



# Article Adsorption Kinetics and Isotherm Study of Basic Red 5 on Synthesized Silica Monolith Particles

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Abstract: The Silica monolith particles (SMP) were prepared from Tetra-Methyl-Ortho-Silicate (TMOS) and characterized by Fourier transforms infrared (FTIR), Scanning electron microscopy (SEM), energy dispersive X-ray spectroscopy (EDX), and surface area analyzer. FTIR analysis showed the Si-O stretching confirming SMP formation. SEM analysis provided information about the mean diameter of SMP ( $1-5 \mu m$ ). EDX confirmed the presence of silicon and oxygen in the SMP. Moreover, the calculated surface area for SMP was found to be around  $367 \text{ m}^2/\text{g}$ , whereas BJH pore size distributed particles were 87.15 along with the total pore volume and pore radius of 0.073 cm<sup>3</sup>/g and 16.627 Å, respectively. Besides, the removal efficiency was found to be about 96%. Various kinetic equations were used to calculate the adsorption parameters. Overall, the results show that the most appropriate model for the kinetics data was the pseudo-second order kinetics model while the mechanism of adsorption was best explained by the Langmuir isotherm. The highest removal of Basic Red 5 dye after 120 min at 298 K was 576 mg/g. Moreover, the thermodynamics parameters (Enthalpy, Gibb's energy, and Entropy) were also estimated. The  $\Delta H^{\circ}$  (0.995 kJ/mol) value depicted the endothermic nature of the process. The non-spontaneous aspect of the process was evident from the  $\Delta G^{\circ}$  values which were 60.431, 328.93, and 339.5 kJ/mol at 293, 303, and 313 K, respectively. From the high removal efficiency value, it can be concluded that the prepared adsorbent can be a potential adsorbent in the reclamation of dyes from wastewater.

Keywords: silica monolith particles; surface area analyzer; thermodynamics parameter; adsorption

# 1. Introduction

The fast growing field of nanotechnology is striving to produce nano-sized materials with the desired properties to be used in various fields. Such attempts have been frequently made from the last decades by scientists due to their wide applications in catalysis,



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**Copyright:** © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). adsorption, bio-analytical, biotechnological, and biomedical processes [1]. Silica (SO<sub>2</sub>) nanomaterials have been used in the construction of photo-voltaic cells [2], drug delivery and gene transfection carriers of ions [3], transport of DNA and other chemicals through plant cells [4], and in the synthesis of the anticancer drugs [5]. Silica has also been used for the adsorption of heavy metals as well as dyes from wastewater [6]. Silica is a mineral that is found naturally in the earth crust mostly in the form of quartz.

There are different forms of silica as their apparent form appears to depend on parameters such as temperature, pressure, and degree of hydration. For instance, the anhydrous form might be quartz, tridymite, or cristobalite. It has been found that the transition temperature of quartz and tridymite is around at 870 °C, while tridymite and cristobalite exist at equilibrium state at the temperature of 1470 °C. It has also been reported that at 1700 °C, cristobalite is changed into the glassy amorphous silica [7,8]. The reported forms of the silica have vast applications in the separation sciences, pharmaceutical industry, catalysis, and in wastewater treatment [9].

Various treatments, broadly classified as chemical, physical, and biological, have been applied to adsorb dyes from contaminated waters. Due to the non-biodegradable and recalcitrant nature of dyes, biological and chemical techniques have not been proved effective in dye removal from water. The typical complex hazardous nature of marketable dyes has not been fully elucidated yet. The basic dyes; azo dyes (Basic Red 5; BR-5), are considered to be the most complex class of dyes resistant to biodegradation. As a result, low-cost approaches such as adsorption are required to remove these dyes from the textile effluents [10].

