

## Removal of methylene blue from aqueous solution by peat

A.N. Fernandes<sup>a,\*</sup>, C.A.P. Almeida<sup>b</sup>, C.T.B. Menezes<sup>c</sup>, N.A. Debacher<sup>a</sup>, M.M.D. Sierra<sup>a</sup>

<sup>a</sup> Departamento de Química, Universidade Federal de Santa Catarina, 88040-900 Florianópolis, SC, Brazil

<sup>b</sup> Departamento de Química, Universidade Estadual do Centro Oeste, 85015-430 Guarapuava, PR, Brazil

<sup>c</sup> Departamento de Engenharia Ambiental, Universidade do Extremo Sul Catarinense, 88806-000 Criciúma, SC, Brazil

Received 19 June 2006; received in revised form 12 October 2006; accepted 17 October 2006

Available online 26 October 2006

### Abstract

In this study, the removal of methylene blue (MB) from aqueous solution by peat was analyzed. The peat was collected from a peatland at Arroio do Silva Beach, in Santa Catarina state, in the south of Brazil. Adsorption was conducted using varied initial concentrations of the MB solutions and three different temperatures (35, 45 and 60 °C). An adsorption time of around 4.5 h was sufficient to reach the equilibrium for all temperatures, in the concentration range studied. Percentage removal was greater for diluted solutions, but the absolute amount of MB adsorbed by the peat at equilibrium increased with an increase of the initial concentration, corroborating the efficacy of the material as an adsorbent. Temperature influenced slightly the reaction, which was endothermic. Results indicated a multi-layered process and the data were analyzed considering pseudo-first-order, pseudo-second-order and intraparticle diffusion approaches. The latter two mechanisms seem to be significant in the rate-controlling step. © 2006 Elsevier B.V. All rights reserved.

**Keywords:** Adsorption; Peat; Methylene blue; Kinetic parameters

### 1. Introduction

The textile industry plays an important role in the economy of many countries. In Brazil, this industry is featured among the eight more important sections of the industrial activity, occupying the first places in direct employments and in billing [1]. Although the technological differences among the small and big industries are quite significant, all of them use great amounts of water. This fact, associated to the low use of the input, makes the textile industry responsible for the generation of great volumes of residues, with high organic charge and strong coloration [2].

Colour is the most obvious indicator of water pollution. Colored dye wastewater arises as a direct result of the production of the dye and also as a consequence of its use in the textile and other industries. The discharge of these wastewaters not only damages the aesthetic nature of receiving water bodies, but also may be toxic to aquatic life [3,4]. When not treated adequately and launched in natural waters, effluents proceeding from the process of dyeing of staple textile fibers can modify

the ecosystem, diminishing the transparency of the water and the penetration of the solar radiation, which can in turn modify the photosynthetic activity [5].

Wastewater containing dyes from the textile industry is very difficult to treat using conventional wastewater treatment methods, since the dyes are stable in the presence of light and oxidizing agents, and are resistant to aerobic digestion [6]. Adsorption techniques to remove dyes in solution have been widely used [3,4,6–10]. The adsorption phenomenon is known since the XVII century, when in 1773, it had seen that porosity materials have the property of adsorbing gases [11,12]. Since then, studies have started to be done in systems formed by solids and gases. In 1785, the same adsorption phenomenon was observed on solutions [12]. At present, adsorption is known as a fundamental phenomenon into many physical, biological and chemical processes that happen in nature [12]. Moreover, adsorption is nowadays one of the most efficient methods to remove dyes from effluents, and activated carbon is the most popular and widely used adsorbent for this purpose [13]. Activated carbon has extended surface area, complex microporous structure, high adsorption capacity and high degree of surface reactivity [13]. However, activated carbon has limited use due to costs [14], and many other materials have been researched as cheaper substituents.

\* Corresponding author. Tel.: +55 48 3331 68 49; fax: +55 48 3331 68 50.  
E-mail address: [andrea@qmc.ufsc.br](mailto:andrea@qmc.ufsc.br) (A.N. Fernandes).

