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Crystal Violet Removal From Aqueous Solution Using Diatomite Mineral

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إزالة صبغة البنفسج البلوري من المحلول المائي باستخدام معدن الدياتوميت

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Abstract:

This study shows that diatomite mineral is viable for the removal of crystal violet dye from its aqueous solutions using batch process. Several parameters that may affect the adsorption process were investigated such as contact time, pH effect, initial dye concentration and adsorbent mass. The optimum removal conditions were obtained at pH 6 at a concentration of 82 mg/L (0.2mM). Langmuir, Freundlich, and Temkin models were applied to investigate the adsorption behaviour. The experimental exchange capacity was found to be 75mg.g-1, whereas that for Langmuir and Freundlich was 131.6 and 0.94 mg.g-1 respectively the latter suggested a physical adsorption behaviour. In contrast to Temkin proposing a chemical behaviour due to the high value of heat of adsorption (B = 93 kJ/mol). Pseudo first order and pseudo second order show good fit with the experimental data with qe=20.93 mg/g; K1=0.207 for the first order and qe=42.19 mg/g and K2=2500 for the second order. The correlation coefficients were R2= 0.9983 and R2 = 0.999 for first and second order respectively.

Keywords: Adsorption, diatomite, crystal violet, adsorption isotherms, exchange capacity.

الملخص:

توضح هذه الدراسة أن معدن الدياتوميت قابل للتطبيق لإزالة صبغة اللون، البنفسجي البلوري من محاليله المائية عبر عملية الدفعات. تم التحقيق في العديد من المتغيرات التي قد تؤثر على طريقة الامتزاز مثل وقت التلامس وتأثير الرقم الهيدروجيني وتركيز الصبغة الأولي وكتلة المادة المازة. تم الحصول على ظروف الإزالة المثلى عند درجة حموضة 6 بتركيز 82 مجم/لتر (0.2 ملي مولار). تم تطبيق نماذج لانجميور وفروندليتش وتيمكين لدراسة سلوك الامتزاز. وُجِد أن سعة التبادل التجريبية كانت 75 ملغم\غم، في حين كانت سعة التبادل 131.6 و 0.94 ملغ\غم للانجميور وفرندليش على التوالي، ويشير الأخير إلى سلوك امتزاز فيزيائي. على النقيض من اقتراح تيمكين لسلوك كيميائي بسبب القيمة العالية لحرارة الامتزاز (B) التي كانت 93 كيلوجول/مول. يُظهر الترتيب الأول والثاني الزائف توافقًا جيدًا مع البيانات الاستقصائية حيث كانت qe=20.93mg/g ؛ K1=0.207 للترتيب الأول و qe=42.19mg/g و K2=2500 للترتيب الثاني. وكانت معاملات الارتباط R2= 0.9983 و R2 = 0.999 للترتيب الأول والثاني على التوالي.

الكلمات المفتاحية: إدمصاص، دايأتومايت، البنفسج البلوري، أيزوثيرمات الادمصاص، السعة التبادلية.

Introduction:

Organic dyes were originally used almost 4,000 years ago, when indigo blue was found in mummy wrappings in Egyptian tombs (Benkhaya et al., 2017). More than 100,000 commercial dyes are available, and more than 7,107 tons of dyes are produced annually worldwide. These dyes are widely used in a number of industries, such as textiles, food, cosmetics, and paper printing, with the textile industry being the largest consumer of dyes (Silveira et al. 2009). Synthetic organic dyes, such as reactive dyes, process dyes, and direct dyes, are increasingly used in textile industry. Fabrics are highly complex due to the variety of dyes and chemicals used in an attempt to produce more attractive and popular colors in a competitive market. Environmental concerns related to the manufacture and use of dyes have increased significantly over the past ten years and are undoubtedly one of the major factors influencing the textile dye industry today (Benkhaya et al., 2017).

Textile dyes are classified based on their chemical structure (such as azo, nitro, indigo, anthraquinone, phthalein, triphenylmethyl, nitrate) or commercial applications. These dyes are complex organic compounds, sustaining various functional groups and aromatic rings that give them their distinct color characteristics (Benkhaya et al., 2017). While dyes often maintain their crystalline or particulate form throughout the application process, they become soluble at some point. The purpose of a dye is to impart color to objects of which they are an essential component. Resonance and color transfer often require an aromatic ring structure with a side chain. (Color arises due to resonance structures that alter or exhibit absorption bands in the visible spectrum of light). Chemical structure has been linked to color in dye synthesis using a chromogen-chromophore with an auxochrome. A chromogen is an aromatic structure containing benzene, naphthalene, or anthracene rings. The chromophore group is the source of colors and is represented by the following radicals, which form the basis of the chemical classification of pigments when combined with chromogens:

Azo (–N=N–); carbonyl (=C=O); carbon (=C=C=); carbon-nitrogen (>C=NH or –CH=N–); nitroso (–NO or N–OH); nitro (–NO_2 or =NO–OH); thio (>C=S, and other carbon-sulfur groups). The chromogen-chromophore structure is often not sufficient to impart solubility and adhesion of the dye to the fiber. Auxochromes or bonding affinity groups are amine, hydroxyl, carboxyl, and sulfone radicals, or their derivatives. These auxochromes are important in the classification of dye uses (Allen, 1993) Some of these dyes are listed below.

