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REMOVAL OF CRYSTAL VIOLET AND METHYLENE BLUE FROM SYNTHETIC INDUSTRIAL WASTEWATER USING FENNEL SEED AS AN ADSORBENT

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Abstract

The removal of Crystal Violet (CV) and Methylene Blue (MB) by fennel seeds was investigated. Batch-adsorption technique was used, and the experiments were performed taking into consideration different factors such as pH, adsorbent dosage, particle size, contact time and dye concentrations. Conventional models like the Langmuir and Freundlich Isotherm models were applied. In order to analyse the kinetics of CV and MB onto fennel seeds, Pseudo first and second-order equations were applied. The adsorption for each CV and MB reached to 86% and 65% at pH 4, 6 respectively. The adsorbent dosages were effective factors and the results were 86% and 62% at 5 g L^{-1} for CV and MB respectively. The particle size results were 94% and 78% at size 75 μm. In addition, the process was contacting time-dependent and results were 84% and 64% after 60 min. Moreover, dye concentrations results were 95% and 80% at 5 mg L^{-1}. Freundlich model was more appropriate to fit the adsorption process than that of the Langmuir model, demonstrating the maximum adsorption of 13.47 mg g^{-1} and 18.24 mg g^{-1} for CV and MB, respectively. The adsorption kinetics was more adequately modelled by using pseudo-second-order model than that of the pseudo-first-order model. Based on the findings in this study, it could be concluded that fennel seeds could be a low-cost adsorbent for dye removal.

Keywords: Adsorption, Crystal violet, Fennel seeds, Freundlich, Langmuir, pseudo, Methylene blue.

1. Introduction

Dyes are utilised in many industries like paper and textile industries those industries produce a huge amount of industrial wastewater effluent that contains a certain amount of dye causing the dye to enter into the environment leading to significant changes in water characteristics like colour, chemical oxygen demand, and pH [1]. Among these dyes, Crystal Violet (CV) and Methylene Blue (MB) are synthetic dyes that are commonly used. Crystal violet is used to colour many kinds of products such as paper and leather. Many industries utilize CV for their manufacturing- some of them for cosmetics, detergents, antibacterial and pharmaceutical products [2]. MB can be used as a pigment in the textile industry to colour acrylic, silk, nylon and wool; it is also used in laboratories for water testing and cell staining [3]. Hamidzadeh et al. [4] mentioned that although CV and MB have wide array of applications, they also have some disadvantageous, CV is harmful, toxic, poisonous, carcinogenic and according to Hossain et al. [5], it causes ulceration of a baby's mouth and throat, mouth cancer and cancer in the digestive tract of animals. MB is toxic, mutagenic, carcinogenic [6] and causes hypertension, pericardial pain, headache, staining of the skin, vomiting, and anaemia [7].

Many methods have been utilized to remove dye from wastewater that has been contaminated with CV or MB. The liquid-phase adsorption process is one of the most economic methods in which, economic materials like those that agricultural wastes [8], industrial wastes [9] and natural materials [10] are usually used, or activated carbon derived from plants' peels or nuts' seeds and shells. Activated carbon is used to treat industrial wastewater and remove CV dye using cocoa shell and golbasi [2, 11] and MB is removed by activated corn husk carbon [7].

In addition, nanotechnology provides a good, fast and active way of removing CV from aqueous solution by nanomagnetic iron oxide. The results showed that the adsorption can take less time [4], is effective and low cost compared to other studies [10]. Waste inexpensive materials are considered as substitution materials to other expensive adsorbents used for dyes removal. Alshabanat et al. [12] mentioned that CV can be successfully treated at low temperature and acidic solution with date palm fibre as an adsorbent. A comparison study between cotton and wool fibre as adsorbents to eliminate MB dye was carried out- cotton yielded better results than wool fibre with optimum factors such as pH, initial concentration, dosage, contact time and temperature [9]. Natural adsorbents can be favourable materials to solve the polluted wastewater problem by the adsorption process.

The objectives of this paper are to study the removal of CV and MB by adsorption onto fennel seeds, and the percentage removal efficiency was studied. Further aim various operating parameters such as pH, adsorbent dosage, particle size, contact time, and adsorbate initial concentration as well as isotherm models and dynamic models were studied.

2. Materials and Methods

2.1. Preparation of fennel seeds

Fennel seeds (*foeniculumvulgare*): Fennel seeds (Fig. 1) were obtained from the local market for herbs. The fennel seeds were rinsed with distilled water numerous times in order to ensure that the seeds were totally clean from dust or impurities. Afterwards, they were dried in the oven at 180 ˚C for 3 hours [13]. Continuously, a grinder mill and sieves were used to obtain a powder, particle size of 75, 150, 300, 600 and 800 µm. Table 1 shows the composition of fennel seed [14].

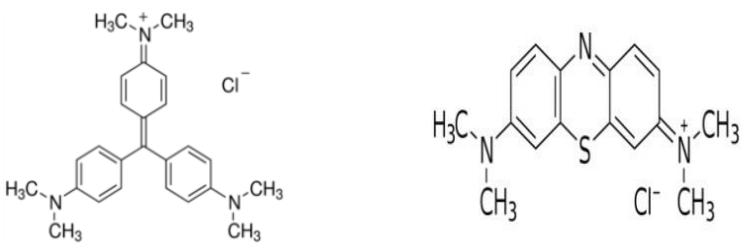
Fig. 1. Fennel seeds.