### Nomenclature

$C_e$	equilibrium concentration ( $\text{mg L}^{-1}$ )
$C_o$	initial concentration ( $\text{mg L}^{-1}$ )
$k_f$	rate constant of pseudo-first-order model ( $\text{h}^{-1}$ )
$k_s$	rate constant of pseudo-second-order model ( $\text{g mg}^{-1} \text{h}^{-1}$ )
$k_1$	rate constant of intraparticle diffusion model in the first stage ( $\text{mg g}^{-1} \text{h}^{-1/2}$ )
$k_2$	rate constant of intraparticle diffusion model in the second stage ( $\text{mg g}^{-1} \text{h}^{-1/2}$ )
$q_e$	amount of dye mass adsorbed at equilibrium ( $\text{mg g}^{-1}$ peat)
$q_t$	amount of adsorption at time $t$ ( $\text{mg g}^{-1}$ peat)
$R_f$	correlation coefficient for pseudo-first-order model
$R_s$	correlation coefficient for pseudo-second-order model
$R_1$	coefficients for the intraparticle diffusion model
$R_2$	coefficients for the intraparticle diffusion model
$t$	time (h)

Recently, peat has been used to remove pollutants, including heavy metals and dyes [4,10,15–19]. Peat may be seen as a viable adsorbent in many countries where it is widely available, as in Brazil [20], Ireland and the UK. It does not require activation, unlike activated carbon, and it has low cost. As many others adsorbents, after adsorption, peat may be burned and utilized for steam rising, or, potentially, as substrate for solid-state fermentation, for protein enrichment [21]. Peat is a light brown to black organic material formed under waterlogged conditions from the partial decomposition of mosses and other bryophytes, sedges, grasses, shrubs or trees [15,22]. Peat, as an adsorbent, is a porous and rather complex material, containing lignin, cellulose, and fulvic and humic acids as its major constituents. The composition of peat from various sources may vary considerably depending on age, the nature of its original vegetation, the regional climate, the acidity of the water and the degree of metamorphosis [15,22]. The constituent compounds carry polar functional groups such as alcohols, aldehydes, carboxylic acids, ketones and phenolic hydroxides, which may bond with sorbed pollutant species. Several investigators have suggested many possible interactions between contaminants and peat (cation exchange, chelate complexes, hydrogen bonds, formation of anion–cation bonds) [16,23]. For all processes, the diffusion of the considered pollutant from the aqueous medium to the peat particle has been recognized as being a requirement.

With the development of the textile industry in Santa Catarina State – Brazil, the discharge of wastewater to the water bodies has increased considerably and increased the environments problems. The state possesses extensive peatlands and thus the possibilities for the use of this material to treat the wastewater become more promising. In this study, Langmuir isotherm was used to evaluate the adsorption of methylene blue (MB) on a peat sample from Arroio do Silva Beach in Santa Catarina State

(Brazil). The aim of this study was to characterize and assess the adsorption potential of this material in relation to textile industry effluent management.

## 2. Materials and methods

After collected, the sample of peat was air dried and then sieved to give a 60 mesh size fraction. Typical characteristics of the peat (such as acidity, density and ash content) were determined by conventional methods and are summarized in Table 1 [24,25]. The determination of the decomposition degree was carried out through the Von Post classification [26]. For classification of the mineral material a scanning electron microscope coupled with an energy dispersive spectrometer (SEM-EDS) model Philips XL 30 was used. Prior to the adsorption experiments, samples were washed with a  $6 \text{ mol L}^{-1}$  HCl solution to remove the inherent metals. A Carlo Erba 1100 CHNS elemental analyzer was used for the structural characterization after washing with the HCl solution.

As the adsorbate, a cationic dye, MB (Fig. 1), was chosen. This dye is not strongly hazardous, but it can cause some harmful effects. Adsorption of MB from the aqueous phase is a useful toll for product control of adsorbents [27].

Batch uptake studies were conducted by placing 0.1 g of peat in contact with 50 mL of MB solution, using several different initial concentrations (200, 400, 600, 700, 800, 900, 1000, 1200,

Table 1  
Elemental analysis and physical characteristics of the Arroio do Silva peat sample

Characteristics	Values
pH <sup>a</sup>	3.49
Density ( $\text{g cm}^{-3}$ )	0.94
Moisture (%)	75.00
Ash (%)	25.89
Von Post classification	6.00–7.00
C (%)	38.33
H (%)	4.18
N (%)	1.93
S (%)	1.40
O (%) <sup>b</sup>	54.16
H/C (%) <sup>c</sup>	1.31
N/C (%) <sup>d</sup>	0.04

<sup>a</sup> For the measurements of pH, peat was dissolved in distilled water (1 g/10 mL).

<sup>b</sup> Value determined by difference at 100%.

<sup>c</sup>  $\text{H/C} = [\% \text{H}/1.00]/[\% \text{C}/12.01]$ .

<sup>d</sup>  $\text{N/C} = [\% \text{N}/14.01]/[\% \text{C}/12.01]$ .

