International Journal of Engineering

Journal Homepage: www.ije.ir

Hexadecyl Trimethyl Ammonium Bromide-Modified Montmorillonite as a Low-Cost Sorbent for the Removal of Methyl Red from Liquid-Medium

Y. Omidi-Khaniabadi [a], B. Kamarehei [a], H. Nourmoradi [b], M. Jourvand [a], H. Basiri [a*], S. Heidari[a]

[a] *Department of Environmental Health Engineering, School of Health, Lorestan University of Medical Sciences, Khorramabad, Iran*
[b] *Department of Environmental Health Engineering, School of Health, Ilam University of Medical Sciences, Ilam, Iran*

PAPER INFO

Paper history:
Received 18 December 2015
Received in revised form 06 January 2016
Accepted 20 January 2016

Keywords:
Adsorption
Montmorillonite
Surfactant
Methyl Red

ABSTRACT

In this study, montmorillonite (MMT) modified with a cationic surfactant (Hexadecyl trimethyl ammonium bromide, (HDTMA)) was used for the removal of methyl red (MR) from aqueous solution. The effect of different parameters like surfactant loading rate, contact time, pH, adsorbent dosage and initial MR content was investigated on the sorption. The sorption capacity was increased by increasing the surfactants loading rate up to 120% cation exchange capacity (CEC) of the MMT. The optimum uptake capacity of the sorbent (84.28 mg/g) was achieved within 30 min at pH of 6. The experimental data of the sorption was well fitted by pseudo-second-order kinetic and Freundlich isotherm models. The results showed that the HDTMA-MMT can be applied as an effective and inexpensive sorbent for the removal of MR from aqueous solution.

***doi**: 10.5829/idosi.ije.2016.29.01a.09*

1. INTRODUCTION

Water pollution owing to development of industrial activities has been considered as one of the most important problems in the world, especially in developing countries [1-3]. The wastewater from many industries such as food processing, leather, paper, plastics, cosmetics, and textile are significant sources of dyestuff pollution [4-6]. Discharging dye containing wastewaters into water bodies because of their toxic properties can cause harmful outcomes on living organisms as well as human [7, 8]. Typically, industrial dyes have synthetics nature that characterized by complex aromatic molecular structures [9, 10]. The most synthetic dyestuffs are toxic, carcinogenic and mutagenic. They are also nearly stable to most of chemical and biological degradation [4, 6]. Therefore, removal of these dyes before their discharge to water bodies is necessary [11]. Methyl red or acid red 2 is a mono-azo dye, which is applied in textile industry and laboratory assay. It can cause skin and eye sensitization and pharyngeal or digestive tract irritation [12, 13]. Several physical, chemical and microbial methods such as advanced oxidation, membrane technologies, coagulation-flocculation, biological degradation, chemical oxidation, electro chemical techniques, and adsorption have been applied for the removal of the dyes from dying wastewaters [11, 14]. Among these methods, adsorption process is widely applied to remove organo-pollutants [11, 15]. This method is one the effective technique via high removal efficiency [16]. Activated carbon because of simplicity, high surface area and high uptake capacity has been generally investigated as sorbent to remove organic and inorganic pollutants from water. However, the main disadvantages of this sorbent are high-cost and difficulty to regeneration [17, 18]. In addition to activated carbon, application of other non-convectional sorbents include banana trunk fibers [14], durian seed [12], annona squmosa [19], galactomyces geotrichum [13], eichornia crassipes [20], kaolin [21], feldspar [22] and tree bark powder [23] have been reported to remove MR from

*Corresponding Author's Email: *: h.basiri29@gmail.com* (H.Basiri)

Please cite this article as: Y. Omidi-Khaniabadi, B. Kamarehei, H. Nourmoradi, G. Goudarzi, M. Jourvand, H. Basiri, S. Heidari, Hexadecyl Trimethyl Ammonium Bromide -Modified Montmorillonite as a Low-Cost Sorbent for the Removal of Methyl Red from Liquid-Medium, International Journal of Engineering (IJE), TRANSACTIONS A: Basics..Vol. 29, No. 1, (January 2016) 60-67

aqueous solution. Nowadays, the interests are focused on using low cost sorbents to uptake dyes from aqueous solutions. Montmorillonite is a type of clay, which has been widely employed as a cheap adsorbent. Other excellent properties of clay like eco-friendly, non-toxicity, high surface area and high sorption capacity make it as an appropriate adsorbent for organic pollutants [24-26]. The raw clay has a hydrophilic nature, thus it is needed that the surface of clay modified by organophilic substance such as surfactants. It has been proved that intercalation of cationic surfactants changes the surface properties of the clay from hydrophilic to hydrophobic [25]. In this study, montmorillonite was used as sorbent and its surface was modified by cationic surfactant (Hexadecyl trimethyl ammonium bromide) and was used to sorption of methyl red from liquid solution. The effect of various parameters include surfactant-loading rate, contact time, pH, adsorbent dosage and dye concentration were evaluated on the sorption.

