Removal of Methylene Blue Dye from Textile Industry Wastewater by Sawdust of Pistachio Tree

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Abstract

Introduction: Dyes are among dangerous contaminants that are often found in textile wastewater. These pollutants have significant health effects on humans, and destructive environmental effects on the ecosystem of aquatic plants and animals, and can alter the physicochemical properties of water. Hence, in this work, the methylene blue (MB) dye removal using sawdust of pistachio tree was investigated.

Materials and Methods: This study was performed experimentally on a laboratory scale. The influence of various factors including dye concentration, pH of the solution, sawdust of pistachio tree dosage, and reaction time on dye removal efficiency was investigated.

Results: The results showed that under optimized conditions of dye concentration of 50 mg L^{-1}, pH of solution equal to 8.0, sawdust of pistachio tree dosage equal to 0.14 g L^{-1} and reaction time of 100 min, was 99.7%. The adsorption process follows the second order kinetics of R^2= 0.9931 and the Langmuir isotherm R^2= 0.9943.

Conclusion: The adsorption process using sawdust of pistachio tree can be used as a high efficiency economic adsorbent in textile wastewater treatment.

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1. Introduction

Today, due to increasing need for water, lack of water resources and finally an increase in water prices, wastewater reuse, especially in industry to meet part of the water needs, has received more attention. The textile industry is a widely used industry in the world and the amount of water consumed by this industry is noteworthy. One of the main problems of the textile industry is the presence of dye molecules in the effluent from this industry [1, 2]. Considering that dyes used are often high molecular weight and also have aromatic rings, they are resistant to biodegradation. Some dyes produce toxic cyclic amines, which lead to the formation of nitroso and amine compounds, which are highly carcinogenic, and consequently cause irreparable damages to humans and the environment [3].

Researchers have shown that dyes in low concentrations cause various problems such as skin allergies, dermatitis, and in high concentrations, cause dysfunction of the immune system and sometimes cancer in humans, and reduces beauty, light transmission, and dissolved oxygen and causes atrophy and disrupts the process of photosynthesis and endangers the life of aquatic animals, especially fish by staining the effluent. Therefore, it is necessary to remove them from aquatic environments. Methylene blue (MB) dye is widely used in various industries, including the textile, leather, cosmetics and pharmaceutical industries. Brightness, ease of use, optimal stability during washing and its low cost are among the factors that cause MB dye to be used widely in the textile industry [4, 5].

There are various methods for removing dyes from wastewater and aqueous solutions including physical treatment processes such as reverse osmosis [6-7], adsorption [8], as well as biological treatment methods such as trickling filter and activated sludge [9], and chemical methods such as advanced oxidation [10] and electrochemical oxidation methods [11] and etc. Biological treatment is inefficient for microorganisms due to complex structure as well as the toxicity of dye molecules. The cost and use of various chemicals during chemical treatment processes have limited the use of this method. Adsorption process (using activated carbon and zeolites as adsorbents on a real scale) is based on simple technologies and is one of the promising techniques that are used in water and wastewater treatment today [12].

Recently, researches have attentive on various adsorbents, which are able to remove contaminants from wastewater with low-cost. Some by-products of industrial and agricultural processes can replace expensive adsorbents in the adsorption process. Sawdust is one of the by-products of agricultural and industrial processes. Sawdust contains functional groups such as -COOH and -OH as well as polar groups such as aldehyde, ketone, acid, lignin, cellulose and hemicellulose and other phenolic compounds, which increases the ability to absorb pollutants on its surface.

Therefore, in this study, MB dye was removed from textile wastewater using sawdust of pistachio tree and the effect of important operational parameters such as concentration of dye, solution pH, sawdust of pistachio tree dosage, and reaction time, as well as kinetics and isotherm processes were investigated.

2. Materials and Methods

Methylene blue dye with chemical formula ($C_{16}H_{18}ClN_3S$), was produced with 99.9% purity, hydrochloric acid (HCl), sodium hydroxide (NaOH), and other chemicals with laboratory grade. A solution of 500 mg L^{-1} of MB dye was prepared as stock and other concentrations used were prepared from it.

2.1- Absorbent Preparation

Sawdust was collected from the branches and wood of pistachio tress. These wastes were crushed by a crusher and washed by water to remove surface contamination, then dried immediately at a temperature of 80-90 °C for 3 hours until reaching a constant weight. Using standard ASTM sieves, they were meshed with 50 mesh (average size of 300 µm) [13].

