



Adsorption properties of aluminum magnesium mixed hydroxide for the model anionic dye Reactive Brilliant Red K-2BP

Yujiang Li^{a,*}, Baoyu Gao^a, Tao Wu^b, Biao Wang^a, Xia Li^a

^a School of Environmental Science & Engineering, Shandong University, Jinan 250100, PR China

^b Key Laboratory of Colloid & Interface Science of Education Ministry, Shandong University, Jinan 250100, PR China

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ABSTRACT

The use of aluminum magnesium mixed metal hydroxide (MMH) as adsorbent to remove Reactive Brilliant Red K-2BP (RBR K-2BP), as a model anionic dye, from aqueous solution was investigated. MMH was prepared by coprecipitation and was characterized by XRD, TEM and average particle diameter. Adsorption experiments were carried out as a function of pH, contact time, concentration of dye, adsorbent dosage, and temperature. The results showed that MMH was particularly effective to remove RBR K-2BP, and that the effective pH range for the dye removal was between 4.0 and 11.0, but at pHs lower than 4, dissolution of MMH took place. A significant decline of dye adsorption occurred at pHs above the isoelectric point (IEP). The adsorption of RBR K-2BP on MMH reached equilibrium within 4 h. The appropriate adsorbent dosage was 1000 mg/L. The interaction between the surface sites of MMH and the dye ions may be a combination of both anion exchange and surface complexation. Three kinetic models have been evaluated to fit the experimental data. It was shown that the pseudo-second-order model best described the adsorption kinetics of RBR K-2BP on MMH. The equilibrium isotherm showed that the adsorption of RBR K-2BP onto MMH was consistent with the Langmuir and Freundlich equations. And the saturated adsorption capacity of MMH for RBR K-2BP was 657.5 mg/g. The adsorption process was endothermic in nature. MMH displayed superior treatment efficiency to the industrial dye effluents from a printing and dyeing plant with a removal efficiency of 93.8–96.7% for colored materials and 77.9–83.6% for COD.

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1. Introduction

The textile industry in China produces large amounts of colored effluents. Wastewater containing dyes is very difficult to treat using conventional wastewater treatment methods. Reactive dyes are, in general, the most problematic among other dyes, as they tend to pass through conventional treatment systems unaffected. Municipal aerobic treatment systems, dependent on biological activity, were found to be ineffective in the removal of these dyes [1,2]. Therefore many methods, such as adsorption, chemical oxidation, coagulation–flocculation and membrane processes are used for the removal of the dyes [1,3–8]. Adsorption is one of the most effective physicochemical processes for the removal of color and treatment of textile effluents. Some commercial systems currently use activated carbon as an adsorbent to remove dyes in wastewater [3,9]. However, the high cost of activated carbon restricts its comprehensive use. In recent years, the search for a new generation of low-cost adsorbents, such as clay minerals [10,11], fly ash [12–14],

activated slag [15,16], and industrial waste products [16], has grown. However, these materials generally have low adsorption capacities and hence, large adsorbent dosage is required to achieve a low dye concentration of the effluents. In order to decrease the cost of wastewater treatment, attempts have been made to find other relative lower-cost adsorbents, which have a higher adsorption capacity.

Some innovative materials have gained importance in effective separation and purification techniques over the last few decades [17]. Promising materials called hydrotalcite-like compounds or layered double hydroxides, with the general formula $[Mg^{2+}_{1-x}Al^{3+}_x(OH)_2]^{x+}[A^{n-}_{x/n} \cdot mH_2O]^{x-}$, where A^{n-} is an n -valent anion, are being considered [18,19]. These layered materials contain positively charged metal hydroxide sheets and require anions such as CO_3^{2-} , Cl^- or NO_3^- , and water molecules, which are present on the surface and/or in the interlayer spaces to maintain an overall neutral charge. The surface and interlayer anions and water molecules can be exchanged with other inorganic and organic anions from contaminated waters [20,21], but the efficiency of uptake is affected considerably by the properties of surface and interlayer anions. Generally, the affinities of metal hydroxide sheets for multivalent anions are higher than that for monovalent anions

* Corresponding author. Tel.: +86 531 88363358; fax: +86 531 88363358.
E-mail address: yujiang@sdu.edu.cn (Y. Li).