Table 1. Composition of fennel seeds.

Proximate composition	Quantity
Moisture	6.2%
Crude protein	9.3%
Crude fat	9.7%
Crude fibre	18.2%
Ash	12.9
NFE	43.4
Potassium	852.4 mg g^{-1}
Calcium	580.6 mg g^{-1}
Sodium	16.2 mg g^{-1}
Iron	9.7 mg g^{-1}
Manganese	211.3 mg g^{-1}

2.2. Adsorbate

Crystal Violet (CV) and Methylene Blue (MB) dyes were supplied from scientific equipment offices in Bab Al-Moatham markets, Baghdad, Iraq, as powder. CV (407.97 g mol^{-1}, λmax= 590 nm), and MB (319.85 g mol^{-1}, λmax= 644 nm) as shown in Fig. 2 [6, 15]. Dye stock was prepared by dissolving 1 g of dye in 1000 mL of distilled water. Dilutions were made to reach the desired concentrations; 100 ml flask volume was used for each concentration [2, 3].



(a) $C_{25}H_{30}N_3Cl$. **(b) $C_{16}H_{18}ClN_3S$.**

Fig. 2. Chemical structure and chemical formula of CV and MB.

2.3. Instrument facilities

The morphology of the particles was examined by a scanning probe microscope (SCPM, AFM image). UV-1800 series was used to measure the wavelength of the dyes. UV Thermo-Genesys 10 UV, USA was used to calculate adsorption behaviour. The pH value of solutions was measured by using Thermo-Orion 3 star, USA was used to gain various pHs, shaker model: URN - 480, made in Taiwan.

Fourier transform infrared spectroscopy (FTIR) analysis was done by [FT-IR spectrometer, Biotech Engineering Management Co. Ltd., United Kingdom]. The experiments were carried out at the College of Engineering, University of AL-Mustansiriyah. The samples were analysed in the Central Service Laboratory, College of Ibn AL-Haithem and Central Service Laboratory, College of Science, University of Baghdad.

2.4. Experimental method

Distilled water was used to prepare solutions at the desired concentrations by diluting the stock solution [16]. Firstly, optimum pH was achieved by placing 1 gm of adsorbent into each flask containing 100 mL of CV and MB solutions individually with 20 mg L^{-1} concentration at different pH 2, 4, 6, 8, and 10, by adding NaOH (1M) or HCl (1M) solutions and shaking it until equilibrium is reached.

The flasks were shaken for 90 minutes to achieve equilibrium at a speed of 200 rpm at room temperature. The solution was filtered using Whatman filter paper (0.45 μm). The dye uptake was measured spectrophotometrically after the absorbance wavelength was measured (λ max 590 nm for CV and 664 nm for MB). Aysu and Kucuk [16] calculated the amount of adsorption at equilibrium, q_e ($mg \cdot g^{-1}$).

$$q_e = \frac{(C_o - C_e) \times V}{m} \tag{1}$$

where C_o and C_e (mg L^{-1}) are the liquid - phase dye concentration at initial and equilibrium, respectively, V is the volume of solution (L), and m is the mass of dry adsorbent (g). The initial concentration was considered for each individual test and 5, 10, 20, 30, 40, 50, 60, 80 and 100 mg L^{-1} concentration of adsorbate solution samples were taken using the same previous procedure.

The percentage removal was studied as a function of adsorbent dosage by preparing adsorbent solutions with fixed dye concentration 20 mg L^{-1} and pH 4 for CV and 6 for MB. Thereafter, the last experiment was done at the optimum result of each condition to confirm the best removal efficiency.

The percentage of removed dye (R%) in the solution was calculated by using Eq. (2) [16].

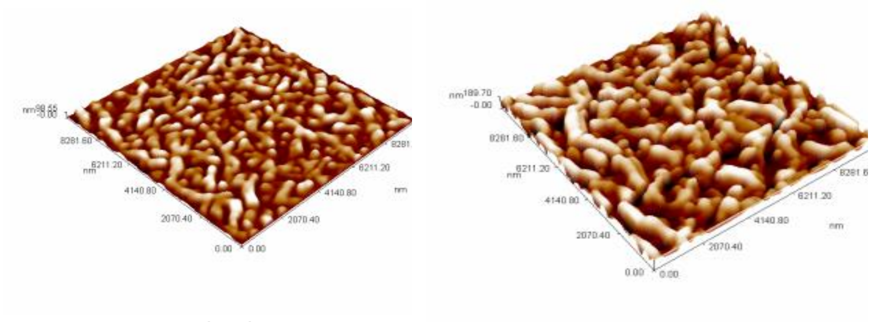
$$R(\%) = \frac{(C_o - C_e)}{C_e} \times 100 \tag{2}$$

The equilibrium data were then fitted using isotherm analysis and kinetic isotherm.