2. EXPERIMENTAL

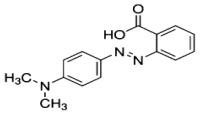
2. 1. Materials Methyl red dye was purchased from Alvan Sabet Co, Iran. The clay, montmorillonite and Hexadecyl trimethyl ammonium bromide were obtained from Laviosa Co, Italy, and Aldrich CO, USA, respectively. H_2SO_4 and NaOH were achieved from Merck Co, Germany. The chemical structure and other properties of MR are presented in Table 1. On the basis of the Sear's method, the cationic exchange capacity (CEC) of MMT was 108 meq/100 g [24]. The solution pH was adjusted via a digital pH-meter (50-pp-sartorious model) by adding 0.1 N H_2SO_4 or NaOH solution. Other chemical used in present study were of analytical grade. The stock solution of MR (1000 mg/L) was made by dissolving 1 g MR in one liter deionized water.

2. 2. Characterization and Analysis The morphology of the modified MMT was specified by a scanning electron microscope (SEM, Jeol Model Jsm-T330). The FTIR spectral analysis (JASCO, FT/IR-6300 Japan) of the sorbent before and after modification was recorded in the region of 400-4000 cm^{-1}. The characterization of the clay was also determined by X-ray diffractometer (Bruker, D8 ADVANCE, Germany) using Ni filtered Cu K*a* radiation (1.5406A^o). The concentration of MR dye in the solution was determined by an UV–Vis spectrophotometer (PG Instrument Limited Model) at the maximum visible absorbance wavelength of 515 nm.

2. 3. Purification of MMT Clay For the purification of the clay, 30 g of MMT was poured in 1 L deionized water. The suspension was mixed by a rotary shaker (250 rpm for 24 h) at room temperature (25 ˚C) and then centrifuged (4000 rpm for 20 min). Because of higher density, the black impurities of the clay include iron oxide and quartz was precipitated at the bottom of the centrifuge tube and the lighter clay was placed at the upper region of the tube. The higher pure MMT was separated from the impurities, then dried at 105 ˚C for 24 h and sieved to particle sizes less than 125 μm [24]. In order to attain HDTMA-MMT in the ranges of 20-150% times of the clay CEC, HDTMA-MMT suspensions were separately prepared into various conical flasks using mixing 5 g the high purity clay with desired amounts of the cationic surfactant in 100 mL diluted water. A stirrer (250 rpm for 24 h) at room temperature agitated the suspensions. The HDTMA-MMT were centrifuged (4000 rpm for 20 min), washed with distilled water (four times), dried (60 ˚C for 24 h) and then passed through an ASTM sieve of 120-mesh (125 μm).

2. 4. Batch Adsorption Experiments Batch sorption method was used to investigate the influence of different factors such as surfactant loading rates (20-150% CEC of the clay), contact time (0-60 min), pH (2-12), HDTMA-MMT dosage (0.5-5 g/L) and dye concentration (50-400 mg/L) on the removal of MR dye from aqueous solutions. All the sorption experiments were conducted by an orbital shaker (150 rpm) at room temperature (25 ˚C). After the mixing period, the suspensions were centrifuged (3500 rpm for 20 min) and MR concentration in the clear supernatant was calculated by UV-Visible spectrophotometer.

TABLE 1. General properties of MR dye

Scientific name	General name	Chemical formula	Chemical structure	Ionization	M_W (g/mol)	λ_{max}(nm)
Methyl Red	Acid red 2	$C_{15}H_{15}N_3O$		Acidic	269.3	515

The experiments were carried out in duplicates and the average values were applied. The adsorption capacity for MR was estimated by the following equation:

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

where, q_e (mg/g) is sorption capacity of HDTMA-MMT. C_0 and C_e (mg/L) are the primary and the equilibrium MR contents, respectively. M (g) is the mass of the sorbent and V (L) is the volume of the solution [27].

3. RESULTS AND DISCUSSION

3. 1. Characterization of Sorbent

3. 1. 1. SEM Image The SEM studies provide useful information regarding the surface morphology of the adsorbent structure. The SEM image of the HDTMA-MMT is illustrated in Figure 1. As seen, the HDTMA-MMT had a homogenous and smooth surface and the surfactant particles are seen upon it.

3. 1. 2. FTIR Analysis The FTIR spectra of Raw-MMT and HDTMA-MMT are indicated in Figure 2 (a). As can be seen, both Raw-MMT and HDTMA-MMT had regular properties of montmorillonite peaks. The characteristic bands at 3627 cm^{-1} and large band at 3436 cm^{-1} were associated -OH and H_2O stretching vibration, respectively [24]. Intensity decrease at the band of 1635 cm^{-1} in HDTMA-MMT illustrated that water content was decreased owing to the substitution of hydrate cations by the surfactant. This process showed that properties of the adsorbent surface were altered from hydrophilic to hydrophobic by the modification via HDTMA. The IR bands at 1036 cm^{-1}, 525 cm^{-1} and 468 cm^{-1} were associated to stretching vibration of Si-O groups, Al-O-Si, and Si-O-Si, respectively [28]. The new peak at the modified adsorbent in 2922 cm^{-1} can be in relation to modification of MMT by HDTMA surfactant. The IR board band at the range of 2800-3000 cm^{-1} in the HDTMA-MMT was assigned to stretching vibration the carbon-hydrogen (C-H) groups, which can has an important role in the sorption of pollutants [7].