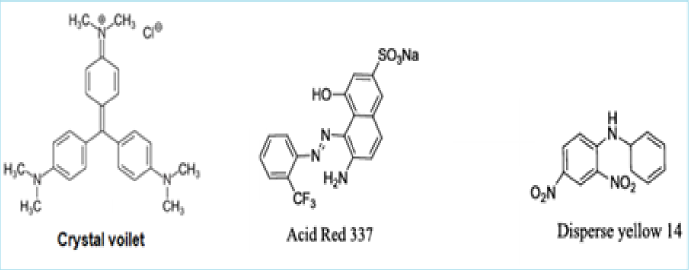


Figure (1): some examples of organic dyes

Synthetic dyes have been widely used in textile, paper, pharmaceutical, food packaging, and other industries, such as plastics industry. Improper processing and dyeing methods used by most of these industries have resulted in the release of tons of dyes into aquatic resources, particularly open waters, amounting to 40,000–50,000 tons (Sulthana et al., 2022). The release of untreated dyes into water sources has disastrous effects on both the marine ecosystem and human health. These dyes can cause genetic mutations, birth defects, or cancer in aquatic species. Potential consequences include serious dysfunctions of the human reproductive system, brain, kidneys, liver, and nervous system. The dye content in industrial wastewater contaminates water bodies by causing discoloration, obstructing sunlight penetration, and restricting biological and photochemical processes in water sources (Wong et al., 2004). As mentioned, the use of natural dyes in the dyeing process was one of the oldest methods used by the ancients. Obtaining dyes from natural sources means extracting them from plants and animals. Colors are derived from natural sources. Dyes can be divided into two categories: natural dyes and synthetic dyes (Ali, 2025). For a substance to be considered as a dye, certain conditions must be met:

- It must have a specific and stable color.
- It must be able to dye fabric directly or indirectly.
- When applied to fabric, it must not fade quickly, i.e., it must be colorfast to light and resistant to water. This gives it, to some extent, better resistance to acids and dilute alkalis, especially the latter due to the alkaline nature of washing soda (Ali 2025).

Crystal violet (CV) is a biochemical tissue dye of the triphenylmethane group. It is known for its mutagenic and mitogenic properties, and therefore must be treated (Abbas et al., 2021).

Adsorbents can be classified into two categories: natural and synthetic. Silicate materials such as Zeolite, sand and clay are the most known examples of inexpensive and plentiful natural adsorbents. However, researchers may employ domestic, industrial, and agricultural waste to create synthetic adsorbents (activated carbon). The distinct surface area and porosity structure of each of these adsorbents improve their adsorption capabilities (Elizabet et al., 2019; Kumar et al., 2022).

Diverse materials have been used for removing crystal violet dye from aqueous solution such as: Adsorption of crystal violet dye onto industrially consumed pepper seeds was conducted by an international team of researchers from several countries (India, Portugal, Saudi Arabia, Australia, and Ethiopia). This study presented many models to study the behavior of the adsorption process (Sulthana et al., 2022). Recently, a group of Iranian researchers conducted a study on the adsorption of crystal violet dye on some nanocomposites made from zinc oxide, a mixture of zinc oxide with iron oxide, and zinc oxide with copper oxide (Tekyeh et al., 2024). A study was conducted on the adsorption of crystal violet dye onto peanut shells, where the study addressed the effect of many variables such as the initial concentration, particle size of the adsorbent, and temperature (Abbas et al., 2021).

In this study, diatomite: a natural local mineral was used for the adsorption of crystal violet dye from the aqueous solution. Diatomite was selected due to its availability, cost-effectiveness, and its mechanical and physical properties, such as porosity, particle size and surface area.

The light, fine-porous rocks called diatomites are mostly composed of diatoms, which are the minuscule opaline skeletons of diatomic algae, or their fragments. Diatomites can be white, light grey, brownish grey, or yellowish grey, among other colours. Because diatomites include organic pollutants like plant remains, they can occasionally appear black and brown. Since the pores and pore walls of diatoms often have nanoscale dimensions, it is appropriate to consider them as nanomaterials. Photomicrographs reveal that each diatomite skeleton has a uniquely ordered micro- and nanoporous structure (Kazan, 1976).