[22,23]. For example, CO_3^{2-} is preferentially adsorbed and not readily replaceable by other anions [24]. When A^{n-} is Cl^- and ammonia is used as precipitating agent in synthesizing process, this material is a sol of aluminum magnesium mixed metal hydroxide (MMH) [25] (essentially a sol solution consists of aluminum magnesium layered double hydroxide in which the surface and interlayer anions are chloride anions, denoted hereafter as MMH). MMH sol not only contains chloride anions which can be easily replaced by other anions, but the MMH colloidal nanoparticles have a small average particle diameter and can diffuse more easily in water solution, by which the adsorption efficiency of other anions is enhanced. So MMH has attracted considerable attention in different areas recently [26] owing to its unique structure and anion exchange ability. However, studies on adsorption of anionic dyes by MMH are limited.

In the present study, MMH was synthesized and characterized in relation to its physicochemical structure. MMH was further used as an adsorbent for the removal of Reactive Brilliant Red K-2BP (denoted hereafter as RBR K-2BP) as a model anionic dye, to obtain information for treating effluents from the textile industry.

2. Methods and materials

2.1. Materials

The MMH sol used was synthesized by coprecipitation. A mixing aqueous solution of AlCl_3 and MgCl_2 was prepared with a definite Mg/Al molar ratio (total cation concentration of 0.5 mol/L), and then diluted ammonia (5:1, v/v) was slowly pumped into the mixing solution by stirring. The final pH (about 9.5) of the suspension was adjusted with ammonia. The precipitate was aged for 2 h in the parent solution at room temperature. The product was filtered and washed in the filter with deionized water to remove excess ammonia. The filter cake was peptized at about 80 °C in an oven to convert it into MMH sol. In order to examine the influence of the Mg/Al ratio on color removal, samples with Mg/Al ratio from 0.5:1 to 4:1 were prepared. The MMH sol was dried at 110 °C overnight for the XRD test.

RBR K-2BP (purity > 99%) was provided by the Jinan Yuanshou Group and used as received. The chemical structure of RBR K-2BP is shown in Fig. 1.

All chemical reagents used are of AR grade.

2.2. Characterization of MMH

MMH were characterized by XRD. The X-ray diffraction patterns were recorded on an X-ray diffractometer (D/max rA model, Hitachi), using CuK radiation. Microstructural characterization of MMH was carried out using a transmission electron microscope (200CX model, JEOL). The average particle diameter of MMH was measured with a Zetasizer (3000 model, Marvern). The zeta poten-

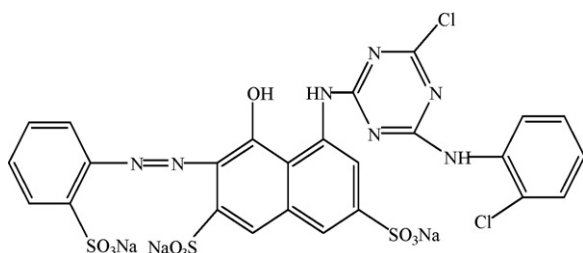


Fig. 1. Chemical structure of Reactive Bright Red K-2BP (chemical formula: $\text{C}_{25}\text{H}_{14}\text{N}_7\text{Cl}_2\text{O}_{10}\text{S}_3\text{Na}_3$; molecular weight: 808.5).

tial of MMH particles was measured by a micro-electrophoretic mobility detector (DXD-II model, Jiangsu Optical Industrial Co.).

2.3. Methods

Adsorption experiments for MMH were undertaken in a batch equilibrium technique. The pH of the dye solution was adjusted using HNO_3 and NaOH . The adsorption of dye was performed by shaking a predetermined amount of MMH in a 200 ml synthetic dye solution (with known initial dye concentration and pH) at 100 rpm in a Jintan SHZ-82 type thermostated shaker at different temperatures. After a given contact time for adsorption, the solid material was separated by centrifugation (using a LG10-2.4A centrifuge at 4000 rpm). The dye concentrations were measured at a wavelength corresponding to the maximum absorbance (λ_{max} is 525 nm for RBR K-2BP) by a UV-Vis spectrophotometer (UV-1601, Shimadzu).