3. 1. 3. XRD Analysis The X-ray diffraction (XRD) patterns of Raw-MMT and HDTMA-MMT are presented in Figure 2(b). The results illustrated that the modification of Raw-MMT by HDTMA surfactant has caused the basic changes in the MMT.

The XRD basal spacing in Raw-MMT was 12.10 Å. The interlayer spacing of the montmorillonite was improved by modification MMT via HDTMA to 18.83 Å. This increment in the basal spacing of HDTMA-MMT showed that the surfactant intercalated in the interlayer space of the modified MMT [24].

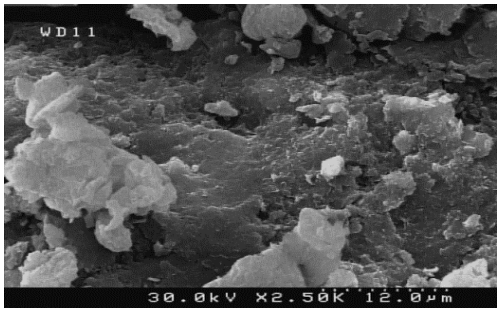


Figure 1. SEM image of the HDTMA-MMT.

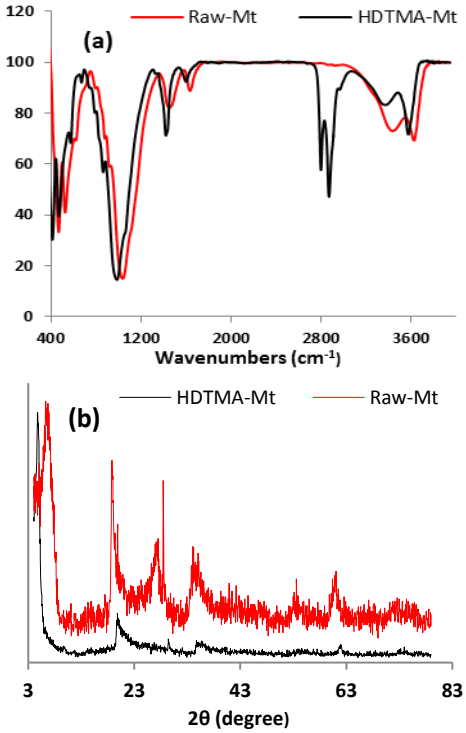


Figure 2. The characteristics of **(a)** FTIR and **(b)** XRD of the raw and modified MMT.

3. 2. Effect of Surfactant Loading Rate Figure 3 illustrates the effect of surfactant loading rates (20 up to 150% CEC of the clay) on the uptake capacity of MR (100 mg/L) at initial pH. As seen, the uptake capacity of HDTMA-MMT for MR was increased via increasing the surfactant loaded onto the modified MMT up to 120% CEC of the clay. This result was in consist with results from study of Jourvand et al. in removal of methylene blue by HDTMA-MMT from aqueous solution [7]. The surfactant modification of MMT

changed the properties of adsorbent from hydrophilic to organophilic [24]. At surfactant loading rates beyond 120% CEC of the clay, the sorption capacity of the sorbent was decreased from 74.26 to 69.78 mg/g. This result can be due to the complete occupancy the internal layers of the clay that caused to lower diffusion of the dye to these areas. Thus, HDTMA-MMT surfactant loading rates of 120% CEC of the clay was selected and all the experiments were conducted by this value surfactant loading rate.

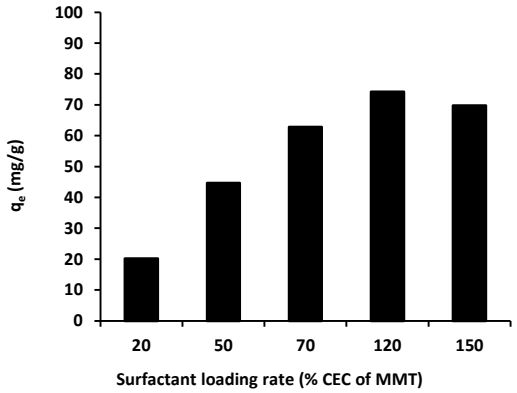


Figure 3. Effect of surfactant loading rate on the clay to sorption of MR dye (initial dye concentration=100 mg/L, contact time=24 h, HDTMA-MMT=1 g/L, and initial pH=7).