2.2- Absorption Experiments

Adsorption experiments were done in a reactor. The effect of selection parameter such as dye concentration, solution pH, sawdust of pistachio tree dosage, and reaction time on dye removal efficiency was investigated using sawdust of pistachio tree. The pH of the samples was adjusted using HCl and NaOH. The specified dosage of sawdust of pistachio tree was added to the reactor at the specified time and was in contact with the dye at a specified concentration. After the reaction was completed, the sample was taken out of the reactor and then centrifuged, and finally, using a UV/Vis spectrophotometer at a maximum wavelength of 610 nm, and the removal efficiency was determined by the bellow equation [14].

$$\%\text{Removal} = \frac{C_0 - C_t}{C_0} \times 100 \quad (1)$$

3. Results and Discussion

3.1- Surface characteristics of sawdust of pistachio tree

The FT-IR spectrum of sawdust of pistachio tree was investigated to investigate the functional groups and is shown in Figure 1.

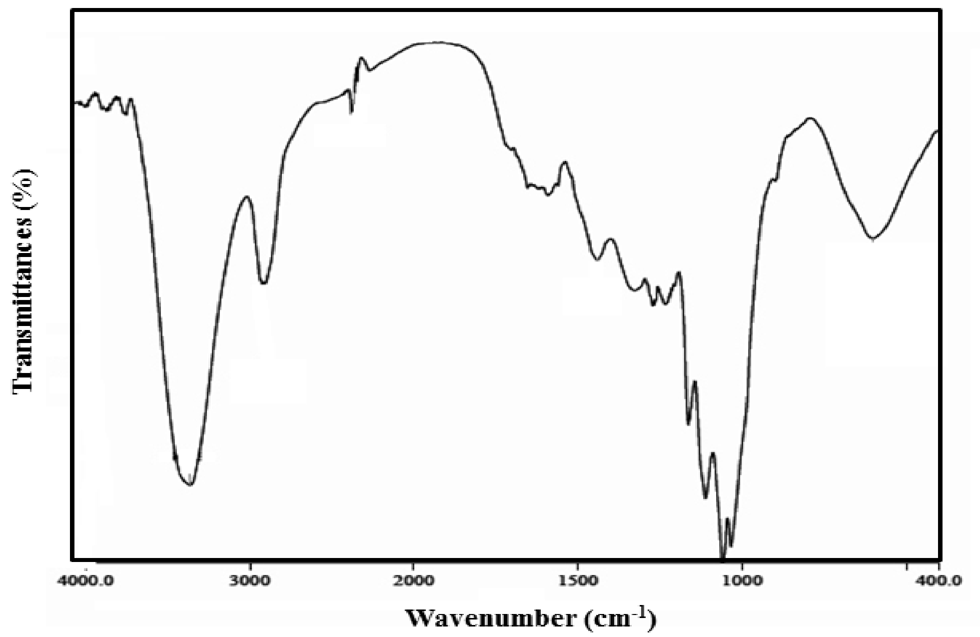

Fig. 1 -Fourier-transform infrared spectroscopy (FTIR) of sawdust of pistachio tree

FTIR of sawdust of pistachio tree was analyzed. According to Figure 1, the wide bands formed in the frequency range of 13200 to 3600 cm^{-1} belong to the -OH groups, in which the frequency spectrum of 3366 cm^{-1} is attributed to this functional group. There is also a wavelength of 2925 cm^{-1} in this spectrum, which indicates the asymmetric elasticity of C-H because the peak position at frequencies of 2700 cm^{-1} to 3000 cm^{-1} belongs to the C-H group. C-O tensile absorption appears in the range of 1000 to 1450 cm^{-1}, with the frequency of 1443 belonging to this spectrum and confirming the existence of the C-O functional group. The peak in the wavelengths of 600 cm^{-1} to 850 cm^{-1} belongs to the group of O-H Cl vibrations, in which the frequency spectrum of 602 cm^{-1} is assigned to this group [15, 16].

3.2- The Effect of Dye Concentration

The concentration of pollutant is one of the factors influencing the removal rate by the treatment process. To determine the effect of dye concentration on the adsorption process using sawdust of pistachio tree, dye concentration of 25 mg L^{-1} to 100 mg L^{-1} was investigated. Figure 2 shows the effect of the concentration of MB dye on the removal efficiency. As shown in Figure 1, increasing the dye concentration reduces the MB dye removal efficiency. Thus, when the dosage of sawdust of pistachio tree is equal to 0.3 g L^{-1}, the pH of the solution is equal to 7, and the reaction time is equal to 100 min, and increasing the dye concentration from 25 mg L^{-1} to 100 mg L^{-1}, decreases the removal efficiency from 83.2% to 41.8%, in other words, a decrease of 41.6% in the removal efficiency. The diagram also shows that in other concentrations studied, including concentrations of 25, 50, 75 and 100 mg L^{-1}, the removal efficiencies are equal to 83.2%, 82.4%, 62.8% and 41.6%, respectively. The maximum removal efficiency obtained in the concentration of 25 mg L^{-1} and 50 mg L^{-1}. Considering that the efficiency of the two mentioned concentrations (25 mg L^{-1} and 50 mg L^{-1}) is very close to each other, therefore, the dye concentration will be considered constant and equal to 50 mg L^{-1}.

