



King Saud University
Journal of Saudi Chemical Society

www.ksu.edu.sa
www.sciencedirect.com

**ORIGINAL ARTICLE**

Kinetic and equilibrium adsorption of methylene blue and remazol dyes onto steam-activated carbons developed from date pits

Sheikha S. Ashour *

Chemistry Department, Applied Science College, Umm El Qura University, Makkah, P.O. Box 1847, Saudi Arabia

Received 8 June 2009; accepted 15 October 2009

Available online 16 December 2009

KEYWORDS

Adsorption;
Dyes;
Active carbon

Abstract Steam-activated carbons DS2 and DS5 were prepared by gasifying 600 °C-date pits carbonization products with steam at 950 °C to burn-off = 20 and 50%, respectively. The textural properties of these carbons were determined from the nitrogen adsorption at –196 °C. The chemistry of the carbon surface was determined from the surface pH and from neutralization of the surface carbon–oxygen groups of basic and acidic type. The kinetic and equilibrium adsorption of MB and RY on DS2 and DS5 was determined at 27 and 37 °C and at initial sorption solution pH 3–7.

DS2 and DS5 have expanded surface area, large total pore volume and contain both micro and mesoporosity. They have on their surface basic and acidic groups of different strength and functionality. This enhanced the sorption of the cationic dye (MB) and of the anionic dye (RY). The adsorption of MB and RY on DS2 and DS5 involves intraparticle diffusion and followed pseudo-second order kinetics. The adsorption isotherms were applicable to the Langmuir isotherm and high monolayer capacities for MB and RY dyes were evaluated indicating the high efficiencies of the carbons for dye adsorption.

© 2009 King Saud University. Open access under [CC BY-NC-ND license](http://creativecommons.org/licenses/by-nc-nd/3.0/).

1. Introduction

Effluents from the dyeing industry contain highly colored species, such wastes are not only aesthetically displeasing but also hinder light penetration and may in consequence disturb biological processes in water bodies (Malik, 2004). In addition, dyes are toxic to some organisms and hence harmful to aquatic animals. Furthermore, the expanded uses of azo dyes have shown that some of them are highly carcinogenic (Boeniger, 1980). Therefore, removal of dyes before disposal of wastewater is necessary.

Currently, several physical and chemical processes are used to treat dye laden wastewaters. However, these processes are

* Fax: +966 2 5573844.

E-mail address: sheikha_s_ashour@hotmail.com

1319-6103 © 2009 King Saud University.

Open access under [CC BY-NC-ND license](http://creativecommons.org/licenses/by-nc-nd/3.0/).

doi:10.1016/j.jscs.2009.12.008



Production and hosting by Elsevier

costly and cannot effectively be used to treat the wide range of wastewater. Among various treatment technologies, adsorption onto activated carbons has proven to be one of the most effective and reliable physicochemical treatment methodology (NcKay, 1996; Gharaibeh et al., 1998; Pala and Tokat, 2020). However, commercially available activated carbons are very expensive. Therefore, there is a need to produce low cost and effective carbons that can be applied to water pollution control. A wide range of low cost materials have been used as precursors for the production of activated carbons at low cost. These materials are of botanic origin (e.g. wood, coconut shells, nut kernels, olive stones, fruit stones. Cotton stalks, rice straw, corn cobs, date pits and others) and degraded or coalified materials.

Activated carbons are obtained by following one of two procedures: chemical activation or physical activation. In chemical activation, the precursor in a divided form is mixed with an activating agent such as zinc chloride, phosphoric acid or potassium salts and the mixture is then carbonized in absence of air or in inert atmosphere at a temperature not exceeding 800 °C (Hourieh et al., 1999). Physical activation is more frequently used and is performed by gasifying non-activated carbon with a stream of an oxidizing gas at 850–1000 °C, to a certain degree of burn-off (Youssef et al., 2005).

The main objects of this investigation are: (i) to study the feasibility of using two steam-activated carbons of burn-off's 20 and 50 wt% as adsorbents for removing methylene blue (MB) and remazol yellow (RY) dyes; (ii) to determine the characteristics of steam-activated carbons developed from date pits; (iii) to determine some parameters affecting sorption of MB and RY dyes, such as the texture of the sorbent, the chemistry of the sorbent surface, the pH of the sorption solution and the sorption temperature and (iv) to determine the applicability of some kinetic models to the sorption results.

2. Experimental

2.1. Materials

Dry clean date pits were crushed to a particle size 0.5–1.5 mm before carbonization in absence of air at 600 °C. The rate of heating was 10°/min and the sample was soaked at 600 °C for 2 h. The carbonization product D was used in the preparation of two steam-activated carbons DS2 and DS5. Steam activation was undertaken by gasifying portions from D with a mixture of nitrogen and steam at 950 °C in a tubular muffle furnace to burn-off 20% to give DS2 and to burn-off 50% to give DS5. Details of steam activation are given elsewhere (Alaya et al., 2000).