3. 3. Effect of Contact Time The effect of different contact times (0-60 min) on the sorption of MR was investigated and the results are presented in Figure 4(a). As seen, the rapid uptake of MR was occurred in the beginning the sorption process and the sorption rate was nearly constant after 30 min. The equilibrium sorption capacity (80.72 mg/g) was achieved at contact time of 30 min. The fast sorption of MR at the initial stage of the sorption can be owing to higher availability of large numbers of vacant sites on the adsorbent surface that readily filled by MR dye. Ahmed et al. reported that the contact time reached to equilibrium at a contact time of 6 hours for removal of MR dye using modified durian seed [12]. In other study by Haris et al. , the equilibrium time of the removal MR by banana trunk fibers was observed at contact time of 45 min [14]. Comparing our contact time results with other abovementioned studies showed that HDTMA-MMT had a higher tendency to MR dye.

3. 3. 1. Kinetic Study In order to reach a better perception of the sorption process, the experimental data were fitted by two kinetics models, pseudo-first-order and pseudo-second-order. The pseudo-first-order model can be shown by Equation (2):

$$\ln(q_e - q_t) = \ln q_e - k_1 t \quad (2)$$

where; q_e (mg/g) and q_t (mg/g) are the amounts of MR dye adsorbed onto the HDTMA-MMT at the equilibrium and at time (min), respectively. Moreover, K_1 (1/min) is the rate constant of the pseudo-first-order kinetic. K_1 and q_e were determined from linear plotting ln (q_e - q_t) against time (min) that was obtained from the slope and intercept of the plot, respectively [25, 29].
The pseudo-second-order kinetic model can be illustrated by the following equation:

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \quad (3)$$

where; K_2 (g/mg.min) is the rate constant of the pseudo-second-order kinetic model. K_2 and q_e can be achieved from the cut-off and slope of t/q_t versus t (min), respectively. Table 2 and Figure 4(b) show the kinetic models parameters of the MR sorption by HDTMA-MMT and the pseudo-second-order kinetic, respectively [25, 29]. As can be seen in Table 2, the highest value of correlation coefficient (R^2) was corresponded to the pseudo-second-order kinetic model. Thus, this kinetic model was well fitted by experimental data from MR sorption onto HDTMA-MMT. Santhi et al. concluded that experimental data of the MR sorption by activated carbon prepared from annona squmosa seed was fitted via pseudo-second-order kinetic model [19].

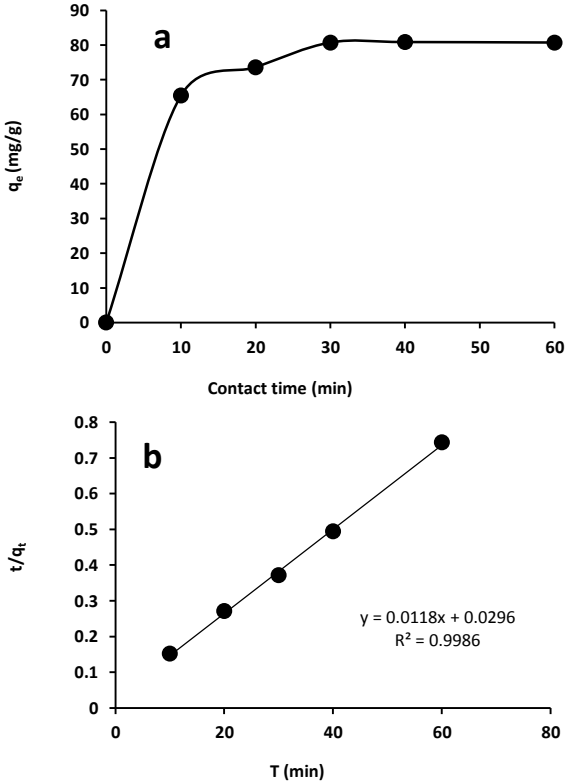


Figure 4. (a) Effect of contact time on the sorption of MR dye (initial dye concentration=100 mg/L, adsorbent dosage=1 g/L, and initial pH=7) and **(b)** Pseudo-second-order kinetic.

TABLE 2. Parameters of pseudo-first-order and pseudo-second-order kinetic models

Adsorbate	Pseudo-first-order			Pseudo-second-order			
	$q_{e,\ calculated}$ (mg/g)	K_1 (1/min)	R^2	$q_{e,experimental}$ (mg/g)	$q_{e,\ calculated}$ (mg/g)	K_2 (g/mg.min)	R^2
MR	1.34	0.010	0.9959	80.72	55.6	0.005	0.9985

3. 4. Effect of Solution pH The solution pH is a significant parameter that affects on the adsorption process [17, 30]. The solution pH has a regulator influence on the ionization, dissociation, nature and surface properties of the adsorbent [1, 2]. The effect of solution pH in the range of 2-12 on the sorption of MR by HDTMA-MMT was investigated and the results are illustrated in Figure 5. As seen, the sorption capacity was increased with increasing the solution pH from 2 to 6. The maximum uptake sorption (84.28 mg/g) was obtained at pH 6. This result may be due to change in surface charge of MR dye molecules and functional groups of the HDTMA-MMT. In the study of Santhi et al., the maximum sorption capacity of the MR by activated carbon was obtained at pH 4 [19]. Abdullah and et al. observed that the efficiency removal of MR dye by sugarcane bagasse was significantly increased at pH range of 3 to 7 [31].

