surfactant (HTAB), which not only makes the zeolite surface more hydrophobic but also neutralizes the negative charges.[7,33,34] The modification process was investigated in the range of 2−5 g/L HTAB concentrations in a bed height of 25 cm, and its effectiveness was tested using a 50 mg/L yellow dye (Reactive Yellow 176) solution. The color removal capacities of the zeolite, which was modified with different HTAB concentrations in the range of 2 and 5 g/L are given in Figure 2 as a function of service time. The breakthrough times (corresponding to $C_b/C_0 = 0.1$) for HTAB concentrations of 2, 3, 4, and 5 g/L exhibited at 330, 480, 300, and 240 min, respectively, and the exhaust times (corresponding to $C/C_0 = 0.9$) were 960, 1080, 780, and 660 min, respectively. Zeolite modified at 3 g/L HTAB concentration showed the best performance, within the concentration range tested, in adsorbing the yellow dye compared to the others.[7]

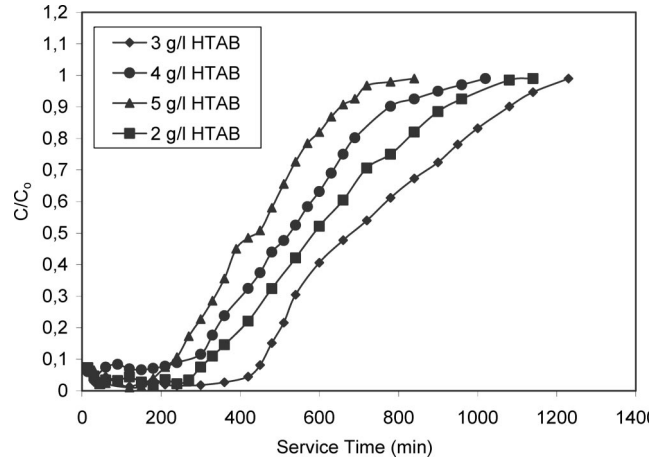

Figure 2. Adsorption of Reactive Yellow 176 dye by zeolite modified at different HTAB concentrations against service time (influent dye conc.= 50 mg/L, dye flow rate = 0.050 L/min, bed height= 25 cm).

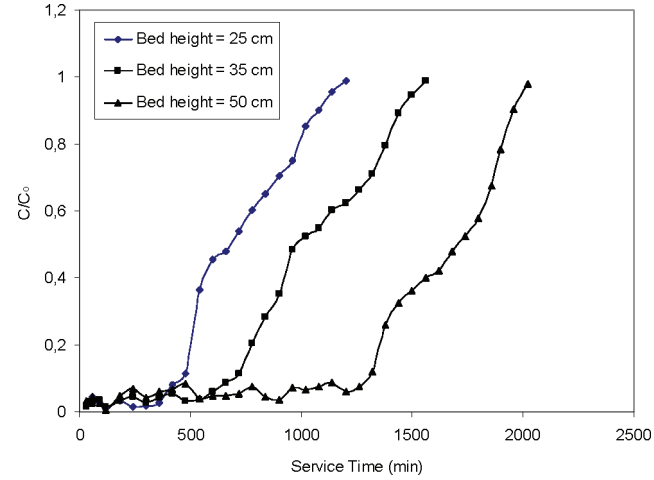

Figure 3. Breakthrough curves of Reactive Yellow 176 dye removal by HTAB-modified zeolite packed columns of different bed heights (HTAB modification conc. = 3 g/L, initial yellow dye conc. = 50 mg/L, flow rate = 0.050 L/min).

Behavior of Adsorption Column Based on Bed Height. Fixed-bed column studies were conducted using column packed with zeolite modified at 3 g/L HTAB concentration for three different heights of 25, 35, and 50 cm. The column was fed with Reactive Yellow 176 textile dye solution in the down-flow mode with a volumetric flow rate of 0.050 L/min and the initial dye concentration was 50 mg/L. The breakthrough curves at different bed heights were shown in Figure 3. The breakthrough times (corresponding to $C_b/C_0 = 0.1$) were found to be 480 min (8 h), 720 min (12 h), and 1320 min (22 h) for the columns having 25, 35, and 50 cm bed heights, respectively, and the exhaust times (corresponding to $C/C_0 = 0.9$) were found to be 1080 min (18 h), 1440 min (24 h), and 1960 min (32.67 h), respectively. Using eq 2, the empty bed contact times (ECBT) obtained were 3.5, 4.9, and 7 min (for 25, 35, and 50 cm bed heights, respectively). From eq 1, the bed volumes and treated wastewater volumes found were 137, 150, and 188 BV (24, 36, and 66 L) at breakthrough points and 308, 294, and 280 (54, 72, and 98 L) at the exhaust times (for 25, 35, and 50 cm bed heights, respectively).