3. Results and Discussion

3.1. Adsorbent structure

Surface morphology was analysed by scanning probe microscope CSPM (AFM image). Figures 3 and 4 characterize that fennel seeds clay has the amorphous and granular surface, the particles are heterogeneous and have a rough surface. This surface exhibits a rough texture, thus making the adsorption process more available and the adhesion easy to take place.



(a) AFM image for fennel seeds before adsorption.

(b) AFM image for fennel seeds after adsorption.

Fig. 3. AFM image for fennel seeds.

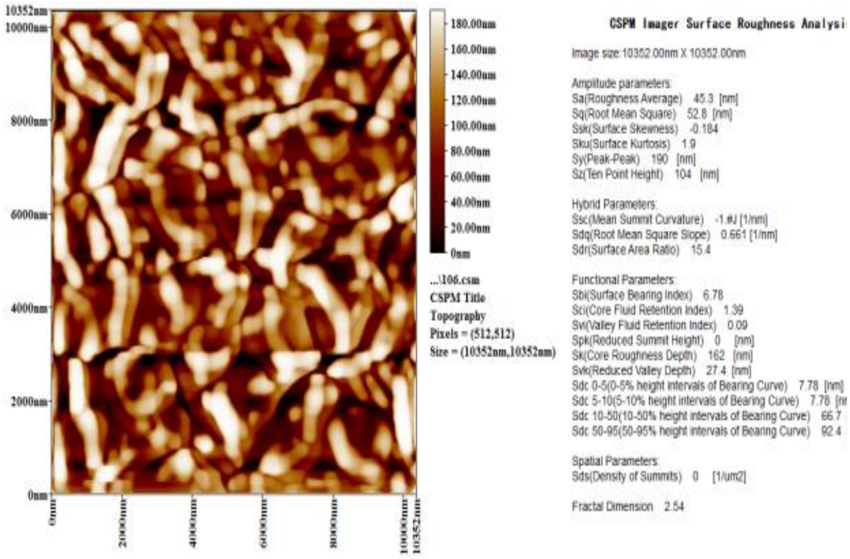


Fig. 4. AFM image of top surface of fennel seeds and roughness analysis before (up) and after (down) the process.

3.2. FTIR analysis

Figure 5 illustrates the FTIR spectra of fennel seeds. FTIR figure shows a number of peaks due to the adsorption process. The exhibition of broadband from 3300 cm^{-1} represents O-H (hydroxyl) functional groups on fennel seeds. The strong peaks from 2900 cm^{-1} to 2800 cm^{-1} is evidence of C-H (carboxylic) stretch vibration. The strong absorption peak at 1711 cm^{-1} is attributed to the presence C = O bond. The vibration at 1600 cm^{-1} is due to the presence of C = C (primary amine). The range of wavelength from 1460 cm^{-1} to 1063 cm^{-1} due to C-O primary alcohol) [13]. These functional groups are usually active for dyes removal [15]. All the previous peaks show a shift to a new wavelength, which is an indication of the participation of the functional groups in the adsorption process and as in Table 2.

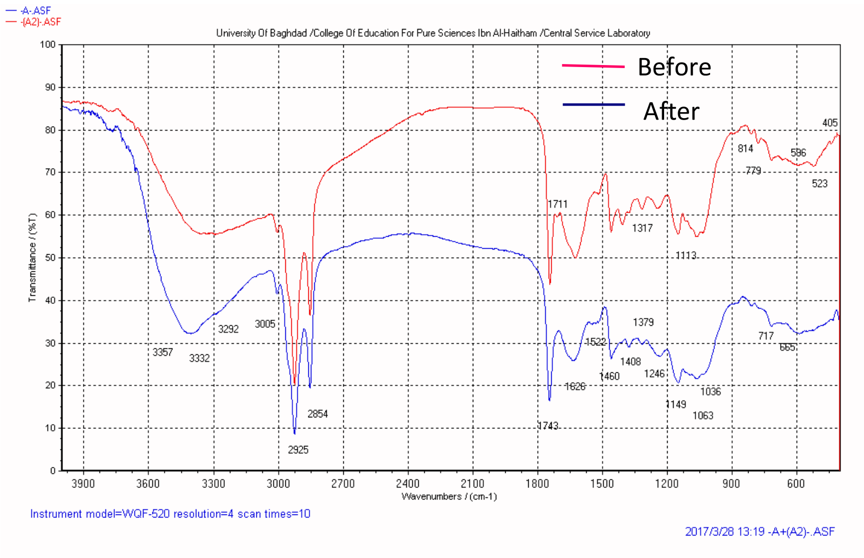


Fig. 5. FTIR analysis of fennel seeds before and after adsorption process.

Table 2. Functional groups in the adsorption process.

