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Removal of crystal violet from aqueous solution using surfactant modified glass waste: kinetic, isotherm, and thermodynamic studies

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ABSTRACT

In this study, powdered glass waste was modified by sodium dodecyl sulfate and used as an adsorbent for the removal of crystal violet from aqueous solution for the first time. The effect of the main adsorption parameters, kinetics, and adsorption isotherms was evaluated. Optimal conditions have been determined using Taguchi experimental design. The best conditions were found at 0.05 mg of adsorbent, 50 mg/L dye concentration, and pH value of 9. The maximum sorption uptake was 28.3 mg/g at 321 K. Adsorption data were well described by the Freundlich model. Calculated thermodynamic parameters showed the endothermic and spontaneous nature of the adsorption process. A mass transfer model (intraparticle diffusion) was applied to the experimental data to examine the mechanism of the rate-controlling step.

Keywords: Adsorption; Glass waste; Crystal violet; Taguchi design

1. Introduction

In recent years, water contamination by synthetic dyes which are discharged from the dyestuff manufacturing, printing, and textile industries has been become a global problem due to their negative eco-toxicological effects and bioaccumulation in wildlife. Color is the first contaminant which can be recognized in the wastewater. For some dyes, even less than 1 ppm is highly visible and undesirable [1]. Various conventional technologies for the removal of dyes from the effluents refer to physical, chemical, and biological processes have been proposed and yet to be evaluated. Among them, adsorption besides being widely used for dye removal also has wide applicability in wastewater treatment [2]. This technique has been recognized as a promising method because of its ease of operation, simplicity of design, high efficiency, and comparable low cost of application in decolorization process [3]. A number of natural materials, solid wastes, or byproducts which are inexpensive and widely available can be used as adsorbents for water treatment [4]. Natural minerals, such as red mud [5], perlite [6], dolomite [7], bentonite [8] or waste/by products, such as stone dust [9], brick dust [10–12], and glass powder [13,14] are adsorbents that have been tested for aqueous solutions treatment. In this way, special attention has been given to mineral wastes due to low cost. Besides, reuse or recycle of the

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undesirable stuffs is a helpful strategy for the waste management [15].

Crystal violet (CV), a triphenylmethane dye, is used in many applications, including the medical affairs (as an active ingredient for classifying bacteria), dyeing of textile fibers, and printing. However, CV causes cancer and also is harmful in the case of inhalation, ingestion, and skin contact. It has a recalcitrant molecule that can be degraded by enzymes hardly, and would persist in a variety of environments. So, the removal of CV from aqueous solutions is an important issue [16–18].

As we know there is no report of using sodium dodecyl sulfate (SDS)-modified glass powder as a low-cost adsorbent and domestic or industrial waste in decolourization process. FTIR, SEM, BET, and XRF analyses were conducted to characterize the adsorbent. The effects of initial solution pH, dye concentration, adsorbent dosage, contact time, and NaCl concentration (ion strength factor) on the adsorption uptake have been investigated and optimized systematically using Taguchi L_{27} orthogonal array. Adsorption kinetics, isotherms, and thermodynamics were also studied.

2. Experimental

2.1. Preparation of surfactant-modified glass powder (MGP)

A domestic waste glass bar was used as an adsorbent. The glass bar was washed carefully with water and ethanol, respectively. It was milled overnight, so fine white glass powders were obtained (250 g). The powders were modified based on the approach reported by Adak and Pal [19]. Glass powder (200 g) was shaken for 24 h with 2 L of SDS solution having a concentration of 20,000 mg/L. To increase the adsorption uptake of the glass powder, NaCl was added to the solution and the pH of the solution was kept low [20]. NaCl (5 g) was added to the solution and the pH was set at 4.4 ± 0.1. The resulting solution was stirred for 24 h with an overhead mixer and then powders were left to be deposited. When deposition was completed, the supernatant was discarded, and the adsorbent was washed with distilled water. The resulted adsorbent was completely dried for 24 h in an oven (60˚C). The product was kept in a closed glass container to be used in the adsorption experiments.

2.2. Batch studies

CV ($C_{25}H_{30}N_3Cl$), SDS, and other materials of analytical grade were supplied from the Merck Company (Germany). The amount of solution pH was adjusted using HCl (0.1 mol/L) or NaOH (0.1 mol/L) solutions. Fig. 1 shows the chemical structure of the CV.