3. 5. Effect of Adsorbent Dosage The influence of different dosages (0.5 to 5 g/L) of HDTMA-MMT on the sorption of MR dye was investigated in an initial concentration of 100 mg/L at 25 ˚C and the results are shown in Figure 6. As can be seen, with increasing the sorbent dosage from 0.5 up to 5 g/L, the uptake capacity was reduced. Decreasing the sorption capacity in higher dosage of HDTMA-MMT can be because of the unavailability of the dye molecules that cannot cover all the surface active sites of the adsorbent. In other words, a large number of the active sites of the sorbent surface cannot reach to saturation state at higher dosages of HDTMA-MMT. Thus, dose of 0.5 g/L was chosen as the optimum dosage for the next stages of the experiments.

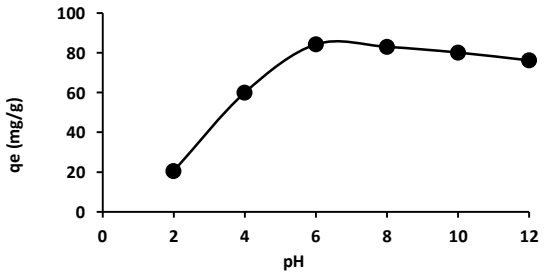


Figure 5. Effect of pH on the sorption of MR dye (contact time=30 min, initial dye concentration=100 mg/L, and adsorbent dosage=1 g/L).

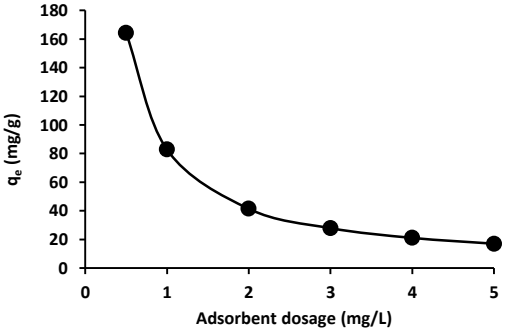


Figure 6. Effect of adsorbent dose on the sorption (contact time=30 min, initial concentration=100 mg/L, and solution pH=6).

3. 6. Effect of Initial Dye Concentration The effect of initial MR concentrations (50 to 400 mg/L) with 0.5 g/L of the sorbent was evaluated on the sorption capacity and the findings are shown in Figure 7(a). As can be seen, the uptake capacity of the sorbent was quickly increased from 68.58 up to 688.58 mg/g via increasing MR content from 50 to 500 mg/L in the solution. This phenomenon can be caused from the increase in driving force of the dye molecules including Wan der Waals's force to the vacant sites of the sorbent surface, which occurs at higher concentrations of MR [1, 2].

3. 6. 1. Isotherm Study The sorption data were investigated by two isotherms, Langmuir and Freundlich models. These models are commonly used to find out sorption mechanism and also to design a sorption system [4, 32]. The Langmuir isotherm assumes that monolayer adsorption happens at binding sites via homogenous energy levels [33]. The Langmuir isotherm is explained by the following equation:

$$\frac{C_e}{q_e} = \frac{C_e}{Q_m} + \frac{1}{bQ_m} \quad (4)$$

where, C_e (mg/L) is the equilibrium content of MR, q_e (mg/g) is the uptake capacity of HDTMA-MMT in the equilibrium time. The parameters of Q_m (maximum sorption capacity) and b (the Langmuir constant) are achieved from the slope and intercept of liner plotting C_e/q_e versus C_e, respectively [11, 25]. A dimensionless constant separation factor, R_L, has been used in associated to Langmuir isotherm model. This

parameter called also the equilibrium factor and is defined by Equation (5):

$$R_L = \frac{1}{1+bC_0} \quad (5)$$

where; b and C_0 were mentioned above for Langmuir isotherm model. The amount of R_L shows that the sorption process is unfavorable ($R_L>1$), irreversible ($R_L=0$), liner ($R_L=1$), or favorable ($0<R_L<1$) [11]. In this study (Table 3), based on the value of $R_L=0.952$, the sorption system of MR dye onto HDTMA-MMT was favorable.

The Freundlich isotherm model can be presented by Equation (6):

$$\ln q_e = \ln k_f + \frac{1}{n} \ln C_e \quad (6)$$

where, K_f (L/g) and n are constants of the isotherm and they show the capacity and intensity of the sorption, respectively.

The parameter of K_f is obtained from the cut-off and n is achieved from the gradient of liner plotting ln q_e against ln C_e [29]. Table 3 and Figure 7(b) show the parameters of Langmuir and Freundlich isotherm models and the Freundlich isotherm plot for the uptake of MR dye on the sorbent, respectively. As shown, the sorption data were well described by the Freundlich isotherm model. Ahmed et al. reported that the experimental data of MR dye onto modified durian seed were clearly fitted by Freundlich isotherm model [12].