The dyes investigated were MB, (MB), Cl = 52, 015, chemical formula $C_{16}H_{18}ClN_3SH_2O$, MW = 337.85 g/mol, λ_{max} = 660 nm was supplied by Panreac and RY, chemical formula $C_{19}H_{19}N_4S_3O_{11}Na_2$, MW = 621 g/mol, λ_{max} = 420 nm was supplied by El-Nasr Co. for textiles and dyeing, Egypt. Aqueous solutions of MB and RY dyes (250 mg/l) were prepared and the initial pH was adjusted with biphtalate/NaOH to the following pH values 3.0, 5.0 and 7.0.

Analytical grade chemicals and doubly distilled water were used for solution preparation.

2.2. Techniques

The textural properties (surface area and porosity) were determined from the nitrogen adsorption isotherms measured at 77 K, using a conventional volumetric apparatus. Prior to nitrogen adsorption, the carbon was degassed at 200 °C under a reduced pressure of 10^{-5} Torr, for 6 h. The total surface basicity of carbons was determined by neutralization with 0.1 M HCl. The surface acidity was determined by neutralization of the surface carbon–oxygen groups of acidic nature following Boehm titration procedure (Boehm, 1990).

Kinetic experiments were carried out in a pyrex glass vessel with 100 mm in inner diameter, 130 mm in height and fitted with four glass baffles (10 mm in width). The aqueous solution (0.5 L) with 0.4 g carbon was agitated at 200 rpm using a thermostated horizontal shaker. Kinetics of adsorption was determined at 27 and 37 °C by analyzing adsorptive uptake of the dye color at different time intervals. Independent bottles containing 100 ml of the dye solution and 50 mg carbon were used during the kinetic study to get accurate results for each point on the graph. The residual dye color was analyzed by centrifuging the reaction mixture and then measuring the absorbance of the sample. Shimadzu UV–Vis spectrophotometer (160 A) was employed for absorbance measurements using silica cells of path length 1 cm. The amount of the dye adsorbed onto the carbon after equilibration for a time t , q_t (mg/g) was calculated by following mass balance relationship:

$$q_t = (C_o - C_t)V/W \quad (1)$$

where C_o and C_t are the dye concentration (mg/l) at initial and at time t , respectively, and V/W is the dose of dried carbon (l/g).

Equilibrium experiments at 27 and 37 °C were carried out by using seven capped conical flasks of 100 ml capacity. To each flask 50 ml of dye solution of known initial concentration in the range 10–250 mg/l. The contact was made using a water bath shaker (200 rpm) at a constant solution temperature 48 h. The dye solutions were separated using a centrifuge and the equilibrium concentration C_e (mg/l) was calculated for each dye solution carbon system using the relationship:

$$q_e = (C_o - C_e)V/W \quad (2)$$

where C_o and C_e (mg/l) are the initial and equilibrium concentrations, respectively, q_e is the equilibrium adsorption capacity under the applied adsorption conditions, V and W have been previously defined.

3. Results and discussion

3.1. Characterization of sorbents

The adsorption of nitrogen at -196 °C by DS2 and DS5 proved to be relatively rapid with the equilibrium attained within 30 min. This indicates that almost all the pores are accessible to nitrogen molecules at -196 °C. With DS2, the desorption points were found to lie on the same isotherm as the adsorption data indicating the absence of hysteresis characterizing multilayer adsorption and the existence of a large fraction of microporosity (Lippens and deBoer, 1965). With DS5, on the other hand, a narrow closed hysteresis loop was observed (Fig. 1) which could be ascribed to the existence of a large fraction of mesoporosity.

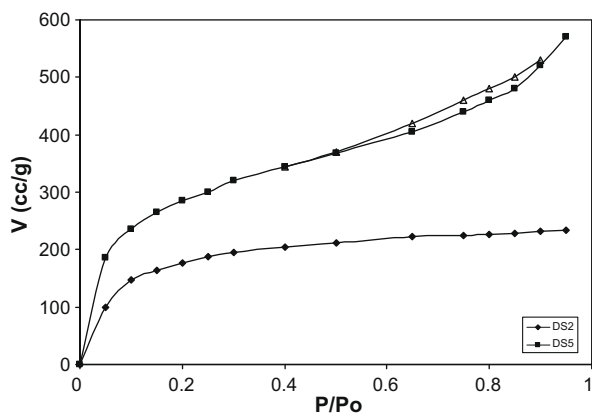


Figure 1 Nitrogen adsorption isotherms of DS2 and DS5 at $-196\text{ }^{\circ}\text{C}$.