Batch adsorption experiments were carried out to investigate the effects of initial CV concentration, contact time, initial pH solution, modified glass powder dosage, and NaCl concentration on the adsorption of CV. For each experimental run, an appropriate amount of the modified glass powder was added to 50 ml of a given concentration of dye solution containing specified amounts of NaCl in an Erlenmeyer flask and agitated in an isothermal shaker at a constant temperature (22˚C) for 60 min to reach adsorption equilibrium. The equilibrium states were achieved after about 60 ± 2 min mixing for all examined dye concentrations. The adsorbent was removed by centrifugation at a speed of 4,500 rpm for 15 min and remaining CV concentrations were determined by a double beam UV–visible spectrophotometer (Shimadzu UV-1800, Japan) at $\lambda_{\max} = 583$ nm. The amounts of CV adsorbed per unit mass of the adsorbent were calculated from the differences between the initial and final CV concentrations in solution by Eq. (1):

$$q_e = (C_0 - C_e)\frac{V}{M} \tag{1}$$

where q_e (mg/g) is the adsorption uptake at the equilibrium time (t_e, min). C_0 and C_e (mg/L) are the initial and final concentration of the CV solution, respectively. V (L) is the volume of CV solution used which was fixed at 50 ml for all experiments. M (g) is the weight of the adsorbent (adsorbent dosage) varied according to the design of the experiments.

2.3. Design of experiments

Conventional and classical methods of studying a process by maintaining other factors involved at an

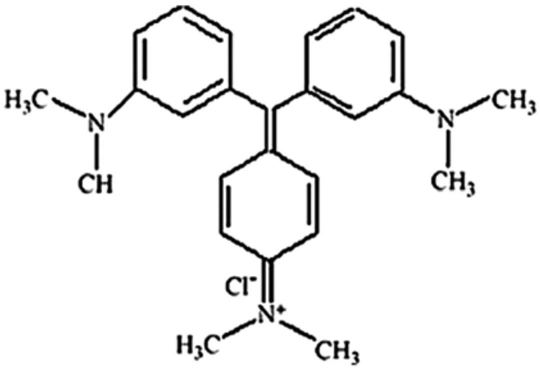

Fig. 1. Chemical structure of CV.

unspecified constant level, the combined effect of all the factors involved, is time consuming. Besides being time-consuming procedure, a number of tests are required to determine the optimum level, which is unreliable. Taguchi experimental design is a suitable tool to conduct a simple and robust systematic investigation and process.

Taguchi L_{27} orthogonal array was selected for design of the experiments. The effects of the four main and effective factors such as adsorbent dosage (factor *A*), dye concentration (factor *B*), pH of the initial solution (factor *C*), and concentration of the sodium chloride solution (factor *D*) were investigated. Studied factors and related levels are given in Table 1.

Accordingly, 27 batch adsorption runs were carried out based on the L_{27} design array [21]. The adsorption uptake (q_e) was selected as the response of the experiments. Results were analyzed using MINITAB software (version16) for Windows. Table 2 gives the combination of the factor and levels for each run (Taguchi L_{27} array).

2.4. Adsorption isotherm

Adsorption isotherm is the most widely method used for representing the equilibrium state in a sorption system. The adsorbent and adsorbate interrelationships are explained by the isotherms [22]. The applicability of the most defined models such as Langmuir, Freundlich, and Temkin for obtained adsorption data was investigated.

The Langmuir model assumes monolayer adsorption onto a surface with a finite number of similar sites to be considered. The equation is introduced by Eq. (2) [23]:

$$\frac{1}{q_e} = \frac{1}{q_m} + \frac{1}{K_L q_m C_e} \tag{2}$$

where q_e (mg/g) is the equilibrium adsorption uptake when a monolayer adsorption occurs. K_L (mg/L) is the Langmuir constant and is related to free energy and binding sites that tend to attract. The amount of the q_m which represents the maximum monolayer adsorption uptake of the used adsorbent and K_L are obtained from plot $1/q_e$ against $1/C_e$.

This isotherm can also be expressed by R_L as follows (Eq. (3)) [23]:

$$R_L = \frac{1}{1 + K_L C_0} \tag{3}$$

If $0 < R_L < 1$ the process is favorable, while $R_L > 1$, $R_L = 1$ indicate poor and nonlinear adsorption. When $R_L = 0$ adsorption process would be irreversible.

