Sorption Behavior of Dye Compounds onto Natural Sediment of Qinghe River

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The objective of this study is to assess the adsorption behavior of C.I. Basic Yellow X-5GL, C.I. Basic Red 13, C.I. Direct Blue 86, C.I. Vat Yellow 2, and C.I. Mordant Black 11 on natural sediment and to identify sediment characteristics that play a predominant role in the adsorption of the dyes. The potentiometric titration experiment is used to investigate acid–base properties of the sediment surface with a constant capacitance surface complexation model. The parameters controlling the sorption such as solution pH and ion strength, as well as the influence of organic carbon and Ca^{2+} ion on the adsorption, are evaluated. It is shown that the titration data can be successfully described by the surface protonation and deprotonation model with the least-squares FITEQL program 2.0. The sorption isotherm data are fitted to the Freundlich equation in a nonlinear form ($1/n = 0.3\text{--}0.9$) for all tested dyes. With increasing pH value, the sorption of C.I. Mordant Black 11 and C.I. Direct Blue 86 on the sediment decreases, while for C.I. Basic Yellow X-5GL and C.I. Basic Red 13, the extent of sorption slightly increases. In addition, ion strength also exhibits a considerably different effect on the sorption behavior of these dye compounds. The addition of Ca^{2+} can greatly reduce the sorption of C.I. Basic Red 13 on the sediment surface, while it enhances the sorption of C.I. Direct Blue 6. The removal of organic carbon decreases the sorption of C.I. Mordant Black 11 and C.I. Direct Blue 86. In contrast, the sorption of C.I. Basic Red 13 and C.I. Basic Yellow X-5GL is obviously enhanced after the removal of organic carbon. The differences in adsorption behavior are mainly attributed to the physicochemical properties of these dye compounds. © 2001 Academic Press

Key Words: natural sediment; acid–base properties; sorption; effect factors; dye compounds.

INTRODUCTION

In natural aquatic systems, sorption processes play a dominant role in the transport and ultimate fate of pollutants. Thus, the adsorption behavior of organic contaminants on natural particles has been of central interest in recent years (1–5). Pignatello

and Xing (6) as well as Luthy *et al.* (7) have reviewed the sorption/desorption of organic compounds on the natural particles. Numerous studies have been devoted to sorption kinetics (8–11), equilibrium modeling, and mechanism (12–17), as well as to the factors that affect adsorption (18–20). It has been shown that the sorption of low-polarity, nonpolar, and nonionic organic compounds onto natural particles occurs largely by the partition of these compounds to organic matter involved in the solid (16, 21–23), and the interface behavior of ionic organic compounds is controlled mainly by the specific chemical and electrostatic interactions (24–28).

Dyes are widely used for textiles, printing, and dyeing, as well as in the food and paper-making industries. In 1988, dye output achieved 146 thousand tons in China (29). Environment researchers have paid special attention to dye compounds because of the extensive environmental contamination arising from dyeing operations. Most studies have focused on the development of a treatment technique and method for dye wastewater, such as a physical–chemical technique destroying the color groups (30, 31), a biodegradation process mineralizing the colorless organic intermediates (32, 33), and chemical oxidation including homogeneous oxidation (34) and heterogeneous photocatalytic oxidation (35–37). However, because of its higher organic concentration, particular toxicity, complex composition, and poor degradability, dye wastewater cannot be efficiently purified and treated. Thus, a large amount of wastewater containing dye compounds in low concentrations may be leaked and released into natural waters, leading to aquatic environmental contamination. The dye compounds may accumulate in sediments at many sites, especially at wastewater discharge, and their toxicity to humans and to aquatic life results in an impact on the ecological balance in the aquatic system.

Accordingly, this study elucidates the factors of solution chemistry, sediment composition, and acid–base characteristics influencing the sorption of dye compounds. The sorption behavior of individual dye compounds on the sediment, as a function of the dye concentration, pH value, and ion strength, is described in detail. The influence of the Ca^{2+} ion and sediment organic matter is also investigated.

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EXPERIMENTAL SECTION

Materials

The dye compounds in this study, C.I. Basic Yellow X-5GL, C.I. Basic Red 13, C.I. Direct Blue 86, C.I. Vat Yellow 2, and C.I. Mordant Black 11, were purchased from Chinese Knitting Mill. The dye molecular structures and maximum absorption wavelengths (λ) in the visible light range are presented in Fig. 1. A stock solution (1000 mg/L) of the dye was prepared with deionized water and was further diluted to various concentrations during the experimental process.