The data obtained from the adsorption tests were then used to calculate the adsorption capacity, q_t (mg/g), of the adsorbent by a mass-balance relationship, which represents the amount of adsorbed dye per amount of dry adsorbent:

$$q_t = \frac{(C_0 - C_t)V}{W} \quad (1)$$

where V is the volume of solution (L), C_0 (mg/L) and C_t (mg/L) are the initial concentration of dye and the concentration at time t , respectively, and W is the mass of adsorbent (g).

The dye removal efficiency, η , was calculated by the following equation:

$$\eta(\%) = \frac{C_0 - C_t}{C_0} \times 100 \quad (2)$$

For the industrial effluent samples, the color concentration (in units of Point Color Pt/Co) was measured with a HACH DR/2000 Spectrophotometer. The COD analyses were performed according to Standard Methods (APHA) [27].

3. Results and discussion

3.1. The effect of the Mg/Al molar ratio on MMH characteristics and color removal

A series of MMH products with various Mg/Al molar ratios (Table 1) were prepared in order to examine the influence of this ratio on the characteristics of MMH and its ability to remove dye.

When $\text{Mg/Al} \geq 2$, the XRD pattern of the samples dried at 110 °C shows typical sharp and symmetric peaks (Fig. 2), which are characteristic of hydroxalcalite-like compounds, and the material consists of only one phase [23]. This indicates that the synthesized MMH has a well-crystallized hydroxalcalite-type structure. But when $\text{Mg/Al} \leq 1$, as in samples MMH0.5 and MMH1 (products A and B), the XRD results also show typical $\text{Al}(\text{OH})_3$ peaks (compared with the diffraction patterns α and β of $\text{Al}(\text{OH})_3$ in Fig. 2). Therefore products A and B were mixtures of MMH and $\text{Al}(\text{OH})_3$.

Removal of RBR K-2BP by the MMH products was studied, keeping the initial dye concentration at 100 mg/L, pH of the dye solution at 6.0 and the MMH dosage at 1000 mg/L.

The effect of the Mg/Al ratio on the properties of the products and their dye removal results are shown in Table 1. The dye removal efficiency increased with the increase of Mg/Al molar ratio until the ratio reached 3.0. This is probably due to the existence of $\text{Al}(\text{OH})_3$ in the products when the Mg/Al molar ratios are lower (samples A and B), as the $\text{Al}(\text{OH})_3$ precipitate has a greater average particle diameter and a lower zeta potential than MMH [28,29]. Further increases in the Mg/Al molar ratio minimally affected the dye removal efficiency. The MMH products showed similar char-

Table 1
Effect of the Al/Mg ratio on properties of the MMH products and their adsorption capability.

Sample	Mg/Al molar ratio	Yield (%)	Zeta potential (mV)	Average particle diameter (nm)	Appearance	Dye removal (%)
A	0.5	51	+41	–	Gel	83.1
B	1.0	42	+43	367.1	Sol	93.3
C	2.0	39	+47	78.9	Sol	97.1
D	3.0	38	+48	68.6	Sol	98.5
E	4.0	31	+46	73.7	Sol	98.5

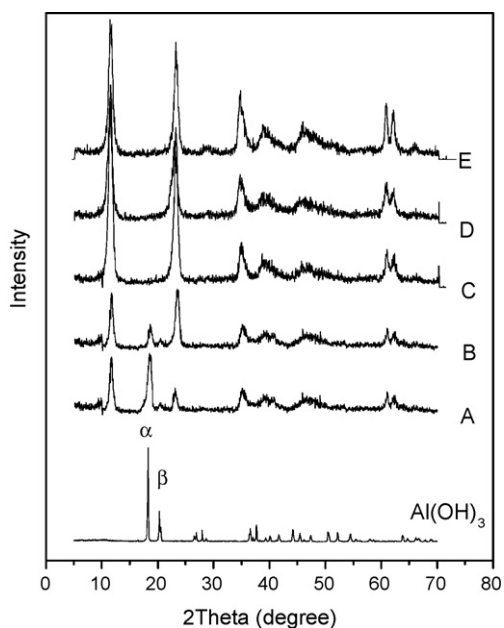


Fig. 2. X-ray powder diffraction patterns of compounds (A–E see Table 1) and $\text{Al}(\text{OH})_3$.

acteristics, such as higher positive zeta potential (+45 mV), lower average particle diameter (<75 nm) and higher dye removal efficiency (>98.0%), once the Mg/Al molar reached 3.0. However, the MMH yield decreased with the increase of Mg/Al molar ratio. Therefore, to optimize yield, zeta potential, average particle diameter and efficiency of dye removal, in the following study only MMH with Mg/Al molar ratio 3 was used as adsorbent for dye removal.