Table 2
Factors and levels combination

Run	*A*	*B*	*C*	*D*	Response (q_e, mg/g)
1	1	1	1	1	2.314286
2	1	1	2	2	4.371429
3	1	1	3	3	0.214286
4	1	2	1	2	7.142857
5	1	2	2	3	3.000
6	1	2	3	1	3.142857
7	1	3	1	3	17.71429
8	1	3	2	1	18.49
9	1	3	3	2	15.57143
10	2	1	1	1	1.721429
11	2	1	2	2	2.307143
12	2	1	3	3	0.335714
13	2	2	1	2	8.721429
14	2	2	2	3	8.978571
15	2	2	3	1	4
16	2	3	1	3	6.714286
17	2	3	2	1	8.428571
18	2	3	3	2	4.428571
19	3	1	1	1	0.371429
20	3	1	2	2	0.385714
21	3	1	3	3	0.174286
22	3	2	1	2	1.78
23	3	2	2	3	1.838571
24	3	2	3	1	1.045714
25	3	3	1	3	4.618571
26	3	3	2	1	4.497143
27	3	3	3	2	2.381429

Table 1
Factors and levels

Factor	Allocated letter	Level 1	Level 2	Level 3
Adsorbent dosage (g)	*A*	0.05	0.1	0.5
Dye concentration (mg/L)	*B*	5	20	50
pH	*C*	6	9	4
NaCl concentration (mg/L)	*D*	0.1	10	100

The Freundlich model is usually for adsorption on heterogeneous surfaces and is expressed by the following equation (Eq. (4)) [24]:

$$\ln q_e = \ln K_F + \frac{1}{n} \ln C_e \tag{4}$$

K_F and n are Freundlich constants which were obtained from the plots $\ln q_e$ vs. $\ln C_e$. The constants indicate the intensity and capacity of adsorption, respectively.

The Temkin isotherm model is shown by Eq. (5) [25]:

$$q_e = \frac{RT}{b_T} \ln K_T + \frac{RT}{b_T} \ln C_e \tag{5}$$

where T is the absolute temperature (K), R is the universal gas constant (8.314 J/(mol K)), b_T represents a constant related to the enthalpy of adsorption, and K_T is the equilibrium constant. K_T and b_T were calculated from the slope and intercept of q_e plot vs. $\ln C_e$.

2.5. Kinetic studies

Pseudo-first and second-order models were used to study the kinetics and adsorption rate. Intraparticle diffusion model was applied to study the adsorption mechanism [26]. Eqs. (6)–(8) give the related formulas (k_1, k_2 and k_{id} are the kinetic model constants).

$$\text{Pseudo-first-order}: \log(q_e - q_t) = \log q_e - \frac{k_1}{2.303} t \tag{6}$$

$$\text{Pseudo-second-order}: \frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \tag{7}$$

$$\text{Intraparticle diffusion}: q_t = k_{id} t^{\frac{1}{2}} + C_i \tag{8}$$

2.6. Thermodynamic parameters

Thermodynamic parameters such as changes in energy (ΔG°), enthalpy changes (ΔH°), and entropy changes (ΔS°) have been studied for the adsorption of CV. These parameters were calculated using Eqs. (9)–(11) [27]:

$$K_D = \frac{q_e}{C_e} \tag{9}$$

$$\Delta G^\circ = -RT \ln K_D \tag{10}$$

$$\ln K_D = \frac{\Delta S^\circ}{R} - \frac{\Delta H^\circ}{RT} \tag{11}$$

ΔS° and ΔH° values can be calculated from the slope and intercept of the $\ln K_D$ plot against $1/T$.

3. Results and discussion

3.1. Characterization of Glass powder

The particle size distribution of GP was evaluated by Laser particle size analyzer (Fritsch, analyst 22 compact). According to the distribution plot shown in Fig. 2, the average particle size is about 13 μm.

SEM micrographs (Carl Zeiss, sigma model, Germany, 15 kV) of the raw (untreated) and modified glass powders were taken to illustrate the adsorbent morphology (Fig. 3). The micrographs magnification factors are 5.00 KX. As it is seen, the untreated glass powder is composed of micron-sized fine particles with a heterogeneous surface. Moreover, the figure shows that the MGP surfaces are nearly smoother and covered by ultra-fine SDS clusters which are adsorbed on the external surface of the row GPs. The surfactant cluster sizes are in the range of ~300 nm to 1 μm. A similar result has been reported for the surfactant modified diatomite [28].