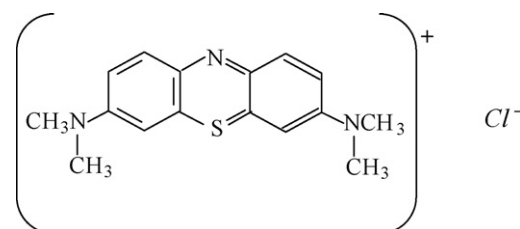


Fig. 1. Structure of methylene blue (MB).

1400 and 1500 mg L<sup>-1</sup>). The flasks with their contents were then stirred for different adsorption times. The adsorption processes were carried out in the temperatures of 35, 45 and 60 °C, with the purpose of comparing the results obtained at different temperatures. The pH of the solutions was kept at 3 with addition of 0.1 mol L<sup>-1</sup> HCl. The stirring speed was kept constant at 250 rpm. At the end of each adsorption period, the supernatant was diluted and centrifuged for 10 min at 2000 rpm. The concentration of MB in the supernatant solution before and after adsorption was determined by diode array spectrophotometer (8452 A, Hewlett Packard, USA) with a 1 cm path length cell, at 664 nm. All chemicals used in this study were purchased from Merck.

### 3. Results and discussions

#### 3.1. Characterization

Peat properties are dependent on several factors, including the environmental conditions during its formation and the extent of its decomposition. The decomposition degree is an important criterion for peat classification since it increases its amorphous nature, enhancing its effectiveness as a sorbent. Von Post classified peats according to the decomposition degree into 10 classes: from H1 to H3, undecomposed material or material with a low decomposition degree; from H4 to H7, partially decomposed materials; from H8 to H10, well decomposed peats [26,28,29]. The peat studied here presented intermediate H values (Table 1) being, consequently, considered a partially decomposed material. This type of peat is fibrous, with good hydraulic and adsorptive characteristics. It has a high total pore volume, capable of retaining significant quantities of pollutants [15,26,28].

The structure of peat ranges from fibric to sapric, and the relative proportions of C, H and O vary, depending upon the botanical composition and the decomposition degree (humification). Typical compositions (moisture and ash free) are in the range 40–60% C, and 4–6% H. These elements generally tend to increase with increasing of decomposition extent, while the O content (30–40%) decreases [22]. The values from the elemental analysis of the peat studied here are in good agreement with those expected for this type of sample (Table 1) [16,28,30]. The low values of H/C ratio indicate a low saturation character, being in agreement with the above cited relatively high decomposition degree [16].

The morphologic characterization is also an important criterion for peat geology research. Mineral matter provides valuable information regarding the depositional conditions, as well as regarding the environmental impacts from peat utilization [31]. The results of the SEM-EDS showed a high level of heterogeneity in terms of particle size and texture (Fig. 2), with structures remaining from wood being found. The sample studied showed a porous structure and a great variety of chemical elements (C, O, Si, Ca, Fe, Al, S, Mg, K), with C and O giving the highest values. In general, the micrograph shows that the particles of peat tend to agglomerate in compact microportions, with forms and varied size.

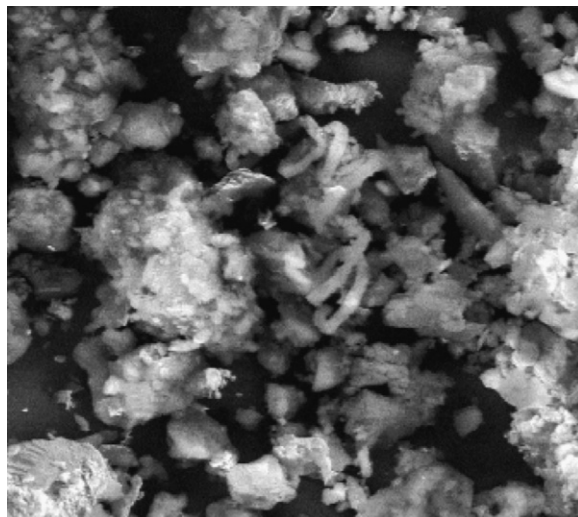


Fig. 2. Photomicrograph of the sample studied amplified 500×.