The conventional BET equation (Brunauer et al., 1938) was applied to determine the specific surface area S_{BET} (m^2/g). The total pore volume V_T (ml/g), expressed as the volume of liquid nitrogen adsorbed per one gram carbon at relative pressure of ca. 0.95 was read from the nitrogen isotherm. Based on the assumption that the space in the pores is similar to the space between two parallel plates, the mean pore radius r_m (nm) could be calculated from the relationship:

$$r_m = 2V_T \times 10^3 / S_{\text{BET}} \quad (3)$$

Table 1 lists S_{BET} , V_T and r_m values for DS2 and DS5. Another independent method, i.e. t -method (Mikhail, 1979) was also applied to analyze the nitrogen adsorption isotherms. In this method the amount of gas adsorbed (ml/g) is plotted versus multiplier thickness t (nm) as measured on a non-porous solid of comparable BET-C constant (not illustrated). The t -method allows determination of the specific surface area S_t , the micropore volume V_m and the non-micropore volume V_n . S_t , V_m and V_n are, respectively, given in columns 5–7 of Table 1.

Inspection of Table 1 reveals that: (i) S_t values are comparable with S_{BET} values indicating that the BET- and t -methods are complementary. (ii) For DS2, more than 36.8% of the surface is located in micropores and the mean pore radius of this sorbent 1.03 nm, lies at the boundary between micropores of $r_m < 1.0$ nm and the mesopores of $r_m > 1.0$ nm. DS5 contains about 59% of the surface located in the mesopores and the r_m of this sorbent, 1.7 nm indicating the domination of this type of porosity.

The adsorption capacity of an activated carbon is determined by its textural properties and also by the chemistry of its surface. In adsorption from solution, the chemistry of the sorbent surface is equally important to its textural properties particularly when the sorption process involves ion exchange or electrostatic interaction between the solute molecules and some active sites on the sorbent surface. The surface chemistry of activated carbon is attributed to the existence on the surface of some carbon–oxygen groups of different functionalities. The surface carbon–oxygen groups are either of acidic type or of the basic type. Chemically-activated carbons are produced by carbonization and activation at temperatures not exceeding $800\text{ }^{\circ}\text{C}$ and are characterized by domination of surface acidic groups. Physically-activated carbons, on the other hand, are obtained by gasification with oxidizing gas such as steam or carbon dioxide at $900\text{--}1000\text{ }^{\circ}\text{C}$ and their surfaces are basic. The surface pH of an activated carbon provides a convenient indicator of the type of its surface functionality. However, more information could be obtained by neutralization of the surface carbon–oxygen groups of basic type with 0.1 M HCl and by neutralization of the surface acidic groups with bases of different strength (Boehm, 1990). 0.1 M of each of NaHCO_3 , Na_2CO_3 , NaOH and NaOC_2H_5 . NaHCO_3 neutralizes carboxylic groups whereas those neutralized by Na_2CO_3 but not by NaHCO_3 were believed to be lactones. The weakly acidic groups neutralized by NaOH but not by Na_2CO_3 were postulated as phenols. Reaction with NaOC_2H_5 was not considered as a true neutralization reaction since it did not involve exchange by H^+ or Na^+ ions. The groups reacting with NaOC_2H_5 but not with NaOH were considered to be carbonyls (Bansal et al., 1988). Table 2 lists the surface pH, total surface basicity and surface acidities of DS2 and DS5. This table indicates that the surfaces of the carbons investigated are mainly basic since their surface pH are considerably higher than 7.0 with this surface pH depending on the extent of gasification with steam at $950\text{ }^{\circ}\text{C}$. Although, the surface of the two carbons investigated contain surface acidic groups but the total surface acidity of each carbon was considerably lower than the total surface basicity.

3.2. Adsorption from solution

3.2.1. Adsorption kinetics

Representative concentration–time profiles for the sorption of MB and RY dyes on DS2 and DS5 carbons are shown in Figs. 2 and 3, respectively. Evidently, steam-activated carbons developed from date pits show high efficiencies to adsorb both dyes

Table 1 Textural properties of DS2 and DS5 carbons.

Carbon	S_{BET} (m^2/g)	V_T (ml/g)	r_m (nm)	S_t (m^2/g)	V_m (ml/g)	V_n (ml/g)
DS2	705	0.361	1.03	713	0.228	0.133
DS5	1040	0.884	1.70	1062	0.365	0.519

Table 2 Surface pH, total surface basicity and surface acidities (meq/g) of DS2 and DS5 carbons.