The surface sediment samples from 0 to 20 cm were collected from Qinghe River (Beijing, China). The sediments were relatively contaminated by anthropogenic organic wastes. After being washed with deionized water, the sediment samples were air-dried, homogenized, and passed through 200-mesh stainless steel sieves. The specific surface area of the sediment sample was determined by the N_2 /BET adsorption method (ASAP-2000). The organic carbon contents involved in the sediment were measured by the potassium dichromate oxidation method. An X-ray diffraction spectrometer (Model D/Max-RC) and an X-ray fluorescence spectrometer (Model 3080) were used to analyze the clay mineral and element composition, respectively. These physicochemical characteristics of the sediment are listed in Table 1. The sediment stock suspension was prepared by adding 10 g of sediment to 1 L of deionized water and stored in a refrigerator for 2 weeks prior to potentiometric titration and adsorption experiments.

Acid–Base Titration

A certain volume of 10 g/L sediment stock suspension was added to a 100-mL flask, and the ionic strength of the suspensions was adjusted with 1 mol/L $NaNO_3$. The initial volume of the suspension was diluted to 80 mL. The suspension was stirred magnetically and continually bubbled with N_2 purified successively through 10% $NaOH$, 10% H_2SO_4 , distilled water, and 0.1 mol/L $NaNO_3$ to purge CO_2 until the electrode potential was stable. Afterward, HNO_3 was added to make the suspension pH value lower than 3, and the back titration process was carried out with the addition of 0.04551 mol/L $NaOH$ in increments of 0.1 mL until the pH of the suspension reached 10.00. During the

FIG. 1. Chemical structure of dye compounds (a) C.I. Mordant Black 11, (b) C.I. Basic Yellow X-5GL, (c) C.I. Basic Red 13, (d) C.I. Direct Blue 86, and (e) C.I. Vat Yellow 2.

titration procedure, the drift of the measured potential should be below 1 mV/h and the temperature kept at $25 \pm 0.5^{\circ}C$. The reference blank was prepared in the same manner as the sample. The acidic suspension with HNO_3 was centrifuged at 10,000 rpm for 30 min. The acidic supernatants as system blanks were obtained and titrated.

Adsorption Experiment

The sorption of dye compounds on the sediment was carried out by a batch technique as a function of pH value, ion strength, and dye concentration. The sediment stock suspension (10 or

TABLE 1
Physicochemical Characters of the Sediment^a

Type of mineral Content (%)	Clay mineral composition (semi-quantitative)						
	Quartz 20	Feldspar 25	Calcite 10	Dolomite 10	Chlorite 10	Illite 20	Amphibole 5
Element composition							
Element	SiO ₂	Al ₂ O ₃	TFe ₂ O ₃	CaO	MgO	Na ₂ O	MnO
Content (%)	52.52	10.99	3.57	7.00	2.530	1.610	0.0602
	±0.16	±0.03	±0.01	±0.02	±0.008	±0.005	±0.0002
							K ₂ O
							1.881
							±0.006

^a Organic carbon content (%): 11.32 ± 0.11 . Specific surface area (m^2/g) 6.28 ± 0.17 .
^b Total Fe, including Fe(II) and Fe(III), expressed as Fe_2O_3 .

25 mL) was placed in a series of 250-mL plastic bottles, followed by addition 0.02% (by weight) of sodium azide that is used to inhibit bacterial growth. Then an appropriate volume of dye stock solution was added to make the dye concentration in the range 25–100 mg/L. Reagent-grade HNO_3 and NaOH were used to adjust the suspension pH value between 2 and 11. The ion strength was adjusted by 1 mol/L NaNO_3 electrolyte solution. The total suspension volume was diluted to 50 mL with deionized water. Each reaction sample was equilibrated at $30 \pm 1^\circ\text{C}$ on an orbital shaker for 12 h according to the preliminary experiment of adsorption kinetics. After centrifugation at 10,000 rpm for 30 min, the supernatant was separated from the solid sediment phase. A part of the supernatant was taken for determination of dye concentration by using a U-3010 spectrophotometer, and the remaining part was used to measure the equilibration pH value.

Effect of Ca^{2+} on Sorption of Dyes

Ca^{2+} is one of more common ions in natural water. Therefore, the test was performed in the same way as that in the above sorption experiment, but prior to the test, 0.1 mol/L of CaCl_2 was added to the slurries of sediments to investigate the competitive sorption behavior between the dye compounds and the Ca^{2+} ion.

