

JAVAD AHMADISHOAR¹
S. HAJIR BAHRAMI¹
BARAHMAN MOVASSAGH²
SEYED HOSEIN AMIRSHAHI¹
MOKHTAR ARAMI¹

¹Textile Engineering Department,
Amirkabir University of
Technology, Tehran, Iran

²Chemistry Department, K.N. Toosi
University of Technology, Tehran,
Iran

SCIENTIFIC PAPER

UDC 631.82/.85:549.67:553:66

<https://doi.org/10.2298/CICEQ150116049A>

REMOVAL OF DISPERSE BLUE 56 AND DISPERSE RED 135 DYES FROM AQUEOUS DISPERSIONS BY MODIFIED MONTMORILLONITE NANOCLAY

Article Highlights

- A modified montmorillonite was used for adsorption of two disperse dyes
- Modified nanoclay could effectively adsorb the disperse dyes from their aqueous dispersion
- The molecular weight and structure of dyes affected the dye adsorption from their aqueous dispersion
- The major interactions between the nonionic dyes and organoclay are of hydrophobic nature
- Modified montmorillonite can be used for dye removal from textile wastewater industries

Abstract

In this study modified montmorillonite was used as an adsorbent for the removal of two selected disperse dyes i.e., Disperse Blue 56 (DB) and Disperse Red 135 (DR) from dye dispersions. The adsorption equilibrium data of dyes adsorption were investigated by using Nernst, Freundlich and Langmuir isotherm models. The adsorption kinetics was analyzed by using different models including pseudo-first-order, pseudo-second-order, Elovich and Intraparticle diffusion model. The Freundlich isotherm was found to be the most appropriate model for describing the sorption of the dyes on modified nanoclay. The best fit to the experimental results was obtained by using the pseudo-second-order kinetic equation, which satisfactorily described the process of dye adsorption. Although different kinetic models may control the rate of the adsorption process, the results indicated that the main rate limiting step was the intraparticle diffusion. The results showed that the proposed modified montmorillonite could be used as an effective adsorbent for the removal of disperse dyes even from highly concentrated dispersions.

Keywords: isotherm, kinetic, modified nanoclay, disperse dye, waste water.

The use and application of synthetic dyes in number of industries such as textile, plastic, paper, leather and cosmetic has gradually increased in recent years. The discharge of large amount of colored effluents, produced from these industries, into water sources leads to water pollution and causes major environmental problems. The removal of dyes

from wastewater is one of the critical issues for the dye manufactures and consumer industries.

The aromatic rings in the structure of most synthetic dyes make them biologically non-degradable [1]. A variety of methods could be suggested to eliminate dyes from wastewater. Some methods, such as ozonation and oxidation, decompose [2,3] the dye molecules to simpler compounds, which are less environmentally hazardous. Techniques such as coagulation and adsorption extract the dye molecules from the solutions, *i.e.*, water.

In general, the most important characteristics of the adsorption based techniques are their lower cost,

Correspondence: H. Bahrami, Textile Engineering Department, Amirkabir University of Technology, Tehran, Iran.
E-mail: hajirb@aut.ac.ir

Paper received: 16 January, 2015
Paper revised: 19 November, 2015
Paper accepted: 28 December, 2015

better availability, high efficiency, and the possibility to treat dyes in higher concentration forms in comparison to the other methods [4]. Various materials have been used as adsorbents for the dye removal, *i.e.*, bagasse [5] and TiO₂ [6]. As described in the literature, the activated carbon is the most widely used among all conventional adsorbents. However economical issues make it an expensive material for water treatment applications [7].

Nanoclays are low-cost adsorbents, which have been widely employed in dye user industries to adsorb dyes from wastewater [8]. Sodium montmorillonite belongs to the smectite group and is composed of 2:1 type layered silicate with two tetrahedral silicates and one octahedral layer with a considerable cation exchange capacity in the octahedral layer. The sodium montmorillonite is the more common form of the five natural varieties of smectite [9-12]. The main characteristic of sodium montmorillonite is its high cation exchange capacity. Due to substitution of cations in the layers, there is a negative charge in the octahedral layer which can be compensated by some cations. Sodium cations in sodium montmorillonite can be replaced by some chemical components. This could lead to surface modifications of the clays [12]. These modifications not only change the surface characteristics of the clays from hydrophobic nature to hydrophilic one, but also increase the adsorption capacity of the clays [13].

The literature survey indicated that the use of such modifications of the clay surface, led to improvement in the adsorption capacity of the different dye classes [14]. Different chemical components have been used for surface modification of nanoclays. Grafting of functional polymers to the surface of the clays [15], using ionic liquids such as imidazolium, pyridinium [16,17] and phosphonium derivatives [18], 1,6-diamino hexane [19] and cationic surfactant [20] are some of the reported modification types on nanoclays. The quaternary ammonium compounds are also typical materials used for nanoclay modification. Modified clays have been used for removal of different classes of dyes from wastewater. Zohra *et al.* [7] used modified bentonite for removal of direct dyes. Modified bentonite was used to remove reactive dyes from waste water [21]. In another report acid dyes were removed from wastewater using modified bentonite [22]. There is another report on removal of cation dyes from wastewater using modified montmorillonite and sepiolite [23,24]. To the best of our knowledge, there have been relatively few works investigating the removal of nonionic dyestuffs, *i.e.*, disperse dyes, from wastewater by using nanoclays.