This study is based on using diatomite to investigate the removal of crystal violet from aqueous solution following batch techniques. The study was conducted at different pH values, initial dye concentrations and adsorbent mass. The natural white diatomite, was used as received without pretreatment and have recently characterized (Issa et al., 2024) using XRF (Bruker S8 Tiger), XRD (Bruker D5005), FTIR (Bruker Vector 22), and SEM (JEOL JSM-5610 LV) techniques to assure its composition and morphology.

Modelling:

Some isothermal models were used to estimate the adsorption behaviour of CV onto diatomite, according to the parameters mentioned previously.

Langmuir isotherm:

Assuming monolayer sorption onto a surface with a finite number of identical sites, the Langmuir sorption isotherm is applied to equilibrium sorption. According to Langmuir (1916), the Langmuir equations are expressed as shown in equations 1 and 2.

$$\frac{1}{\mathrm{q_e}} = \frac{1}{\mathrm{Q_m}} + \frac{1}{\mathrm{bQ_mC_e}} \qquad (1)$$

The separation factor (R_L), which is provided as follows (Cheruiyot et al., 2019), can also be used to express the form of this isotherm:

$$\mathrm{R_L} = \frac{1}{1 + \mathrm{K_LC_0}} \qquad (2)$$

Where K_L is Langmuir constant (L/mg) related to the affinity of binding sites and the free energy of sorption. q_e is the experimental data of the equilibrium capacity (mg/g). Ce is dye concentration at equilibrium in solution (mg/l). Q_m is the equilibrium capacity obtained by calculating from the model (mg/g). Q_m is calculated from equation 3, and K_L is calculated from equation 4.

$$Q_{max} = \frac{1}{slope} \qquad (3)$$

$$k_L = \frac{1}{Q_{max} \times intercept} \qquad (4)$$

Freundlich isotherm:

Freundlich's adsorption mechanism is another concept that has been proposed. This isotherm agrees with the formation of heterogeneous adsorbate layers, which can be empirically explained. Equation 5 (Alkherraz, 2025; Pathania et al., 2017) represents the Freundlich equation for heterogeneous surface energy systems.

$$\log(q_e) = logK_F + \frac{1}{n} logC_e \qquad (5)$$

Where K_F and n are Freundlich constants, determined from the plot of ln q_e versus ln C_e. The parameters K_F and 1/n are related to sorption capacity and the sorption intensity of the system. The magnitude of the term (1/n) gives an indication of the favourability of the adsorbent/adsorbate systems (Malik, 2003). K_F is calculated from equation 6, 1/n is the slope (eq. 7).

$$logK_F = intercept \qquad (6)$$

$$\frac{1}{n} = slope \qquad (7)$$

Temkin isotherm:

The Temkin equation is an adsorption isotherm model that describes how the heat of adsorption decreases linearly with surface coverage, reflecting adsorbent-adsorbate interactions (Sulthana et al.,2022). It is commonly stated in a linear form, as shown in equation 8.

$$\mathrm{q_e} = \mathrm{B_T lnk_T} + \mathrm{B_T lnC_e} \qquad (8)$$

where q_e is the amount of adsorbate at equilibrium, C_e is the equilibrium concentration, K_T is the binding constant, B_T is the constant related to the heat of adsorption, and R and T are the gas constant (8.314 J/mol K) and absolute temperature in Kelvin, respectively, and b is the Temkin constant related to heat of sorption (J/mg).

Equation 9 can be used to compute Temkin constant (b_T), which is directly connected to the heat of adsorption (ΔH) and indicates whether the process is physical or chemical.

$$B_T = slope \qquad (9)$$

K_T (Equilibrium Binding Constant): The equilibrium bind constant (K_T) reflects the highest binding energy available throughout the adsorption phase and was determined using equation 10.

$$K_T = e^{(intercept/b_T)} \qquad (10)$$

Experimental:

Analytical grade chemicals and deionised water, were used throughout the experiments. Hydrochloric acid (from Readel de Haen), sodium hydroxide (from Readel de Haen), crystal violet dye (from BDH), diatomite was provided from industrial research center (Tajoura Libya). Ordinary glassware and apparatus, DR3900 spectrophotometer.

For the effect of contact time, 30mL of 0.3mM of the dye solution was taken to 50mL plastic centrifuge tube, pH was adjusted to 6 for the series of 7 tubes, making total volume of 40mL. 0.08 g of the adsorbent (diatomite) was added to each tube, kept static for 1.5hrs at room temperature, centrifuged at 3000rpm for 30 minutes using Ohaus model. The clear aliquot solutions were taken to measure the absorbance at 589nm. Thus, the concentration was calculated from the regression equation obtained from the calibration curve. The same procedures were followed for all other experiments (i.e effect of pH, initial dye concentration and adsorbent mass).