TEM analysis showed that the MMH sol particles with Mg/Al molar ratio = 3.0 are hexagonal particles (Fig. 3). Zeta potential measurements showed a potential +48 mV for MMH in suspension.

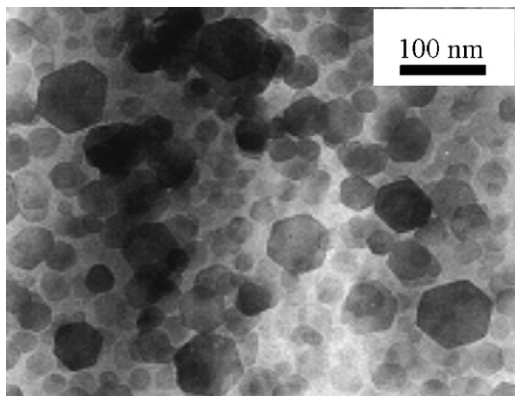


Fig. 3. TEM of MMH sample D with Mg/Al molar ratio = 3.0.

3.2. Effect of contact time and initial dye concentration

The effect of adsorption time on RBR K-2BP removal by MMH is shown in Fig. 4. Amounts of RBR K-2BP adsorbed increased rapidly within the first 60 min and remained almost unchanged after 3 h, indicating an equilibrium state. The initial concentration of RBR K-2BP had no significant effect on the equilibration time. In order to ensure complete adsorption equilibrium, 4 h was chosen as the contact time in each batch equilibrium adsorption experiment.

Kinetic modeling not only allows estimation of adsorption rates but also leads to suitable rate expressions characteristic of possible reaction mechanisms. In this respect, several kinetic models including the pseudo-first-order equation (Eq. (3)) [30,31], pseudo-second-order equation (Eq. (4)) [31,32] and intraparticle diffusion model (Eq. (5)) [33] were tested.

$$\ln(q_e - q_t) = \ln(q_e) - k_1 t \quad (3)$$

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \quad (4)$$

$$q_t = k_i t^{0.5} + C \quad (5)$$

where q_e and q_t are the adsorption capacities of the adsorbate (mg/g) at equilibrium and at time t (min). k_1 and k_2 are the pseudo-first-order and pseudo-second-order rate constants, k_i is the intraparticle diffusion rate constant and C is the intercept.

The calculated kinetic parameters for RBR K-2BP adsorbed by MMH are given in Table 2. Of the three kinetic equations tested, the pseudo-second-order model best described the adsorption kinetics of RBR K-2BP on MMH, based on the correlation coefficient (R^2).

Zhu et al. [34] reported that the adsorption process for anionic dye Brilliant Blue R required 9 h on calcined and 18 h on uncalcined layered double hydroxide to reach equilibrium. In contrast, MMH reached equilibrium within 4 h. The reason why MMH rapidly adsorbs the dye might be that the MMH colloidal nanoparticles have a small average particle diameter and little internal diffusion resistance.

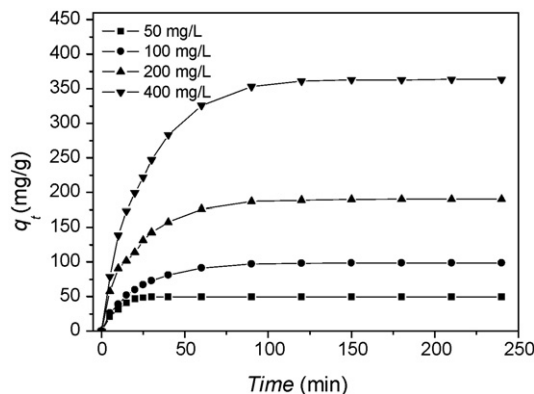


Fig. 4. Effect of contact time on the uptake of RBR K-2BP by MMH at different initial concentrations ($T = 30^\circ\text{C}$, MMH dosage 1000 mg/L, pH 6.0).

Table 2

Comparison of the pseudo-first-order, second-order and intraparticle diffusion adsorption constants at different initial concentrations.