In this study, a modified montmorillonite with an aromatic quaternary ammonium modification was used for the removal of aqueous dispersions of two disperse dyes with different structures and molecular weights. Some physicochemical aspects of the removal reaction such as adsorption isotherm, equilibrium conditions and adsorption kinetics were investigated.

MATERIALS AND METHODS

A modified montmorillonite nanoclay (Nanofil 3010, QA-MMN) was purchased from Süd-Chemie Company. Sodium montmorillonite (Cloisite-Na⁺, MMN) with a cation exchange capacity of 92.6 cmol/kg, was obtained from Southern Clay Products, Inc. Two commercial grade disperse dyes, *i.e.*, Serilen Blue RI (Disperse Blue 56 from Yourkshire Chemical) and Sumikaron Red S-GG (Disperse Red 135 from Sumitomo Chemical) were selected as disperse dyes and denoted as DB and DR, respectively. The chemical structures of the employed dyes are illustrated in Figure 1. The other chemicals, including sodium hydroxide, hydrochloric acid and ethanol, were of analytical grade, supplied by Merck and used without any purification.

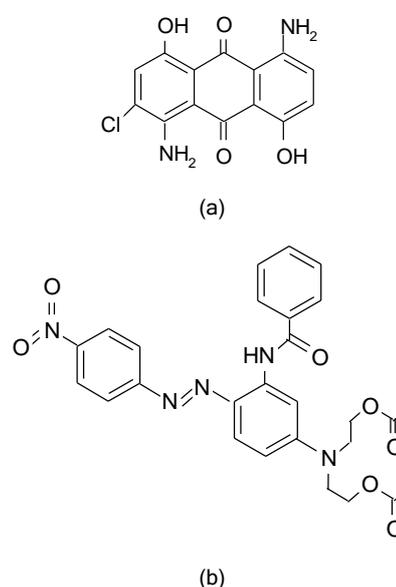


Figure 1. Chemical structure of dye: a) Disperse Blue 56, b) Disperse Red 135.

Adsorption experiment

All the adsorption experiments were carried out at 24 °C with a constant agitation speed of 500 rpm. Dye dispersions with specified concentrations were prepared. Then the nanoclays (MMN and QA-MMN) were added to the separate dispersions and stirred by a mechanical stirrer. After the adsorption processes

the nanoclay was centrifuged for 5 min at 5000 rpm. The concentration of the residual dye in the bath was measured using a Carry 100 UV-Vis spectrophotometer. The decrease in the dye concentration in the dye bath was accepted to be the amount of dye adsorbed by the nanoclays. In order to ensure the complete dissolution of the dye dispersion, a 10 volumetric parts of the dispersion was mixed with 90 volumetric parts of pure ethanol. The adsorption capacity (q_e) was calculated as follows:

$$q_e = (c_0 - c_e)V / W \quad (1)$$

where c_0 (g/L) is the initial concentration of the dye, c_e (g/L) is the concentration of the dye at equilibrium, V (L) is the volume of the dye dispersion, and W (g) is the mass of the adsorbent. The quantity of the adsorbed dye at time t , q_t (g/g), was calculated using the following equation:

$$q_t = (c_0 - c_t)V / W \quad (2)$$

where c_t (g/L) is the concentration of the dye at any time t .

Adsorption Isotherm

The dye adsorption isotherm was investigated by treating 200 ml dye dispersions having concentrations in the range of 0.1-1 g/L at pH 5 with 1 g of the modified nanoclay. In order to analyze the isotherm data, three models, *i.e.*, Nernst, Langmuir and Freundlich, were employed.

Adsorption kinetic models

Although several adsorption kinetic models were suggested for such an adsorption process, they should be confirmed by the mechanism of the dye adsorption on a sorbent [4]. The adsorption experiments were carried out by treating 100 ml dye dispersions with concentration of 1 g/L at pH 5 with 1 g of the nanoclay for different times. In order to investigate the dye adsorption kinetics, three adsorption models were used - intra-particle diffusion, pseudo-first-order and pseudo-second-order.

RESULTS AND DISCUSSION

The effect of pH on the adsorption process

The initial pH value of the dye dispersion is an important parameter, which controls the adsorption process and affects the surface charges of nanoclay. The adsorption study for disperse dyes on modified nanoclay was carried out using 100 ml dye dispersion with concentration of 0.2 g/L and 0.2 g adsorbent at 24 °C and pH in the range of 3-11 for 2 h.

The results showed that the adsorption of the two disperse dyes on clay depended on the initial pH of the dye dispersions. It could be seen from Fig. 2 that the amount of dye adsorbed on the nanoclay increased as the pH of DR and DB decreased from 7 to 3 and from 9 to 3, respectively. At higher values of pH, a small increase in the adsorbed amount of dyes was observed. Non-ionic dyes are negatively charged in solution [25,26] and the modified nanoclay has positively charged surface [7] especially at lower pH. The electrostatic interactions between the negatively charged dye molecules and the positively charged clay surface resulted in a higher dye removal at lower pH. At higher pH, the abundance of OH⁻ competing with the negatively charged dye molecules for the adsorption sites led to lower adsorption of both disperse dyes on the modified nanoclay. Similar observations were reported in other studies [19,25,27].