#### 3.2. Adsorption experiments

##### 3.2.1. Effect of contact time, initial concentration and temperature

The adsorption of MB onto the peat was investigated at three different temperatures, using different adsorption times and initial concentrations. Fig. 3 shows the results at 35 °C; for the other two temperatures, 45 and 60 °C, the plots have the same general features. The complete set of data collected is presented in Table 2. In general, the mass of MB adsorbed at equilibrium increases with the initial dye concentration. An adsorption time of around 4.5 h was sufficient to reach the equilibrium concentration for the three temperatures studied, at all concentrations, with dye removals exceeding 90% for the more diluted solutions (200–400 mg L<sup>-1</sup>) (Table 2). Such a short time for equilibrium, coupled with a high removal indicates a high affinity of peat for MB, indicating a probable chemical adsorption process, resulting from the cation exchange between the H ions found in the –COOH of the peat with cationic groups of the dye. In previous

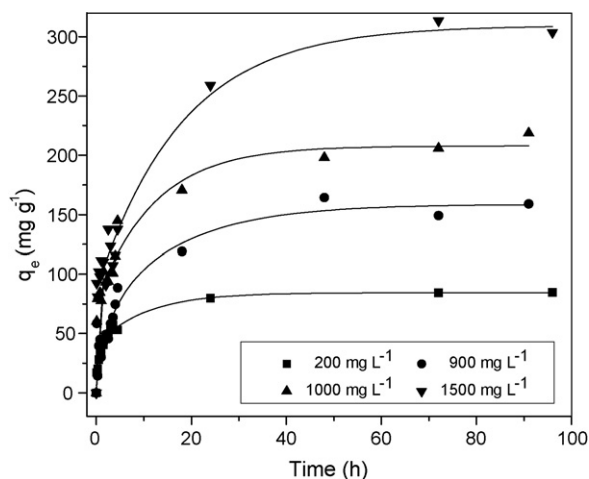


Fig. 3. Progressive removal of MB from aqueous solutions by peat, for different initial concentrations, at 35 °C.

Table 2

Mass of MB adsorbed and percentage of removal, at equilibrium, by the Arroio do Silva peat sample

$T^a$ (°C)	Initial concentration of MB in $\text{mg L}^{-1}$ ( $C_0$ )									
	200	400	600	700	800	900	1000	1200	1400	1500
Amount of MB mass adsorbed by peat in $\text{mg g}^{-1}$ ( $q_e$ )										
35	84.8	174.4	181.1	182.7	181.7	159.0	218.7	316.7	324.0	303.6
45	92.8	189.3	177.1	179.0	183.3	196.9	202.5	213.0	285.7	284.7
60	92.4	189.6	188.5	218.2	226.8	232.9	210.6	286.8	325.6	320.1
Percentage of removal of MB by peat (%)										
35	98.4	85.7	55.0	50.1	41.5	34.2	38.5	49.7	45.7	40.8
45	99.6	90.3	62.2	51.9	44.3	43.2	40.1	36.3	38.7	36.4
60	99.3	90.4	74.4	67.1	59.8	52.7	45.1	48.8	44.1	41.0

<sup>a</sup> Temperature.

experiments using barro branco (aluminum-silicate) as the material adsorbent, with the same concentrations and temperatures employed in this study, for example, a contact time of about 48 h was necessary to reach the equilibrium concentration [32]. This can be due to the fact that peat is an organic material and contains in its structural functional groups capable to carry out the cation exchange, while barro branco is an inorganic material and does not contain this kind of active sites in its structure taking more time to reach the equilibrium concentration.

The percentage of removal decreased at higher concentrations (Table 2). For the three temperatures studied, the removal of dyestuff decreased from ~99% to ~40% with an increase of the initial concentration from 200 to 1500  $\text{mg L}^{-1}$ . In spite of this, the absolute amount of MB adsorbed at equilibrium increased in all cases, from ~90 to ~300  $\text{mg g}^{-1}$  peat, with an increase of the initial concentration from 200 to 1500  $\text{mg L}^{-1}$ , attesting to the efficacy of removal process (Table 2).

An increase in temperature produced a slightly positive effect in relation to the mass of MB adsorbed in the initial concentration range from 200 to 900  $\text{mg L}^{-1}$ . After that, the trend is not very clear, with a negative effect being observed in some cases. The endothermic nature of the reaction may be due to the fact that at higher temperatures, an increase in the free volume in adsorbent pores occurs due to increased movement of the solute [10]. This may result from a relative increase in the tendency of MB molecules to escape from the solid phase to the bulk phase with increasing temperature of the solution [33]. It may also be caused by the dissolution of the sorbing species, changes in the size of the pores, and enhanced rate of intraparticle diffusion of adsorbent [34]. At higher concentrations (1000–1500  $\text{mg L}^{-1}$ ) this positive effect is not distinguishable because, as will be discussed below, other factors are involved.