Functional groups	Before (cm^{-1})	After (cm^{-1})
O-H	3357	3408
C-H	2924	2925
C-H	2858	2860
C = O	1711	1743
C = C	1600	1626
C-O	1430	1460
C-O	1120	1149

3.3. pH results

The effect of initial solution pH was defined by shaking 1 g of fennel seeds sorbent and 100 mL of dye solution of initial dye concentration of 20 mg L^{-1} for each of CV and MB dyes at room temperature and 600 µm particle size using different solution pH ranging from 2 to 10. Patel and Vashi [15] commented that shaking was provided for 90 minutes contact time, in order to reach equilibrium, and the shaking speed was

200 rpm. The removal efficiency was calculated by Eq. (2). Figure 6 shows the percentage removal of CV and MB respectively. It is clear that when pH was increased from 2 to 10, the highest removal percentage of MB at pH 6 was 65.21 %, and for CV at pH 4 was 86.554% and thereafter it decreased. At different pH, adsorbent and adsorbate are charged negative or positive charges, therefore, attraction or repulsion forces will act between them. Moreover, the functional groups in the adsorbent and adsorbate, can be protonated or not in different pH and perform the adsorption process [12]. Almost similar readings were obtained when dye solutions were treated with date palm fibre [12].

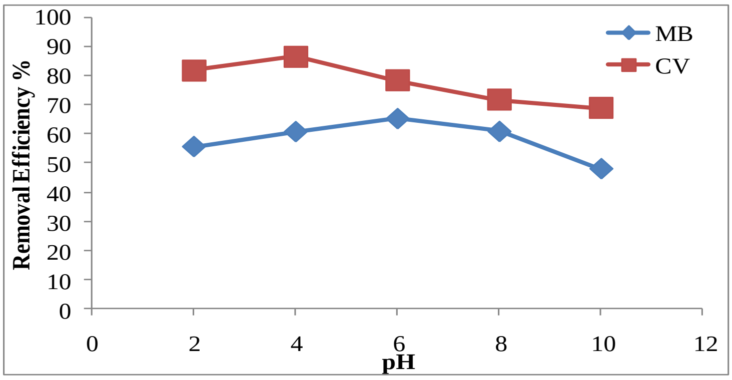


Fig. 6. Effect of pH on CV and MB dye removal efficiency using fennel seed as an adsorbent.

3.4. Dosage results

In order to determine the ability of the adsorbent for a given initial concentration of dye solution, the adsorbent dosages experiments were carried out. The amount of adsorbent dosages varied from 1.5 to 30 g L^{-1} solution for each CV and MB dyes with an initial concentration of 20 mg L^{-1}, 600 µm of particle size, pH 6 for MB and pH 4 for CV at shaking speed of 200 rpm for 90 min.

The results are shown in Fig. 7 for CV and MB dyes. From the results, it was observed that by increasing the dosage of adsorbent, the percentage removal of CV and MB dyes also increased for the first dosage (5 g L^{-1}), then after that, the percentage removal started to decrease.

The maximum removal was 86.49% for CV and 62.649% for MB at 5 g L^{-1} dosage. However, it was less than 86.49% for CV and 62.649 % for MB above and below this dosage. For sufficient adsorption, a maximum surface area is needed, and this was proved to be at 5 g L^{-1} dosage of adsorbent [17].

On the other hand, when the dosage increased to 30 g L^{-1}, the percentage removal decreased to 65.45% for CV and 46.164% for MB because the adsorption sites were unsaturated through the adsorption process [15]; it can be seen that similar data were obtained when MB was treated with *Ricinus Communis* stem powder [18].

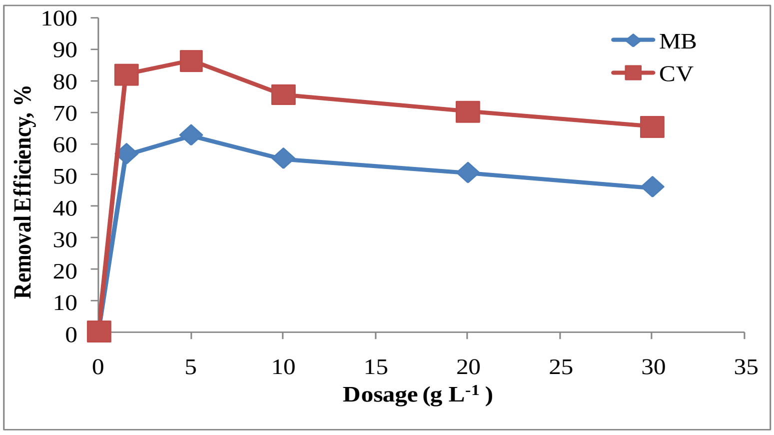


Fig. 7. Effect of adsorbent dosage on CV and MB dye removal efficiency using fennel seed as an adsorbent.

3.5. Particle size results

To study the outlines of the effect of the particle size, fennel seeds samples were taken with their different particle sizes as follows: 75, 150, 300, 600, and 800 µm and were stirred with 100 mL of 20 mg L^{-1}dye solutions, 5 g L^{-1} dosage with time 60 min and 90 min, pH 4 and 6 for CV and MB respectively at stirring speed of 200 rpm. The removal efficiencies of fennel seeds with respect to particle sizes are shown in Fig. 8, which also indicates that increasing the particle size results in a decrease in removal efficiency. The maximum result in removal efficiency was seen in particle size 75 µm. For large particle size, dye concentration decreased compared to small particle size, so the amount of dye adsorbed was small, this because of the inverse relation between the particle size and the surface area, when the particle size decreases, the active sites on the adsorbent increase, so the metal uptake increases [19, 20].