Carbon	Surface pH	Total basicity	Carboxyl	Lactonic	Phenolic	Carbonyl	Total acidity
DS2	8.3	0.89	0.09	0.08	0.11	0.13	0.41
DS5	9.5	1.68	0.03	0.04	0.05	0.10	0.22

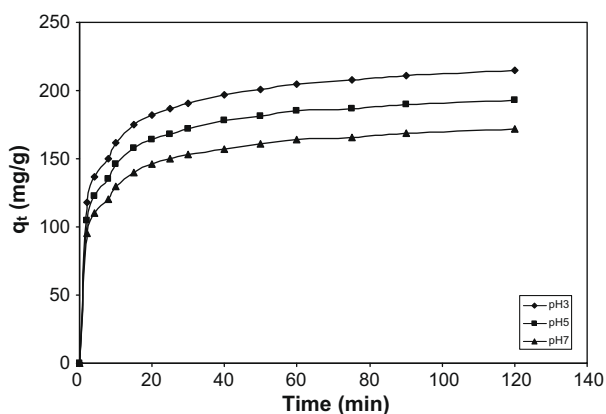


Figure 2 Representative kinetic adsorption curves of MB adsorption at 27 °C on DS5, initial sorption solution pH 3–7.

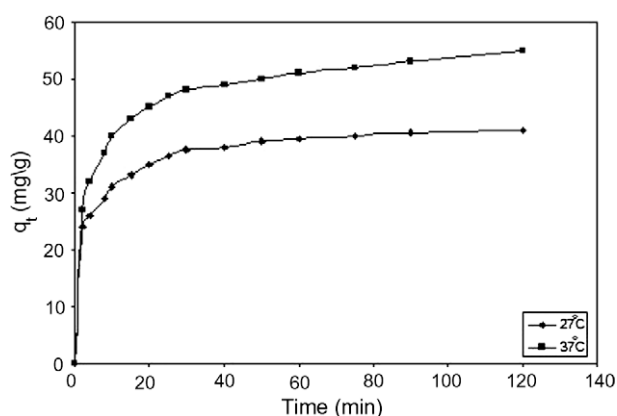


Figure 3 Representative kinetic adsorption curves of RY adsorption at 27 and 37 °C on DS2, initial sorption solution pH 3.

from their aqueous solutions. The adsorption process attained equilibrium gradually because activated carbon is composed of porous structure of large internal surface area and wide pore volume distribution (Juang et al., 2001). Three consecutive mass transport steps are associated with the adsorption of a solute from solution by a porous sorbent (Faust and Aly, 1983). First, the solute migrates through the solution to the external surface of the sorbent particles by molecular diffusion (film diffusion), followed by solute movement from particle surface to interior sites (pore diffusion) and finally the solute is adsorbed onto these sites. Figs. 2 and 3 depict that the time profile of dye uptake is a single, smooth and continuous curve leading to saturation, suggesting also the possible monolayer coverage of dyes on the sorbent surface. Figs. 2 and 3 show also that the contact time required to attain equilibrium is almost 120 min for both the dyes and carbons investigated.

The representative dye sorption–time profiles were selected to show the effect of changing the solution pH from 3.0 to 7.0, keeping the sorption temperature constant at 27 °C and to show also the effect of increasing the sorption temperature from 27 to 37 °C, keeping the dye solution pH constant at 3.0.

Concerning the effect of sorption solution pH, the increase of pH from 3.0 to 5.0 and further to 7.0 was associated with a considerable decrease of the dye uptake. This was true for MB

and RY dyes. This may be ascribed to the influence of the initial pH of the sorption solution on the surface properties of the sorbent and ionization–dissociation properties of the adsorbate molecule. The maximum uptake of MB and RY dyes by DS2 and DS5 at pH 3.0 could be attributed to the basic character of steam-activated carbons thermally treated at 950 °C (Galiastatou et al., 2002). Steam-activated carbons are hydrophobic in nature and take on a positive charge by adsorbing H^+ ion when immersed in water. Low pH leads to an increase in hydrogen ion concentration $[H^+]$ and the surface of the active carbon acquires positive charge by adsorbing H^+ ions. As the carbon surface is positively charged at low pH, a significant strong electrostatic attraction appears between the positively charged carbon surface and anionic dye molecules leading to maximum adsorption of this dye. Similar trend of pH effect was observed for the sorption of congo red and acid violet by activated carbons from coir pith (Namasivayam and Kavitha, 2002; Namasivayam et al., 2001). The activated carbons DS2 and DS5 were found to be efficient in the removal of both anionic (RY) and cationic dye (MB). This can be ascribed to the existence on the carbon surface, of groups of different functionalities. Thus DS2 and DS5 present simultaneously acidic and basic sites able to act as anchoring sites for basic and acidic dyes, respectively, as a result of electrostatic attraction (Castilha, 2004).