### 3.2.2. Adsorption isotherms

Fig. 4 shows the adsorption isotherms for the adsorption of MB onto peat for the three temperatures studied. For all temperatures, a rapid increase in the mass of dye adsorbed is observed with an increase in the initial concentration from 0 to 400  $\text{mg L}^{-1}$ . Between 400 and ~1000  $\text{mg L}^{-1}$  the mass of MB adsorbed remains approximately constant. At 35 °C, above this

concentration, a further increase occurs, with a second plateau at higher concentrations. For the experiments at 45 and 60 °C, this second plateau is not well defined, but the results are comparable. These features are typical of processes where the saturation of more than one layer occurs. In the first stage, at lower concentrations, most of MB in solution is transferred to the superficial layer of the peat due to the great availability of reactive sites. As a consequence, the mass of MB adsorbed increases with the initial concentration whereas the equilibrium concentration remains almost constant and closer to zero. For initial concentrations of 400 to ~1000  $\text{mg L}^{-1}$  no sign of further adsorption is observed, indicating the saturation of the superficial sites of the peat. At this stage, the equilibrium concentration increases because all of the MB beyond 400  $\text{mg L}^{-1}$  remains in the solution phase. For initial concentration values higher than 1000  $\text{mg L}^{-1}$  a new adsorption process, with a second saturation stage, seems to occur. Data like these are not well described by the isotherms equations of Langmuir and Freundlich, whose basic assumption is that, once a sorbing molecule occupies a site, no further adsorption can take place at that site [35,36]. The plots of  $C_e/q_e$  versus  $C_e$  and  $\ln q_e$  versus  $\ln C_e$ , which are used in Langmuir and Freundlich type calculations, were not linear for our data and are not shown here. Similar results were found by Allen and collaborators on analyzing isotherms of basic dye adsorption onto sphagnum peat [37]. Their isotherms deviated from the Langmuir and Freundlich equations and such a deviation was attributed to the pressure of adsorbed molecules creating new surfaces by expanding the adsorption particle. In fact, according to McKay and Allen the adsorption of a dye onto peat can be described by a two (or more) resistance model, incorporating a surface or external resistance in the liquid film surrounding the adsorbent particle [38,39]. First, dye molecules migrate through the solution to the external surface of peat particle and then, they move within the particle in a diffusion process. The dye molecules are then adsorbed at sites at the interior surface of the peat particle. The adsorbate molecules can then be attached to molecular wedges creating access to a new surface and effectively clearing blocked pores. A similar interpretation can be made for our data: when the concentration of MB in the solutions is sufficiently high (above ~1000  $\text{mg L}^{-1}$ ), intraparticle diffusion takes place. The peat contains negatively charged groups