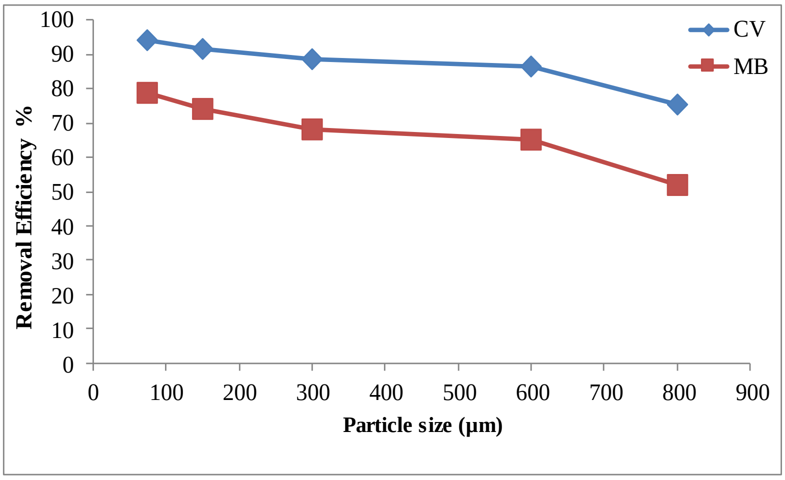


Fig. 8. Effect of adsorbent particle size on CV and MB dye removal efficiency using fennel seed as an adsorbent.

3.6. Contact time results

To determine the effect of contact time and the time to reach equilibrium for the adsorption of CV and MB onto fennel seeds, a solution of 20 mg L^{-1} for each CV and MB, particle size 600 µm, pH 6 for MB and pH 4 for CV and 5 g $L^{-1}$of an adsorbent were shaken for 120 minutes [21]. Samples were taken every 10 minutes to be analysed. The maximum adsorption rate after 60 min of shaking for CV and MB were 84% and 64% respectively, remaining at a constant rate to the end of the experiment. At the beginning of the process, there was a sufficient surface area for adsorption. However, after some time all active sites were saturated and did not allow further adsorption [22]. Figure 9 shows the removal rate versus the contact time for CV and MB.

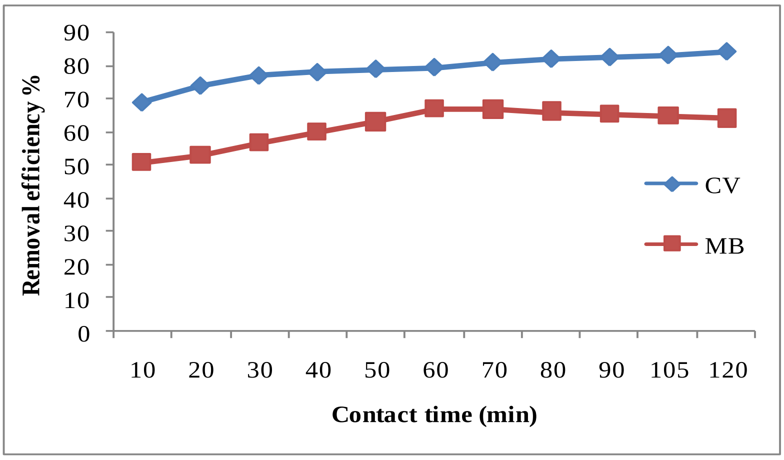


Fig. 9. Effect of contact time on CV and MB dye removal efficiency using fennel seed as an adsorbent.

3.7. Adsorbate initial concentration results

The percentage of dye removal is highly dependent on the initial amount of dye concentration. The effect of the initial dye concentration factor depends on the immediate relation between the dye concentration and the available binding sites on an adsorbent surface. Different initial concentrations were utilized to study the treatment process by adsorption and different solutions contained CV and MB (5, 10, 20, 30, 40, 50, 60, 80 and 100 mg L^{-1}) individually, at pH 6 for MB and pH 4 for CV, 600 µm of particle size, adsorbent dosage 5 g L^{-1} and contact time of 60 minutes [21].

Figure 10 shows that the percentage removal of CV and MB dyes decreased when the concentration increased. The maximum adsorption was at 5 g L^{-1} for CV and MB at rate 95% and 80% respectively. While the percentage removal increased when the concentration decreased, the fennel seed particles were saturated especially at 50 mg L^{-1} of CV and MB solutions respectively, and no more changes in removal efficiency were shown when the solution concentration increased. This was due to the lack of active sites on the surface of the fennel seed particles. However, at low concentrations, unsaturated sites were sufficient to uptake the dye molecules.

These results match the study of the removal of dye by activated carbon derived from *Ficus Carica* and sugar cane stalk [8, 17]. An additional experiment was done for confirmation of removal of CV and MB using optimum conditions, pH 4 and 6, particle size 75 µm, contact time 60 min, dye concentrations 5 mg L^{-1} and adsorbent dosages 5 g L^{-1}, removal efficiency for CV and MB were 97% and 86% respectively.