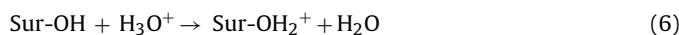
Run no.	C ₀ (mg/L)	First-order			Pseudo-second-order			Intraparticle diffusion		
		q _{e,cal}	k ₁ (×10 ⁻²)	R ²	q _{e,cal}	k ₂ (×10 ⁻²)	R ²	k _i	C	R ²
1	50	37.9	13.68	0.7864	50.8	69.43	0.9992	2.35	25.44	0.4925
2	100	71.4	3.22	0.9706	107.5	6.52	0.9982	6.38	24.96	0.8148
3	200	120.9	3.03	0.9683	204.1	3.86	0.9988	11.88	53.09	0.8109
4	400	245.8	2.71	0.9499	399.6	1.38	0.9981	24.62	74.11	0.8575

3.3. Effect of pH on dye removal

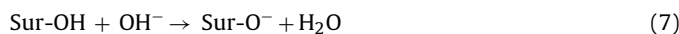
The effect of pH on dye removal was studied within the range of 2–13. The adsorption of RBR K-2BP on MMH was found to be a function of pH (Fig. 5). When the initial solution pH was between 4.0 and 11.0 the removal of dye was favored, with the increase of the solution pH the dye removal efficiency decreased slightly in this pH range. However, a significant decline in dye adsorption occurred when the pH was greater than 11.0. There was also a decrease in dye adsorption when the solution pH was lower than 4.0.

MMH is a hydrotalcite-like compound, and its colloidal particles possess not only permanent positive charges because of isomorphous replacement, but variable charges due to the adsorption of ions from solution [28,29], such as H⁺ or OH⁻.

At low pH:



At high pH:



where Sur denotes the surface of MMH.

The pH at which the zeta potential equals zero is called the isoelectric point (IEP) and it can be used to qualitatively assess the adsorbent surface charge. At values below the IEP, the hydrated surface of MMH is protonated and therefore is positively charged. At pH values higher than the IEP, the hydrated surface of MMH is deprotonated, thereby negatively charged.

The IEP of MMH is pH 10.9 as measured by a microelectrophoretic mobility detector. On dissolution of RBR K-2BP, the sodium ions attached to the anionic dye dissociate in aqueous solution rendering the dye negatively charged. Therefore, at pH values below the IEP, there may be two possible mechanisms for dye adsorption onto MMH. The main mechanism is anion exchange, via which the Cl⁻ ions that are associated with the surface or interlayer of MMH exchange with the anionic dye molecules in solution, which may be written as:

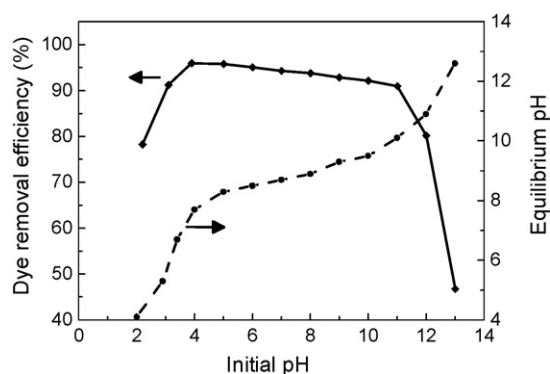
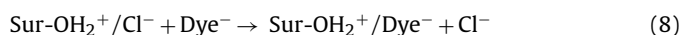
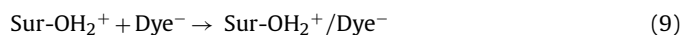


Fig. 5. Effect of initial pH on decolorization and equilibrium pH (MMH dosage 1000 mg/L, initial RBR K-2BP concentration 200 mg/L, $T = 30^\circ\text{C}$, $t = 4$ h).

Another mechanism may be surface complexation, by means of association between the positively charged surface of MMH and the dye anions, which may be written as:



As the pH increases, the positive charge on the surface of MMH decreases, and the dye removal efficiency decreases slightly from pH 4 to 11.

At pHs above the IEP, on the one hand, the anionic dye must be in competition with the OH⁻ in the solution for exchange with the Cl⁻ ions that are associated with the surface or interlayer of MMH; on the other hand, the adsorbent surface becomes negatively charged due to deprotonation and will be associated with positively charged ions of the solution. Thus a significant decrease in dye adsorption occurred at pHs greater than 11.0.