The textural characteristics of the raw and modified glass powder were measured by nitrogen gas adsorption at 77 K using a PHSCHINA (PHS-1020, China) gas sorption instrument. Samples were degassed at 150˚C for 1 h before measurements. The specific surface area of the samples measured by the Brunauer–Emmett–Teller (BET) method and the other results are presented in Table 3. According to the Table 3 data, the specific surface area of the GP is greater than the surface area of the MGP which could be attributed to the micropore filling during the

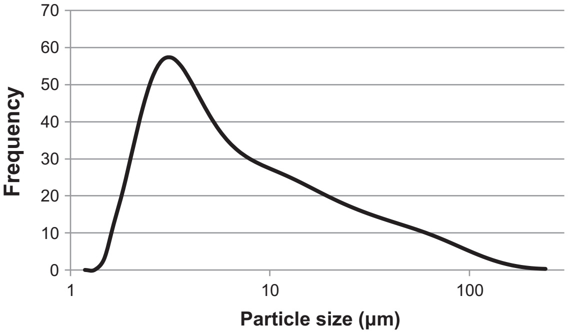

Fig. 2. Particle size distribution of glass powder.

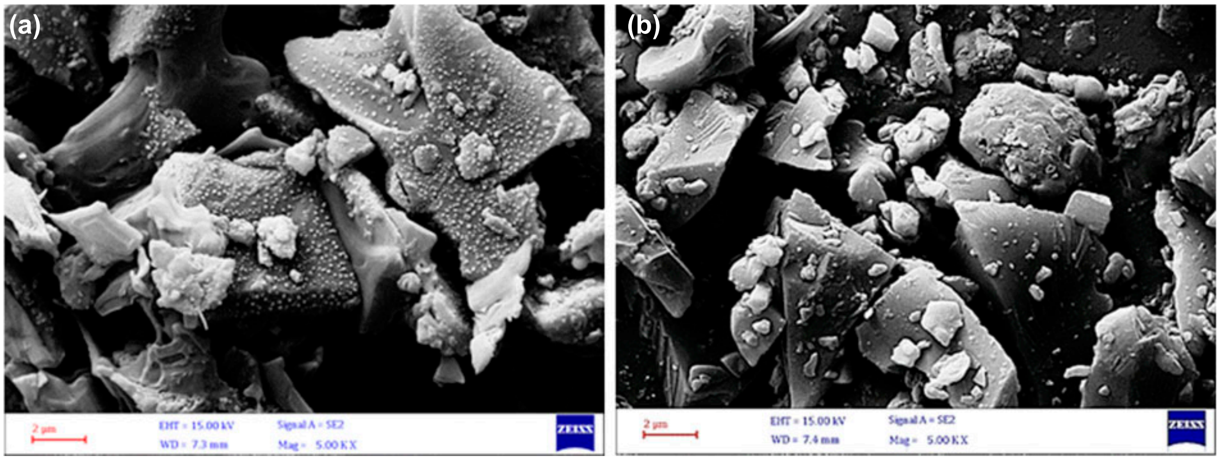

Fig. 3. SEM micrograph of (a) SDS modified glass powder and (b) raw glass powder.

Table 3
Textural characteristics of the GP and MGP

Sample	S_{BET} (m^2/g)	Total pore volume (cm^3/g)	Micropore pore volume (cm^3/g)	Average pore diameter (nm)
GP	58.456	0.247	0.147	6.18
MGP	39.987	0.137	0.054	9.86

modification of the glass surface by SDS. The average pore diameter in the mesopore range was increased due to blocking of the relatively fine micropores by the surfactant molecules. This micropore blocking would leave behind comparatively wide pores. Similar results have been obtained for the surface modification of the montmorillonite and bentonite [29,30].

The chemical composition of the adsorbent was analyzed by X-ray fluorescence spectrometer (XRF) supplied from Philips (PW 1800). Data are given in Table 4. Over 70% of the adsorbent weight unit is composed of silica and alumina.