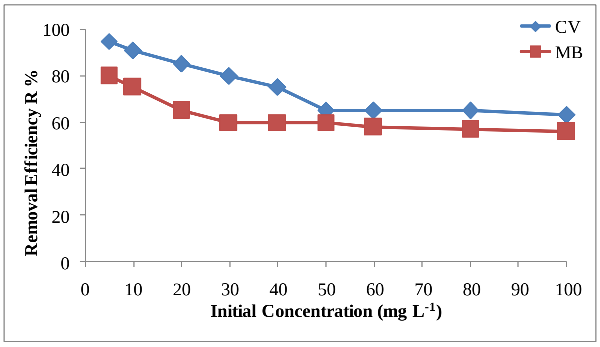


Fig. 10. Effect of adsorbate initial concentration on CV and MB dye removal efficiency using fennel seed as an adsorbent.

3.8. Adsorption isotherm models

To study the proper model, the isotherm data were analysed and were fitted into two models: Freundlich and Langmuir, as they are the most suitable and employed models.

Equilibrium uptake of CV and MB was investigated with sorbent weight of 0.5 g of fennel seeds in contact with 100 mL of solutions and at pH 4 for CV and 6 for MB. The flasks were shaken at 200 rpm and the equilibrium concentration of the remaining CV and MB was determined by the spectrometer. The analysis of the isotherm data is important to make sure that the models represent the results.

3.8.1. Langmuir isotherm

The Langmuir model is suitable for studying the monolayer adsorption because the process takes place at homogeneous sites, constant energy process and there is a saturated monolayer of adsorbate molecules on the adsorbent particle surface [13].

Rao et al. [13] proposed the Langmuir model:

$$q_e = \frac{q_m K_L C_e}{1 + K_L C_e} \tag{3}$$

where C_e is the equilibrium concentration (mg L^{-1}), q_e is the amount adsorbed at equilibrium (mg g^{-1}), q_m is the maximum amount of adsorption on the adsorbent surface (mg g^{-1}) and K_L is the Langmuir constant related to energy adsorption capacity (L mg^{-1}). Langmuir equation can be fitted into a straight line equation as follows:

$$\frac{C_e}{q_e} = \frac{1}{K_L q_m} + \frac{C_e}{q_m} \tag{4}$$

The values of K_L and q_m were calculated from the slope and intercept of the linear plots of C_e, q_e versus C_e. Dimensionless equilibrium parameter separation factor R_L [8] that characterizes adsorption is defined by Eq. (5):

$$R_L = \frac{1}{1+K_L C_o} \tag{5}$$

where C_o is the initial dye concentration (mg L^{-1}). R_L constant could conclude whether or not the adsorption is favourable. Adsorption is favourable if R_L values follows $0 < R_L < 1$, $R_L > 1$ (unfavourable), $R_L = 1$ (linear) and $R_L = 0$ (irreversible). The linear plot of the Langmuir isotherm for CV and MB adsorption is shown in Fig. 11 and Table 3 respectively. The maximum adsorption capacity q_m for complete monolayer coverage is found to be 13.47 and 18.24 mg g^{-1}, for CV and MB, respectively. Two values were between 0 and 1 and R_L value obtained is listed in Table 3. R_L values (0.65 and 0.87) for CV and MB, show that the adsorption process was favourable. K_L obtained values are 0.1076 and 0.0298 L g^{-1} for CV and MB the lower value of K_L mean that the particle radius of fennel seed was small towards adsorption.

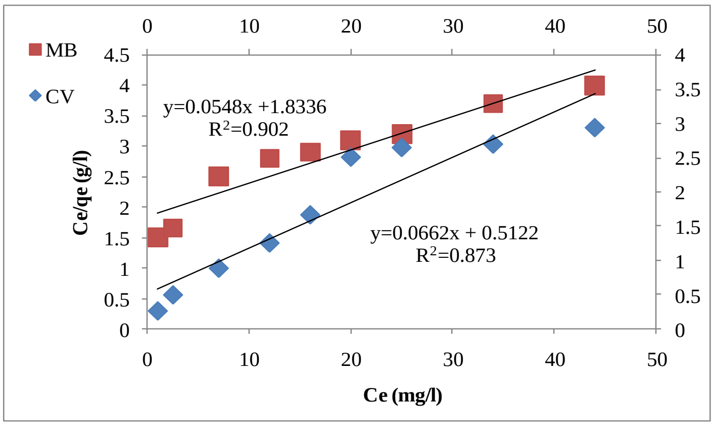


Fig. 11. Langmuir isotherm plot of CV and MB dye adsorption onto fennel seed.

Table 3. Langmuir and Freundlich parameters for adsorption of CV and MB onto fennel seeds.