Modern technologies such as membranes separation are quite effective in the removal of pollutants from water, but are associated with high cost of operations in terms of electricity and frequent cleaning, making them non practical to be used worldwide. On the other hand, adsorption is considered a chief and economic process that is frequently used for the removal of dyes and pigments from wastewater [10] raw materials of the plants' waste products or rocks materials that are easily available everywhere. A number of adsorbents have been used for the removal of dyes from water. Among them, silica monolith particles have been applied for the removal of both classes of acidic and basic dyes successfully [11]. According to the literature, cationic dyes easily adsorbed to them because of the positive interactions between cationic dyes and the surfaces of the silica. On the other hand, the anionic dyes adsorbed to the silica due to the formation of hydrogen bonding. Dyes removed from water through silica so far are: acid orange-10, acid orange-12 [12], basic blue-3 [13], basic blue-69 [14], and basic blue-2.

In the present study, silica monolith particles (SMPs) were synthesized using Tetra Methyl Ortho Silicate (TMOS) as a raw material, and characterized through various instrumental techniques such as surface area analyzer, SEM, FTIR, etc. The synthesized SMPs were evaluated for the adsorption of cationic dye BR5 in aqueous solution. Different isotherm and kinetics models were applied to estimate the values of different adsorption parameters.

#### 2. Material and Methods

# 2.1. Chemicals and Instrumentation

Different chemicals used in the experiment were used as supplied without further purification/processing. Urea (NH2)2CO was obtained from the British Drug Houses, London, England. Poly ethylene glycerol (PEG), acetic acid (CH3COOH), tetramethyl-orthosilicate (TMOS), and BR5 dye were obtained from Sigma Aldrich, Munich, Germany. The structure of the selected dye is presented in Figure 1, while its physicochemical properties are summarized in Table 1.



Figure 1. Chemical structure of Basic Red 5.

Table 1. Physico-chemical properties of Basic Red 5.

Name of Dye	Basic Red 5
(M.F) Molecular Formula	C <sub>15</sub> H <sub>17</sub> ClN <sub>4</sub>
(M.W) Molecular Weight	288.78 g/mol
UV- visible $\lambda_{max}$	540 nm
Dye content	>90%
Water solubility	Soluble in water

The Scanning Electron Microscope (SEM) (JSM5910, JEOL, Kyoto, Japan) was used for the investigation of the sample's surface morphology. Energy dispersive X-ray spectroscopy EDX technique was used for the elemental analysis (EDX/INCA 200 Oxford Instruments; London, England). Fourier-transform infrared spectroscopy (FTIR) analysis was carried out using the Shimadzu 8201-PC FTIR (Shimadzu Scientific Instruments Inc., Tokyo, Japan) equipped with a FT/COM-1 computer control unit. The dye concentration was determined using a double beam UV–vis spectrophotometer (UV-1800, Shimadzu Scientific Instruments Inc., Tokyo, Japan) measuring a Basic Red 5dye at a wavelength of 490 nm. Adsorption experiments were conducted in a shaker (thermostat water-bath shaker). The pH of the solutions was determined by a pH meter.

## 2.2. Synthesis of Silica Monolith Particles

The silica monolith particles were synthesized by a modified method already reported in the literature [15]. The silica monolith particles were obtained by mixing specified amount of 1 g PEG, and 1.25 g urea in 0.01 N acetic acid. In the next step, the whole mixture was vigorously stirred for 15 min. The mixture temperature was kept at 0 °C and 3 mL of TMOS was added to it when the desired temperature was achieved. The reaction mixture was incubated at 40 °C in an oven for 50 h, followed by another incubation period of 50 h at 120 °C. The prepared particles were grinded into fine powder. In the last step, silica particles were calcinated at 550 °C for 50 h. Silica monolith particles prepared, were then used as adsorbent for the removal of BR5 dye from water.