Different parameters for the zeolite column such as time required for the adsorption zone to move its own height (t_z), height of adsorption zone (h_z), rate at which the adsorption zone is moving down through the bed (U_z), bed saturation, and empty

Table 2. Design Parameters for Modified Zeolite Fixed-Bed Column

param	bed height 25 cm	35 cm	50 cm	average value
t_z (h)	10	10.36	10.67	10.34
h_z (cm)	18.38	19.68	20.91	19.66
U_z (cm/h)	1.84	1.90	1.96	1.90
EBCT (min)	3.5	4.9	7	
bed saturation (%)	68	69	72	

bed contact time (ECBT) have been calculated. The values of these design parameters for bed depths of 25, 35, and 50 cm are shown in Table 2.

From the breakthrough times (corresponding to $C_b/C_0 = 0.1$) and the exhaust times (corresponding to $C/C_0 = 0.9$) for 25, 35, and 50 cm bed heights, Figure 4 was plotted as the bed height versus service time for 10 and 90% saturation of zeolite column as follows

$$t = 0.5684Z - 6.8421 \quad \text{for 10\% saturation} \qquad (15)$$

$$t = 0.5861Z + 3.3995 \quad \text{for 90\% saturation} \qquad (16)$$

As seen in the slopes of these equations, the lines in Figure 4 were nearly parallel and the horizontal distance between the lines was 18.86 cm. This horizontal distance is called the height of exchange zone.[33] Its theoretical value was calculated as 19.66 cm (Table 2) with a difference of 4.2% compared to the literature.[29,35] From the slope and intercept of the 10% saturation line, design parameters of N_0 and k_{ad} can be calculated using eqs 13 and 14, respectively. The values of k_{ad} and N_0 were found to be 6.432×10^{-3} L/(mg h) and 12.05 g/L, respectively. The minimum bed height (Z_0) necessary to produce an effluent concentration of C_b was found to be 12.02 cm using eq 11.

Comparative Evaluation of Simulated and Real Textile Wastewaters. In the adsorption column experiments, simulated textile wastewater and real textile wastewater also were used. Simulated textile wastewater was prepared in 5 L of water having 50 mg/L Reactive Yellow 179 dye, 0.059 g/L chelating agent ($C_{10}H_{14}N_2Na_2O_8.2H_2O$), 0.95 g/L NaCl, 0.24 g/L Na_2CO_3, and 0.05 g/L acetic acid (CH_3COOH).[36] Real textile wastewaters having different reactive dyes were maintained from a textile industry in Bursa, Turkey.

The color removal efficiency of the aqueous yellow dye solution having only 50 mg/L Reactive Yellow 179 was compared with these two wastewaters. The breakthrough times (corresponding to $C_b/C_0 = 0.1$) were found to be 480 min (8 h), 360 min (6 h), and 180 min (3 h) for the yellow dye solution, the simulated textile wastewater, and the real textile wastewater, respectively (Figure 5). Consequently, adsorption capacity in the simulated textile wastewater and the real textile wastewater showed 25 and 62% decrease compared to the yellow dye solution. This decrease can be explained as competitive adsorption between other colorants and colorless textile effluent pollutants.[32]