Results and discussion:

Stability of Crystal Violet Dye:

Because organic dyes are generally unstable and easily degradable, a preliminary experiment was conducted to determine the dye's stability, as shown in Figure 2. It was found that the dye could withstand and maintain its structure for about an hour, with a standard deviation of ±0.0017, around an average absorbance of 0.626. Based on this, the researchers ensured that the pH of the target solutions in each experiment was adjusted and that the adsorbent was added as early as possible before the end of the specified stability period.

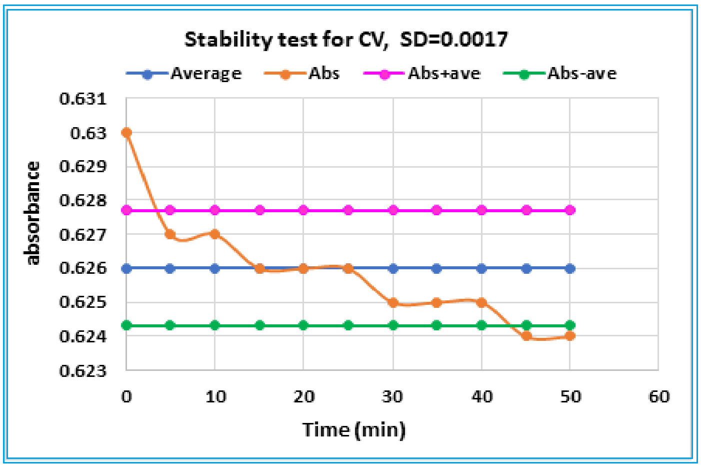


Figure (2): The stability of crystal violet

Maximum Wavelength (l_{max}):

A spectroscopic scan of a 0.1 mM crystal violet solution was conducted over the 200-800 nm range. The maximum wavelength was found to be 589 nm, as shown in Figure 3. This is consistent with a previous study in which the maximum wavelength was 590 nm (Sulthana et al., 2022). Some other studies, due to the relatively high dye concentrations conducted, utilised slightly different wavelengths, such as 580 nm (Cheruiyot et al., 2019) and 583 nm (Castekkar-Ortega et al., 2022).

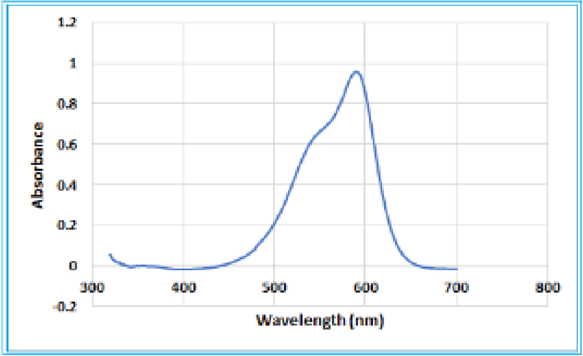


Figure (3): Maximum wavelength (l_{max}) for the CV dye.

Calibration curve:

A series of solutions with concentrations ranging from 0.005 to 0.02 millimoles per liter (mM/L) of crystal violet dye were prepared. The absorbance of these solutions was measured at a wavelength of 589 nm using a DR3900 spectrophotometer. The relationship between the concentration on the x-axis and the absorbance on the y-axis was plotted, as shown in Figure 4.

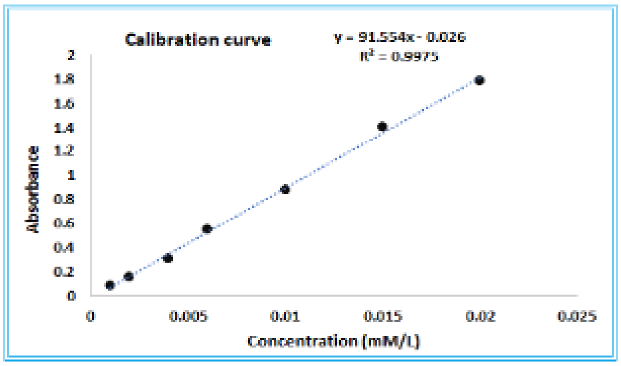


Figure (4): Calibration curve for CV dye

From Figure 4, it is clear that the relationship between concentration and absorbance is a linear relationship consistent with the Beer-Lambert law, a linear equation $y = 91.554x - 0.026$ and the correlation coefficient was $R^2 = 0.9975$. From the curve in Figure 3.3, it is clear that the lower limit of measurement (LOD) = 0.0013 mM/L.