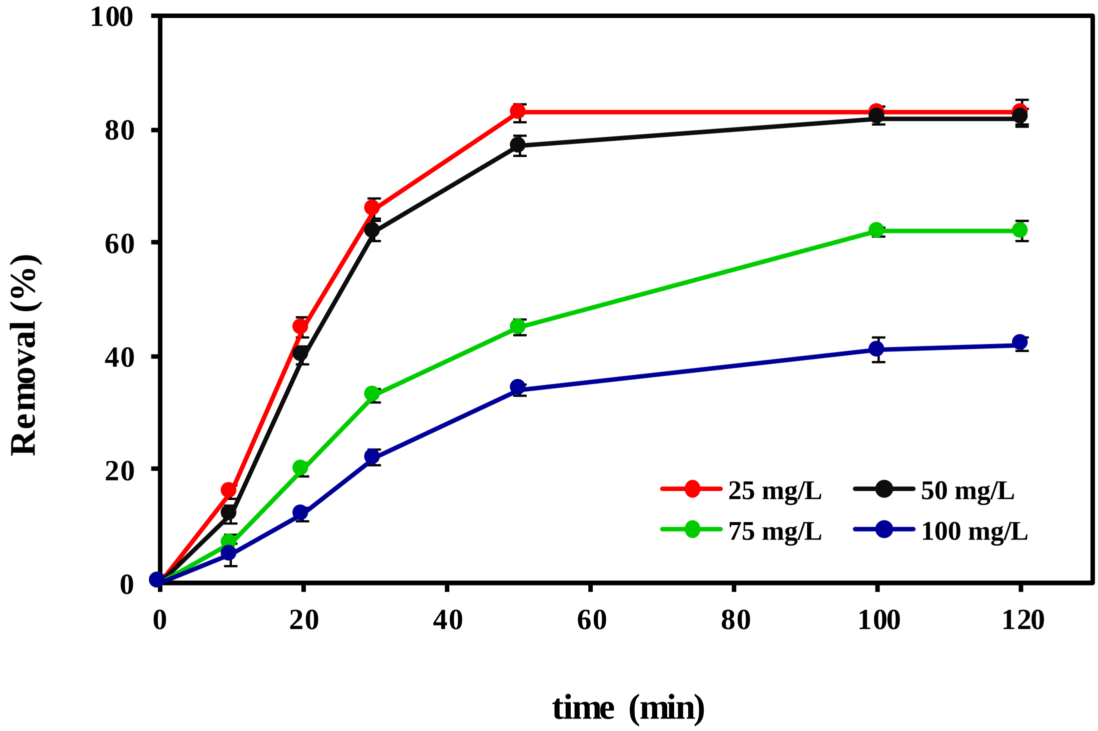

Fig. 2- The effect of MB concentration on removal efficiency

3.3- Effect of pH of Solution

The pH of the solution effects the chemistry of aqueous environment and the planar junction. To determine the effect of pH of the solution on the treatment of MB dye using sawdust of pistachio tree, pHs of 4 to 10 were studied. Experiments were conducted by considering other parameters constant; including dye concentration equal to 50 mg L^{-1}, sawdust of pistachio tree dosage equal to 0.3 g L^{-1}, and reaction time equal to 100 min, and MB dye removal efficiency was tested and the experimental results are shown in Figure 3.