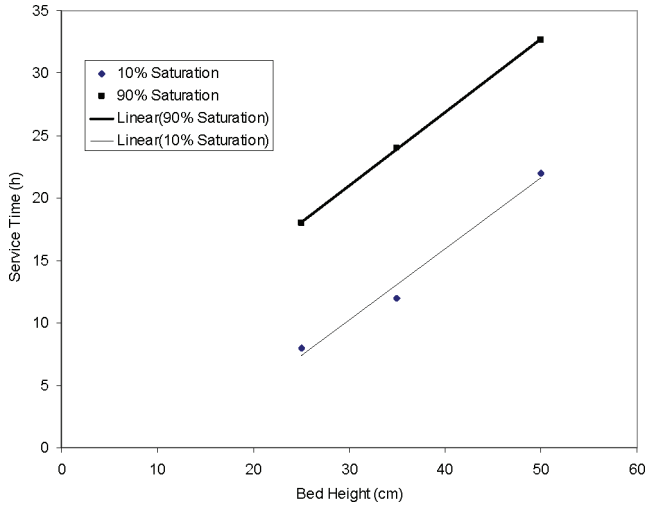

Figure 4. Bed heigth versus service time plot at 10 and 90% saturation of zeolite column.

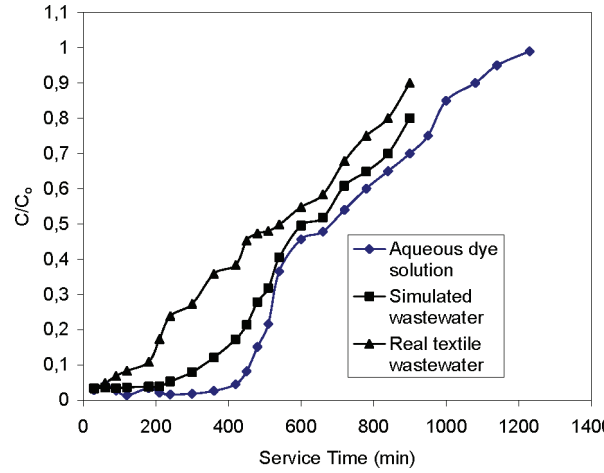

Figure 5. Color removal efficiency from aqueous yellow dye solution, simulated wastewater, and real textile wastewater.

Column Regeneration Based on Temperature. The adsorption process was terminated whenever the normalized effluent concentration (C/C_0) of Reactive Yellow 176 reached the value of 0.9 at about the exhaust time and the regeneration started. In the zeolite column having 25 cm bed height, the breakthrough time (corresponding to $C_b/C_0 = 0.1$) was found to be 480 min (8 h) and the exhaust time (corresponding to $C/C_0 = 0.9$) was found to be 1080 min (18 h). From eq 1, the bed volumes and treated wastewater volumes were found to be 137 BV (24 L) at the breakthrough point and 308 BV (54 L) at the exhaust time, respectively. In addition, treated wastewater volume at $C/C_0 = 0.99$ was obtained as 61.5 L (Figure 3).

The column regeneration was carried out for HTAB-modified zeolite using a solution consisting of 30 g/L NaCl and 1.5 g/L NaOH at pH 12 for the exhausted 25 cm height dye adsorbed zeolite medium. In the beginning, the bed accelerated with the air flow from the bottom of the bed, and the regeneration solution with a flow rate of 0.050 L/min was then fed to the top of bed. Also, the effect of the temperature on the regeneration was investigated at 30 and 60 °C.

The regeneration of modified zeolite at 60 °C was found to have achieved a significant unload of 164 mg/L dye concentration in the first 5 min and then reached 26 mg/L dye concentration after 15 min and the regeneration was completed in 70 min (Figure 6). Desorption efficiencies can be determined calculating the mass of Reactive Yellow 176 removed from wastewater during the adsorption process and the dye desorbed from particles during desorption process. From Figure 3, dye adsorption mass can be calculated as the following way

$$((50\ \text{mg/L dye} \times 1230\ \text{min}) - 0.99C/C_0 \times 50\ \text{mg/L dye} \times (1230 - 480)\ \text{min}/2)) \times 0.050\ \text{L/min} = 2147\ \text{mg of dye}$$

On the other hand, from Figure 6, desorption mass can be found as

$$(164\ \text{mg/L dye} \times 15\ \text{min} + 26\ \text{mg/L dye} \times (70 - 15)\text{min}/2) \times 0.050\ \text{L/min} = 1945\ \text{mg of dye}$$

Consequently, dye desorption efficiency during regeneration process was obtained as

$$\text{Desorption efficiency} = 1945 \text{ mg of dye}/2147 \text{ mg of dye} = 90.6\%$$