Effect of contact time:

To determine the optimal time for dye adsorption onto diatomite, a series of experiments were conducted using a single concentration (0.3 mM) of dye, at various times ranging from 15 minutes to 3.5 hours. Figure 5 shows that the system reached equilibrium starting at approximately 1.0 hours, furthermore all experiments were conducted at 1.5hrs intervals.

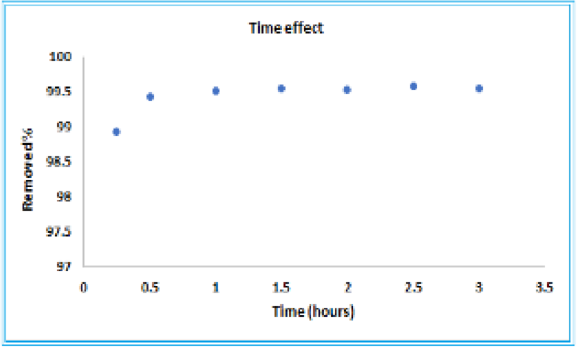


Figure (5): Effect of contact time of the adsorption of CV onto diatomite

Effect of Ph:

By plotting the relationship between pH and % removal, Figure 6 shows that maximum removal was achieved at pH = 6, above pH=6 the system almost reached an equilibrium state. This is consistent with a previous study in which crystal violet dye was removed from the sheath powder of the royal palm frond (Sen et al., 2024). Only a slight increase in % removal was observed (98% at pH = 2 to 98.7% at pH = 6,). Although some studies have shown a decrease in crystal violet removal with increasing pH (Abbas et al., 2021). The reason for the increased dye removal rate (CV) at pH>6 may be due to the availability of more active sights (Sulthana et al., 2022).

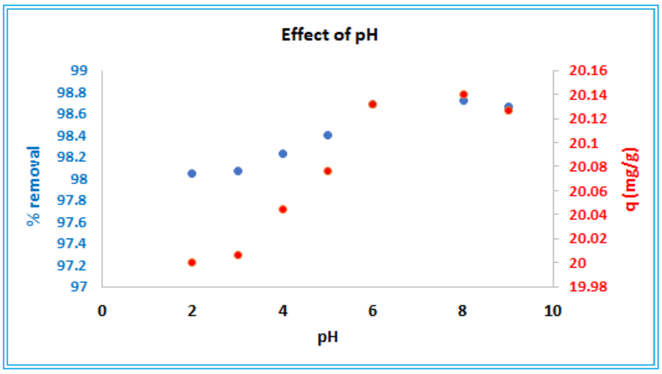


Figure (6): Effect of pH on the adsorption of CV onto diatomite

Functional groups that can be protonated (added protons) or deprotonated to produce distinct surface charges in pH-varying solutions may be found in both the adsorbent and the adsorbate, resulting in electrostatic attraction or repulsion between the charged dyes and the adsorbent materials. Figure 6 depicts the exchange capacity, which was determined as mg/g. Although the increase was negligeable, it coincided with the shift in removal ratio, which increased from around 20 mg/g to about 20.2 mg/g. We believe that the change in either removal ratio or equilibrium exchange capacity was not substantial across the pH range of 2 to 9.

Effect of Initial Ion Concentration:

To study the effect of the initial concentration of the crystal violet ion, a series of solutions with concentrations between 0.15 and 0.40 mmol/L were prepared. 0.08 g of diatomite was added to a total volume of 40 ml at a pH of 6. After following the steps mentioned in the practical section, the absorbance of each solution was measured, resulting in the adsorption behaviour as shown in Figure 7.

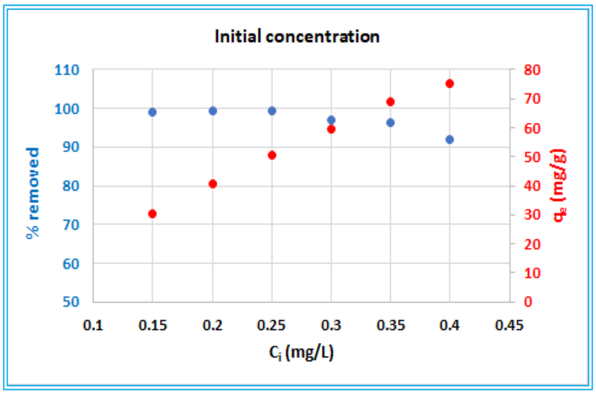


Figure (7): Effect of initial ion concentration on the adsorption of CV onto diatomite

As shown in Figure 7, the removal rate appears to be stable when the initial concentration changes from 0.15 to 0.25 mM per liter. The % removal was approximately 99%. As the initial dye concentration increased, the removal rate gradually decreased until it reached approximately 92% at a concentration of 0.4 mM. The decrease in the removal rate with increasing sorbent concentration is due to the saturation of the sorbent surface active sight (Sulthana et al., 2022). On the other hand, Figure 3.6 shows that the experimental exchange capacity increases linearly with increasing adsorbent concentration. The experimental exchange capacity at equilibrium increased from 30 to approximately 75 mg/g, as shown in the figure. This increase is consistent to that reported by Castellar-Ortega et al. (2022), showing an increase from 30 to approximately 85 mg/g.