The decrease in dye adsorption when the solution pH was lower than 4.0 may be caused by the dissolution of MMH at low solution pHs.

The relationship between the initial and equilibrium pHs for dye adsorption suggests that MMH has a high pH buffering capacity (Fig. 5). When the initial pH was low, the pH increased due to dissolution of MMH, which resulted in the buffering of H⁺ by OH⁻. When the initial pH was high, compared with the initial pH the equilibrium pH decreased because of the adsorption of OH⁻ from the solution by MMH.

3.4. Effect of adsorbent dosage

The effect of MMH dosage on RBR K-2BP removal is shown in Fig. 6. The removal efficiency of RBR K-2BP increased with increasing dosage of MMH up to a maximum efficiency, probably implying that the amount of adsorption sites also increased with increasing dosage of MMH during adsorption process. For the concentration in the range of 50–200 mg/L the dye solutions were treated using 1000 mg/L MMH, all the dye removal efficiency exceeded 95.0%; for dye concentration of 400 mg/L, however, the dye removal efficiency

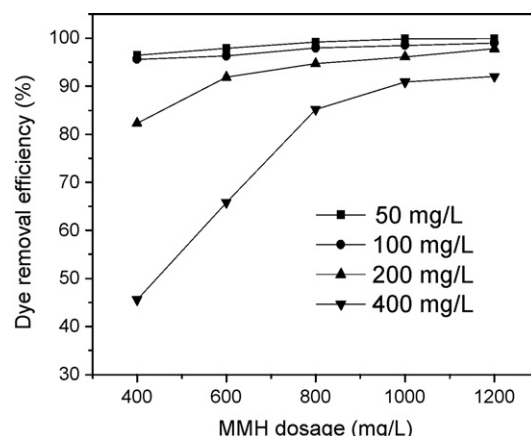


Fig. 6. Effect of MMH dose on dye removal ($T = 30^\circ\text{C}$, pH 6.0, $t = 4$ h).

only reached 90.3%, after which an increase in MMH dosage does not further improve the dye removal, implying that a complete dye removal could not be achieved even though using large amount of the MMH.

3.5. Adsorption isotherm

The adsorption isotherm of RBR K-2BP onto MMH is illustrated in Fig. 7. The batch experimental data were fitted to the Langmuir and Freundlich isotherm models, using a least squares method based on an optimization algorithm. The models are represented mathematically as follows:

$$q = \frac{q_m K_L C_e}{1 + K_L C_e} \quad (10)$$

$$q = K_F C_e^{1/n} \quad (11)$$

q is the amount of the dye adsorbed by MMH, q_m saturated adsorption of the dye by MMH, K_L a constant of the Langmuir isotherm, and C_e the concentration of the dye solution. K_F and n are parameters of the Freundlich isotherm.

The equilibrium isotherm (Fig. 7) showed that the adsorption of RBR K-2BP onto MMH was consistent with the Langmuir and Freundlich equations, and the correlation coefficient for the Langmuir model was appreciably larger than that for the Freundlich model ($R_L^2 = 0.9761$, $R_F^2 = 0.9622$). The best-fit Langmuir parameters are $q_m = 657.5$ mg/g, $K_L = 0.059$ L/mg. The best-fit Freundlich parameters are $K_F = 79.3$, $n = 2.54$ and the n value in the range of 2–10 indicates a favorable adsorption process [35].

The removal of dyes by different adsorbents has been studied extensively and dye adsorption capacities were reported in some of the studies. Although the published values were obtained under different experimental conditions, they may be useful as a criterion for comparing the adsorption capacities. It can be seen from Table 3 that the adsorption capacity of MMH obtained in this study is much higher than that of most low-cost solid adsorbents and higher than that of many other previously reported adsorbents except chitosan beads. The higher adsorption capacity of MMH means it has great potential for application in dye removal from wastewater.

3.6. Effect of temperature

The effect of temperature on the adsorption of RBR K-2BP by MMH at pH 6 is shown in Fig. 8. The amount of RBR K-2BP adsorbed increased with increasing temperature.