Effect of Organic Carbon on Sorption of Dyes

In this experiment, sediment organic matter was removed by adding 300 mL of H_2O_2 to 100 g of the dried sediment sample, which was placed at room temperature for 2 h, and then heated to 70°C for 1 h. This treatment was repeated four times, and the sediments were rinsed with deionized water and dried. After H_2O_2 treatment, the sediment organic carbon showed a removal of 80–90%. The adsorption experiments with H_2O_2 -treated sediments were carried out as described above.

RESULTS AND DISCUSSION

Surface Acid–Base Properties

The natural sediment surface can be considered to be an amphoteric surface site with surface hydroxyl groups ($\equiv\text{XOH}$), which can be generally represented by the following protonation and deprotonation reactions:

Potentiometric titration provides a measure of the sequential binding of the proton by the surface functional groups of sediment. The total concentration of surface sites (H_S , mol/L) on the sediment can be obtained by using the *in situ* Gran plot method (38–40), plotting Gran function (G) versus the volume of added

strong base (V_B). For the hydroxide back titration, Gran functions are expressed as

$$\text{acidic side: } G = (V_0 + V_{AT} + V_B) \times 10^{E/59.175} \quad [3]$$

$$\text{alkaline side: } G = (V_0 + V_{AT} + V_B) \times 10^{-E/59.175}, \quad [4]$$

where V_0 is the initial volume of suspension (mL), V_{AT} is the total volume of strong acid added (mL), and E is the potential of the glass electrode (mV). On the basis of the linear regression analysis of Gran plots, the two equivalence points for each suspension (V_{e1} and V_{e2}) or for the blank system ($V_{e'1}$ and $V_{e'2}$), which are the intercepts at the V axis in acidic and alkaline side, are obtained. Figure 2 shows the Gran plot of a 5 g/L suspension and the relative acidic blank system in 0.01 mol/L NaNO_3 . Thus, the H_S value can be estimated by the equation

$$H_S = [(V_{e2} - V_{e1}) \times C_B - (V_{e'2} - V_{e'1}) \times C_B]/V_0, \quad [5]$$

where C_B is the concentration of added base.

Furthermore, the constant capacitance model has been used to determine the surface acidic constants of the natural particle.

FIG. 2. Gran plots for a 5 g/L suspension and a blank system in 0.01 mol/L NaNO_3 .

Theoretically, only one plane in the interfacial region for the adsorption of H^+ , OH^- , and all specifically adsorbed solutes is considered, and all of the specific adsorbed ions are arranged as inner-sphere complexes by the surface coordination reactions in this model. The surface charge (ρ_0)–potential (ψ_0) relationship used in the model is $\rho_0 = C\psi_0$, where C is the electric capacity of particle–water interface. The electrical double layers are Helmholtz, like a parallel plate capacitor (41, 42). In the model calculations, an electric capacity (C), two intrinsic acidic constants (K_{a1} and K_{a2}), and the total concentration of surface sites (H_S) are arranged as adjustable parameters. The potentiometric titration data sets, in the format of TOTH (total concentration of reacted proton) vs pH, are input into the FITEQL 2.0 program with a nonlinear least-squares optimization procedure (43), in which TOTH can be calculated by the calibration of the zero titration point (V_{e1}):

$$\text{TOTH} = -(V_B - V_{e1}) \times C_B / (V_0 + V_{AT} + V_B) \quad (\text{mol/L}). \quad [6]$$

Then, by changing electric capacity C values, the best fit is achieved. The surface acidic constants and the optimized total concentration of surface sites for sediment suspension in different electrolyte concentrations are listed in Table 2. As we can see, the H_S values estimated and optimized are of the same order of magnitude, and for the two calculations in 0.01 and 0.5 mol/L NaNO_3 systems, the values of overall variance (V_Y), which are the indicators of the goodness of fit, are respectively 44.82 and 53.10, and the standard deviations (σ) for optimized parameters are within 0.0397. This result shows that the protonation and deprotonation reactions model can successfully describe the acid–base behavior of the natural sediment surface. In turn, the derived parameters are incorporated into the models to reproduce a titration curve as shown in Fig. 3. It is obvious that the sediment sample is negatively charged over a large pH range, and model calculation results match well with the experimental results.