Effect of Adsorbent Quantity:

In this experiment, the effect of adsorbent quantity on the adsorption efficiency of crystal violet dye onto diatomite was studied. A series of solutions containing the same concentration of dye ions were prepared with various amounts of adsorbent, ranging from 0.05 to 0.16 grams of diatomite, were added, as shown in Figure 8.

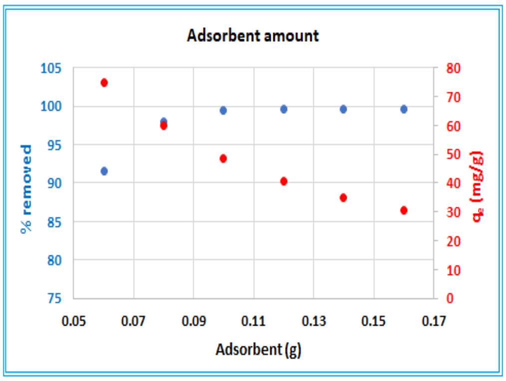


Figure (8): Effect of adsorbent amount on the adsorption of CV onto diatomite

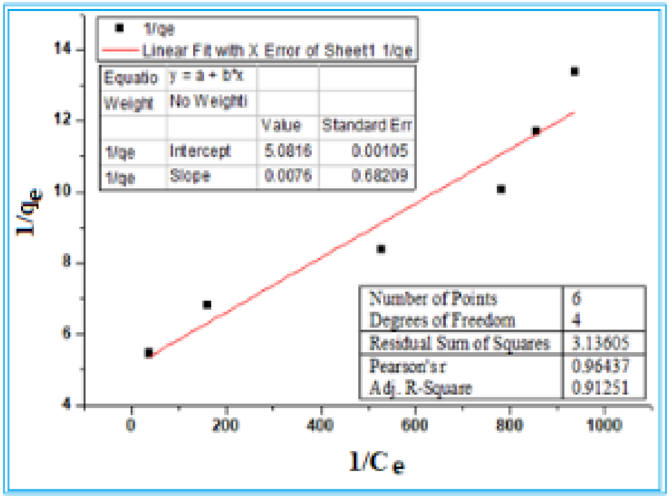
From Figure 8, we observe that as the adsorbent amount increased, the removal rate increased. The removal rate increased, from approximately 92% at adsorbent amount of 0.06 g to approximately 97% at an adsorbent amount of 0.08 g. Between 0.08 g and 0.10 g of adsorbent, a slight increase in the removal rate was observed, from 97% to approximately 99%. As shown above, there was no significant change above 0.1g, and the system reached equilibrium until the adsorbent amount was 0.16 g. The maximum removal rate was 99.6%. The removal rate in this case is very close to that observed when the initial dye ion concentration changes, as shown in Figure 7, although the removal rate varies slightly with that reported previously (Abbas et al., 2021). From the figure, we note that the exchange capacity decreases with increasing adsorbent quantity, as the active sites increase with increasing adsorbent quantity, especially when the applied concentration is constant. The exchange capacity decreased from 74 to approximately 34 mg/g when the adsorbent quantity increased from 1.5 to 4 g/L. This behavior is similar to previous studies on the adsorption of crystal violet dye onto diatomite (Sulthana et al. 2022), and is also consistent with a study on the adsorption of crystal violet dye onto laboratory-synthesized zinc oxide and other composite materials (Tekyeh et al., 2024).

Isotherm Model Diagrams:

The adsorption of a crystal violet dye onto diatomite was studied using a variety of mathematical models, including the Langmuir model, the Freundlich model, and the Temkin model. Understanding the mechanism of the adsorption process requires an understanding of the interaction between the adsorbent and the adsorbate. This facilitates fitting the adsorption data to different adsorption isotherms controlled by different models.