#### 2.3. Adsorption Studies

## 2.3.1. Kinetic Studies

To obtain the equilibration time for the adsorption of dye on silica monolith particles,  $2 \times 10^{-3}$  Molar solution of BR-5 was prepared by dissolving 0.598 g in 1 dm<sup>3</sup> distilled water. Later, 20 mL of the dye solution was shaken with 0.2 g of SMPs sample. At room temperature of 298 K, the mixture was well-shaken in the thermos-stated water-bath shaker for different time intervals of 5, 10, 15, 20, 25, 30, 60, 120, 240, 360, and 480 min. After shaking, the adsorption mixture was filtered and the remaining concentration of BR-5 was

$$Cd\Phi = \frac{C_{do} - C_{d\sigma}}{W}V \tag{1}$$

The  $C_{do}$  and  $C_{d\sigma}$  represent the initial and final concentrations of the adsorbate (mol/L). *V* stands for the volume of the dye solution, whereas, *W* is the weight of the SMPs.

From the obtained data equilibrium time and other kinetics parameters were estimated.

# 2.3.2. Isothermal Studies

Isothermal studied were carried with various concentrations of 0.0008, 0.001, 0.0012, 0.0014, and 0.0016 mg/L and the amount of adsorbent used was 0.2 g. After 45 min of stirring, the remaining concentration in slurry was determined through spectrophotometer. Different isotherm models were applied to enumerate the values of different adsorption parameters.

## 2.3.3. Effect of Temperature

The effect of temperature on adsorption was evaluated for the dye solution (0.0012 mg/L) contacted with a specified amount (0.2 g) of the adsorbent at 293 K, 303 K, and 313 K. From the obtained data, thermodynamic parameters were estimated.

# 3. Results and Discussion

# 3.1. Characterization

3.1.1. Scanning Electron Microscopy (SEM)

The morphology of the Silica monolith particles was visualized through SEM. The SEM images revealed that the prepared silica nanoparticles have sizes ranging from 50 to 55 nm with holes of varied dimensions, channels, and active sites for the adsorption of the selected dye molecules (Figure 2a). The SEM image after adsorption of BR-5 on silica nanoparticles is given in Figure 2b which clearly shows the aggregates of dye molecules around the adsorption sites.



Figure 2. SEM image of silica monolith particles: (a) before BR5 adsorption; (b) after BR5 adsorption.

# 3.1.2. Electron Dispersive X-rays (EDX)

The elemental analysis showed different percentages of elements present in the synthesized silica monolith particles. The highest percentages of elements presented were Si (52%) and O (48%), as shown in Table 2.

Element	Weight%	Atomic%
О	47.87	61.72
Si	52.13	38.28
Total	100	100

Table 2. Elemental composition of synthesized silica monolith particles (SMPs).

# 3.1.3. Fourier-Transform Infrared Spectroscopy (FTIR)

The FTIR spectra of synthesized silica monolith particles had shown the characteristic stretching of Si–O bond at certain wave numbers. The spectrum of synthesized silica monolith particles is shown in Figure 3. The characteristic peaks of Si–O bond was observed from 800 to 1300 cm<sup>-1</sup>, confirming the existence of silica in the SMPs sample.



Figure 3. FTIR spectra of synthesized silica monolith particles.

## 3.1.4. Surface Area of SMP

The surface area of the silica monolith particles was determined using the Brunauer– Emmett–Teller (BET) equation [16] which is based on the  $N_2$  gas multilayer formation on the surface of the silica particles.

$$\frac{1}{w[(p_o/p) - 1]} = \frac{A - 1}{w_m A} \left(\frac{p}{p_o}\right) + \frac{1}{w_m A}$$
(2)

where p and  $p_o$  corresponds to equilibrium and the saturation pressures of adsorbates, respectively. The amount of gas adsorbed at a relative pressure  $p/p^o$  and  $w_m$  is the amount of adsorbate (N<sub>2</sub>) forming uni-layer on the surface of adsorbent, A is called BET constant and is correlated with the energy of the first adsorbed layer and its value point towards the extent of the interaction between adsorbate and adsorbent. A is given as:

$$A = exp\left(\frac{E_1 - E_f}{RT}\right) \tag{3}$$

 $E_1$  stands for heat of sorption for the 1st adsorbed layer, and  $E_f$  is the heat for continuing layers. Equation (2) was used to receive the adsorption isotherm by plotting:  $1/[w(p/p^o)-1]$  against  $\beta = p/p^o$ .