The regeneration process resulted in a highly concentrated dye solution in a small volume of regenerant. The concentration factor (CF), which can be used to assess the overall success of the adsorption process, can be defined as the ratio of the volume of dye solution passing the column or effluent treated (in adsorption process) to that of regenerant used or the dye desorbed (in desorption process) can be calculated as follows

$$\text{CF} = V_F/V_D = 61.5 \text{ L}/3.5 \text{ L} = 17.6 \qquad (17)$$

In a similar study, Vijayaraghavan et al.[37] obtain a concentration factor of 8.8. In additon, a similar result was given for the removal of the concentrates in membrane processes.[38] The results generally indicate that zeolite has significant advantages over the other alternative adsorbents.[23,34,39]

On the other hand, the desorption efficiency of exhausted modified zeolite at 30 °C was found as 23% (Figure 6). Consequently, higher temperature (60 °C) was found to be more effective than lower temperature (30 °C) for the desorption of yellow dye. According to Gorensek,[40] higher temperature (>60 °C) and higher pH (>10) might cause reactive dyes to hydrolyze, which will affect the experimental results.

Before the adsorption process operated in the fixed-bed column using regenerated zeolite, the modification process was repeated with HTAB concentration of 3 g/L at constant feed flow rate of 0.025 L/min. During the regeneration process, a few amount of HTAB surfactant desorbed into the desorbed concentrated dye solution. This caused decreasing of the adsorption capacity of zeolite with the decrease of the amount of HTAB on the zeolite. As seen in Figure 7, the area between the first modification curve and the modification after regeneration curve can be found as a reduction of HTAB surfactant in the zeolite bed.

The adsorption capacity of the regenerated zeolite for 0.5−1 mm size fraction using aqueous dye solution containing Reactive Yellow 176 (50 mg/L) are given as a function of time in Figure 8. The breakthrough points (corresponding to $C/C_0 = 0.1$) were found to be 480 min (8 h) and 360 min (6 h) for original (untreated) and regenerated modified zeolites, respectively, whereas the exhaust times (corresponding to $C/C_0 = 0.9$) were found to be 1080 min (18 h) and 840 min (14 h), respectively. Consequently, the regenerated zeolite appears to have a lower

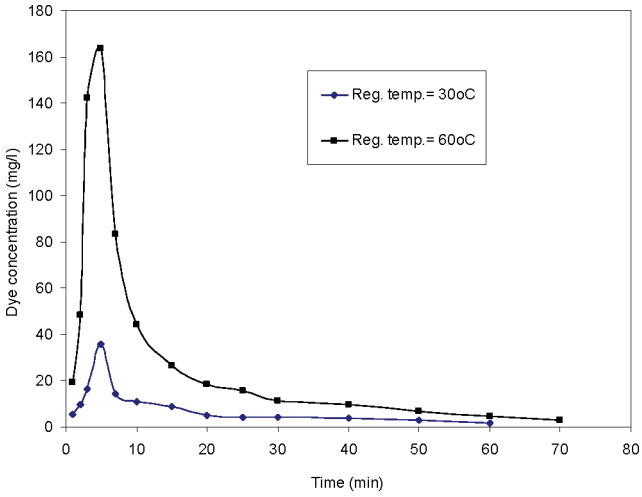

Figure 6. Desorption of yellow dye from zeolite column at different temperature versus time (Regenerant flow rate = 0.050 L/min, bed height = 25 cm).

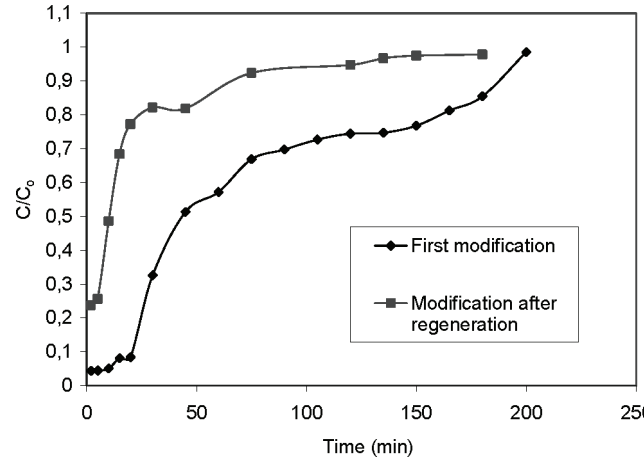

Figure 7. Modification of original and regenerated zeolite as a function of time (HTAB conc. = 3 g/L, HTAB flow rate = 0.025 L/min, bed height= 25 cm).