TABLE 3. Parameters of Langmuir and Freundlich isotherms obtained from present study.

Adsorbate	Langmuir isotherm				Freundlich isotherm		
	Q_m (mg/g)	b (l/mg)	R^2	R_L	K_f (l/g)	n	R^2
MR	1428.5	0.0005	0.8502	0.952	0.52	0.9	**0.999**

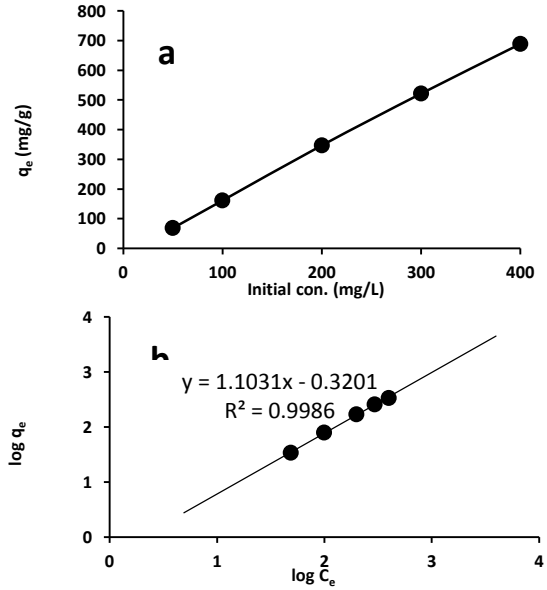


Figure 7. Effect of initial concentration on the sorption of MR dye (contact time 30 min, adsorbent dosage 0.5 g/L, and pH 2) and (b) Freundlich isotherm model.

3. 7. Comparison with Other Studies The maximum uptake capacity of MR dye by HDTMA-MMT in the present study was 1428.5 mg/g. This value has been compared via Q_m obtained from other studies (Table 4). It can be concluded in Table 4 that HDTMA-MMT can be considered as a very effective adsorbent for the removal of MR dye from aqueous solution.

TABLE 4. Comparison of maximum sorption capacity HDTMA-MMT with other sorbents.

Adsorbent	Maximum adsorption capacity (mg/g)	Ref.
Feldspar	0.7	[22]
Rice Hulls	3.3	[34]
Annona squmosa	40.5	[19]
Kaolin	64.1	[21]
Modified durian seed	348.6	[12]
Modified-BTF	555.6	[14]
HDTMA-MMT	**1428.5**	**This study**

4. CONCLUSION

In this study, Hexadecyl trimethyl ammonium bromide (as a cationic surfactant) modified montmorillonite (HDTMA-MMT) was used as a low cost adsorbent for the removal of methyl red (MR) from aqueous solutions. The effect of various parameters such as surfactant loading rate, contact time, pH, adsorbent dosage, and initial dye concentration was assessed on the sorption. The optimum contact time in the sorption process was achieved 30 min. Furthermore, the optimum pH was also obtained at pH 6. The experimental data were well fitted by pseudo-second-order kinetic and Freundlich isotherm model. The results illustrated that HDTMA-MMT as a low cost, eco-friendly, non-toxicity and high capacity sorbent towards other sorbents can be used as an effective material for the removal of MR from aqueous solution.