Slope "*m*" and intercept "*c*" were used to determine the uni-layer of N<sub>2</sub> adsorbed, i.e.,  $w_m$ . BET constant A, the relationship of  $w_m$ , and the constant-A are given by the following equations:

$$w_m = \frac{1}{m+c} \tag{4}$$

$$A = 1 + \frac{m}{c} \tag{5}$$

The total and the specific surface area can be determined by the following equations:

$$S_{total} = \frac{w_m N_A S}{V_{molar}} \tag{6}$$

$$S_{BET} = \frac{S_{total}}{O}$$
(7)

In the above equations,  $V_m$  is the molar volume of N<sub>2</sub> gas; *S*,  $N_A$ , *Q*, and  $V_m$  represent the cross section of N<sub>2</sub> gas, the Avogadro's number, the quantity of the adsorbent in grams, and the molar volume of adsorbate (N<sub>2</sub> gas), respectively.

The surface area of the silica monolith particles was obtained from the plot of  $1/[w(p_0/p)-1]$  vs.  $p/p_0$  and was found to be 368 m<sup>2</sup>/g. The BJH pore size distribution was 87.15, whereas the total pore volume and pore radius of SMP were 0.073 cm<sup>3</sup>/g and 16.627Å, respectively.

# 3.2. Adsorption Kinetics Study

The adsorption kinetics models, i.e., pseudo-first order, pseudo- second order, and intraparticle diffusion models were applied to investigate the kinetics and different kinetics parameters. The experimental data in raw form is first obtained as effect of contact time on adsorption, which an important factor while evaluating the kinetics of adsorption processes. The effect of contact time is shown in Figure 4, from which the equilibrium time estimated is around 45 min.



Figure 4. Effect of contact time on the adsorption of BR-5 on SMPs.

# 3.2.1. Pseudo 1st Order Kinetics

The linear form of pseudo 1st order kinetics model is:

$$\ln\left(C_{de} - C_{d\phi}\right) = \ln C_{de} - k_1 t \tag{8}$$

Here,  $C_{de}$  is the amount adsorbate at equilibrium, and  $C_{d\phi}$  the amount of adsorbate in various interval of time (*t*) before the equilibrium is established, and  $k_1$  (min<sup>-1</sup>) is the rate-constant for pseudo 1st order kinetics.

 $ln (Cde - Cd\phi)$  vs. t plot is shown in Figure 5, where the kinetic parameter  $k_1$  can be determined from the slope of the plot (as shown in Table 3).



**Figure 5.** Basic Red 5 adsorption on SMPs. (**a**) Different temperatures, (**b**) Pseudo 1st order, (**c**) Pseudo 2nd order, (**d**) Power function, (**e**) Natarjan and khalaf, and (**f**) Intraparticle diffusion.

Parameters			Adsorption Temperature					
1 arameters		-	293 K		303 K		313 K	
		Units	value	R <sup>2</sup>	value	R <sup>2</sup>	value	R <sup>2</sup>
Pseudo 1st order	k <sub>1</sub>	$Min^{-1}$	0.00180	0.997	0.00185	0.991	0.00195	0.988
Pseudo 2nd order	k <sub>2</sub>	$g \cdot mg^{-1} \cdot min^{-1}$	29787.5	1	30568.5	1	30597.0	1
Power – function _		$lpha  imes 10^{-3}$	0.1918		0.1936		0.1954	
	β		0.00760		0.00691		0.00624	
	R <sup>2</sup>		0.932		0.974		0.958	
Natrajan — and Khalaf _		K <sub>n</sub>	0.016121		0.029939		0.064484	
		Intercept	1.472		1.589		1.691	
		R <sup>2</sup>	0.992		0.997		0.982	
Intraparticle – diffusion _		K <sub>ip</sub>	0.00179		0.00187		0.00191	
		Intercept	1.9347		1.9527		1.9698	
		R <sup>2</sup>	0.997		0.990		0.987	

Table 3. Kinetics parameters for the adsorption of Basic Red 5 dye on the SMPs.