The thermodynamic parameters of the adsorption process such as change in standard free energy (ΔG), enthalpy (ΔH), and entropy (ΔS) were obtained from experiments at various temperatures

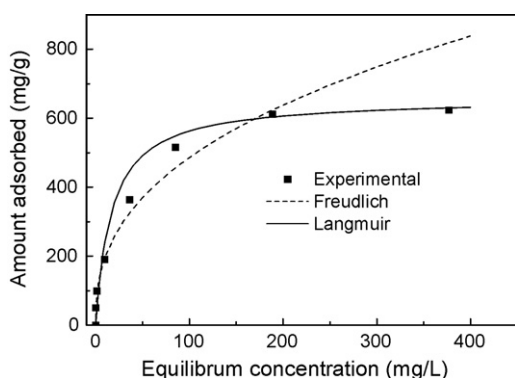


Fig. 7. Adsorption isotherms of RBR K-2BP onto MMH (MMH dosage 1000 mg/L, $T = 30^\circ\text{C}$, initial pH 6.0).

Table 3

Adsorption capacities of dyes on various adsorbents.

Dyes	Adsorbent	Adsorption capacity (mg/g)	Reference
Reactive Red 189	Chitosan beads	1189–1936	[36]
Reactive Black 5	Chitosan flakes	480	[37]
Reactive Red X-3B	Carbon aerogel	565–609	[38]
Reactive Black 5	Modified clay	120.5	[11]
Reactive Black 5	Modified zeolite	60.6	[11]
Reactive Red 141	Modified chitin	124	[39]
Reactive Black 5	Surfactant-modified zeolite	15.9	[40]
Reactive Red 239	Surfactant-modified zeolite	12.9	[40]
Reactive Black 5	Activated carbon	434	[41]
Reactive Yellow 2	Activated sludge	333	[42]
Acid Blue 80	Activated carbon	385	[43]
Reactive Red 11	Chitin	170	[37]
Acid Blue 113	Carbonaceous adsorbent	221.2	[16]
Acid Blue 29	Fly ash	15.17	[44]
Acid Brilliant Blue R	Hydrotalcite	54.6	[34]
Acid Brilliant Blue R	Calcined hydrotalcite	613.6	[34]
RBR K-2BP	Sludge activated carbon	35.7	[45]
RBR K-2BP	MMH	657.5	This work

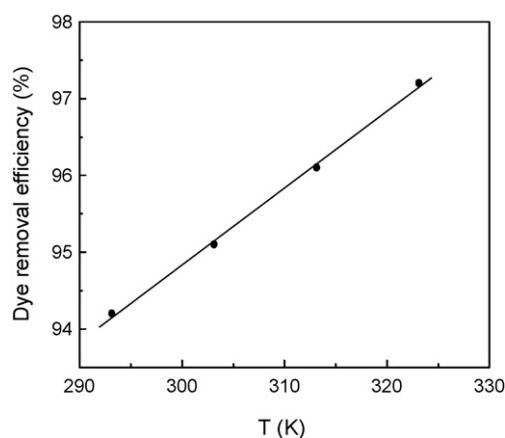


Fig. 8. Effect of temperature on dye removal (MMH dosage 1000 mg/L, initial dye concentration 200 mg/L, pH 6, $t = 4$ h). Results represent averages of five replicated experiments.

using the following equations [46]:

$$\Delta G = -RT \ln K_D \quad (12)$$

$$\ln K_D = \frac{\Delta S}{R} - \frac{\Delta H}{RT} \quad (13)$$

where K_D is the distribution coefficient (amount of removed dye per gram of material divided by its concentration in the liquid phase), R the molar gas constant, T the absolute temperature. ΔH and ΔS were calculated from the slope and intercept of van't Hoff plots of $\ln K_D$ versus $1/T$ (see Fig. 9). The ΔG , ΔH , and ΔS values are listed in Table 4.

Table 4

Values of thermodynamic parameters for RBR K-2BP removal with MMH.