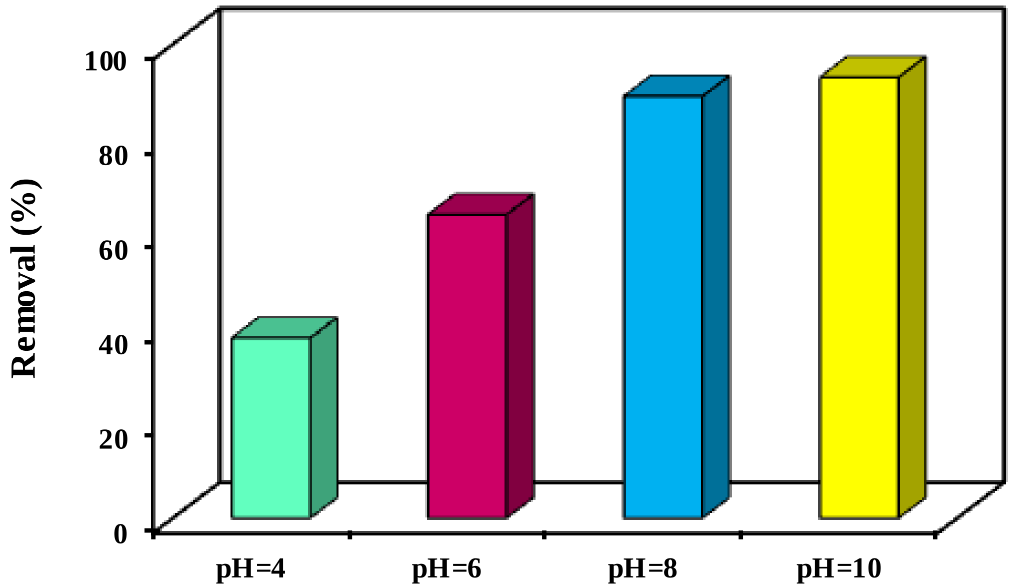

Fig. 3- Effect of solution pH on MB dye removal efficiency

According to Figure 2, by increasing the pH, the removal efficiency of MB increases so that at pHs 4, 6, 8 and 10, the removal efficiency was equal to 38.1%, 64.4%, 89.8%, and 93.6% respectively. It can also be noted that by increasing the solution pH from 4 to 10, the removal efficiency increases by 55.5%. The obtained data showed that at alkaline pHs of 8 and 10, the removal efficiency increased by less than 40%, which is very small, and on the other hand, alkaline conditions equal to 10 cause corrosion in equipment and increases consumption of chemicals to adjust the pH. Therefore, the optimal pH was considered to be 8.

3.4- The Effect of Sawdust of Pistachio Tree

To determine the effect of sawdust of pistachio tree on MB dye treatment, experiments were performed by considering the parameters constant, including dye concentration equal to 50 mg L^{-1}, pH of solution equal to 8, and the dosage of sawdust of pistachio tree were tested in different dosage from 0.1 g L^{-1} to 0.5 g L^{-1}, and the results are shown in Figure 4. As Figure 4 shows, with increasing the adsorbent, the dye removal efficiency increases so that in different sawdust of pistachio tree dosage 0.1 g L^{-1}, 0.2 g L^{-1}, 0.3 g L^{-1}, 0.4 g L^{-1} and 0.5 g L^{-1}, the removal efficiency will follow an ascending trend and will be equal to 31.7%, 67.1%, 89.4%, 99.5% and 99.7%, respectively. According to the obtained data, the sawdust of pistachio tree dosage at 0.4 g L^{-1} and 0.5 g L^{-1}has remained constant, so the concentration of 0.4 g L^{-1} is regarded as the optimal dosage of sawdust of pistachio tree.

3.5- The Effect of Reaction Time

The reaction time of the present study was investigated at 10 to 120 min. According to Figure 5, increasing reaction time increases the dye removal efficiency so that under constant conditions including the dye concentration of 50 mg L^{-1}, the pH of the solution equal to 8, and the sawdust of pistachio tree dosage equal to 0.4 g L^{-1} during 10, 20, 30, 50, 100 and 120 min, the removal efficiency were obtained as 23.3%, 41.5%, 57.4%, 99.5%, and 99.3% respectively. According to Figure 5, the dye removal process reaches equilibrium at 100 min, so the optimal time is equal to the equilibrium; 100 min.