The effect of the temperature on the sorption capacity was found to be very small. Thus, for the adsorption of MB on SD2 and SD5 and also for RY sorption on DS5 the increase of the sorption temperature from 27 to 37 °C was found to be associated with a small decrease in the sorption capacity. The only exceptional case was observed with the adsorption of RY on DS2 where considerable increase was determined upon raising the sorption temperature from 27 to 37 °C. This can be explained as follows: RY molecule is more bulky compared with MB molecule. The latter is accessible to a large fraction of the pores of DS2 whereas the more bulky RY molecule seems to be inaccessible to a large fraction of the DS2 pores. The rise of the sorption temperature from 27 to 37 °C may enhance the sorption of RY via increasing its intraparticle diffusion.

3.2.2. Intraparticle diffusion

The possibility of intraparticle diffusion was examined using the intraparticle diffusion model (Youssef, 2004), taking into account that during the course of adsorption the adsorbed amount is proportional to the square root of the contact time.

$$q_t = K_d t^{0.5} \quad (4)$$

where K_d is the intraparticle diffusion constant. Eq. (4) was applied to the adsorption data with contact time changing from 20 to 120 min, corresponding to the linear portion of the curves. The rate constant was calculated from the slope of the linear portion. Representative q_t versus $t^{0.5}$ are shown in Fig. 4. The K_d values as calculated for MB and RY are listed in Table 3 their correlation coefficient values R^2 . The high values of R^2 indicate the significant contribution of the intraparticle diffusion process. The K_d values of MB uptake are higher than those of RY which may be ascribed to the bulkiness of the latter. Also the K_d of RY uptake by DS2 at 27 °C was considerably lower than that of the uptake of this dye at 37 °C by DS2 indicating that sorption of the bulky RY molecule in this microporous sorbent is a diffusion controlled process.

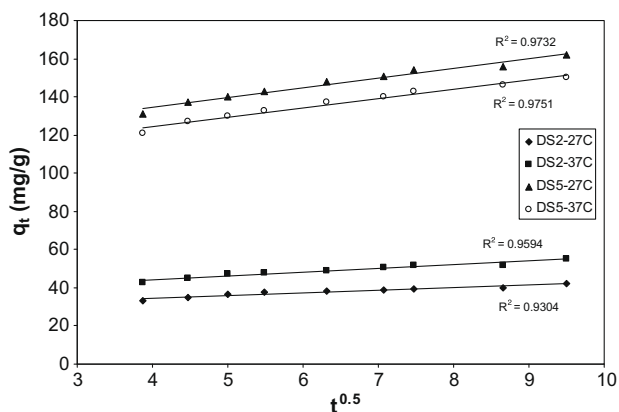


Figure 4 Representative q_t versus $t^{0.5}$ plots for RY sorption on DS2 and DS5 at 27 and 37 °C, initial pH 3.

3.2.3. Sorption kinetic model

The kinetic adsorption data were processed to understand the dynamics of the adsorption process in terms of the order of the rate constant. Kinetic data were treated with the pseudo-first order kinetic model (Carg et al., 2004). The differential equation is:

$$dq_t = k_1(q_e - q_t) \quad (5)$$

where q_e and q_t refer to the amount of dye adsorbed (mg/g) at equilibrium and at time t (min), respectively, and k_1 (min^{-1}) is the equilibrium rate constant of the pseudo-first order reaction. Integrating Eq. (5) for the boundary conditions $t = 0$ to $t = t$ and $q_t = 0$ to q_t , gives Eq. (6) which is the integrated rate law of pseudo-first order reaction.

$$\log(q_e/q_e - q_t) = k_1 t / 2.303 \quad (6)$$

Eq. (6) can be arranged to obtain a linear form:

$$\log(q_e - q_t) = \log q_e - k_1 t / 2.303 \quad (7)$$

Values of the rate constant k_1 and the equilibrium adsorption capacity q_e could be respectively obtained from the slope and the intercept of the straight line representing the adsorption data. Fig. 5 shows representative plots of $\log(q_e - q_t)$ versus t . Although the correlation coefficients were found to be higher than 0.96, the calculated equilibrium adsorption capacities (q_e values) were by far lower than the experimental values. Moreover, the straight line relationship was valid only within a limited range of contact time, i.e. the sorption of MB and RY by the carbons investigated is not an ideal first order reaction.