Dye	Langmuir				Freundlich		
	q_m(mg g^{-1})	K_L(L gm^{-1})	R_L	R^2	n	K_f(mg g^{-1})	R^2
CV	13.47	0.1076	0.65	0.873	2.26	2.02	0.992
MB	18.24	0.0298	0.87	0.902	1.443	0.81	0.993

3.8.2. Freundlich isotherm

The Freundlich model is an equation dependent on the adsorption on heterogeneous surfaces. El-Sayed et al. [8] expressed it as the Freundlich model.

$$\ln q_e = \ln K_f + \frac{1}{n} \ln C_e \tag{6}$$

where q_e is the mass of adsorbate adsorbed per unit mass of adsorbent (mg g^{-1}), C_e is the equilibrium concentration of adsorbate (mg L^{-1}), K_f indicates adsorption capacity and n an intensity factor of the adsorption process, which varies with the heterogeneity of the adsorbent. The adsorption is more favourable when 1/n is greater. The fractional values of 1/*n* ranged between 0 and 1. The constants K_f and 1/*n* were calculated from the intercept and slope of the plot of lnq_e vs. lnC_e. Figure 12 shows the linear plot of Freundlich isotherm for adsorption of CV and MB onto fennel seeds. The calculated parameters are shown in Table 3. The Freundlich isotherm model was found best fitted with experimental data as the value of R^2 equal to 0.992 and 0.993 for CV and MB in Table 3. K_f is a Freundlich constant that shows the adsorption capacity on heterogeneous site levels. The adsorption intensity given by the Freundlich coefficient (1/*n*) is smaller than the unit indicating the favourable adsorption. These results indicate that the Freundlich equation represents a better fit than Langmuir for CV and MB. The Langmuir equation shows homogeneous adsorption while the Freundlich equation demonstrates heterogeneous adsorption. The correlation coefficients are shown in Table 3. R^2 results suggest that the Freundlich model could be applied to the adsorption of CV and MB onto fennel seeds; this indicates that the heterogeneous adsorption occurred on the surfaces [5] and almost similar results were concluded when CV dye was treated by natural adsorbents [19].

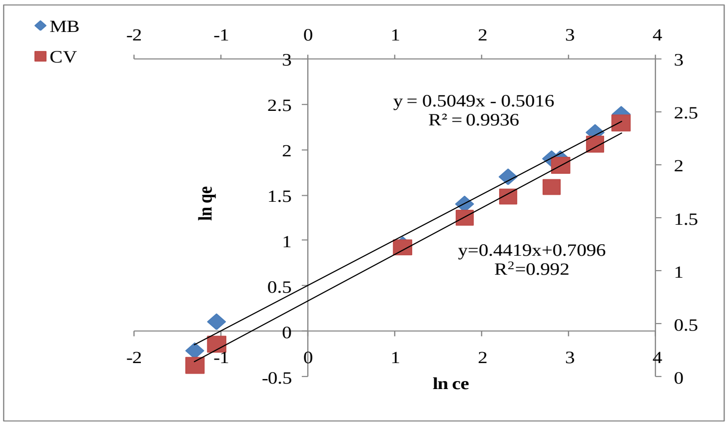


Fig. 12. Freundlich isotherm plot of CV and MB dyes adsorption onto fennel seed.

3.9. Adsorption dynamics

Pseudo first order and pseudo second-order were used to analyse the kinetics of CV and MB onto fennel seeds. The value of R^2 is an indicator of the success of the process. When R^2 values were close to 1, high value, the best adsorption process occurred [23, 24]. The Pseudo first order is given in Eq. (7):

$$\log(q_e - q_t) = \log q_e - \frac{K_1}{2.303} \times t \tag{7}$$

where q_e is a CV or MB amount adsorbed onto the unit weight of adsorbent at equilibrium (mg g^{-1}), q_t is CV or MB amount adsorbed onto the unit weight of adsorbent at any time t (mg g^{-1}) and K_1 is the rate constant for pseudo-first-order model (L min^{-1}).

The value of q_e and K_1 was found from slope and intercept of the linear relation between log (q_e - q_t) with t at the given concentrations. The straight line between log (q_e - q_t) and the time emphasizes the applicability of Eq. (7) in Fig. 13.

The pseudo-second-order is given in Eq. (8) [21]:

$$\frac{t}{q_t} = \frac{1}{K_2 q_e^2} + \frac{1}{q_e} t \tag{8}$$

where q_e is a CV or MB amount adsorbed onto the unit weight of adsorbent at equilibrium (mg g^{-1}), q_t is CV or MB amount adsorbed onto the unit weight of adsorbent at any time t (mg g^{-1}) and K_2 is the rate constant for pseudo-second-order model (L min^{-1}).

The value of q_e and K_2 was found from the slope and intercept of the linear relation between t/q_t at the given concentrations. The straight line between t/q_t and the time emphasizes the applicability of Eq. (8) in Fig. 14. Table 4 shows each of the following parameters K_1, K_2, R^2 at different initial CV and MB concentrations. It was found that q_e values from pseudo-second-order model were better fitted appreciably than the pseudo-first-order model values.

The values of q_e indicated that pseudo-second-order model was better obeyed. The data also shows that the values of the determination coefficient (R^2) for pseudo-second-order model were 0.999 and 0.996 for CV and MB, respectively, whereas R^2 for pseudo-first-order model were 0.985 and 0.945, for CV and MB, respectively. The higher correlation factor coefficient R^2 values of pseudo-second-order for both dyes indicate that pseudo-second-order model is better fits the adsorption kinetics than pseudo-first-order.