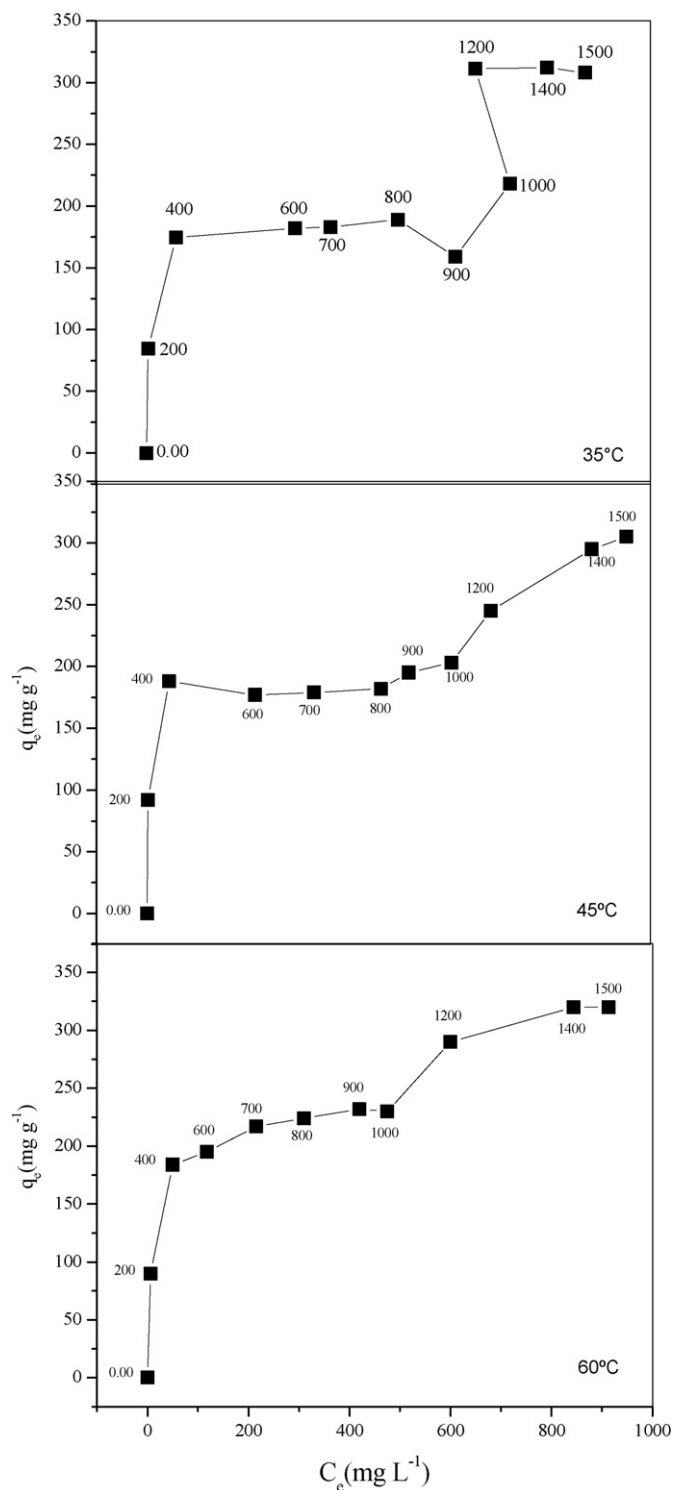


Fig. 4. Adsorption isotherms of MB adsorption onto peat at 35, 45 and 60 °C.

and exchangeable ions (such as  $H^+$ ) associated with humic substances. The basic dyes could be adsorbed by electrostatic interactions, ion exchange and chemical reactions. In our case, at higher temperatures, the isotherms show that there is not a well-defined limit between the process of occupation of the first and further layers, probably because saturation and diffusion processes occur simultaneously.

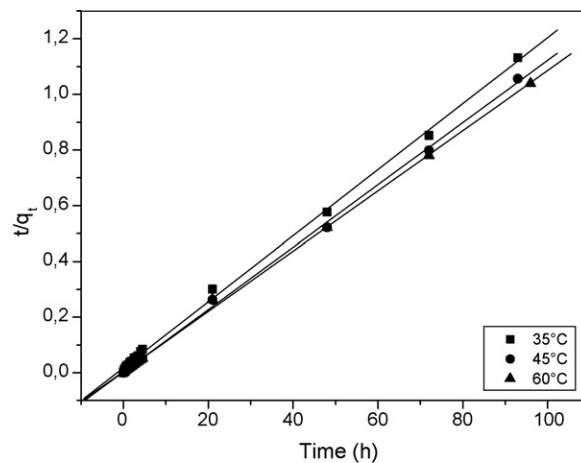


Fig. 5. Pseudo-second-order kinetics of MB adsorption onto peat at 35, 45 and 60 °C. Initial dye concentration: 200 mg L<sup>-1</sup>.

### 3.2.3. Kinetic parameters

The rate constants of chemical sorption and intraparticle diffusion for the MB adsorption onto peat were determined using the equations of the pseudo-first-order, or Lagergren, and pseudo-second-order mechanisms and the intraparticle diffusion process of Weber and Morris [40–43]. The trend of the correlation coefficients values ( $R$ ) were pseudo-second-order > intraparticle diffusion  $\geq$  pseudo-first-order for all conditions (Tables 3–5). The correlation coefficients for pseudo-second-order ( $R_s$ ) were higher than 0.95 for all initial concentrations and temperatures, strongly suggesting a second-order chemical reaction process (Fig. 5). A pseudo-second-order fit indicates that the overall process is both dependent on the amount of dye and on the available sites in the peat. The process was also slightly influenced by temperature, *i.e.*, the greater the temperature the higher the  $R_s$  values (Tables 3–5). The values of the pseudo-second-order rate constant ( $k_s$ ) increased from  $0.23 \times 10^2$  to  $5.82 \times 10^2$  g mg<sup>-1</sup> h<sup>-1</sup> for the initial dye concentration range studied, the highest value being measured at 60 °C in the most diluted solution.