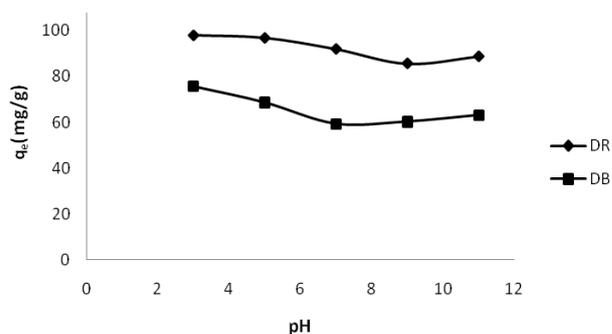


Figure 2. Effect of initial pH on the adsorption of disperse dyes on modified nanoclays (QA-MMN).

Rate of adsorption

In order to study the adsorption rate and to ensure complete adsorption of the dyes, the experiments were carried out for more than 4 h. The amount of the adsorbed dye on two types of clays (g/L) as a function of the contact time (in minutes) is shown in Fig. 3. The results showed that the rate of dye adsorption on nanoclay in the initial stage of the contact period was significantly high and the maximum adsorption rate was registered in the initial 20 min of the contact time for both dyes. After the initial stage of the adsorption process, the rate of dye adsorption gradually decreased and reached a steady-state value identified as the equilibrium loading capacity, q_e . Similar trend was reported in other studies [1,27-29].

The sharp slope in the first stage (higher initial sorption rate) could be attributed to a large number of vacant adsorption sites on the surface of the clay available in the initial stage of the adsorption process [7]. This led to an increase in the dye concentration gradient between the dispersion and the surface of

the adsorbent [7]. As time passed, the surface of the clay was gradually occupied by dye molecules, which resulted in less number of sites on the clay surface accessible to the dye molecules. This led to decrease in the tendency of the dye towards the clay surface [1,28]. The reduced adsorption rate showed a possible presence of a mono-layer of dye molecules on the nanoclay surface [1,4,29,30], which was evident for both disperse dyes.

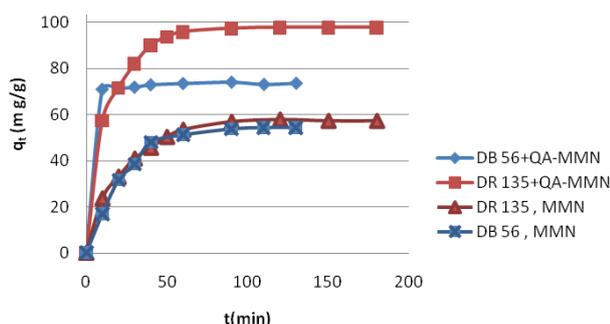


Figure 3. Effect of contact time for adsorption of DB and DR on MMN and QA-MMN

Figure 3 also showed differences in the dye adsorption in the first and last stage of the adsorption process for both disperse dyes. In the first stage of the adsorption process (the first 20 min), the amount of DB dye adsorbed on the nanoclay surface was rather higher than the amount of DR dye. However after this period, the adsorption behavior of the dyes changed and the DB dye showed slower adsorption rate in comparison to DR dye. Consequently at steady state the amount of the adsorbed DR dye on

the clay surface is higher than the one of DB dye. It seemed that, the differences could be related to the molecular structures of the employed dyestuffs. In fact, the smaller structure and lower molecular weight of DB led to a higher mobility of the dye during the first stage of the adsorption process in comparison to DR and consequently to a higher adsorption rate. In the next step it seemed that the major contributive forces between the nonionic dye and organoclay were the van der Waals forces and hydrophobic interactions [7, 14].

The negatively charged surface of the nanoclay may adsorb the cationic surfactants in two steps. Firstly *via* an ion exchange mechanism, a monolayer of cationic surfactants on the surface of the clay was formed. The positively charged ends of the cationic surfactants were exchanged with the interlayer exchangeable cations of the clay (Na^+) and the hydrophobic head of the cationic surfactants was arranged outward (Fig. 4a). Secondly through hydrophobic-hydrophobic interactions, cationic surfactant alkyl chains were attached to the outer alkyl chain of the monolayer (Fig. 4b) [31]. For the Nanofil 3010 sample, a diffraction peak at $2\theta = 7.65^\circ$ corresponding to a basal spacing of 11.56 Å was observed. According to the calculated basal spacing, it could be ensured that the monolayer arrangement was formed [32].

In our study, according to the adsorption/partition model, the organic fraction of the surfactant modified clay, containing a long alkyl chain, behaved as a partition medium and the partition occurred through interaction of the dyes with the cationic surfactant of the modified nanoclay. The cationic surf-