5. REFERENCES

1. Omidi-Khaniabadi, Y., Jafari, A., Nourmoradi, H., Taheri, F. and Saeedi, S., "Adsorption of 4-chlorophenol from aqueous solution using activated carbon synthesized from aloe vera green wastes", ***Journal of Advances in Environmental Health Research***, Vol. 3, No. 2, (2015), 120-129.
2. Basiri, H., Nourmoradi, H., Moghadam, F.M., Moghadam, K.F., Mohammadian, J. and Khaniabadi, Y.O., "Removal of aniline as a health-toxic substance from polluted water by aloe vera waste-based activated carbon". ***Der Pharma Chemica,*** Vol. 7, No.11, (2015), 149-155
3. Masomi, M., Ghoreyshi, A., Najafpour, G. and Mohamed, A., "Adsorption of phenolic compounds onto the activated carbon synthesized from pulp and paper mill sludge: Equilibrium isotherm, kinetics, thermodynamics and mechanism studies", ***International Journal of Engineering-Transactions A: Basics***, Vol. 27, No. 10, (2014), 1485-1494.
4. Elmoubarki, R., Mahjoubi, F., Tounsadi, H., Moustadraf, J., Abdennouri, M., Zouhri, A., El Albani, A. and Barka, N., "Adsorption of textile dyes on raw and decanted moroccan clays: Kinetics, equilibrium and thermodynamics", ***Water Resources and Industry***, Vol. 9, (2015), 16-29.
5. Ajemba, R., "Adsorption of malachite green from aqueous solution using activated ntezi clay: Optimization, isotherm and kinetic studies", ***International Journal of Engineering-Transactions C: Aspects***, Vol. 27, No. 6, (2013), 839-854.
6. Cheng, Z., Zhang, L., Guo, X., Jiang, X. and Li, T., "Adsorption behavior of direct red 80 and congo red onto activated carbon/surfactant: Process optimization, kinetics and equilibrium", ***Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy***, Vol. 137, (2015), 1126-1143.
7. Jourvand, M., Khorramabadi, G.S., Omidi-Khaniabadi, Y., Godini, H. and Nourmoradi, H., "Removal of methylene blue from aqueous solutions using modified clay" ***Journal of Basic Research in Medical Science,*** Vol. 2, No. 1, (2015), 32-41..
8. Demarchi, C.A., Campos, M. and Rodrigues, C.A., "Adsorption of textile dye reactive red 120 by the chitosan–fe (iii)-crosslinked: Batch and fixed-bed studies", ***Journal of Environmental Chemical Engineering***, Vol. 1, No. 4, (2013), 1350-1358.
9. Almeida, C., Debacher, N., Downs, A., Cottet, L. and Mello, C., "Removal of methylene blue from colored effluents by adsorption on montmorillonite clay", ***Journal of colloïd and interface science***, Vol. 332, No. 1, (2009), 46-53.
10. Rehman, R., Mahmud, T. and Irum, M., "Brilliant green dye elimination from water using psidium guajava leaves and solanum tuberosum peels as adsorbents in environmentally benign way", ***Journal of Chemistry***, Vol. 2015, (2015).
11. Nourmoradi, H., Ghiasvand, A. and Noorimotlagh, Z., "Removal of methylene blue and acid orange 7 from aqueous solutions by activated carbon coated with zinc oxide (zno) nanoparticles: Equilibrium, kinetic, and thermodynamic study", ***Desalination and Water Treatment***. ahead-of-print, (2014), 1-11.
12. Ahmad, M.A., Ahmad, N. and Bello, O.S., "Modified durian seed as adsorbent for the removal of methyl red dye from aqueous solutions", ***Applied Water Science***, (2014), 1-17.
13. Jadhav, S., Kalme, S. and Govindwar, S., "Biodegradation of methyl red by galactomyces geotrichum mtcc 1360", ***International Biodeterioration & Biodegradation***, Vol. 62, No. 2, (2008), 135-142.
14. Haris, M. and Sathasivam, K., "The removal of methyl red from aqueous solutions using modified banana trunk fibers", ***Archives of Applied Science Research***, Vol. 2, No. 5, (2010), 209-216.
15. Dawood, S. and Sen, T.K., "Review on dye removal from its aqueous solution into alternative cost effective and non-conventional adsorbents", ***Journal of Chemical and Process Engineering***, Vol. 1, No. 1, (2013), 1-11.
16. Chen, D., Chen, J., Luan, X., Ji, H. and Xia, Z., "Characterization of anion–cationic surfactants modified montmorillonite and its application for the removal of methyl orange", ***Chemical Engineering Journal***, Vol. 171, No. 3, (2011), 1150-1158.
17. Liu, Q., Yang, B., Zhang, L. and Huang, R., "Adsorption of an anionic azo dye by cross-linked chitosan/bentonite composite", ***International journal of biological macromolecules***, Vol. 72, (2015), 1129-1135.
18. Gupta, V., Agarwal, A. and Singh, M., "Belpatra (aegel marmelos) bark powder as an adsorbent for the color removal of textile dye "torque blue"", ***International Journal of Scientific Engineering and Technology***, Vol. 4, No. 2, (2015), 56-60.
19. Santhi, T., Manonmani, S. and Smitha, T., "Removal of methyl red from aqueous solution by activated carbon prepared from the annona squmosa seed by adsorption", ***Chemical engineering research bulletin***, Vol. 14, No. 1, (2010), 11-18.
20. Tarawou, T., Horsfall, M. and Vicente, J.L., "Adsorption of methyl red by water-hyacinth (eichornia crassipes) biomass", ***Chemistry & biodiversity***, Vol. 4, No. 9, (2007), 2236-2245.
21. Dey, D., "Adsorption of methyl red on local kaolin from spiked aqueous solution", ***Adsorption***, Vol. 2, No. 9, (2014).
22. Awala, H. and El Jamal, M., "Equilibrium and kinetics study of adsorption of some dyes onto feldspar", ***Journal of the University of Chemical Technology and Metallurgy***, Vol. 46, No. 1, (2011), 45-52.
23. DIM, P.E., "Adsorption of methyl red and methyl orange using different tree bark powder", ***Adsorption***, Vol. 4, No. 1, (2013).
24. Nourmoradi, H., Nikaeen, M. and Khiadani, M., "Removal of benzene, toluene, ethylbenzene and xylene (btex) from aqueous solutions by montmorillonite modified with nonionic surfactant: Equilibrium, kinetic and thermodynamic study", ***Chemical Engineering Journal***, Vol. 191, (2012), 341-348.
25. Nourmoradi, H., Avazpour, M., Ghasemian, N., Heidari, M., Moradnejadi, K., Khodarahmi, F., Javaheri, M. and Moghadam, F.M., "Surfactant modified montmorillonite as a low cost adsorbent for 4-chlorophenol: Equilibrium, kinetic and thermodynamic study", ***Journal of the Taiwan Institute of Chemical Engineers***, (2015).
26. Zhu, R., Chen, Q., Liu, H., Ge, F., Zhu, L., Zhu, J. and He, H., "Montmorillonite as a multifunctional adsorbent can simultaneously remove crystal violet, cetyltrimethyl ammonium, and 2-naphthol from water", ***Applied Clay Science***, Vol. 88, (2014), 33-38.
27. Anbia, M. and Davijani, A., "Synthesis of ethylenediamine-modified ordered mesoporous carbon as a new nanoporous adsorbent for removal of cu (ii) and pb (ii) ions from aqueous media", ***International Journal of Engineering-Transactions C: Aspects***, Vol. 27, No. 9, (2014), 1415-1422.
28. Silva, M.M., Oliveira, M.M., Avelino, M.C., Fonseca, M.G., Almeida, R.K. and Silva Filho, E.C., "Adsorption of an industrial anionic dye by modified-ksf-montmorillonite: Evaluation of the kinetic, thermodynamic and equilibrium data", ***Chemical Engineering Journal***, Vol. 203, (2012), 259-268.
29. Nourmoradi, H., Zabihollahi, S. and Pourzamani, H., "Removal of a common textile dye, navy blue (nb), from aqueous