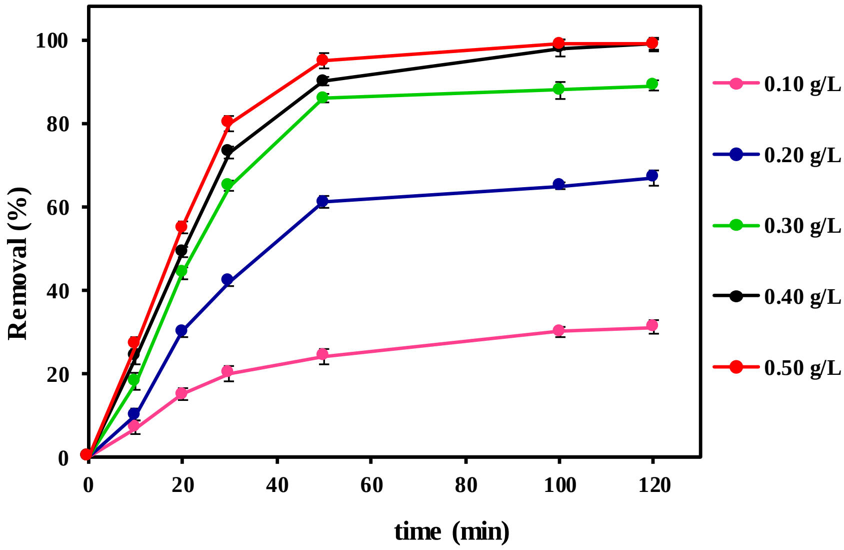

Fig. 4- The effect of sawdust of pistachio tree on MB dye removal efficiency

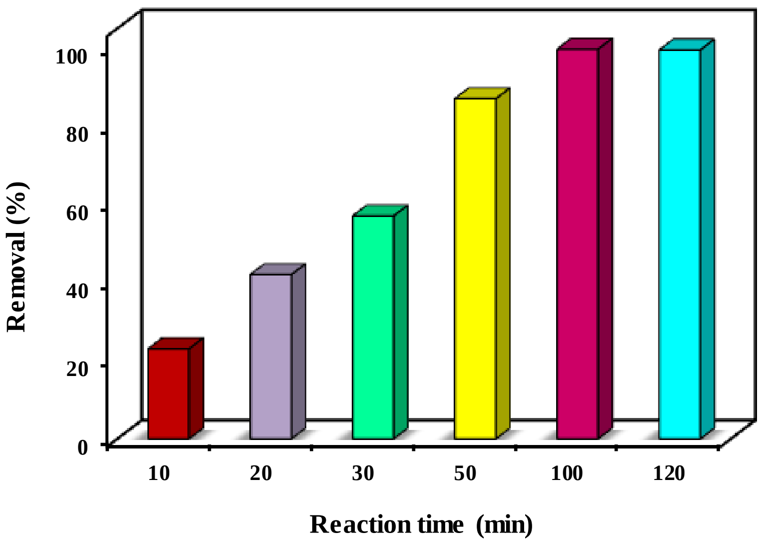

Fig. 5- the effect of reaction time on MB dye removal efficiency

3.6- Adsorption Kinetics

Adsorption kinetics depends on the physicochemical properties of the sawdust of pistachio tree as adsorbent, that affect the adsorption mechanism. In fact, kinetic studies are used to describe the transfer behavior of pollutant molecules per unit of time or to study variables affecting the reaction rate. The linear form of the first order kinetics is shown in Eq (2) and the linear relation of the second-order kinetics is shown in Eq (3) [17].

$$\log(q_e - q_t) = \log(q_e) - k_1 t/2.303 \quad (2)$$

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \quad (3)$$

q_t: (mg g^{-1}), q_e: (mg g^{-1}), k_1: (min^{-1}), and K_2: (g $mg^{-1}min^{-1}$).

The parameters and coefficients related to the kinetics of the adsorption process were presented in bellow table (Table 1).

Table 1- Coefficients and parameters of first and second order kinetics

First-order kinetics			Second-order kinetics		
R^2	q_e (mg g^{-1})	K_1 (min^{-1})	R^2	qe (mg g^{-1})	K_2 (g $mg^{-1}min^{-1}$)
0.9361	65.1	0.2704	0.9931	26.12	0.058

3.7- Adsorption Isotherms

In this study, two isotherms of Freundlich and Langmuir were studied. The Langmuir model has valid and limited uniform adsorption sites for monolayer adsorption on the adsorbent surface. The linear equation of the Langmuir isotherm is as Eq.(4) [18]. (4)

$$\frac{Ce}{qe} = \frac{1}{bqm} + \frac{Ce}{qm} \quad (4)$$

q_e: (mg g^{-1}), q_m: (mg g^{-1}), C_e: (mg L^{-1}), b: Langmuir constant

Freundlich isotherm is located on heterogeneous adsorption sites with unequal and dissimilar energies based on monolayer adsorption. In other words, Freundlich equation expresses the absorption at a heterogeneous level in terms of adsorption energy and is defined as Eq.(5) [19, 20].

$$Lnq_e = Ln\ K_f + 1/n\ LnC_e \quad (5)$$

In the Freundlich isotherm, when K_f increases, the adsorption capacity of the adsorbent to adsorb the desired pollutant increases, and also a value of n between 1 and 10 indicates the appropriate adsorption process. When the value of n is close to 1, the heterogeneity of the surface becomes less important, and when the value is close to 10, the heterogeneity of the surface becomes more important. The parameters of the Langmuir and Freundlich isotherms are presented in Table 2.