Kinetic data were further treated with the pseudo-second order kinetic model (Ho and McKay, 2000). The differential equation is

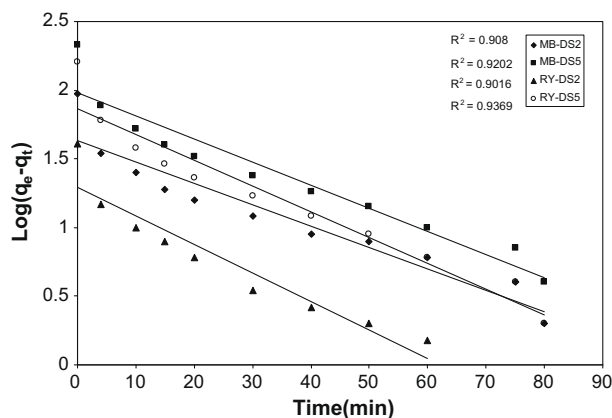


Figure 5 Application of pseudo-first order model on the kinetic adsorption data of MB and RY on DS2 at 27 °C, initial sorption solution pH 3 (representative plots).

$$Dq_t/dt = k_2(q_e - q_t)^2 \quad (8)$$

where k_2 is the equilibrium rate constant of the pseudo-second order adsorption (g/mg min). Integration of Eq. (8) for the boundary conditions $t = 0$ to $t = t$ and $q = 0$ to q_e gives

$$t/(q_e - q_t) = 1/k_2 q_e^2 + t/q_e \quad (9)$$

If the pseudo-second order model is applicable to the adsorption data, the plot of t/q_t versus t should be linear with the intercept equals $1/q_e$ and the slope $1/k_2 q_e^2$. Fig. 6 depicts representative plots of t/q_t versus t for the adsorption of MB and RY onto DS2 and DS5 at 27 and 37 °C when the initial pH of the sorption solution was 3.0. Table 4 lists k_2 , q_e and R^2 for each dye-carbon system at 27 and 37 °C pH of the sorption solution 3.0 are given on the corresponding linear plots of Fig. 6. The values of R^2 range between 0.9981 and 0.9988 indicating thus that the adsorption of methylene blue and remazol fits very well pseudo-second order kinetics.

3.2.4. Adsorption isotherms

The adsorption isotherms of MB and RY at 27 and 37 °C onto DS2 and DS5 and at initial sorption solution = 3.0 are shown in Fig. 7. The isotherms are of the L type according to Giles classification (Giles and MacEwan, 1959). These isotherms express the adsorption amount as a function of equilibrium concentration. Two isotherm equations are widely used to describe experimental adsorption data. These are Freundlich equation and Langmuir equation. The former is an empirical equation and the latter which is more widely used, is based on the assumption that maximum adsorption corresponds to the sat-

Table 3 Intraparticle diffusion constant k_d of MB and RY sorption at 27 and 37 °C onto DS2 and DS5 carbons. Sorption solution pH 3, 5 and 7.

Carbon	Sorption solution pH	k_d for MB at 27 °C	k_d for MB at 37 °C	k_d for RY at 27 °C	k_d for RY at 37 °C
DS2	3	2.40	2.32	0.81	1.36
	5	1.89	1.89	0.93	1.20
	7	2.05	1.91	0.79	1.02
DS5	3	5.15	4.37	4.01	3.81
	5	4.72	4.40	3.46	3.14
	7	4.01	3.44	3.10	2.77

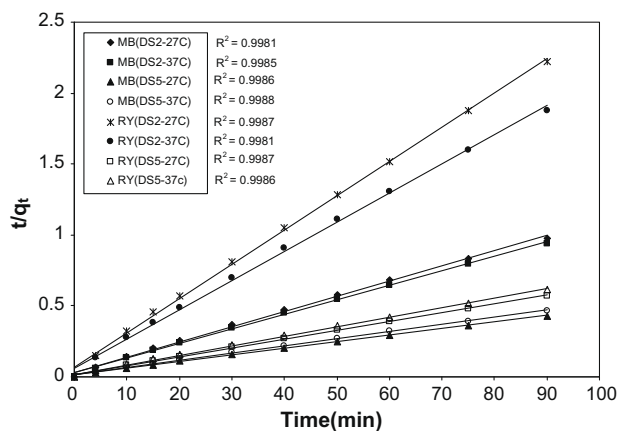


Figure 6 Application of pseudo-second order kinetic model on sorption of MB and RY data at 27 and 37 °C on DS2 and DS5, initial sorption solution pH 3 (representative plots).