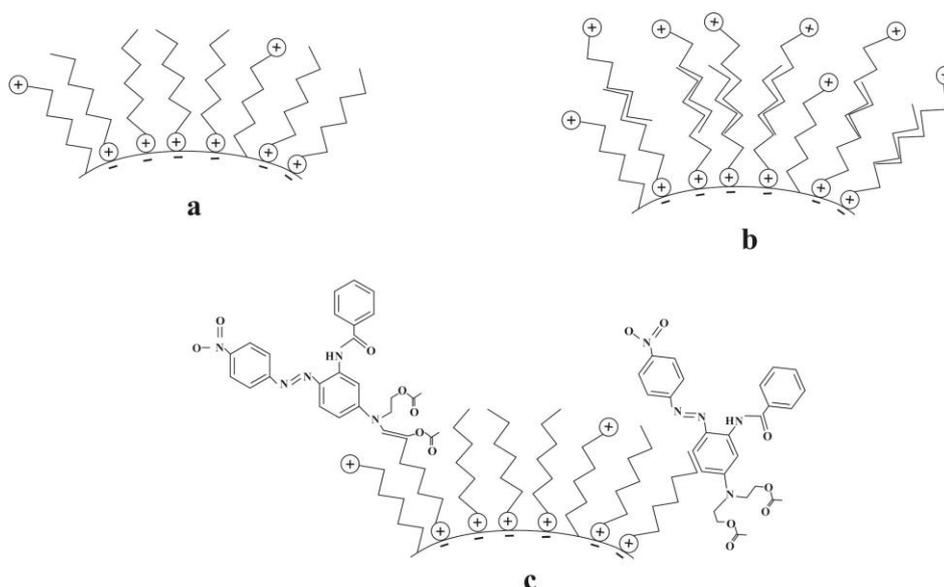


Figure 4. Schematic diagram of the formation of surfactant on the surface of the clay a) monolayer, b) bilayer formation and c) the interactions of DR molecules with the surfactant modified adsorbent.

actants created hydrophobic regions [33]. The hydrophobic portion of the adsorbent surface had greater affinity for dissociated species of dyes in aqueous solution and the major contributive forces between the nonionic dye and the organoclay were the Van der Waals forces and hydrophobic interactions (Figure 4c). The partition of the dyes into hydrophobic regions plays an important role in the dye uptake.

The dye with the larger molecular structure (DR) could be adsorbed better than the DB dye on the nanoclay surface due to the stronger van der Waals and hydrophobic interactions (interaction between the phenyl ring of the dyes and the CH₂ group of the modified adsorbent). A good example of a high sorption of the disperse dyes on the clay surface modified with quaternary ammonium with aromatic rings was the sorption of disperse dyes on Cloisite 10A, where the Van der Waals forces were the main interaction forces between the aromatic systems [14]. The affinity of montmorillonite (MMN) toward these dyes from dispersion was lower in comparison to the modified nanoclay (QA-MMN). From the results shown in Fig. 3 it could also be concluded that the times for achieving the maximum adsorption for DB and DR were 60 and 120 min respectively, which were chosen for the next experiments in this study.

Adsorption isotherm

The adsorption isotherm indicated the distribution of dye adsorbed on the nanoclay and dye in bath in equilibrium state. The isotherm plots for both dyes are shown in Fig. 5.

Figure 5 showed the experimental and predicted data for three isotherms. The parameters of these isotherms for the employed dyes are given in Table 1. Based on the individual plots and the high regression correlation coefficient R^2 , it could be concluded that the Freundlich isotherm had better fits than the other isotherms.

Adsorption kinetic models

The determination of the adsorption kinetics can provide information about the rate of dye adsorption on the adsorbent surface from dye dispersion as well as the adsorption mechanism [4,30]. In order to study the adsorption kinetics in this study, the experimental data were analyzed using pseudo-first-order, pseudo-

second-order, Elovich equation and intra-particle diffusion models. The linear regression correlation coefficient, R^2 , was used as a criterion to select the model, which gives the best fit to the experimental data.

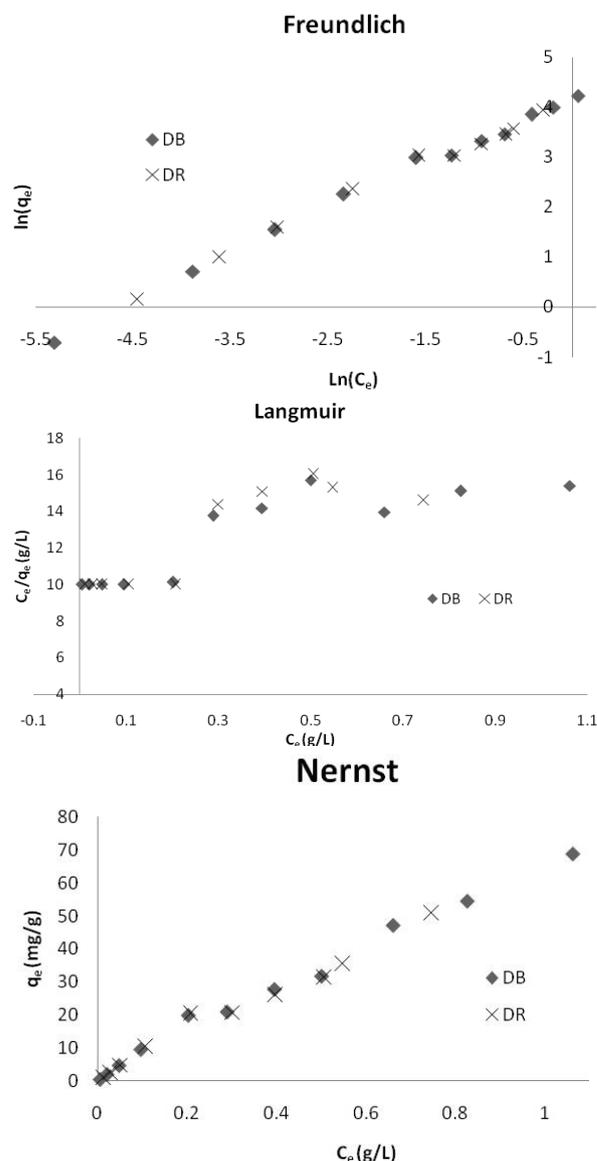


Figure 5. Adsorption isotherm of two disperse dyes on QA-MMN.