Table 2- Parameters of Freundlich and Langmuir isotherm

Langmuir isotherm				**Freundlich isotherm**		
q_m (mg g^{-1})	b (L mg^{-1})	R_L	R^2	K_f	N	R^2
70.34	3.8	0.005	0.9943	33.21	3.12	0.9238

4. Discussion

4.1 The effect of concentration MB dye

The concentration of MB dye was investigated at 25 to 100 mg L^{-1}. The experimental results indicated that the concentration of MB had a negative effect on the removal efficiency. In other words, increasing the concentration of MB reduces the removal efficiency. The results of the study of Mashkoor et al. (2020) which removed MB dye using Tectona grandis sawdust showed that the removal efficiency decreases with increasing the concentration of MB dye [21]. Naza et al. (2019) removed MB dye using sawdust of Malus domestica as an adsorbent and observed that with increasing the concentration of MB dye, the removal efficiency decreases [22]. The reason for the decrease in removal efficiency with increasing MB concentration can be explained by the fact that in a constant dosage of pistachio tree sawdust (adsorbent), active adsorption sites are constant, but with increasing MB dye concentration, the number of pollutant molecules in the reaction medium increases, and therefore the removal efficiency decreases.

4.2- Investigating the Effect of pH

Solution pH was applied in the range of 4 to 10 and its effect on the MB dye removal was studied and evaluated. The pH_{pzc} of sawdust of pistachio tree is equal to 5.2, then at pHs below pH_{pzc} the surface charge of the sawdust of pistachio as adsorbent is positive and cationic, and at pHs above 5.2, the surface charge of sawdust is anionic. On the other hand, MB dye is one of the cationic dyes and its predominant charge is positive. Therefore, at pHs higher than 5.2, since sawdust of pistachio tree (adsorbent) has a negative charge and MB molecule has a positive charge, electrostatic attraction and adsorption take place. At pH less than 5.2, the adsorbent and MB dye have a positive and like charge, and an electrostatic repulsion is generated and the removal efficiency is reduced [23, 24].

4.3- The Effect of Sawdust of Pistachio Tree Dosage

The sawdust of pistachio tree dosage was investigated at 0.1 to 0.5 g L^{-1} and the experimental results indicated that with increasing the sawdust of pistachio tree dosage, the removal efficiency increases. The results of the study conducted by Gardazi et al. (2019) who removed MB dye using white cedar sawdust showed that the removal efficiency increases with increasing the sawdust of pistachio tree dosage [25]. Un et al. (2019) also removed MB dye using poplar sawdust. The results of their study showed that with increasing the sawdust of pistachio tree dosage, the removal efficiency of MB dye increases [26] and this phenomenon is due to high adsorption sites and surface area of sawdust of pistachio tree. It can also be stated that at a constant of all condition, with increasing the sawdust of pistachio tree dosage, the ratio of active sites present on the sawdust of pistachio tree surface to MB dye molecules will be high and therefore, the removal efficiency will increase, while at low sawdust of pistachio tree dosage the ratio of active sites to dye molecules decreases and as a result the removal efficiency decreases [27, 28].

4.4- The Effect of Reaction Time

Reaction time and equilibrium time are among the important and basic parameters in the design of adsorption processes. Therefore, technically, investigating the reaction time is an integral part of any technique, especially the adsorption technique. In this study, the reaction time of 10 to 120 min was studied. The experimental results revealed that the MB dye adsorption has an increasing trend for up to 100 min and from 100 min onwards, the adsorption process reaches equilibrium and shows a relatively constant trend. The effect of reaction time can be expressed in this way: increasing the contact time, increases the probability of the pollutant molecule colliding with the adsorbent and thus the removal efficiency increases [29, 30].

4.5- Investigation of Adsorption Kinetics and Isotherms

The two models of adsorption kinetics that are widely utilized for adsorption processes are models of first and second kinetics. First-order kinetics shows that adsorption occurs by penetration through a layer, and second-order show that chemosorption is a step-by-step process that manage this process. The results of kinetics showed that the removal MB by sawdust of pistachio tree follows the second-order model. The amount of R^2 in the removal of MB was 0.9931. The coefficient K_2 was equal to 0.058 and the value of q_e was equal to 26.12 mg g^{-1}.

In this study, Freundlich and Langmuir isotherms were investigated. As can be seen in Table.2, The R^2 for Freundlich isotherm was equal to 0.9238 and for Langmuir isotherm was equal to 0.9943, which shows that the adsorption process has a linear relationship with the amount of R^2 higher than Langmuir isotherm. Also, b values were equal to 3.8 and also the q_m was equal to 70.34 mg g^{-1} of pollutant/gram of adsorbent. In Langmuir model, a dimensionless coefficient called separation factor (R_L) was used to express the main feature and characteristic of isotherm which can be applied to estimate the suitability of sawdust pistachio tree for MB adsorption. The status of the isotherm can be interpreted according to the value of the separation factor. If R_L value is more than 1, the adsorption is undesirable, if it is equal to 1, the adsorption is linear, if it is zero, the adsorption is irreversible, and if it is between 0-1, the adsorption is optimal. The value of R_L in this study was equal to 0.005, which is between 0-1 so absorption is desirable [31,32]. Tounsadi et al. (2020) TR dye removal from the textile industry using Acacia sawdust showed that the adsorption follows the second-order and the Langmuir model. Equilibrium time (t_e) and maximum absorption capacity (q_m) in this study were 120 min and 230 mg g^{-1}, respectively [33].