### 3.2.2. Pseudo 2nd Order Kinetics

The linear form of pseudo second order kinetics model can be given by Equation (9):

$$\frac{T}{C_{d\phi}} = \frac{1}{C_{de}} T + \frac{1}{k_2 C_{de}^2}$$
(9)

Here, the  $k_2$  (g·mg<sup>-1</sup>·min<sup>-1</sup>) is the rate constant for the pseudo 2nd order kinetics model. In Figure 5,  $T/C_{d\Phi}$  has been plotted against time (t). The constants values estimated from the slope and intercept are given in Table 3. The regression ( $\mathbb{R}^2$ ) values for BR-5 adsorption are close to 1 as shown in Table 3. This showed that the adsorption of BR5 follows pseudo 2nd order kinetics.

## 3.2.3. Intraparticle Diffusion Model

The linear form of the intraparticle diffusion model is given in Equation (10):

$$q_t = k_{\mathrm{id}} t_{\frac{1}{2}} + C \tag{10}$$

In Equation (10),  $K_{id}$  is rate constant of intraparticle diffusion and C is the intercept obtained from the linear plot drawn between  $q_t$  and  $t_{1/2}$  as shown in Figure 5. According to this model, the uptake plot should be linear if the intraparticle diffusion is involved in the adsorption process and if these lines pass through the origin, then intra-particle diffusion is the rate controlling step. The curve obtained is a straight line confirming the intraparticle diffusion to be the sole rate limiting factor in the adsorption of the selected dye on the prepared adsorbent [17].

# 3.2.4. Power Function Model

The Power Function kinetics model was used to validate and explain the obtained results. The Power Function kinetic model in linear form can be given as follows:

$$logC_b = \beta logt + log\alpha \tag{11}$$

The log  $C_b$  vs. *log t*, plot was drawn, which gave a slope,  $\beta$ , and intercept, log  $\alpha$  (Figure 5). The values of  $\alpha$  and  $\beta$  are given in Table 3. The constant  $\alpha$  value increased with an increase in temperature, which showed the process of adsorption as ideal at a high temperature. The values of R<sup>2</sup> were close to 1, which showed that the data obtained by the adsorption of the dye on the SMP were well adjusted by the power function kinetics model.

## 3.2.5. Natarajan and Khalaf Model

The Natarajan and Khalaf kinetic model was also used for the explanation of the experimental results obtained. The straight-line form of this model can be given as [18]:

$$log\left(\frac{C_{do}}{C_{d\sigma}}\right) = \frac{K_n}{2.303}t + C \tag{12}$$

Log  $C_{do}/C_{d\sigma}$  vs. *t* plot is shown in Figure 5 where  $K_n/2.303$  is the slope, while *C* is the intercept. The value  $K_n$  (min<sup>-1</sup>) is given in Table 3. The  $K_n$  values showed an increment with increase in temperature from 293 K to 313 K, which showed that the adsorption was favored at a high temperature.

## 3.3. Isotherm Models

For the determination of the SMP surface properties and affinity towards the adsorbate, different isotherm models were applied. The isotherm study is essential for the investigation of the interaction between adsorbent and adsorbate. It also gives information about the surface coverage (monolayer or multilayer formation).