Besides the SEM micrographs, Fourier Transform Infrared Spectroscopy (FTIR-RXI, Perkin-Elmer) was used to evaluate the adhesion of the surfactant containing organic functional groups on the adsorbent. Fig. 4 shows the obtained FTIR spectra of row adsorbent (GP), surfactant modified adsorbent (MGP), and the used surfactant (SDS), respectively. The obtained patterns are reported in transmittance mode. Obviously, MGP spectrum characteristics lay between two other spectra. Two sharp peaks in the region of 2,850–3,000 cm^{-1} are assigned to the stretching vibrations of $–CH_3$ and $–CH_2$, respectively [31]. The mentioned bands appear in the spectra of MGP and SDS but not in the FTIR spectrum of GP. So the methyl groups were not added to the surface of the glass powder directly. In fact, the methyl groups are detected on the surface of the sorbent according to the adsorption (adhere) of the main containing methyl group of the macro molecule (SDS). According to the Fig. 4, new appearing bands at 2,920 and 2,850 cm^{-1} are attributed to asymmetric and symmetric C–H stretching vibrations of SDS [32]. It proves the modification of the adsorbent by surfactant groups.

3.2. Effect of contact time

To examine the effect of time, several flasks with the same condition, containing 50 ml of CV solution

Table 4
XRF analysis of GP

Component	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	K_2O	MgO	TiO_2	Others
Weight (%)	71.22	2.57	0.11	7.62	12.89	0.68	3.23	0.057	1.623

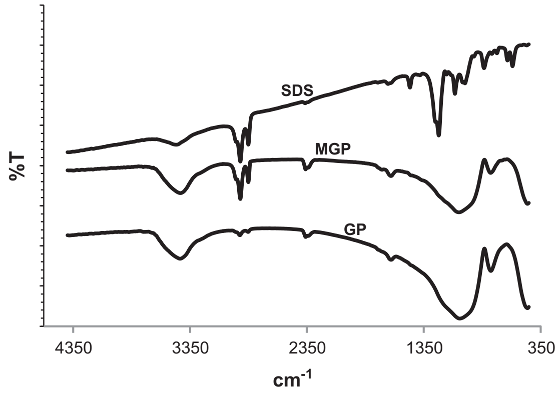

Fig. 4. FTIR of SDS and glass powder before (GP) and after modification (MGP).

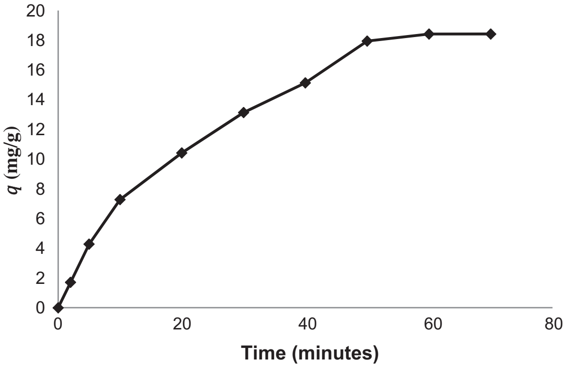

Fig. 5. Effect of contact time.

(5 mg/L) and 50 mg of adsorbent were prepared and placed in a shaker at the same time. The concentrations of the solutions were determined every 5 min. Fig. 5 shows that the adsorption process remained unchanged after about 58 min. The equilibrium states were achieved after about 60 ± 2 min for all examined samples. Accordingly, 60 min was fixed as the contact time for the other tests.

3.3. Analysis of experimental data and prediction of performance

Adsorption uptake was selected as the response of the batch experiments. Results are given in the Table 2. The next step in Taguchi optimization is factor effect (E_i, and $i = A, B, C$ and D) calculation. For E_i analysis [33], the mean value of the response should be computed for each level of the factors (level effect). Then, E_i which is a criterion for analyzing the influence of each factor on the response can be obtained from the lowest mean value of a factor level subtracted from the highest one. Results (factor importance or ranking) are listed in Table 5. According to Table 5, Factor B (dye solution concentration) has the biggest impact on the adsorption uptake. Factors can be sorted as $B > A$ (Adsorbent dosage) > C (pH) > D (NaCl concentration) based on their effects (E_i). The main effect plot of quantitative factors (Fig. 6) and data given in Table 6 demonstrate that the combination of $A1$, $B3$, $C2$, and $D2$ results in the most effect on the increasing of the MGP adsorption uptake. Based on the Fig. 6 increasing the dye concentration and assumed adsorbent decrease would result more q_e. It also can be inferred from Eq. (1). Another result comes from the amount of added NaCl. Adsorption of CV on the MGP is almost not affected by the ionic strength alteration based on the addition of NaCl salt to the solution. It has been reported that addition of NaCl would change the zeta potential of the adsorbent (glass powder) [34]. This value is negative over the examined pH range. Surface of the glass would become more neutral in the solutions with higher NaCl concentrations. So it is reasonable that the adsorption uptake would decrease in the 100 mg/L electrolyte solution by a negative surface charge alteration effect. On the other hand, dye adsorption may become more efficient because of salt bridges formation between the surfactant molecules and the adsorbing sites in the presence of salt ions. So the maximum adsorption uptake would be achieved at an optimum NaCl concentration (Fig. 6). In fact, addition of NaCl would increase the pH of the solution very slightly. With an increase in the pH value, the free ends of the anionic surfactant become more negatively charged and react with positive cationic dye efficiently, causing more removal [35,36]. As it can be inferred from Fig. 6, increase in the solution pH has a positive effect on the adsorption uptake. Again it can be attributed to the decrease in the