Pseudo-first-order model

The pseudo-first-order model is expressed by Eq. (3):

Table 1. Calculated isotherms parameters

Dye	Freundlich			Nerst		Langmuir		
	$k_f / L g^{-1}$	n	R^2	$K / mL g^{-1}$	R^2	$q_m / mg g^{-1}$	$k_b / L mg^{-1}$	R^2
DR	135.64	0.872	0.99	126.4	0.979	0.2154	0.942	0.744
DB	128.38	0.9	0.994	127.5	0.991	0.3279	0.592	0.749

$$\frac{dq_t}{dt} = k_1(q_e - q_t) \quad (3)$$

where q_t is the amount of the adsorbed dye at time t , k_1 is the rate constant of the pseudo-first-order model (min^{-1}); t is the time (min) and q_e is the adsorption capacity in equilibrium (mg/g). After definite integration by applying the conditions: $q_t = 0$ at $t = 0$ and $q_t = q_t$ at $t = t$, Eq. (3) becomes [34]:

$$\ln(q_e - q_t) = \ln q_e - k_1 t \quad (4)$$

The linear relation between the $\ln(q_e - q_t)$ and t confirmed the validity of the model while k_1 and q_e are the slop and intercept of the proposed line, respectively. The results listed in Table 2, showed that value of the the correlation coefficient for DR is higher than the one for DB and the values of q_e obtained by Eq. (4) for both dyes are not in agreement with the real values (0.08056 and 0.0977 g/g for DB and DR, respectively). The results showed that the experimental data are not in agreement with the pseudo-first-order kinetic model and this model cannot fully describe the adsorption kinetics. In Fig. 6a and b are shown the pseudo-first-order plots for DB and DR, respectively.

Pseudo-second-order model

The experimental data were also analyzed by using pseudo-second-order model. The obtained results showed that the pseudo-second-order model was suitable for low initial concentration of the dye solution [34]. Dogan *et al.* [1, 29] suggested that the rate of this model depends on the amount of the adsorbate on the surface of the adsorbent and the capacity of the adsorbent at equilibrium. The model is represented by Eq. (5):

$$\frac{dq_t}{dt} = k_2(q_e - q_t)^2 \quad (5)$$

where k_2 is the pseudo-second-order rate constant ($\text{g}/(\text{mol min})$). By integration at boundary conditions: $q_t = 0$ at $t = 0$ and $q_t = q_t$ at $t = t$, Eq. (5) becomes [34]:

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \quad (6)$$

Again, the model was confirmed by linear relation between t/q_t and t . As seen from Table 2, the correlation coefficient values for DR and DB are 0.9995 and 0.9992, respectively and q_e for both dyes are in agreement with the real values (80.56 and 97.72 mg/g for DB and DR, respectively). The plots of