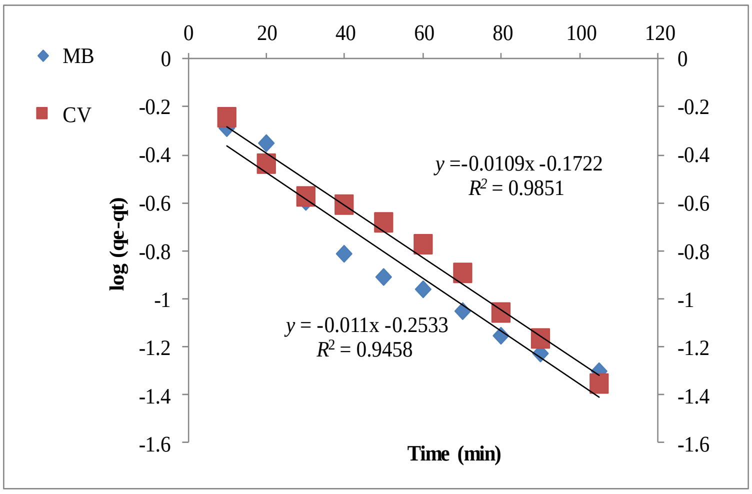


Fig. 13. Pseudo first order kinetics for adsorption of CV and MB dyes onto fennel seed.

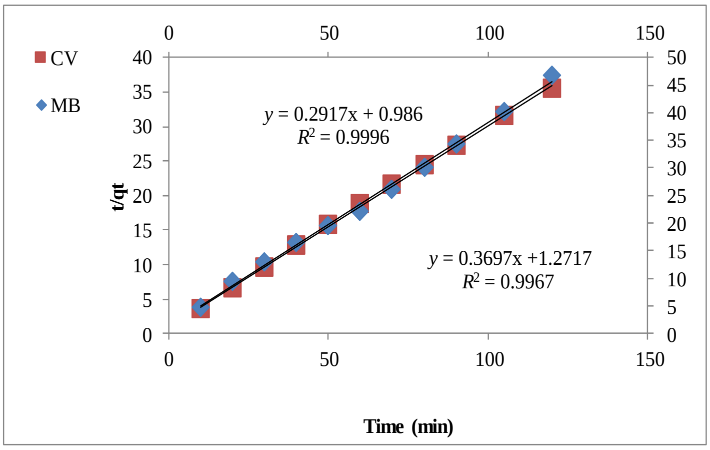


Fig. 14. Pseudo second order kinetics for adsorption of CV and MB dyes onto fennel seed.

Table 4. Pseudo first and second order parameters.

Dye	Pseudo-first order			Pseudo-second order		
	K_1(min^{-1})	q_e(mgg^{-1})	R^2	K_2(min^{-1})	q_e(mgg^{-1})	R^2
CV	0.0251	0.673	0.9851	0.0894	3.428	0.999
MB	0.0253	0.558	0.9458	0.1078	2.705	0.996

4. Conclusion

The best removal performance of CV and MB are 86%, 65% for pH 4, 6, 86% , 62% for 5 g L^{-1} dosage, 94% and 78% for particle size 75 µm, 84% and 64% for contact time 60 min, 95% and 80% for 5 mg L^{-1} dye concentration. Moreover, by using optimum conditions, pH 4 and 6, particle size 75 µm, contact time 60 min, dye concentrations 5 mg L^{-1} and adsorbent dosages 5 g L^{-1}, removal efficiency for CV and MB were 97% and 86% respectively. The adsorption removal of CV and MB by using fennel seeds in this study follows the Freundlich adsorption process, with coefficients n for CV and MB =2.26,1.443 and K_f for CV and MB = 2.02, 0.81 with R^2 = 0.992 and 0.993 for CV and MB. The adsorption kinetics of CV and MB onto fennel seeds in this research is suited with the pseudo-second-order kinetics, with parameters K_2 for CV and MB = 0.0894 min-1, 0.1078 min^{-1} and q_e for CV and MB =3.428 mg g^{-1}, 2.705 mg g^{-1} with R^2= 0.999 and 0.996 for CV and MB.

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Nomenclatures

C_e	Equilibrium concentration of CV or MB solutions, mgL^{-1}
C_o	Initial concentration of CV or MB solutions, mgL^{-1}

K_1	Rate constant for pseudo-first-order model, L min^{-1}
K_2	Rate constant for pseudo-second-order model, L min^{-1}
K_f	Freundlich constant
K_L	Langmuir constant, L mg^{-1}
m	Mass of dry adsorbent, g
n	Freundlich constant
q_e	Amount of CV or MB adsorbed onto unit weight of adsorbent at equilibrium, mg g^{-1}
q_m	Maximum amount of adsorption for CV or MB on the adsorbent surface, mg g^{-1}
q_t	Amount of CV or MB adsorbed onto unit weight of adsorbent at any time t, mg g^{-1}
R	Removal efficiency of CV or MB
R^2	Correlation coefficient
R_L	Constant could conclude whether or not the adsorption is favourable
t	Time, min
V	Volume of solution, L

Abbreviations

AFM	Atomic Force Microscopy
FTIR	Fourier Transform-Infrared Radiation

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