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Research Article

The usage of palm *(Washingtonia filifera)* fibers for the removal of crystal violet from synthetic dye solution by adsorption

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ABSTRACT

The objective to obtain cheap and easily synthesized adsorbents from natural materials is gaining importance day by day. Adsorbents should be environmentally friendly, non-toxic, easily produced, insoluble in water, have a porous structure, have a large surface area, and be scientifically accepted. In this study, the removal of crystal violet dye from synthetic dyestuff solution was investigated using palm tree *(Washingtonia filifera)* fibers. In order to determine the contact time, the first set of experiments employed 0.5 g of palm fibers and initial dye concentrations between 2.5-160 mg/L. As a result of the study, it was determined that the crystal violet removal was 87.96% at the end of the 180-minute contact time at equilibrium, and the removal complied with the pseudo-second-order kinetic model type 1. The equilibrium time for the highest initial adsorbate concentration (160 mg/L) was 2880 minutes (2 days) in stationary phase systems while it was 180 minutes (3 hours) in mobile phase systems. It was also understood that palm fiber, which is an environmentally advantageous material, can be used in the removal of crystal violet dyestuff.

Keywords: *Washingtonia filifera*, dyestuff removal, crystal violet, chemical kinetic.

Sentetik boyar madde çözeltisinden kristal viyolenin adsorpsiyonla gideriminde palmiye (*Washingtonia filifera*) liflerinin kullanılması

ÖZ

Doğal malzemelerden düşük maliyetli ve kolay sentezlenen adsorbanlar elde etme hedefi her geçen gün önem kazanmaktadır. Adsorbanlar çevre dostu, toksik olmayan, kolayca üretilebilen, suda çözünmeyen, gözenekli bir yapıya sahip, geniş bir yüzey alanına sahip ve bilimsel olarak kabul görmüş olmalıdır. Bu çalışmada, palmiye ağacı *(Washingtonia filifera)* lifleri kullanılarak sentetik boyarmadde çözeltisinden kristal viyole boyanın giderimi araştırılmıştır. Temas süresini belirlemek için, ilk deney grubu 0,5 g palmiye lifi ve 2,5-160 mg/L arasındaki başlangıç boya konsantrasyonları kullanılmıştır. Araştırma sonucunda ise dengeye 180 dakikalık temas süresi sonunda kristal viyole gideriminin %87,96 olduğu ve giderimin yalancı ikinci dereceden kinetik model tip 1'e uygun olduğu belirlenmiştir. En yüksek başlangıç adsorbat konsantrasyonu (160 mg/L) için sabit fazlı sistemlerde 2880 dakika (2 gün), mobil fazlı sistemlerde ise 180 dakikada (3 saat) dengeye ulaşılmıştır. Çevre açısından avantajlı bir malzeme olan palmiye lifinin de kristal viyole boyar maddelerin uzaklaştırılmasında kullanılabileceği tespit edilmiştir.

Anahtar Kelimeler: *Washingtonia filifera*, boyarmadde giderimi, kristal viyole, kimyasal kinetik.

1. INTRODUCTION

Today, dyestuffs are used as auxiliary substances in the production activities of industries that include printing and dyeing processes such as paper, cosmetics, leather, pharmaceuticals, especially the textile industry. The amount and type of dyestuffs used in the relevant production processes are highly variable according to the production process and product variety.[1-3] It is estimated that the amount of dyestuff produced annually in the world is more than 70,000 tons and that more than 10,000 types of dyestuffs are introduced to the market every year.[4] All of the dyestuffs produced for industrial utilization are not used efficiently in the process, and their residues pass into the wastewater of the process.[1,5] In the case of dyestuff containing wastewater discharges

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to receiving environments, the dyestuff reduces the light transmittance of the system. On the other hand, the photosynthetic ability of the system with reduced light transmittance decreases and the amount of dissolved oxygen originating from photosynthesis decreases.[4] As a result of this undesirable situation, the organisms living in the water are adversely affected and the efficiency obtained from the system decreases. As a result of such discharges to the receiving environment, the ecosystem of the receiving environment is adversely affected and an aesthetically undesirable appearance occurs. In addition, dyestuffs can cause various acute and chronic health problems for living things due to the impurities in their structure. Therefore, it is important for the environment and public health to treat and monitor wastewater containing dyestuffs regularly before they are discharged to receiving environments.[3,6]