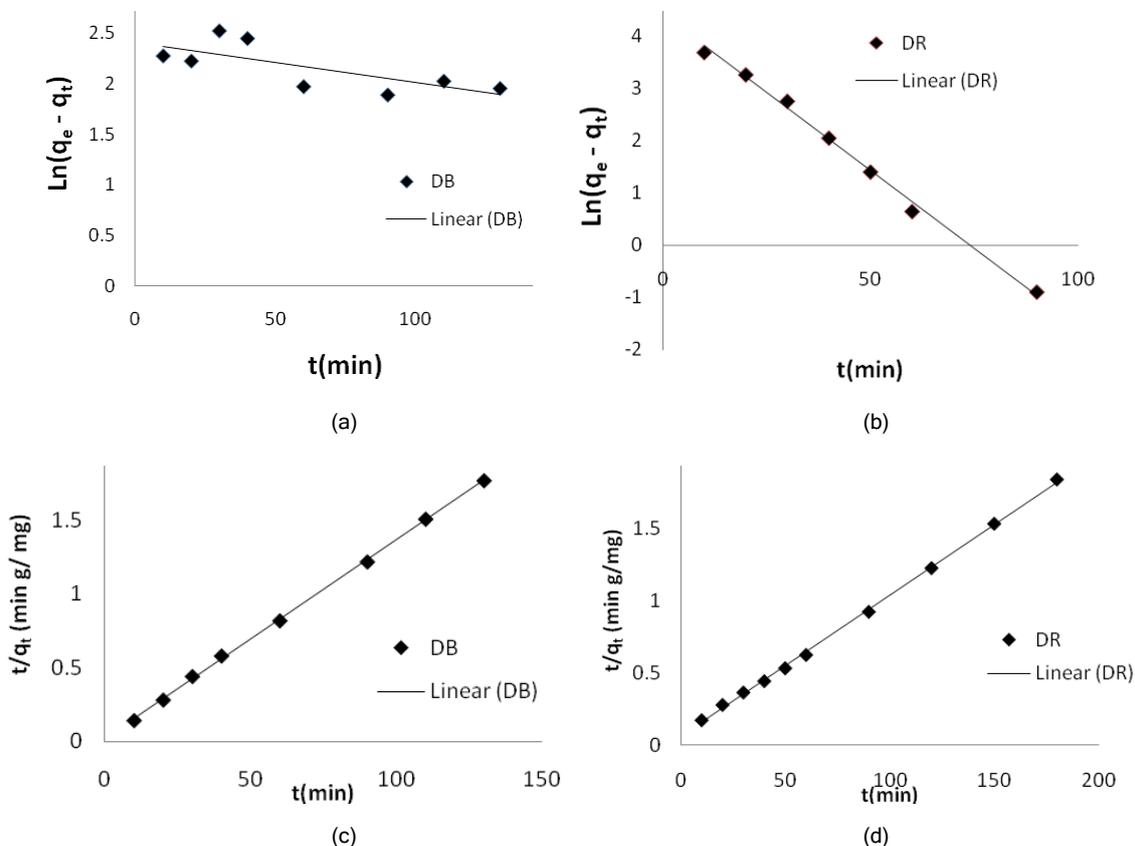


Figure 6. Plot of $\ln(q_e - q_t)$ vs. time (t), a: DB, b: DR and Plot of t/q_t vs. t , c: DB, d: DR.

Table 2. Kinetics data calculated for adsorption of DB and DR on QA-MMN

Dye	$q_{e, \text{exp}}$ mg/g	Pseudo-first order			Pseudo-second order			Elovich equation		
		R^2	$K_1 \times 10^2 / \text{min}^{-1}$	$q_{e, \text{cal}} / \text{mg g}^{-1}$	R^2	$K_2 / \text{g mg}^{-1} \text{min}^{-1}$	$q_{e, \text{cal}} / \text{mg g}^{-1}$	α	β	R^2
DB	80.56	0.5371	0.39	11.056	0.9995	0.00889	76.92	1.71×10^{11}	2.352	0.739
DR	97.72	0.9956	5.9	81.451	0.9992	0.00135	111.11	0.819	13.74	0.847

the pseudo-second-order model for DB and DR are presented in Fig. 6c and d, respectively.

Clearly, the pseudo-second-order kinetic equation could satisfactorily describe the dye adsorption and the experimental results were best fitted by using this model.

Elovich equation

The validity of this equation suggests the presence of reactions involving chemical adsorption of adsorbate on the adsorbent [4,35]. Equation (8) represents the mathematical form of the Elovich equation:

$$\frac{dq_t}{dt} = \alpha \exp(-\beta q_t) \quad (7)$$

where, α is the initial adsorption rate (mol/(g min)) and β is the desorption constant (g/mol). To simplify the Elovich equation, it was assumed that $\alpha\beta t \gg 1$. By taking this into account and applying the boundary conditions: $q_t = 0$ at $t = 0$, the simple form of the Elovich equation could be expressed as [1]:

$$q_t = \beta \ln(\alpha\beta) + \beta \ln t \quad (8)$$

The straight line plot of q_t vs. $\ln t$ confirmed the validity of the Elovich equation as a suitable model describing the kinetics of the adsorption process. The correlation coefficients of the plots of q_t vs. $\ln t$ for DB and DR are 0.739 and 0.8476, respectively which indicated that this model is not valid for this system.

Intraparticle diffusion model

Any adsorption process may consist of the following transportation steps: a) diffusion of the adsor-

bate in the surface of the adsorbent, b) intraparticle or pore diffusion and c) sorption of adsorbate on the adsorbent [1,4,36]. The intra particle diffusion model would be valid, if the plot of q_t vs. $t^{0.5}$ showed a linear relation and the intraparticle diffusion is the rate-limiting step. According to Weber *et al.* [37], the equation of intraparticle diffusion could be expressed by Eq. (9):

$$q_t = K_p t^{0.5} + C \quad (9)$$

where q_t is the amount of the adsorbed dye (mg/g) at time t , K_p (mg/(g min^{1/2})) is the rate constant for intraparticle diffusion and C is the intercept. The intraparticle diffusion plots for both dyes are shown in Fig. 7.

The values of the intercept are proportional to the thickness of the boundary layer and the larger intercept corresponds to a greater boundary layer effect [1,38,39]. As shown in Fig. 7 the adsorption process occurred in two steps and the plots of q_t vs. $t^{0.5}$ consist of two linear steps with different slopes for each of the employed dyes. Similar trends were reported in other studies [1,4,13,35,40]. They suggested that the sorption process occurred in two steps, *i.e.*, surface sorption and intraparticle diffusion [4]. In the first step, the dye molecules adsorbed on the external surface of the clays and the rate of this step was relatively fast. The second step occurred when the external surface of the clays was saturated by the dye. In this case, the dye molecules diffused in the clays and were adsorbed on their internal surface. Alkan *et al.* [1,4] suggested that the first step of the diffusion process could be attributed to the macro-pore diffusion indicating boundary layer effect and

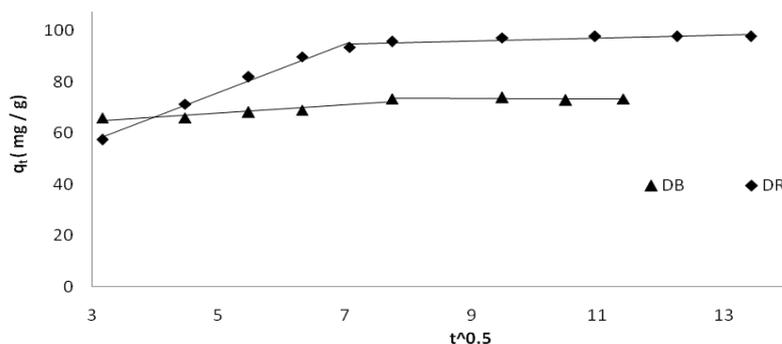


Figure 7. Intra-particle diffusion plots for adsorption of DR and DB on QA-MMN.

the second step of the diffusion process was due to the intraparticle or pore diffusion and was attributed to micro-pore diffusion. The rate constants (K_{p1} and K_{p2}) of the intraparticle diffusion model for the employed dyes are shown in Table 3.