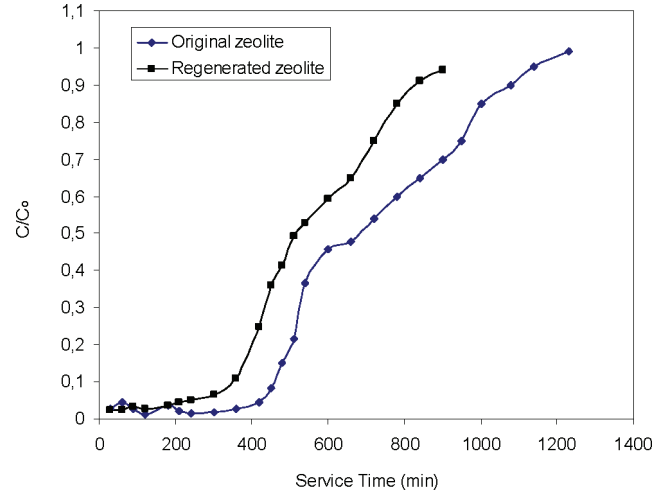

Figure 8. Breakthrough curves of Reactive Yellow 176 dye removal by original and regenerated modified zeolites in adsorption column (HTAB modification conc. = 3 g/L, initial yellow dye conc. = 50 mg/L, dye flow rate = 0.050 L/min, bed height = 25 cm).

efficiency than the untreated zeolite; regeneration hinders the performance of zeolite column by approximately 25%. The result is fitted to the finding of zeolite/lead system by Turan et al.[23] and modified zeolite/fulvic acids by Wang et al.[34]

Textile dyeing wastewaters contain high concentrations of organic components (dyes and additives such as antifoam agents) and inorganic components (salts, used to regulate the rate of dye fixing on the textile). Generally, the removal of exhausted zeolite and/or desorbed dye solution can be explained in the following categories: (1) reuse, (2) incineration, and (3) land-filling. Recycling of dyes or other chemicals is generally not possible because the composition of the desorbed concentrated dye solution is too complex and because the components are often modified by, for example, hydrolysis.[38] Zeolite is cheap and abundantly available; therefore, regeneration/reuse is not required. Besides, the exhausted zeolite can be used as animal feed or as fertilizer after the dyes have been completely desorbed. The common application on the removal of exhausted zeolite and/or desorbed dye solution is disposal of the waste material to landfill or by incineration.[37]

Cost Analysis. The cost of the cheapest variety of commercially available carbon is about US$2000/ton. Natural zeolite costs about US$70/ton, including the cost of its purchase, transport, and processing (chemicals, electrical energy, and labor required in the process), whereas modified zeolite costs about

US$420/ton. Also, modified zeolite can be considered as a good alternative to commercially available activated carbon.

Conclusions

The removal of Reactive Yellow 176 from dyeing wastewater was achieved successfully using HTAB modified zeolite. The bed depth service time (BDST) model was applied to the results of this study. The calculated and theoretical values of the exchange zone height were found to have a difference of 4.2%. The breakthrough times (corresponding to $C_b/C_0 = 0.1$) were found to be 8, 6, and 3 h for the aqueous yellow dye solution, the simulated textile wastewater, and the real textile wastewater, respectively. This decrease can be explained as competitive adsorption between other colorants and colorless textile effluent pollutants. The zeolite column was regenerated at different temperatures of 30 and 60 °C. The desorption efficiency was 90.6% at higher temperature (60 °C), whereas the efficiency was 23% at at lower temperature (30 °C). The higher temperature (60 °C) with a desorption efficiency of 90.6% was found to be more effective than that at lower temperature (30 °C) with a desorption efficiency of 23%, by means of the desorption of yellow dye. All of these findings show that the modified zeolite fixed-bed can be advantageously applied for the reactive dye removal and it can be successfully regenerated.

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