Table 5
Factors effects and ranking

Level	Factor *A*	*B*	*C*	*D*
1	7.996	1.355	5.678	4.890
2	5.071	4.406	5.811	5.232
3	1.899	9.205	3.477	4.843
E_i	6.097	7.850	2.334	0.389
Rank	2	1	3	4

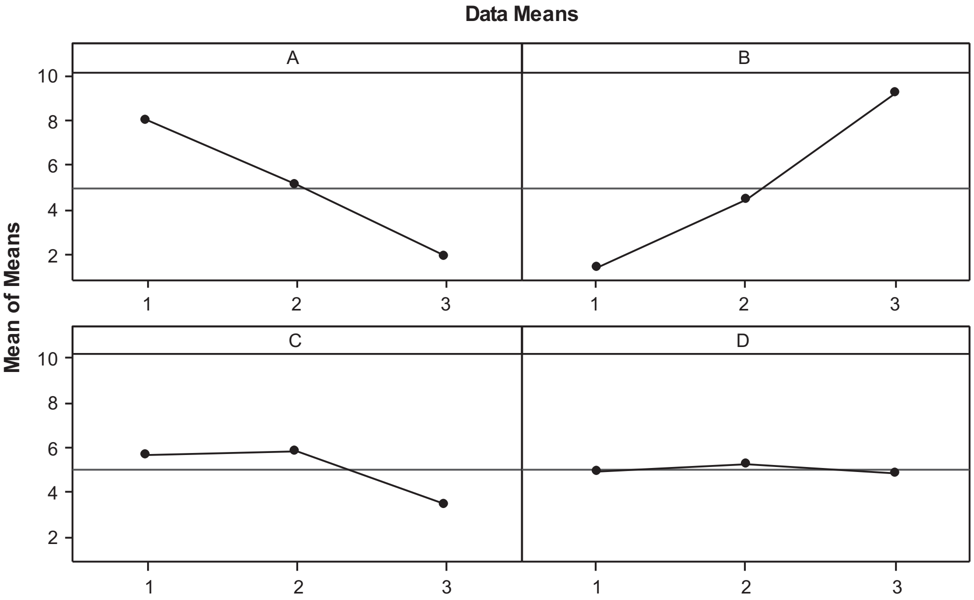

Fig. 6. Main effect plot of mean.

adsorbent surface charge. The zeta potential of the GP surface decreases by adsorption of the SDS. So the attraction and adsorption of the CV^+ would be improved by surfactant modification of the GP.

3.3.1. Statistical ANOVA

Besides the factor mean effect analysis, ANOVA indicates which factors are statistically significant. Procedures for resolving the total variance of a set of variants into component variances that are associated with defined factors affecting the variants are called variance analysis [37]. The ANOVA outputs are summarized in Table 7. The effects of four major factors and interactions *AB*, *AC*, and *AD* were considered in the design. The order of influence of each operational variable of the response was determined in the Response Table for Means (Table 5). In the ANOVA table, more effective parameters have the smaller *p*-values. In the same cases, the value of sum of square (SS) would judge (larger SS in equal *p*-values, is a more effective factor). It can be seen that ANOVA table confirms the response table (Table 5). According to Table 7, the most important interaction is *AB*. As it was mentioned previously, adsorption uptake is strongly dependent on the adsorbent dosage and dye concentration.