Table 3. Intraparticle diffusion model parameter

Dye	$K_{p1} / \text{mg g}^{-1} \text{min}^{-1/2}$	R_1^2	$K_{p2} / \text{mg g}^{-1} \text{min}^{-1/2}$	R_2^2	$C_1 / \text{mg g}^{-1}$
DB	1.62	0.877	0	0.0165	59.7
DR	9.49	0.989	0.55	0.711	28.55

The results listed in Table 3 showed that the value of the first diffusion rate parameter (k_{p1}) for DR was different from the one for DB [3]. As discussed in the previous paragraph, the first diffusion rate was correlated to the surface sorption. The stronger hydrophobic properties of the DR dye in comparison to the one of DB and its affinity to the hydrophobic nanoclay were the reasons for the higher adsorption rate of the DR dye.

The slope of the second linear stage determined the rate parameter corresponding to the intraparticle diffusion. The value of this parameter for DR is higher than the one for DB. The linear regression and the comparison of the regression coefficients R_1^2 and R_2^2 for both dyes showed that the regression for both dyes is linear but the plots do not pass through the origin. This result is more obvious for DB. It suggested that the adsorption involved intraparticle diffusion and the diffusion could be accepted as a rate-limiting step. However, the diffusion is not the only rate-controlling step [1,7,25,26,39] and other kinetic models may also control the rate of adsorption.

CONCLUSIONS

In this study, the adsorption behavior of two disperse dyes on modified montmorillonite was investigated. Modified montmorillonite could effectively adsorb the disperse dyes from their aqueous dispersion and could be used for dye removal from textile wastewater industries. Changing the pH of the dye dispersion could affect the dye removal from dye dispersion. An increase of the pH to values of above 7 led to increase in the adsorption of both disperse dye on modified nanoclays. The adsorption rate study showed that the adsorption of dyes on modified clays involved two stages and the first stage of the adsorption process was faster than the second stage for both dyes. The selected dyes had different molecular weight and structure. This affected the dye adsorption process on the absorbent surface. The isotherm

model, which showed the best fit to the experimental data for both dyes was the Freundlich linear model ($R^2 > 0.99$). The kinetics studies showed that the adsorption of the two disperse dyes could be well defined by pseudo-second-order kinetic equation with

a high correlation coefficient ($R^2 > 0.99$). The results showed that the adsorption process involved intraparticle diffusion and the diffusion could be a rate-limiting step. However, the diffusion was not the only rate-controlling step and other kinetic models could also control the rate of adsorption.

REFERENCES

- [1] M. Dogan, Y. Ozdemir, M. Alkan, *Dyes Pigm.* **75** (2007) 701-713
- [2] H. Selcuk, *Dyes Pigm.* **64** (2005) 217-222
- [3] A.E. Papadopoulos, D. Fatta, M. Loizidou, *J. Hazard. Mater.* **146** (2007) 558-563
- [4] M. Alkan, M. Dogan, Y. Turhan, O. Demirbas, P. Turan, *Chem. Eng. J.* **139** (2008) 213-223
- [5] J. X. Yu, J. Zhu, L.Y. Feng, R.A. Chi, *J. Colloid Interface Sci.* **451** (2015) 153-160
- [6] J. Feng, J. Zhu, W. Lv, J. Li, W. Yan, *Chem. Eng. J.* **269** (2015) 316-322
- [7] B. Zohra, Kh.Aicha, S. Fatima, B. Nourredine, D. Zoubir, *Chem. Eng. J.* **136** (2008) 295-305
- [8] T.S. Anirudhan, M. Ramachandran, *Process Saf. Environ. Prot.* **95** (2015) 215-225
- [9] H.H. Murray, *Applied Clay Mineralogy*, Elsevier, Amsterdam, 2007, pp. 5-32
- [10] M.J. Wilson, *Clay Mineralogy*, Chapman & Hall, London, 1995, pp. 300-326
- [11] M.J. Wilson, *A Hand Book Of Determinative Methods in Clay Mineralogy*, Chapman & Hall, London, 1987, pp. 1-23
- [12] A.C.D. Newman, *Chemistry of Clays and Clay Minerals*, Wiley, New York, 1987, pp. 12-116
- [13] A. Khenifi, B. Zohra, B. Kahina, H. Houari, D. Zoudir, *Chem. Eng. J.* **146** (2009) 345-354
- [14] Y. Yang, Sh. Han, *Text. Res. J.* **75** (2005) 622-627
- [15] P. Liu, *Appl. Clay Sci.* **38** (2007) 64-76
- [16] N.H. Kim, S.V. Malhotra, M. Xanthos, *Microporous Mesoporous Mater.* **96** (2006) 29-35
- [17] S. Livi, J. Duchet-Rumeau, J. Gerard, *J. Colloid Interface Sci.* **353** (2011) 225-230
- [18] G. Huang, J. Gao, X. Wang, *Appl. Surf. Sci.* **258** (2012) 4054-4062