#### 3.3.1. Langmuir Isotherm Model

To describe the adsorption of the dye on the SMP, the Langmuir isotherm was used. This model defines the sorption process as taking place at specific homogenous sites on the adsorbent leading to monolayer formation. The linear form of this model can be given as follows:

$$\frac{1}{q_e} = \frac{1}{K_l q_{max}} \frac{1}{C_e} + \frac{1}{q_{max}}$$
(13)

Here,  $C_e$ ,  $q_e$ ,  $K_L$ , and  $q_{max}$  are the equilibrium concentrations of the adsorbed dye (mg/L), the amount of dye adsorbed at equilibrium (mg/g), the Langmuir constant (L/g), and the maximum adsorption capacity (mg/g), respectively. The adsorption behavior is shown in Figure 6 which indicates the linear relationship between  $1/q_e$  and  $1/C_e$ . To find the values of  $K_L$  and  $q_{max}$ ,  $1/q_e$  versus  $1/C_e$  were plotted (from slope and intercept); the values along with the correlation coefficients R<sup>2</sup> are given in Table 4. The maximum adsorption capacity as a parameter of Langmuir isotherm was found to be at 0.00145. The Langmuir isotherm showed the best correlation coefficient (R<sup>2</sup>) value and, therefore, correlated best with the data.

 Table 4. Langmuir and Freundlich isotherm model parameters for the adsorption of the BR-5 on SMPs.

Langmuir Adsorption Isotherm Model					
$\begin{array}{cccc} intercept & slope & q_{max}  (mg/g) & K_L  (g/mg) & R^2 \\ 23.52 & 0.096 & 0.0425 & 0.44 & 0.988 \end{array}$					
Freundlich Adsorption Isotherm Model					
intercept 0.804	slope 0.949	1/n 0.949	Kf (mg/g) 6.37	R <sup>2</sup> 0.982	



Figure 6. Langmuir adsorption isotherm model of the Basic Red 5 on SMP.

#### 3.3.2. Freundlich Isotherm Model

The Freundlich adsorption isotherm is one of the most frequently used isotherm to estimate adsorption capacity of adsorbate in equilibrium condition [19]. The Freundlich Isotherm model defines the behavior of adsorption as non-ideal, reversible, and non-restricted to the monolayer formation. This model can be applied to the adsorption on heterogeneous surfaces (multilayer adsorption) with the non-uniform distribution of adsorption heat and affinities of the sites over the adsorbent surface. The Freundlich adsorption isotherm model of the BR-5 on the SMP is shown in Figure 7.



Figure 7. Freundlich adsorption isotherm model of the Basic Red 5 on the SMPs.

The linear form of this model can be given as follows:

$$logQ_e = logk_f + \frac{1}{n}logC_e \tag{14}$$

where  $Q_e$ ,  $C_e$ ,  $K_f$ , and 1/n represent the amount of the dye adsorbed at equilibrium, the dye equilibrium concentration in solution, the adsorption capacity at unit concentration, and the adsorption intensity, respectively. When 1/n = 0, the type of isotherm will be irreversible and when 0 < 1/n < 1, then the reaction is favorable and when 1/n > 1, then the

process will be unfavorable. To find the value of  $K_f$  and 1/n, a plot of  $log Q_e$  versus  $log C_e$  was constructed and the values of n and  $K_f$  were calculated from the slope and intercept of the data. The values of parameters such as n and  $K_f$  are given in Table 4. The value of 1/n was found to be 0.94934, which indicated that the dye adsorption on SMP was favorable.

## 3.4. Thermodynamic Parameters Study

Equation (15) shows the integral form of the Arrhenius equation, which was used for the calculation of the activation energy ( $E_a$ ):

$$ln\frac{k_2}{k_1} = \frac{E_a}{R} \left[ \frac{T_2 - T_1}{T_1 T_2} \right]$$
(15)

In Equation (15),  $k_1$  and  $k_2$  are the rate constants at initial and final temperatures ( $T_1$  and  $T_2$ ) and R is the universal gas constant. The activation energy value for silica monolith particles is shown in Table 5. The  $E_a$  value general limit for the macrosporous and mesoporous materials is about 40 kJ/mol. The materials which have pore size less than 19.9 Å are consider microporous, thus the diffusion of BR5 molecules may be decreased with a decrease in temperature. The diffusion-coefficients are regularly observed according to the  $E_a$  and can reach values even higher than 101 kJ/mol [20]. The  $E_a$  values for the synthesized silica monolith particles were 3.431 kJ/mol.