solutions by combined process of coagulation–flocculation followed by adsorption", ***Desalination and Water Treatment***. ahead-of-print, (2015), 1-12.

30. Faghihian, H., Nourmoradi, H. and Shokouhi, M., "Removal of copper (ii) and nickel (ii) from aqueous media using silica aerogel modified with amino propyl triethoxysilane as an adsorbent: Equilibrium, kinetic, and isotherms study", ***Desalination and Water Treatment***, Vol. 52, No. 1-3, (2014), 305-313.
31. Abdullah, A.L., Salleh, M.M., Mazlina, M.S., Noor, M.M.M., Osman, M., Wagiran, R. and Sobri, S., "Azo dye removal by adsorption using waste biomass: Sugarcane bagasse", ***International Journal of Engineering and Technology***, Vol. 2, No. 1, (2005), 8-13.
32. Liu, S., Ding, Y., Li, P., Diao, K., Tan, X., Lei, F., Zhan, Y., Li, Q., Huang, B. and Huang, Z., "Adsorption of the anionic dye congo red from aqueous solution onto natural zeolites modified with n, n-dimethyl dehydroabietylamine oxide", ***Chemical Engineering Journal***, Vol. 248, (2014), 135-144.
33. Debnath, S., Ballav, N., Maity, A. and Pillay, K., "Development of a polyaniline-lignocellulose composite for optimal adsorption of congo red", ***International Journal of Biological Macromolecules***, Vol. 75, (2015), 199-209.

Hexadecyl Trimethyl Ammonium Bromide-Modified Montmorillonite as a Low-Cost Sorbent for the Removal of Methyl Red from Liquid-Medium

Y. Omidi-Khaniabadi [a], B. Kamarehei [a], H. Nourmoradi [b], M. Jourvand [a], H. Basiri [a], S. Heidari[a]

[a] *Department of Environmental Health Engineering, School of Health, Lorestan University of Medical Sciences, Khorramabad, Iran*
[b] *Department of Environmental Health Engineering, School of Health, Ilam University of Medical Sciences, Ilam, Iran*

P A P E R I N F O

Paper history:
Received 18 December 2015
Received in revised form 06 January 2016
Accepted 20 January 2016

Keywords:
Adsorption
Montmorillonite
Surfactant
Methyl Red

چکیده

در این مطالعه، مونت مورینولیت (MMT) اصلاح شده با یک سورفکتانت کاتیونی (هگزا دسیل تری متیل آمونیوم بروماید، HDTMA) برای حذف متیل رد از محلول آبی استفاده گردید. اثر پارامترهای مختلف مانند میزان بارگذاری سورفکتانت، زمان تماس، پی اچ، دوز جاذب وغلظت اولیه متیل رد روی ظرفیت جذب، بررسی گردید. ظرفیت جذب جاذب با افزایش میزان بارگذاری سورفکتانت تا ۱۲۰٪ ظرفیت تبادل یونی مونت مورینولیت، افزایش داشته است. ظرفیت جذب بهینه جاذب (۸٤/۲۸ میلی گرم بر گرم) در زمان ۳۰ دقیقه و پی اچ برابر ٦ بدست آمد. داده های آزمایشگاهی به خوبی با مدل های کینتیک درجه دوم کاذب و ایزوترم فروندلیچ متناسب بودند. نتایج نشان داد که HDTMA-MMT میتواند به عنوان یک جاذب موثر و ارزان برای حذف متیل رد از محلول آبی بکار برده شود.

***doi**: 10.5829/idosi.ije.2016.29.01a.09*