5. Conclusion

In this study, the efficiency of adsorption process using sawdust of pistachio tree adsorbent in removing MB dye from textile wastewater was investigated. The influence of variables of dye concentration, pH of solution, sawdust of pistachio tree dosage and reaction time on dye removal efficiency was studied. The results showed that sawdust of pistachio tree is highly efficient in removing MB dye and under optimal conditions, including MB concentration of 50 mg L^{-1}, sawdust of pistachio tree dosage of 0.4 g L^{-1}, solution pH of 8, and the reaction time of 100 min, the efficiency was 99.7%. According to the obtained experimental results, the sawdust of pistachio tree can be used as a green and environmentally friendly technique in textile wastewater treatment using the least amount of chemicals.

Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this article.

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References

1- Zhang P, O'Connor D, Wang Y, Jiang L, Xia T, Wang L, Tsang DC, Ok YS, Hou D. A green biochar/iron oxide composite for methylene blue removal. Journal of hazardous materials. **2020**;384:*121286*.

2- Mashkoor F, Nasar A. Magsorbents: Potential candidates in wastewater treatment technology-A review on the removal of methylene blue dye. Journal of Magnetism and Magnetic Materials. **2020**;500:*166408*.

3- Sriram G, Kigga M, Uthappa U, Rego RM, Thendral V, Kumeria T, Jung H-Y, Kurkuri MD. Naturally available diatomite and their surface modification for the removal of hazardous dye and metal ions: A review. Advances in Colloid and Interface Science. **2020**:*102198*.

4- Wazir MB, Daud M, Ali F, Al-Harthi MA. Dendrimer assisted dye-removal: A critical review of adsorption and catalytic degradation for wastewater treatment. Journal of Molecular Liquids. **2020**:*113775*.

5- Ajormal F, Moradnia F, Taghavi Fardood S, Ramazani A. Zinc Ferrite Nanoparticles in Photo-Degradation of Dye: Mini-Review. Journal of Chemical Reviews. **2020**;2:*90-102*.

6- Al-Bastaki N. Removal of methyl orange dye and Na 2 SO 4 salt from synthetic waste water using reverse osmosis. Chemical Engineering and Processing: Process Intensification. **2004**;43(12):*1561-7*.

7- Raghu S, Basha CA. Chemical or electrochemical techniques, followed by ion exchange, for recycle of textile dye wastewater. Journal of Hazardous Materials. **2007**;149(2):*324-30*.

8- Yagub MT, Sen TK, Afroze S, Ang HM. Dye and its removal from aqueous solution by adsorption: A review. Advances in colloid and interface science. **2014**;209:*172-84*.

9- Vilaseca M, Gutiérrez M-C, Lopez-Grimau V, Lopez-Mesas M, Crespi M. Biological treatment of a textile effluent after electrochemical oxidation of reactive dyes. Water environment research. **2010**;82(2): *176-82*.

10- Nidheesh P, Gandhimathi R, Sanjini N. NaHCO 3 enhanced Rhodamine B removal from aqueous solution by graphite-graphite electro Fenton system. Separation and Purification Technology. **2014**;132:*568-76*.

11- Nandi BK, Patel S. Effects of operational parameters on the removal of brilliant green dye from aqueous solutions by electrocoagulation. Arabian Journal of Chemistry. **2013**;165:*531-40.*

12- Brillas E, Martinez-Huitle CA. Decontamination of wastewaters containing synthetic organic dyes by electrochemical methods. An updated review. Applied Catalysis B: Environmental. **2015**;166: *603-43*.

13- Davoudi M, Alidadi H, Mehrabpour M, Dolatabadi M. The Study of Efficacy of Sawdust Melia Azedarach for Dye & Heavy Metal Removal from Textile Industry Effluents. Rahavard Salamat Journal. **2017**;3(2):*54-69*.

14- Alidadi H, Dolatabadi M, Mehrabpour M, Dehghan A. The efficacy of ciprofloxacin removal by Chitosan/Zeolite composite from aqueous solution: Response surface methodology, kinetic and isotherm studies. Journal of Health in the Field. **2017**;5(1): *1-12*.