The plots for adsorption at time ( $q_t$ ) versus the square root of the adsorption time ( $time^{0.5}$ ) (intraparticle diffusion approach) for all initial dye concentrations and temperatures indicated a two-step process (Fig. 6). Two intraparticle diffusion constants ( $k_1$  and  $k_2$ ) and their respective correlation coefficients ( $R_1$  and  $R_2$ ) were then calculated (Tables 3–5). This information confirms the previously discussed assumption based on the isotherms, that the adsorption of MB on peat particles is multi-molecular layered,  $k_1$  and  $k_2$  expressing the diffusion rates of the distinct stages of adsorption, with the order of the adsorption rate of the first stage ( $k_1$ ) being much greater than that of the second stage ( $k_2$ ). The results suggest that the MB is adsorbed by the exterior surface of peat particle, in a rapid first step ( $k_1$ ). When the adsorption of the exterior surface reaches saturation, in the second step ( $k_2$ ), the molecular dye enters the peat particle through pores and is adsorbed by the interior surface. With a decrease in the dye concentration of the solution, the diffusion rate becomes progressively lower and the diffusion process reaches the final equilibrium stage. Similar results have been

Table 3  
Kinetic parameters<sup>a</sup> of the removal of MB from aqueous solution by the Arroio of Silva peat sample, at 35 °C

$C_0$ (mg L <sup>-1</sup> )	Pseudo-first-order equation: $\ln(q_e - q_t) = \ln q_e - k_f t$		Pseudo-second-order equation: $\frac{1}{q_s} = \frac{1}{k_s q_e^2} + \frac{t}{q_e}$		Intraparticle diffusion equation: $q_t = t^{1/2} k$			
	$10^2 k_f$ (h <sup>-1</sup> )	$R_f$	$10^2 k_s$ (g mg <sup>-1</sup> h <sup>-1</sup> )	$R_s$	$k_1$ (mg g <sup>-1</sup> h <sup>-1/2</sup> )	$R_1$	$k_2$ (mg g <sup>-1</sup> h <sup>-1/2</sup> )	$R_2$
200	21.44	0.93	4.03	0.99	24.78	0.97	1.08	0.98
400	14.47	0.92	2.77	0.99	38.20	0.93	3.13	0.97
600	15.45	0.91	2.21	0.97	39.48	0.93	7.92	0.81
700	13.99	0.94	1.46	0.95	37.83	0.95	7.63	0.93
800	15.66	0.91	nd <sup>b</sup>	nd <sup>b</sup>	49.06	0.95	5.66	0.76
900	11.70	0.83	1.36	nd <sup>b</sup>	35.08	0.94	6.91	0.72
1000	13.31	0.84	2.48	0.97	42.41	0.87	9.51	0.98
1200	7.04	nd <sup>b</sup>	nd <sup>b</sup>	0.97	37.58	0.51	11.13	0.99
1400	7.03	0.66	2.93	0.96	31.67	nd <sup>b</sup>	13.32	0.99
1500	6.34	0.67	5.08	0.98	38.69	nd <sup>b</sup>	10.39	0.91

<sup>a</sup>  $C_0$  = initial MB concentration;  $k_f$  = rate constant for pseudo-first-order model;  $R_f$  = correlation coefficient for pseudo-first-order model;  $k_s$  = rate constant for pseudo-second-order model;  $R_s$  = correlation coefficient for pseudo-second-order model;  $k_1$  = rate constant for intraparticle diffusion model in the first stage;  $R_1$  = correlation coefficient for intraparticle diffusion model in the first stage;  $k_2$  = rate constant for intraparticle diffusion model in the first stage;  $R_2$  = correlation coefficient for intraparticle diffusion model in the first stage.

<sup>b</sup> Not determined.

Table 4  
Kinetic parameters<sup>a</sup> of the removal of MB from aqueous solution by the Arroio of Silva peat sample, at 45 °C

$C_0$ (mg L <sup>-1</sup> )	Pseudo-first-order equation: $\ln(q_e - q_t) = \ln q_e - k_f t$		Pseudo-second-order equation: $\frac{1}{q_s} = \frac{1}{k_s q_e^2} + \frac{t}{q_e}$		Intraparticle diffusion equation: $q_t = t^{1/2} k$			
	$10^2 k_f$ (h <sup>-1</sup> )	$R_f$	$10^2 k_s$ (g mg <sup>-1</sup> h <sup>-1</sup> )	$R_s$	$k_1$ (mg g <sup>-1</sup> h <sup>-1/2</sup> )	$R_1$	$k_2$ (mg g <sup>-1</sup> h <sup>-1/2</sup> )	$R_2$
200	47.87	0.89	3.87	1.00	28.95	0.82	0.30	0.98
400	34.05	0.96	0.67	1.00	58.85	0.94	1.36	0.94
600	11.98	0.85	2.36	0.98	33.41	0.87	4.15	0.96
700	10.84	0.84	3.73	0.99	33.60	0.90	5.88	0.99
800	16.84	0.91	2.00	0.98	45.86	0.95	2.16	0.95
900	12.89	0.86	3.16	0.98	40.82	0.92	7.73	0.98
1000	13.49	0.86	3.16	0.99	41.03	0.91	4.49	0.95
1200	23.13	0.93	0.81	0.99	68.88	0.93	nd <sup>b</sup>	nd <sup>b</sup>
1400	25.75	0.91	0.47	1.00	80.12	0.87	0.30	nd <sup>b</sup>
1500	23.00	0.85	0.50	1.00	79.67	0.86	1.36	0.80

<sup>a</sup> Abbreviations have the same meaning as in Table 3.