The last important step of the Taguchi statistical analysis is prediction of the response at the optimum condition. Whenever the optimum combination of the factors and levels are gained from the ANOVA and factor mean effect analysis, the prediction of the optimized characteristic value of the product will be obtained from the following formula [38]:

$$q_{\text{pred}} = \bar{q} + \left(\bar{A}_1 - \bar{q}\right) + \left(\bar{B}_3 - \bar{q}\right) + \left(\bar{C}_2 - \bar{q}\right) + \left(\bar{D}_2 - \bar{q}\right) = 18.9162\,\text{mg/g} \tag{12}$$

Table 6
Optimum level of the operational variables

Factor	Level	Value
Adsorbent dosage (g)	1	0.05
Dye concentration (mg/L)	3	50
pH	2	9
NaCl concentration (mg/L)	2	10

Table 7
ANOVA for means

Source	DF	SS	MS	*F*	*P*
A	2	167.344	83.672	56.81	0.000
B	2	281.878	140.939	95.69	0.000
C	2	30.917	15.459	10.50	0.011
D	2	0.812	0.406	0.28	0.768
*A***B*	4	189.751	47.438	32.21	0.000
*A***C*	4	6.236	1.559	1.06	0.452
*A***D*	4	6.873	1.718	1.17	0.412
Residual error	6	8.837	1.473		
Total	26	692.649			

Table 8
Kinetic constants for the adsorption of dyes on MGP

		Pseudo-first-order kinetic model			Pseudo-second-order kinetic model			Intraparticle diffusion kinetic		
T (K)	$q_{\mathrm{e,exp}}$ (mg/g)	$q_{\mathrm{e,exp}}$ (mg/g)	k_1 (1/min)	R^2	$q_{\mathrm{e,exp}}$ (mg/g)	k_1 (1/min)	R^2	$q_{\mathrm{e,exp}}$ (mg/g)	k_1 (1/min)	R^2
295	18.42857	22.86255	0.144398	0.8713	27.24796	0.001249	0.9859	19.12	2.6834	0.9951

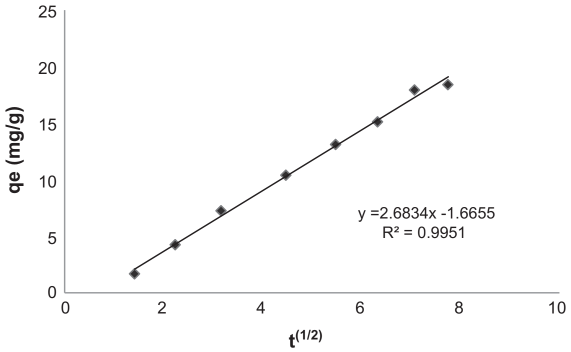

Fig. 7. The plot of Intraparticle diffusion kinetic model fitted for the dye adsorption on MGP.

In Eq. (12), q_{pred} is the predicted adsorption uptake at the optimum condition ($A1$, $B3$, $C2$, and $D2$). In this equation, $\bar{q}$ is the grand average of the 27 obtained responses (4.9885 mg/g). A confirmation test should be conducted to evaluate the accuracy of the prediction. This run should be under the optimum condition. Resulted value was 18.49 mg/g. The difference between predicted (18.9162 mg/g) and achieved value (18.49 mg/g) is negligible and the obtained error (~1%) confirms the predictability of the process, accuracy of the experiment results and statistical analyses.

3.4. Adsorption kinetic

Pseudo-first and second-order models were applied to study the kinetics and adsorption rate and intraparticle diffusion model was used to evaluate the adsorption mechanism. The calculated values of the rate constants (k_i) and q_{cal} for the three models are summarized in Table 8. The kinetic data exhibited an excellent compliance with intraparticle diffusion equation ($R^2 = 0.9951$). The plot of q_t against $t^{½}$ for the intraparticle model is shown in Fig. 7.

3.5. Adsorption isotherms

The adsorption equilibrium data for CV adsorption under different concentrations were fitted to the three mentioned isotherm equations and corresponding calculated parameters are tabulated in Table 9. According to the results, the value of R^2 obtained from Freundlich isotherm equation is higher than the others. This fact indicated that Freundlich isotherm model could well describe the CV adsorption onto MGP.