15- Felvey NW, Meloni MJ, Kronawitter CX, Runnebaum RC. Ethane dehydrogenation over Cr/ZSM-5: characterization of active sites through probe molecule adsorption FTIR. Catalysis Science & Technology. **2020**;10(15):*5069-81*.

16- Vessey CJ ,Schmidt MP, Abdolahnezhad M, Peak D, Lindsay MB. Adsorption of (Poly) vanadate onto Ferrihydrite and Hematite: An In Situ ATR–FTIR Study. ACS Earth and Space Chemistry. **2020**;4(4):*641-9*.

17- de Carvalho HP, Huang J, Zhao M, Liu G, Dong L, Liu X. Improvement of Methylene Blue removal by electrocoagulation/banana peel adsorption coupling in a batch system. Alexandria Engineering Journal. **2015**;54(3):*777-86*.

18- Toor M, Jin B. Adsorption characteristics, isotherm, kinetics, and diffusion of modified natural bentonite for removing diazo dye. Chemical Engineering Journal. **2012**;187: *79-88*.

19- Siddiqui MN, Redhwi HH, Al-Saadi AA, Rajeh M, Saleh TA. Kinetic and computational evaluation of activated carbon produced from rubber tires toward the adsorption of nickel in aqueous solutions. Desalination and Water Treatment. **2015**:*1-9*.

20- Vimonses V, Lei S, Jin B, Chow CW, Saint C. Kinetic study and equilibrium isotherm analysis of Congo Red adsorption by clay materials. Chemical Engineering Journal. **2009**;148(2):*354-64*.

21- Mashkoor F, Nasar A. Magnetized Tectona grandis sawdust as a novel adsorbent: preparation, characterization, and utilization for the removal of methylene blue from aqueous solution. Cellulose. **2020**;27(5):*2613-35*.

22- Naza S, Alamb S, Rehanc K, Sultanad S. Adsorptive removal of new methylene blue from water by treated Malus domestica sawdust as a low cost biosorbent-equilibrium, kinetics and thermodynamic studies. Desalination and Water Treatment. **2019**;166:*72-82*.

23- Ozacar M, Şengil IA. Adsorption of metal complex dyes from aqueous solutions by pine sawdust. Bioresource technology. **2005**;96(7):*791-5*.

24- Hameed B, Ahmad A, Latiff K. Adsorption of basic dye (methylene blue) onto activated carbon prepared from rattan sawdust. Dyes and pigments. **2007**:75:*143-9*.

25- Gardazi SMH, Shah JA, Ashfaq T, Sherazi TA, Ali MA, Pervez A, Rashid N, Iqbal J, Amin BAZ, Bilal M. Equilibrium, kinetics and thermodynamic study of the adsorptive removal of methylene blue from industrial wastewater by white cedar sawdust . Environment Protection Engineering. **2019**;45(3) **2019**;45:*3-12*.

26- Un UT, Ates F. Low-cost adsorbent prepared from poplar sawdust for removal of disperse orange 30 dye from aqueous solutions. International Journal of Environmental Science and Technology. **2019**;16(2):*899-908*.

27- Kandisa RV, Saibaba KN, Shaik KB, Gopinath R. Dye removal by adsorption:

A review. Journal of Bioremediation and Biodegradation. **2016;**7:*206-11*.

28- Garg V, Gupta R, Yadav AB, Kumar R. Dye removal from aqueous solution by adsorption on treated sawdust .Bioresource Technology. **2003**;89(2):*121-4*.

29- Shukla S, Pai RS. Adsorption of Cu (II), Ni (II) and Zn (II) on dye loaded groundnut shells and sawdust. Separation and Purification Technology. **2005**;43(1):*1-8*.

30- Cemin A, Ferrarini F, Poletto M, Bonetto LR, Bortoluz J, Lemee L, Guegan R, Esteves VI, Giovanela M. Characterization and use of a lignin sample extracted from Eucalyptus grandis sawdust for the removal of methylene blue dye. International Journal of Biological Macromolecules. **2021**;170:*375-89*.

31- Ren X, Tan Y, Lai X, Zhu K. Adsorption performance of biochars from agricultural and forestry wastes. IOP Conference Series: Earth and Environmental Science; **2021**: IOP Publishing.

32- Souidi R, Belarbi L, Bousalem S. Methylene Blue Adsorption from aqueous solution by low cost vine-wood biomass. **2021**;12: *25-32*.

33- Tounsadi H, Metarfi Y, Barka N, Taleb M, Rais Z. Removal of Textile Dyes by Chemically Treated Sawdust of Acacia: Kinetic and Equilibrium Studies. Journal of Chemistry. **2020**;12:*7234218*.