TABLE 2
Surface Acid–Base Characteristic Parameters
of the Sediment

Parameter	System (5 g/L particle)	
	0.01 mol/L NaNO_3	0.5 mol/L NaNO_3
Estimated H_S (mol/L) ^a	1.196×10^{-3}	1.151×10^{-3}
$C(\text{F/m}^2)$	23.25	35.01
K_{a1}	3.286	2.917
K_{a2}	3.925	3.751
Optimized H_S (mol/L)	2.893×10^{-3}	2.728×10^{-3}
V_y	44.82	53.10
σ_{H_S}	1.838×10^{-5}	1.912×10^{-5}
$\sigma_{pK_{a1}}$	3.681×10^{-2}	3.970×10^{-2}
$\sigma_{pK_{a2}}$	2.775×10^{-2}	2.433×10^{-2}

^a Values are estimated from Eq. 5.

FIG. 3. Model curves of the potentiometric titration for the sediment suspension and the corresponding experimental data.

Sorption Isotherm

The adsorption isotherms of the dye compounds are shown in Fig. 4. Equilibrium sorption data are calculated based on the Freundlich model,

$$C_s = K_f C_w^{1/n}, \quad [7]$$

where K_f and $1/n$ are the Freundlich sorption coefficient and the Freundlich exponent, respectively, and C_s (mg/g) and C_w (mg/L) denote the concentration in the solid and in the aqueous phase, respectively. The relative sorption parameters of the studied dyes on the sediment are summarized in Table 3. It is shown that, over the range of dye concentrations studied, all experimental data are fitted very well by the nonlinear Freundlich-type sorption isotherm, and the regression coefficients (R^2) are 0.94–0.99. This nonlinearity of sorption behavior is mainly attributed to organic and mineral matrices involved in sediment.

FIG. 4. Adsorption isotherms of dye compounds on the sediment (experimental conditions: ionic strength, 0.01 mol/L; particle concentration, 5 g/L; pH, 6–7).

TABLE 3
Sorption Parameters of Dye Compounds on Sediment

Dye	Freundlich coeff K_f (mg/L · mg/g)	Freundlich exponent $1/n$	r^2	K_{oc}
C.I. Mordant Black 11	3.48	0.319	0.972	30.8
C.I. Basic Yellow X-5GL	7.04	0.386	0.941	62.3
C.I. Basic Red 13	7.01	0.687	0.981	62.0
C.I. Direct Blue 86	0.120	0.812	0.950	1.06
C.I. Vat Yellow 2	0.162	0.932	0.985	1.43

As for their sorption on sediment, dye compounds can be divided into two groups. One is C.I. Mordant Black 11, C.I. Basic Yellow X-5GL, and C.I. Basic Red 13, which have extremely nonlinear sorption isotherms ($1/n = 0.32$ – 0.69) and relatively high sorption coefficients ($K_f = 3.5$ – 7.0). The other group is C.I. Direct Blue 86 and C.I. Vat Yellow 2, showing only minor sorption coefficients ($K_f = 0.12$ – 0.16) and almost linear isotherms ($1/n = 0.81$ – 0.93).

The distribution coefficient (K_d) denotes a concentration ratio of the adsorbed amount in solid sediment and the concentration in solution at equilibrium:

$$K_d = C_s / C_w. \quad [8]$$

For nonlinear sorption isotherms, K_d is a function of the solute concentration ($K_d = K_f C_w^{1/n-1}$) and equals K_f at an aqueous concentration of 1 mg/L. The sorption coefficient normalized by the organic carbon content (K_{oc}) can be calculated on the basis of the fraction of organic carbon C_{org} and K_f at an aqueous concentration of 1 mg/L:

$$K_{oc} = K_f / C_{org} \quad [9]$$

The K_{oc} values for the dye compounds are also listed in Table 3. The sorption of the dyes on the sediment can be explained by three primary driving forces: hydrophobic exclusion of aromatic cyclic and alkyl compounds, specific chemical interaction of functional groups such as sulfonate with the sediment, and electrostatic interaction of the charged solute molecule with the charged sediment surface. On the basis of the K_{oc} values (see Table 3), the hydrophobic interaction is likely to be more important for C.I. Direct Blue 86, C.I. Vat Yellow 2, and C.I. Mordant Black 11 than for C.I. Basic Yellow X-5GL and C.I. Basic Red 13.