3.6. Adsorption thermodynamic calculations

Eq. (11) was used for determination of the Gibbs free energy change of adsorption. Accordingly, slope and intercept of the fitted line resulted

Table 9
Isotherm constants for the adsorption of dyes on MGP

Langmuir			Freundlich			Temkin		
q_{m} (mg/g)	K_{L} (L/mg)	R^2	K_{F} (mg/g)(L/mg)$^{1/n}$	$1/n$	R^2	b_{T} (J/mol)	K_{T} (L/g)	R^2
21.9298	0.084	0.9507	2.47094	0.5806	0.9865	435.6484	0.497017414	0.9398

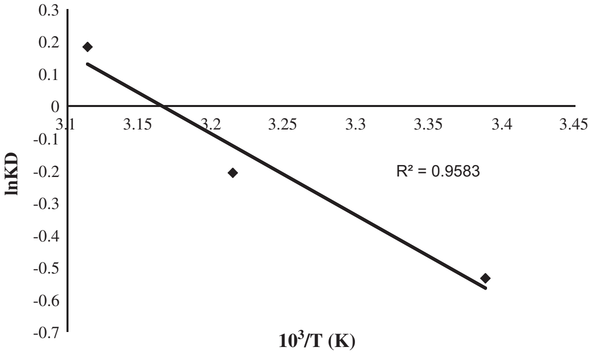

Fig. 8. ln K_D vs. $10^3/T$ for evaluating ΔH° and ΔS°.

Table 10
Thermodynamic parameters for the adsorption of dyes on MGP

ΔH° (kJ/mol)	ΔS° (kJ/(mol K))	ΔG° (kJ/mol)
18.04138	110.3268	−19,826.6

Table 11
Adsorption uptake and Gibbs free energy changes at different temperatures

Temprature (K)	q_e (mg/g)	ΔG° (J/mol)
295	18.490	1,308.336
311	22.429	534.1624
321	28.3	−489.689

from ln K_D vs. $1/T$ data were calculated (Fig. 8). Obtained thermodynamic results are reported in Table 10.

The total negative Gibbs free energy change (ΔG°) at higher temperatures and the positive value of ΔH° indicate that the adsorption process is spontaneous and endothermic, respectively. Endothermic reaction mechanism described the uptake of CV by MGP as the increase in temperature lead to further increase in adsorption. Adsorption of SDS by GP would increase the negative charge of the sorbent surface and make it almost hydrophobic [39,40]. Accordingly, stripping off of some water molecules and other negative charge species in the solution (like chlorides) can form an energy barrier as CV molecules closely approach the surface and make the adsorption process endothermic. It has been reported similarly for the adsorption of safranine-O (a cationic dye) on the glass powder [36]. Further, the positive value of entropy change (ΔS°) shows the random nature of the solid surface in contact with a solution of CV [27]. The data in Table 11 indicate that the maximum adsorption uptake is obtained at 321 K.

3.7. Comparison of MGP with other sorbents

Table 12 summarizes the comparison of the maximum CV adsorption capacities of various sorbents including MGP. The comparison shows that MGP has a higher sorption capacity of CV than many of the other low cost or mineral reported adsorbents. This approach of reusing waste stuffs as adsorbent supports two targets: energy recovery and waste management energy. In addition, MGP is an inexpensive adsorbent.

Table 12
Comparison of the maximum adsorption of capacities of various adsorbents for CV removal

Adsorbent	q_{max} (mg/g)	Refs.
Bottom ash	11.446	[23]
Activated carbon	19.8	[24]
Zeolites from coal fly ash (ZFA)	19.6	[24]
Zeolites from coal bottom ash (ZBA)	17.6	[24]
Orange peel	14.3	[25]
Coir pith	2.56	[26]
Activated sintering process red mud	60.5	[27]
Calatropis procera leaf	4.14	[41]
Jalshakti® polymer	12.9	[42]
SDS-modified glass powder	28.3	This study

4. Conclusions

Studied batch adsorption experiments showed that removal of CV by glass powder is dependent upon process parameters such as dye concentration and adsorbent dosage. Sorption followed intraparticle diffusion kinetics equation. The experimental equilibrium sorption data obtained from batch studies at optimized conditions fit well to the Freundlich adsorption isotherm equation. Negative change in Gibbs free energy and positive value of ΔH° indicates that the adsorption process is spontaneous and endothermic, respectively. Adsorption process was designed and successfully optimized using the Taguchi statistical method. Confirmation test result (18.42 mg/g) obtained under obtained optimum conditions ($A1$, $B3$, $C2$, and $D2$) in agreement with the predicted value (18.9162 mg/g) proved the success of optimization and statistical analyses. The maximum adsorption uptake was obtained under optimum condition at 321 K (28.3 mg/g).

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