<sup>b</sup> Not determined.

Table 5  
Kinetic parameters<sup>a</sup> of the removal of MB from aqueous solution by the Arroio of Silva peat sample, at 60 °C

$C_0$ (mg L <sup>-1</sup> )	Pseudo-first-order equation: $\ln(q_e - q_t) = \ln q_e - k_f t$		Pseudo-second-order equation: $\frac{1}{q_s} = \frac{1}{k_s q_e^2} + \frac{t}{q_e}$		Intraparticle diffusion equation: $q_t = t^{1/2} k$			
	$10^2 k_f$ (h <sup>-1</sup> )	$R_f$	$10^2 k_s$ (g mg <sup>-1</sup> h <sup>-1</sup> )	$R_s$	$k_1$ (mg g <sup>-1</sup> h <sup>-1/2</sup> )	$R_1$	$k_2$ (mg g <sup>-1</sup> h <sup>-1/2</sup> )	$R_2$
200	nd <sup>b</sup>	0.45	5.82	1.00	32.82	0.88	0.23	0.95
400	46.30	0.97	0.81	1.00	63.10	0.94	1.97	0.66
600	21.32	0.91	1.41	0.98	55.91	0.95	5.20	0.98
700	17.91	0.86	2.93	0.99	53.12	0.91	6.45	0.92
800	21.78	0.92	1.97	0.99	60.62	0.94	3.49	0.59
900	17.97	0.84	3.37	0.99	53.99	0.89	4.46	0.74
1000	10.43	0.75	3.42	0.98	41.56	0.85	7.95	0.70
1200	65.46	0.88	0.23	1.00	73.06	0.91	12.23	0.78
1400	nd <sup>b</sup>	0.82	0.26	1.00	81.93	0.87	6.49	0.66
1500	nd <sup>b</sup>	0.59	0.44	1.00	91.92	0.86	4.36	0.99

<sup>a</sup> Abbreviations have the same meaning as in Table 3.

<sup>b</sup> Not determined.

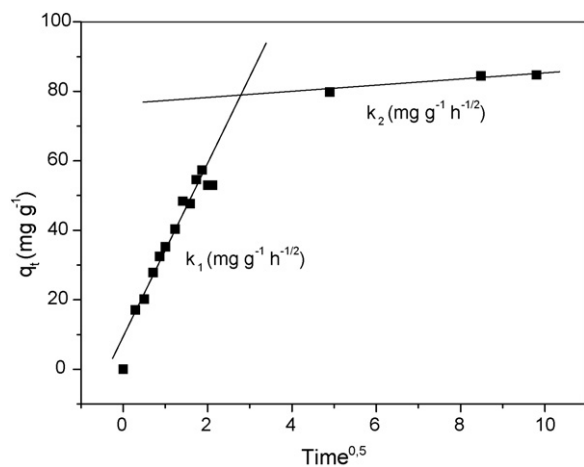


Fig. 6. Intraparticle diffusion kinetics of MB adsorption onto peat at 35°C. Initial dye concentration: 200 mg L<sup>-1</sup>.

found in other studies [6,37,44]. Briefly, the overall rate of the sorption process appears to be controlled by two mechanisms: pseudo-second-order and intraparticle diffusion.

#### 4. Conclusions

Peat was found to be highly effective in the removal of MB from aqueous solution with removals exceeding 90% in some case. The percentage of adsorption of MB from aqueous solution by peat was found to be higher at lower concentrations but, even so, the effective mass of MB adsorbed at equilibrium increased with an increase in the initial concentration and temperature. Overall results were not described by the isotherm equations of Langmuir and Freundlich and the process appears to be multi-molecular layered. The overall rate of the sorption process appears to result from a combination of two mechanisms (pseudo-second-order and intraparticle diffusion). The peat exhibited sufficient potential for its consideration as an effluent treatment material, in the context of the removal of dyes from aqueous solutions.

#### Acknowledgements

This work was supported by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq, Brazil).

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