Effect of pH on Sorption of Dye Compounds

The effect of pH on the sorption of dye compounds is shown in Fig. 5. It is observed that the extent of sorption for C.I. Mordant Black 11 and C.I. Direct Blue 86 decreases with increasing pH values. For the sorption of C.I. Basic Yellow X-5GL and C.I. Basic Red 13, a slight increase is found with increasing pH values and the adsorption percentage approaches 80–90% of added dyes in the studied pH range. Generally, the pH dependence of sorption for organic compounds onto natu-

ral aquatic particles can be attributed to specific pH-dependent reactions containing surface complexation or ligand exchange, electrostatic interactions resulting from surface charge, and the hydrophobic effect (44). It is well known that the unbound surface species ($\equiv XOH$) can be formed on the natural sediment surface. The ion-exchange reaction of C.I. Mordant Black 11 and C.I. Direct Blue 86 as anion dye species (RSO_3^-) with OH^- of $\equiv XOH$ may occur through the following equilibrium (45):

Obviously, an increasing pH value reduces the ion-exchange competition of the anion RSO_3^- with the OH^- of $\equiv XOH$, thereby decreasing the adsorption possibility of the dye anion on the sediment. Moreover, with a decreasing pH value, the fraction of neutral dye species increases, which enhances the hydrophobic effect of the dye compounds from the bulk solution, leading to an increased adsorption.

It is remarkably noted from acid–base titration experiments that the sediment surface is negatively charged in a wide pH range. With increasing pH values, the adsorption of C.I. Basic

FIG. 5. Effect of pH value on the sorption of dye compounds (experimental conditions: ionic strength, 0.01 mol/L; particle concentration, 5 g/L; initial concentration of dye, 25–100 mg/L).

Yellow X-5GL and C.I. Basic Red 13 onto the sediment tends to increase, which can be explained by the electrostatic interaction of dye cationic species with the negatively charged surface. The electrostatic attraction force of the dye compounds with the sediment surface is likely to be raised when the pH value increases.

Effect of Ionic Strength on Sorption of Dye Compounds

As shown in Fig. 6, the effect of ionic strength on the adsorption of dye compounds onto the sediment can be divided into three types. One type is that the ionic strength promotes the adsorption of C.I. Vat Yellow 2 on the sediment. On the basis of the surface chemistry theory, when dye molecules approach the sediment particle surface, the two phases are surrounded by an electric double layer due to electrostatic interactions. As a result of increasing the concentration of the electrolyte, the thickness of the diffuse double layer can be significantly compressed; thus the van der Waals forces become remarkable, leading to an increase of the sorption for C.I. Vat Yellow 2 on the particle surface. Furthermore, as the solubility of the dye compound decreases with increasing ionic strength, the increased adsorption at a higher ionic strength can also be explained by an increase of the hydrophobic effect. The second type is that the ionic strength inhibits the adsorption of C.I. Basic Yellow X-5GL, C.I. Basic Red 13, and C.I. Direct Blue 86 on the sediment. The decreased sorption of the dyes at higher ionic strength can be attributed to the cation exchange of C.I. Basic Red 13 and C.I. Basic Yellow X-5GL with the particle surface, as well as to the ligand exchange mechanism of C.I. Direct Blue 86 with the natural organic anion ligands. Electrolyte ions such as Na^+ and NO_3^- at higher concentrations may be adsorbed onto the particle surface by competing exchange sites with dye molecules. Thus the amount of dye exchanged on the particle surface is likely to be reduced. The third type is that, with increasing ionic strength, the sorption percentage for C.I. Mordant Black 11 decreases first in the lower ionic strength range, and then goes up. This behavior

FIG. 6. Effect of ionic strength on the sorption of dye compounds onto sediment (experimental conditions: particle concentration, 5 g/L; initial concentration of dye, 25–100 mg/L; pH, 6–7).

FIG. 7. Effect of added Ca^{2+} on the adsorption of dyes onto sediment.

is due to the cooperative interaction mechanisms of the special chemical reaction and the hydrophobic effect.