T ($^\circ\text{C}$)	$\ln K_D$	ΔG (kJ/mol)	ΔH (kJ/mol)	ΔS (J/(mol K))
20	2.79	-6.79	19.94	90.83
30	2.97	-7.47		
40	3.23	-8.41		
50	3.55	-9.53		

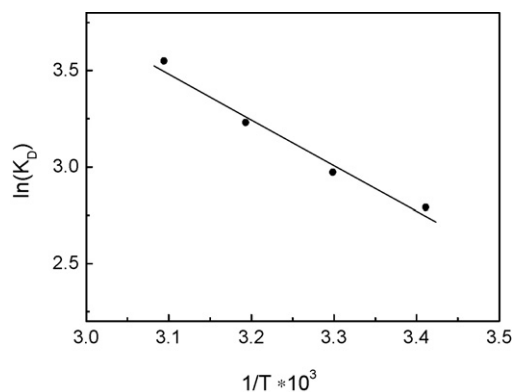


Fig. 9. A plot of $\ln(K_D)$ against $1/T$ (MMH dosage 1000 mg/L, initial RBR K-2BP concentration 200 mg/L, pH 6, $t = 4$ h).

The Gibbs free energy change (ΔG) was negative and ΔH was positive, so the adsorption process is spontaneous and endothermic. The positive entropy change may be due to the release of water molecules and the chloride anions from the MMH ion exchange. The molecular weight of RBR K-2BP is much larger than that of water, and the adsorption of a dye molecular on MMH would result in the desorption of two chloride anions and large numbers of water molecules from MMH. So the increasing value of entropy due to the releasing of water molecules and the chloride anions may be larger than the decreasing value of entropy due to the adsorption of a dye molecule.

3.7. Dye removal treatment of industrial dye waste

Tests were carried out on industrial effluents from a printing and dyeing factory in Jinan that utilizes different anionic dyes and chemical substances such as dispersants, detergents and salts. Their amounts in effluents vary in different production processes. RBR K-2BP is one of the major dyes that are utilized in the factory. The industrial dyeing effluent was collected from the equalization pond of the plant during normal production. A preliminary test showed that at pH 6–9 an MMH dosage of 2300 mg/L was optimal for color removal. Therefore samples were collected on different days which utilized RBR K-2BP (and also other reactive dyes, normal 3–4 kinds of dyes from different workshops) in production, and treated with MMH dosage of 2300 mg/L of wastewater at origin pH. The characteristics of the industrial dyeing effluent and the treatment results are summarized in Table 5. The removal efficiencies of 93.8–96.7% for colored matter and 77.9–83.6% for COD obtained, respectively. MMH displayed excellent efficiency for treatment of the industrial effluents. MMH cost about 1700 yuan (RMB) per ton in China, about 242.8 US dollar/ton. The cost price is about 0.56 US dollar/m³ effluent with MMH dosage of 2300 mg/L.

Table 5

The characteristics and the treatment results of the industrial dyeing effluent.

Sample	Parameter	Effluent	Treated	Removal (%)
1	pH	6.7	7.9	–
	Conductivity ($\mu\text{S}/\text{cm}$)	10,230	11,020	–
	Turbidity (NTU)	21.3	3.6	83.1
	Point color	900	30	96.7
	COD (mg/L)	1070	176	83.6
2	pH	8.1	8.7	–
	Conductivity ($\mu\text{S}/\text{cm}$)	9370	9920	–
	Turbidity (NTU)	19.3	4.3	77.7
	Point color	800	50	93.8
	COD (mg/L)	870	193	77.9

The efficiency of dye removal from the effluents was lower than for synthetic dye solutions. The reason may be that the industrial effluents are more complex, and the chemical additives in effluents have interfered with the adsorption of dyes onto MMH.

4. Conclusion

Aluminum magnesium mixed metal hydroxide is a promising adsorbent for the removal of dyes from aqueous systems. It displayed the potential to effectively removing negatively charged dyes from aqueous solution. The above studies show that the effective range of pH for dye removal was between 4.0 and 11.0. Lower pH could cause dissolution of MMH. At pHs above IEP (pH > 10.9) there was a significant decline of dye adsorption because the surface became negatively charged. This result indicates that the interaction between the surface sites of the MMH and dye ions is a combined effect of both anion exchange and surface complexation. The experimental equilibrium data can be interpreted by Langmuir and Freundlich equations. The saturated adsorption capacity of MMH for RBR K-2BP was 657.5 mg/g. The adsorption kinetics can be successfully fitted by pseudo-second-order kinetics. The adsorption process was endothermic in nature. MMH also displayed excellent treatment efficiency for the industrial dyes effluents from a printing and dyeing plant and shows promise as an inexpensive and effective dye removal agent.

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