uration monolayer of adsorbate molecules on the adsorbent surface. The Langmuir equation (Langmuir, 1916) can be expressed as:

$$q_e = q_m K_L C_e / (1 + K_L C_e) \quad (10)$$

where K_L (l/mg) is the Langmuir constant related to the energy of adsorption and q_m is the maximum amount adsorbed corresponding to the complete monolayer coverage (mg/g). The constant K_L and q_m can be determined from the following linearised form:

$$1/q_e = 1/q_m + 1/(K_L q_m C_e) \quad (11)$$

The linear plots of $1/q_e$ versus $1/C_e$ are shown in Fig. 8 which depicts satisfactory straight lines with very high values of R^2 (0.9897–0.9944). The values of q_m and K_L for each dye-carbon system are listed in Table 5. Evidently, good agreement could be found between the calculated q_m values and those determined experimentally. Conformation of the experimental data into Langmuir isotherm model indicates the homogeneous nature of date pits carbon surface. The results also demonstrated the monolayer coverage (Mohan et al., 2002). The equilibrium adsorption capacities evaluated from Langmuir equation and the pseudo-second order rate model show that the evaluated values are reasonable, i.e., steam-activated carbons developed from date pits are promising sorbents for the removal of dyes from wastewater. This can be ascribed to the presence of different groups containing oxygen on the surface of the activated carbons.

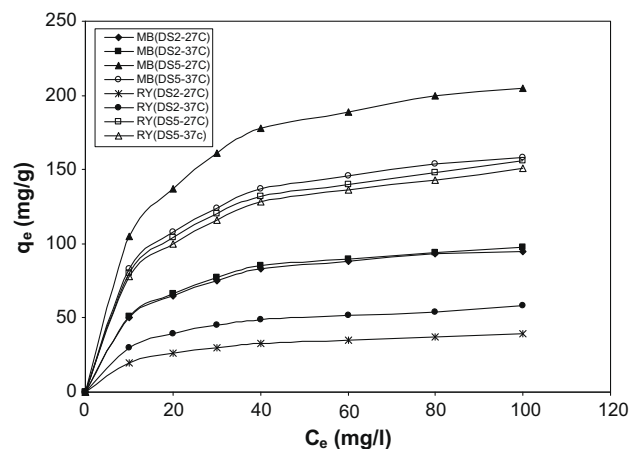


Figure 7 Adsorption isotherms of MB and RY at 27 and 37 °C on DS2 and DS5, initial pH 3.

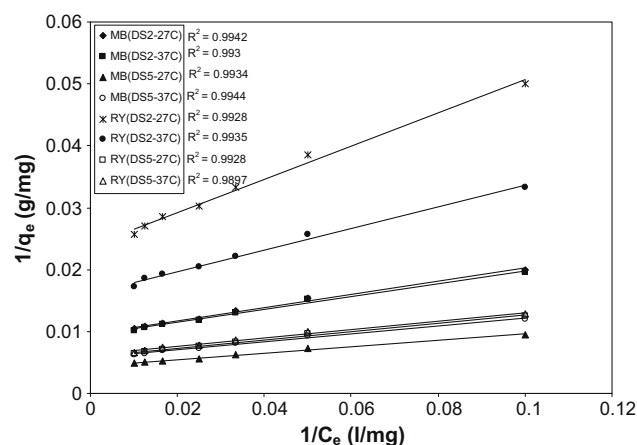


Figure 8 Linear langmuir plots for MB and RY sorption at 27 and 37 °C on DS2 and DS5, initial pH 3.

As a consequence, these carbons present simultaneously acidic and basic sites able to act as anchoring sites for basic and acidic dyes, respectively, as a result of electrostatic interactions. Another possible adsorption mechanism that may occur in the case of solutes containing conjugated systems such as methylene blue and remazol may be considered. π - π dispersive interactions can take place between the aromatic rings, $-N=C-C=C-$ system for methylene blue and also aromatic

Table 4 q_e (mg/g) and $k_2 \times 10^3$ (g/mg min) of MB and RY sorption onto DS2 and DS5.

Carbon	Sorption solution pH	MB/27 °C		MB/37 °C		RY/27 °C		RY/37 °C	
		q_e	k_2	q_e	k_2	q_e	k_2	q_e	k_2
DS2	3	84.6	2.4	97.6	2.6	42.1	4.7	55.0	2.7
	5	68.1	3.1	88.8	2.7	37.4	4.8	50.4	2.9
	7	64.0	3.0	76.9	2.4	33.6	4.1	44.0	3.3
DS5	3	220.0	1.6	200.0	0.8	164.0	1.4	152.2	1.7
	5	194.6	0.9	168.5	0.9	147.6	1.3	136.3	1.9
	7	174.1	0.8	148.6	0.9	129.9	1.3	123.1	1.9

Table 5 q_m (mg/g) and K_L (l/mg) $\times 10^4$ as determined by the application of Langmuir isotherm to the adsorption data of MB and RY onto DS2 and DS5 at 27 and 37 °C. Initial sorption solution pH 3.