Langmuir isotherm model:

The Langmuir isotherm curve assumes that the adsorption surface is uniform, meaning that each point that can be used to interact with the adsorbent has an equal amount of uniform energy (Langmuir, 1916). The assumptions used are for a monolayer adsorption scenario, where adsorbent molecules do not migrate across the surface. The maximum exchange capacity calculated from the Langmuir curve (Figure 9) was 131.58 mg. g^{-1}, which is somewhat larger than the experimental value of 75 mg. g^{-1} as shown in Figure 7. Figure 4.1 shows that the correlation coefficient for the points used in the model is good ($R^2 = 0.913$). The separation factor (R_L), a crucial factor, can be predicted because the Langmuir isotherm equation is derived from thermodynamic principles (Weber et al., 1974). According to the criteria of linearity ($R_L = 1$), suitability ($0 < R_L < 1$), unsuitability ($R_L > 1$), or irreversibility ($R_L = 0$), the separation factor is an indicator of the adsorption system conditions. The R_L values obtained in this experiment were 0.94 and 0.78 for concentrations ranging from 40.78 to 184 mg/L, indicating good adsorption of the dye onto diatomite.



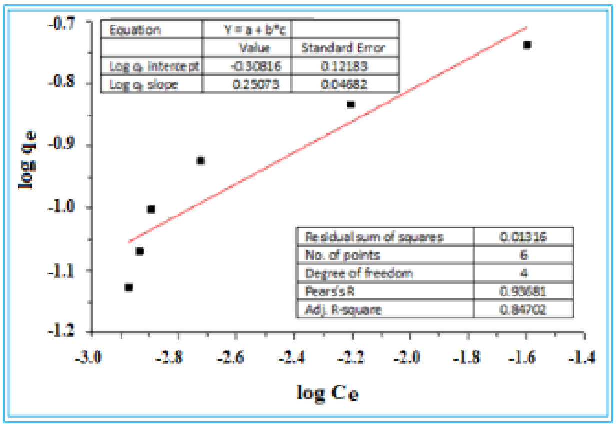
Equatio	y = a + b*x		
Weight	No Weighti		
		Value	Standard Err
1/qe	Intercept	5.0816	0.00105
1/qe	Slope	0.0076	0.68209

Number of Points	6
Degrees of Freedom	4
Residual Sum of Squares	3.13605
Pearson's r	0.96437
Adj. R-Square	0.91251

Figure (9): Langmuir isotherm of CV adsorbed onto diatomite

Freundlich isotherm model:

The Freundlich thermodynamic curve can be used to measure a parameter known as the heterogeneity factor (n_F). Accordingly, the adsorption mechanism is classified as linear ($n_F = 1$), physical adsorption ($n_F > 1$), or chemisorption ($n_F < 1$). Additionally, this value can be used to determine whether the process adheres to the usual Freundlich thermodynamic curve [$(\frac{1}{n_F}) > 1$] rapidly. The results of this study showed that the adsorption was physical adsorption, with $n_F = 3.99$ (Figure 10). The experimental data obtained show the Freundlich and Langmuir isotherms (R^2 = 0.912 and 0.847, respectively). The correlation coefficient indicates that the Langmuir model performs slightly better than the Freundlich model for the adsorption of crystal violet dye onto diatomite. The maximum exchange capacity (Q_{max}) obtained by the Freundlich model (0.693 mg.g^{-1}) was much smaller than that obtained experimentally (75 mg. g^{-1}).



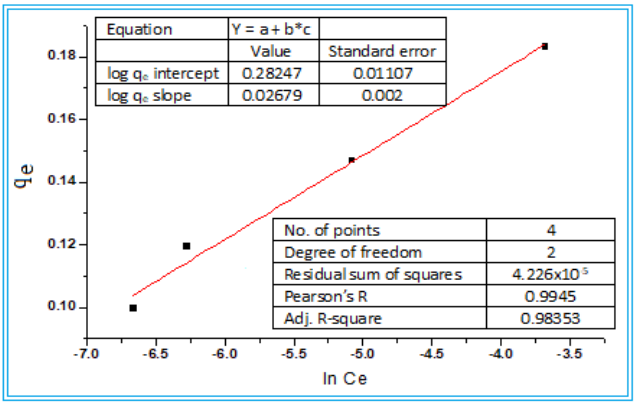
Equation	Y = a + b*c	
	Value	Standard Error
Log q. intercept	-0.30816	0.12183
Log q. slope	0.25073	0.04682

Residual sum of squares	0.01316
No. of points	6
Degree of freedom	4
Pears's R	0.93681
Adj. R-square	0.84702

Figure (10): Freundlich isotherm of CV adsorbed onto diatomite

Temkin isotherm model:

The Temkin thermodynamic equation describes multiple layers and their potential interactions using a thermodynamic approach. The Temkin thermodynamic equations are based on the assumption that the maximum adsorption energy is evenly distributed, and that the molecules in the covered layer lose heat of adsorption linearly. (Sulthana et al., 2022). Temkin constant can be used to approximate the thermodynamic coefficient constant b_T using the temperature T in kelvin [K] and the gas constant R = 8.314 J. K^{-1}.mol^{-1}. The heat of adsorption, $B = RT/b_T$, is calculated using this expected value of b_T (Figure 11). Generally, when the value of B is less than 40 kJ/mol, the adsorption is called physical, while if the value of B is greater than this, the adsorption is called chemical. In our case, B = 93 kJ/mol, and therefore the adsorption is considered chemical, contrary to what the Freundlich model suggests. The Temkin model exhibits a good correlation coefficient R^2 = 0.9835. It is considered the best compared to the Langmuir model and the Freundlich model.



Equation	Y = a + b*c	
	Value	Standard error
log q_e intercept	0.28247	0.01107
log q_e slope	0.02679	0.002

No. of points	4
Degree of freedom	2
Residual sum of squares	4.226×10^{5}
Pearson's R	0.9945
Adj. R-square	0.98353

Figure (11): Temkin isotherm of CV adsorbed onto diatomite

Kinetic experiments: Using the data from the effect of time experiment, two model for kinetic adsorption have been plotted.

Pseudo-first order:

Figure 12 shows a curve for ln(q_e-q_t) against time (t), expressing a pseudo-first-order model. The correlation coefficient R^2=0.9983 indicates that the model is well fit with experimental data. q_e was calculated from the equation $q_e = e^{intercept}$ and found to be 20.93 mg/g. $K_1 = -slope$, was 0.2073.

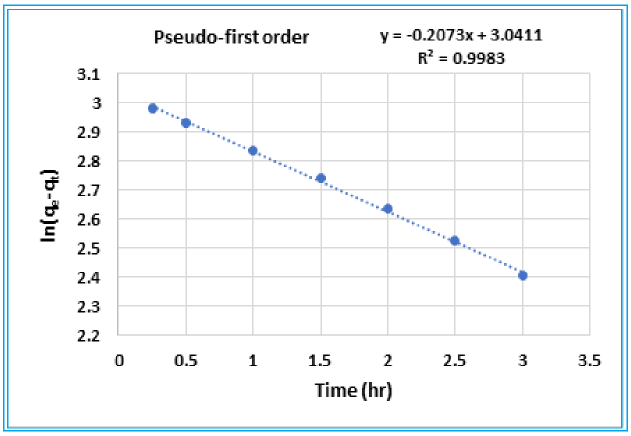


Figure (12): Pseudo-first order model

Pseudo-second order:

Figure 13 shows a curve for t/q_t against t/q_e corresponding to Pseudo-second model. The correlation coefficient R^2= 0.9999, q_e = 42.19 mg/g, K_2 = 2500, shows perfect fit of the model with the experimental data, according to the equations: $\frac{t}{q_e} = \frac{1}{K_2 q_e^2} + \frac{1}{q_e}$, $intercept = \frac{1}{K_2 q_e^2}$, $K_2 = \frac{1}{intercept}$ and $q_e = \frac{1}{slope}$.

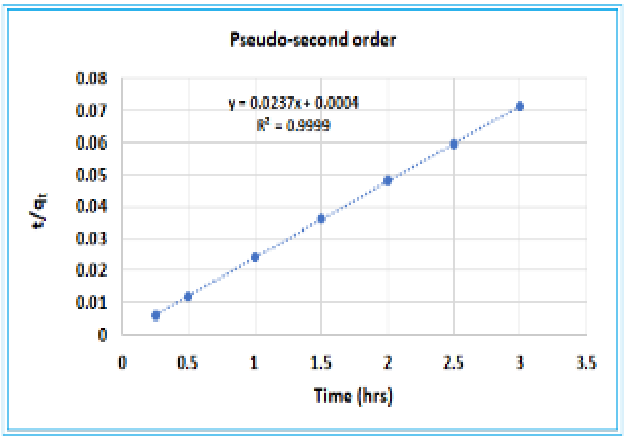


Figure (13): Pseudo-second order model

Conclusion:

The results obtained in this study indicate that crystal violet dye can be removed significantly from aqueous solutions using natural diatomite. Laboratory experiments showed that more than 90% of the dye can be removed at low concentrations ranging from 61 to 102 mg/L (0.15-0.25mM). The same percentage can be achieved using an adsorbent quantity not exceeding 4 grams per liter of dye solution at room temperature. The adsorption isotherms models of Langmuir, Freundlich, and Temkin were studied, and all gave encouraging results for the use of diatomite ore in removing crystal violet dye. The kinetic adsorption models, i.e. pseudo first order and Pseudo second order show perfect fit with the obtained experimental data.

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