Effect of Ca^{2+} Ion on Sorption of Dyes

The influence of Ca^{2+} on the adsorption of C.I. Basic Red 13 and C.I. Direct Blue 86 is shown in Fig. 7. Obviously, the sorption dependence of the two dye compounds with or without 0.1 mol/L of Ca^{2+} is quite different. The addition of Ca^{2+} greatly reduces the sorption of C.I. Basic Red 13 on the sediment surface. The inhibition phenomenon is mainly due to the competitive adsorption of Ca^{2+} ion with the dye cation on the sediment surface, resulting in the decrease of available surface exchange sites. Nevertheless, the presence of Ca^{2+} enhances the sorption of C.I. Direct Blue 86 on the sediment. Generally, the sediment surface is charged negatively; thus the Ca^{2+} ion can be adsorbed directly onto the sediment interface, reducing the negative surface charge and the electrostatic repulsion between C.I. Direct Blue 86 anion and the negatively charged surface. In addition, C.I. Direct Blue 86 can form a positively charged complex with Ca^{2+} as follows (44):

The complex cation is likely to be adsorbed on the sediment surface by electrostatic attraction or cation exchange.

Effect of Organic Carbon (OC) on Sorption of Dyes

The adsorption of organic compounds on natural particles is attributed to mineral and organic carbon fraction (46). Much research indicates that the contribution of organic carbon to the sorption of organic chemicals comes mainly from possible binding mechanisms such as the ion exchange of cationic molecules, hydrogen bonds, charge transfers, and London–van der Waals dispersion forces or the hydrophobic effect of hydrophobic molecules (3, 47, 48). The mineral fraction in sediment plays a great part in the adsorption of organic compounds by dipole–cation interactions and coordination bonds between

FIG. 8. Comparison of dye adsorption on the sediment after and before removing organic carbon.

exchangeable cations involved in mineral and organic cations. Generally, anionic molecules are weakly adsorbed on pure mineral fractions. Figure 8 shows a comparison of the adsorption percentages of the dye compounds on the sediment before and after removal of sediment organic carbon by H_2O_2 treatment. The organic carbon-rich sediment has a far greater adsorption percentage for C.I. Mordant Black 11 and C.I. Direct Blue 86 than the sediment with organic carbon removed. Removal of organic carbon decreases the sorption of C.I. Mordant Black 11 and C.I. Direct Blue 86 by about 25 and 40%, respectively. These results strongly suggest that sediment organic carbon is an important factor controlling the sorption processes of C.I. Mordant Black 11 and C.I. Direct Blue 86. The extent of this reduction is dependent on the physicochemical properties of the dye compound.

In contrast, a significant increase in the sorption of C.I. Basic Yellow X-5GL and C.I. Basic Red 13 on the sediment is observed after removal of organic carbon. These observations show that the mineral surface sites at which cation exchange takes place play a critical role in the adsorption of the two dyes on the sediment. The oxidation of the sediment by H_2O_2 treatment can enrich mineral surfaces, and more ion-exchange sites participating in the interfacial reaction are exposed on the mineral surfaces after removal of sediment organic carbon.

CONCLUSION

The sorption of dye compounds on natural sediment represents an important control on their transport, degradation, and ultimate fate in the natural aquatic environment. This investigation has shown the potential of the sediment collected from the Qinghe River to adsorb dye compounds that may enter the river system through the disposal of municipal and industrial effluents. The potentiometric titration experiment shows that, based on the constant capacitance model, the surface protonation and deprotonation model of the sediment can successfully describe the titration data. The parameters optimized with the help of FITEQL program 2.0, such as surface acidic constants and the total concentration of surface sites for sediment in different elec-

trolyte concentrations, are obtained (see Table 2). The adsorption data suggest that, for all tested dyes, sorption isotherms are fitted very well by the nonlinear Freundlich equation over the range of dye concentrations studied, and the regression coefficients (R^2) are 0.94–0.99. The pH value and ionic strength of solution show considerably different influences on the adsorption of the studied dye compounds, which are related to the physicochemical properties of these dyes. With increasing pH values, the sorption percentages of C.I. Mordant Black 11 and C.I. Direct Blue 86 decrease, and the sorptions of C.I. Basic Yellow X-5GL and C.I. Basic Red 13 slightly increase. Organic carbon involved in the sediment and Ca^{2+} ion are also the most important factors controlling the adsorption of the dyes onto the sediment. The presence of Ca^{2+} greatly inhibits the sorption of C.I. Basic Red 13 on the sediment surface but promotes the sorption of C.I. Direct Blue 86. The removal of organic carbon decreases the sorption of C.I. Mordant Black 11 and C.I. Direct Blue 86. In contrast, a significant increase was found in the sorption of C.I. Basic Red 13 and C.I. Basic Yellow X-5GL after removal of organic carbon.

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