Table 5. Thermodynamic parameters for adsorption of BR5 on SMPs.

$\Delta \mathbf{G}^\circ$ (KJ/mol)			ΔH°	ΔS°	ΔE <sub>a</sub>
			(KJ/mol)	(KJ/mol·K)	(kJ/mol)
293 K 87.983	303 K 89.976	313 K 93.739	0.995	-297	3.431

The other thermodynamics parameters  $\Delta S^{\circ}$ ,  $\Delta H^{\circ}$ , and  $\Delta G^{\circ}$  were calculated by the following Equations (16)–(18), respectively [21–24]:

$$\Delta H^{\circ} = \Delta E - RT \tag{16}$$

$$\Delta S^{\circ} = R \left[ ln \frac{kh}{K_b T} + \frac{\Delta H^{\circ}}{RT} \right]$$
(17)

$$\Delta G^{\circ} = \Delta H^{\circ} - T \Delta S^{\circ} \tag{18}$$

In Equation (17), the rate constants are symbolized by k,  $K_b$  as Boltzmann constant and h is the Planck constant. The values of enthalpy, entropy, and Gibbs free energy changes are given in Table 3. If the energy of adsorption is less than 8.0 kJ/mol, it is physical-adsorption; if it ranges from 8 to 16 kJ/mol, then this process is termed as ion exchange, but if the values are larger than 16.0 kJ/mol, the process is considered to be chemo-adsorption [25–29]. The obtained results showed that at a positive value of  $\Delta H^\circ$ , the process was endothermic in nature. On the other hand, the non-spontaneous nature and orderliness of the process were authenticated from the negative and positive values of  $\Delta S^\circ$  and  $\Delta G^\circ$ , respectively (Table 5).

#### 3.5. Regeneration

The regeneration process employed was the heating of the used sample in furnace at 873 K for 72 h. During continuous heating, the adsorbed dye becomes burnt and the SMPs are regenerated as SMPs can tolerate higher temperature than 873 K. At up to 6 cycles, the adsorption efficiency dropped to 85% of its initial value.

#### 3.6. Comparison of SMPs Adsorption Capacity with Other Adsorbents

Table 6 presents a comparison of the present adsorbent adsorption capacity with other adsorbents.

Adsorbents	Dyes	Adsorption Capacity (mg/g)	Reference
NaOH treated saw dust	Brilliant Green	55.86	[30]
Pine tree leaves	Basic Red 46	71.94	[31]
Lemonpeels/sodium alginate (Activated Carbon)	Methylene Blue	841.37	[32]
Rice husk Silica monolith particles	Methylene Blue Basic Red-5	1350 0.0425	[33] Present work

Table 6. Comparison of silica monolith particle adsorption capacity with other adsorbents.

# 4. Conclusions

The adsorption of Basic Red 5 was explored as a function of time. The silica monolith particles were characterized through FTIR, SEM, EDX, and surface area analyzer. The prepared silica monolith particles had a high surface area ( $368 \text{ m}^2/\text{g}$ ); therefore, a high adsorption capacity was recorded for the prepared adsorbent. The equilibrium of adsorption was reached after approximately 45 min. The best fit of kinetics data was achieved with the pseudo 2nd order model while, for the equilibrium data, it was achieved with Langmuir. From the thermodynamics parameters values, the process was found to be endothermic and non-spontaneous. The prepared adsorbent could be effectively used for other dyes however, further investigations are needed in this connection.

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