Various treatment processes, including biological, chemical and physical methods, are used in the removal of dyestuffs from wastewater. Biological treatment methods are evaluated under aerobic and anaerobic systems. Biological treatment methods are systems utilizing living organisms and cannot be operated efficiently at high dyestuff concentrations. In addition, due to the living organisms it contains during the operation of the biological system, biological treatment methods are more sensitive to contents of the wastewater than chemical and physical processes.[4] Coagulation-flocculation and precipitation method, Fenton process, and various oxidation processes are among the chemical methods used in dyestuff removal. Various operational problems such as energy consumption, use of chemicals and formation of chemical waste sludge are among the disadvantages of these processes.[5] Membrane filtration methods, ion exchange, and adsorption methods can be given as examples of physical treatment methods. Physical treatment methods have been preferred more than biological and chemical treatment methods in recent years in terms of high removal efficiency and ease of operation in dyestuff removal.[4,5]

Membrane filtration systems, which are among the physical treatment methods, are pressurized systems and the protection of the membranes is important for the efficiency of the system. In addition, the disposal of the concentrated waste formed within the membrane is a disadvantage of this system. In the ion exchange process, not only the dyestuff is removed, but also the anions and cations present in the wastewater are removed. In this case, the operating time of the system will decrease and the regeneration will be needed in shorter periods. The adsorption method, on the other hand, is more popular among physical treatment methods and is widely preferred because it can be used for high dyestuff concentrations. In addition, obtaining high removal efficiencies by the adsorption method is also an important criterion in the preference of the process.[4,5,7]

The adsorbents to be used in the adsorption process should primarily be of low cost and sufficient efficiency. Nowadays, due to the increasing environmental pollution, adsorbents produced from wastes instead of conventional activated carbon or materials prepared by carbonization attract more attention today. Adsorbents should also be environmentally friendly, non-toxic, easily produced, insoluble in water, have a porous structure, large surface area, and scientifically accepted.[5,7,8] Adsorption is similar to an equilibrium reaction and continues until a dynamic equilibrium is reached between the solute concentration remaining in the solution and the solute concentration attached onto the adsorbent surface. In order to indicate the adsorption equilibrium, the amount of adsorbate in unit weight of the solid adsorbent against the solute concentration remaining in the solution at constant temperature is plotted. Generally, these curves are non-linear and are called adsorption isotherms.[9]

Adsorption is an effective way to obtain high quality effluent that does not produce any harmful waste in the treatment of high-flow wastewater.[10] Activated carbon columns are used in many industries for the treatment of toxic, non-biodegradable wastes and also as a final treatment step after biological oxidation processes.[11] Activated carbon is an effective adsorbent widely used in dye removal, and adsorption is still the leading treatment method. However, some problems arise in the use of activated carbon. Activated carbon is an expensive product and the higher the quality, the higher the price. From this point of view, the interest for a cheap and easily available adsorbent for dye removal is increasing day by day.[12] There are many researchers doing various studies to find such an adsorbent. Among these researches, it is possible to come across various biological materials, both dry and wet.[13] These include lichen,[14] algae,[15] tree and fruit residues,[16-19] seeds,[20-23] and aquatic plants.[12,24]

Although some adsorption studies with palm species were found among previous studies, no adsorption studies with *Washingtonia filifera* fibers were found. In this study, palm (*Washingtonia filifera*) tree fibers were used to remove the crystal violet dyestuff. In addition, the removal values obtained in the removal study were used as data in the zero-order, first-order, second-order, four types of false-second-order, and Elovich kinetic models, and to determine which kinetic model could explain the removal better.

2. MATERIALS AND METHODS

2.1. Materials

2.1.1. Adsorbent

The palm tree *(Washingtonia filifera)* used in this study is widely distributed in the Mediterranean region. During

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the preparation of the adsorbent, *Washingtonia filifera* fibers were first soaked in water until the woody layer on it was peeled off. Following the soaking process, the brown woody layer on the palm fibers was peeled off and then the fibers were washed and left to dry at room temperature. Following the drying process, the fibers were cut to 1 cm in length and the adsorbent preparation process was completed.