Carbon	MB/27 °C		MB/37 °C		RY/27 °C		RY/ 37 °C	
	q_m	K_L	q_m	K_L	q_m	K_L	q_m	K_L
DS2	103	9.1	106	8.0	43	180.0	66	5.8
DS5	244	36.0	184	37.0	173	150.0	170	5.3

rings, $-N=N-$ and $-N=C-C=C-$ for remazol. A similar situation has been previously reported (Pereira et al., 2003).

4. Conclusions

1. Steam-activated carbons developed from date pits are characterized by expanded surface area, large total pore volume and contain both micro and mesopores. The type of pores dominating depend on the percentage of burn-off.
2. The surface of steam-activated carbons contain carbon-oxygen groups of basic type and of acidic type. However, the surface pH of these carbons is higher than 7, the surface basic groups dominate. These carbons adsorb considerable amounts of cationic and anionic dyes.
3. The adsorption of MB and RY dyes involves intraparticle diffusion and follows pseudo-second order kinetic model. Electrostatic attraction between the charged surface and charged dye molecule may be considered as the principal adsorption mechanism.
4. The adsorption of MB and RY dyes decreased with increasing initial pH of the sorption solution from 3.0 to 5.0 and further to 7.0. The effect of temperature on the sorption capacity is very limited when the pore structure is accessible to dye molecules but the sorption of bulky dye molecules considerably increased with the increase of temperature in case of carbons containing large fraction of micropores.
5. The adsorption isotherms of MB and RY onto steam-activated carbons are described by the Langmuir isotherm. High adsorption capacity towards MB and RY was exhibited particularly by high burn-off carbons.

References

- Alaya, M.N., Hourieh, M.A., Youssef, A.M., El-Sejarirh, F., 2000. *Adsorpt. Sci. Technol.* 18, 27.
- Bansal, B.C., Donnet, J., Stoeckli, F., 1988. *Active Carbon*. Marcel-Dekker, p. 179.
- Boehm, H.P., 1990. *High Temp. High Press.* 22, 275.
- Boeniger, M.F., 1980. Carcinogenity of azodyes derived from benzidine (NIOSH), Pub. No. 8-119 Cincinnati OH, USA.
- Brunauer, S., Emmett, P.H., Teller, E., 1938. *J. Am. Chem. Soc.* 60, 309.
- Carg, V.G., Amita, M., Kumar, R., Gupta, R., 2004. *Dyes Pigments* 63, 243.
- Castilha, C.M., 2004. *Carbon* 42, 83.
- Faust, D.C., Aly, M.O., 1983. *Chemistry of Wastewater Treatment*. Butterworth, London.
- Galiastatou, P., Metayas, M., Kasselouri-Rigopolou, V., 2002. *J. Hazard. Mater.* 91, 187.
- Gharaibeh, S.H., Moore, S.V., Buck, A., 1998. *J. Chem. Technol. Biotechnol.* 71, 291.
- Giles, C.H., MacEwan, T.H., 1959. In: *Proceedings of the Second Congress on Surface Activity*, London, p. 457.
- Ho, Y.S., McKay, G., 2000. *Water Res.* 34, 1999.
- Hourieh, M.A., Alaya, M.N., Youssef, A.M., El-Sejarirh, F., 1999. *Adsorpt. Sci. Technol.* 17, 675.
- Juang, R.S., Tseg, R.I., Wu, F.C., 2001. *Adsorption* 7, 65.
- Langmuir, I., 1916. *J. Am. Chem. Soc.* 38, 2221.
- Lippens, B.C., deBoer, J.A., 1965. *J. Catal.* 70, 467.
- Malik, P.K., 2004. *J. Hazard. Mater.* 93, 124.
- Mikhail, R.Sh., El-Nabarawy, Th., Youssef, A.M., 1979. *J. Colloid Interf. Sci.* 70, 467.
- Mohan, S.V., Rao, W.C., Karthickryan, J., 2002. *J. Hazard. Mater.* 90, 189.
- Namasivayam, C., Kavitha, D., 2002. *Dyes Pigments* 54, 47.
- Namasivayam, C., Radhika, R., Suba, S., 2001. *Waste Manage.* 21, 381.
- McKay, G., 1996. *Use of Adsorbents for Removal of Pollutants from Waste-waters*. CRC Press, Boca Raton.
- Pala, A., Tokat, E., 2000. *Water Res.* 36, 2920.
- Pereira, M.F.R., Soares, S.F., Orfao, J.I.M., Figueiredo, J.L., 2003. *Carbon* 41, 811.
- Youssef, A.M., El-Nabarawy, Th., Samra, S.E., 2004. *Colloid Surf.* 235, 153.
- Youssef, A.M., Radwan, N.R.E., Abdel-Gawad, I., Singer, G.A.A., 2005. *Colloid. Surf. A* 252, 143.