- [19] Ö. Gök, A. S. Özcan, A. Özcan, *Appl. Surf. Sci.* **256** (2010) 5439-5443
- [20] M. Kozak, L. Domka, *J. Phys. Chem. Solids* **65** (2004) 441-445
- [21] A. Tabak, N. Baltas, B. Afshin, M. Emirik, B. Caglar, E. Eren, *J. Chem. Technol. Biotechnol.* **85** (2010) 1199-1207
- [22] P. Baskaralingam, M. Pulikesi, D. Elango, V. Ramamurthi, S. Sivanesan, *J. Hazard. Mater., B* **128** (2006) 138-144
- [23] G. Rytwo, S. Nir, M. Grespin, L. Margulies, *J. Colloid Interface Sci.* **222** (2000) 12-19
- [24] C.A.P. Almeida, N.A. Debacher, A.J. Downs, L. Cottet, C.A.D. Mello, *J. Colloid Interface Sci.* **332** (2009) 46-53
- [25] Q. Li, Q. Y. Yue, H. J. Sun, Y. Su, B. Y. Gao, *J. Environ. Manage.* **91** (2010) 1601-1611
- [26] Q.Y. Yue, Q. Li, B.Y. Gao, Y. Wang, *Sep. Purif. Technol.* **54** (2007) 279-290
- [27] M. Dogan, M. Alkan, *Chemosphere* **50** (2003) 517-528
- [28] I. Mall, V. Sirvastava, N. Agarwal, *Dyes Pigm.* **69** (2006) 210-223
- [29] M. Dogan, M. H. Karaoglu, M. Alkan, *J. Hazard. Mater.* **165** (2009) 1142-1151
- [30] D. Shen, J. Fan, W. Zhou, B. Gao, Q. Yue, Q. Kang, *J. Hazard. Mater.* **172** (2009) 99-107
- [31] M. Foroughi, H. Abolghasemi, M. Esmaielia, Gh. Nazari, B. Rasem, *Process Saf. Environ. Prot.* **95** (2015) 226-236
- [32] Z. Jianxi, H. Hongping, G. Jiugao, Y. Dan, X. Xiande, *Chin. Sci. Bull.* **48** (2003) 368-372
- [33] T.S. Anirudhan, M. Ramachandran, *Process Saf. Environ. Prot.* **95** (2015) 215-225
- [34] S. Azizian, *J. Colloid Interface Sci.* **276** (2004) 47-52
- [35] M. Dogan, M. Alkan, O. Demirbas, Y. Ozdemir, C. Ozmetin, *Chem. Eng. J.* **124** (2006) 89-101
- [36] J. Ahmadishoar, S.H. Amirshahi, R.M. Malek, *J. Appl. Polym. Sci.* **112** (2009) 1030-1036
- [37] W.J. Weber, J.C. Morris, *J. Sanit. Eng. Div.* **89** (1963) 31-60
- [38] N. Kannan, M. M. Sundaram, *Dyes Pigm.* **51** (2001) 25-40
- [39] B.H. Hameed, *Colloids Surfaces, A* **307** (2007) 45-52
- [40] E. Eren, O. Cubuk, H. Ciftci, B. Eren, B. Caglar, *Desalination* **252** (2010) 88-96.

JAVAD AHMADISHOAR¹

S. HAJIR BAHRAMI¹

BARAHMAN MOVASSAGH²

SEYED HOSEIN AMIRSHAHI¹

MOKHTAR ARAMI¹

¹Textile Engineering Department,
Amirkabir University of Technology,
Tehran, Iran

²Chemistry Department, K.N. Toosi
University of Technology, Tehran, Iran

NAUČNI RAD

UKLANJANJE DISPERZNIH BOJA PLAVA 56 I CRVENA 135 IZ VODENIH DISPERZIJA POMOĆU MODIFIKOVANE MONTMORILONITNE NANOGLINE

U ovom radu korišćen je modifikovani montmorilonit kao adsorbent za uklanjanje dve izabrane disperzne boje disperzno plavo 56 (DB) i disperzno crveno 135 (DR) iz disperzija boja. Podaci za adsorpcionu ravnotežu su analizirani korišćenjem Nernstovog, Frojndlihovog i Lengmirovog izoternskog modela. Kinetika adsorpcije je analizirana korišćenjem modela pseudo-prvog i pseudo-drugog reda, Elovichevog i modela unutrašnje difuzije. Frojndlihov izoternski model se pokazao kao nabolji za sorpciju boje na modifikovanoj nano glini. Jednačina kinetike pseudo-drugog reda na zadovoljavajući način opisuje brzinu adsorpciju boje i najbolje fituje dobijene eksperimentalne podatke. Na osnovu dobijenih rezultata može se zaključiti da se brzina adsorpcija može opisati modelom unutrašnje difuzije. Ova difuzija se može smatrati kao stupanj koji limitira brzine, ali ne i kao jedini, s obzirom na to da i ostali modeli mogu kontrolisati brzinu adsorpcije. Dobijeni rezultati ukazuju da predloženi modifikovani montmorilonit može biti efikasan adsorbent za uklanjanje disperznih boja čak i u slučaju jako koncentrovanim disperzijama.

Ključne reči: izoterma, kinetika, modifikovana nano glina, disperzna boja, otpadna voda.