2.1.2. Preparation of dyestuff (Crystal Violet) solution

Crystal violet dyestuff ($C_{25}H_{30}N_3Cl$) was obtained from Merck and the dyestuff solution to be used in this research was prepared synthetically. Synthetic wastewater solutions were prepared to contain 1.25, 2.5, 5, 10, 20, 40, 80, and 160 mg/L crystal violet concentration. The general structure of the crystal violet dyestuff is given in Figure 1.

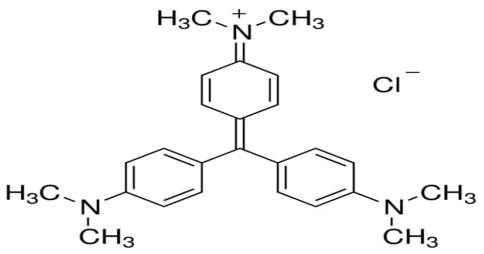

Figure 1. General structure of crystal violet dyestuff. [25]

2.2. Method

2.2.1. Adsorption experiments

Dye removal studies were carried out separately at 8 different dye concentrations (1.25, 2.5, 5, 10, 20, 40, 80 and 160 mg/L) under stationary and mobile phase (300 rpm). The amount of adsorbent to be used in the study was chosen as 0.5 g, and the study was carried out at 25°C ambient temperature with the initial pH value of 6.5. The removal study was carried out with a contact time of 4 day in the absence of the mixing and was limited to 4 hours in the reactor where the mixing was maintained. In addition, the sampling was done for 9 (60, 120, 180, 240, 300, 1440, 2880, 4320 and 5760 minutes) and 13 (5, 10, 15, 30, 45, 60, 80, 100, 120, 150, 180, 210 and 240 minutes) different time periods in stationary and mobile reactors, respectively. The amount of adsorption at equilibrium, q_e (mg/g), was calculated by Equation 1.

$$q_e = \frac{(C_0 - C_e)xV}{W} \quad \text{(Equation 1)}$$

In Equation 1, C_0 and C_e are the liquid-phase concentrations of dye at initial and after a certain time (mg/L), V (L) ise the volume of the solution, and W (g) is the dry mass of sorbent used.

The crystal violet removal was observed after specified time periods. The dyestuff measurements in this study were carried out at 590 nm, where the crystal violet dyestuff demonstrates the highest adsorbance value using Perkin Elmer brand Lambda 35 UV/VIS model spectrophotometer.

2.2.2. Kinetic analysis

Data obtained in adsorption experiments were applied to zero-order, first-order, second-order, four types of pseudo-second-order and Elovich kinetic models. The equations, linear expressions, indices, and kinetic parameters of the related kinetic models are given in Table 1. The calculation of the q_t value shown in Table 1 is done using Equation 2.[26]

Table 1. Kinetic Models and Linear Expressions (KN= Intercept, E= Slope).

Model	Equation	Lineer Description	Plot	Parameters
Zero Order	$q_t = q_e - k_0 t$	$q_t = q_e - k_0 t$	q_t *and* t	$q_e = KN$ $k_0 = -E$
First Order	$q_t = q_e \exp(k_1 t)$	$\ln\frac{q_e}{q_t} = k_1 t$	*ln* q_t *and* t	$q_e = KN$ $k_1 = -E$
Second Order	$q_t = q_e/(1 + q_e k_2 t)$	$q_t^{-1} = q_e^{-1} + k_2 t$	q_t^{-1} *and* t	$q_e = KN^{-1}$ $k_2 = E$
Elovich	$q_t = \beta \ln(\alpha\beta t)$	$q_t = \beta \ln(\alpha\beta) + \beta \ln t$	q_t *and ln* t	$\beta = E$ $\alpha = \frac{1}{E} e^{(\frac{KN}{E})}$
Pseudo Second Order	$q_t = \frac{k_{2p} q_e^2 t}{(1 + q_e k_{2p} t)}$	Type (1) $t/q_t = 1/k_{2p}q_e^2 + t/q_e$	t/q_t *and* t	$q_e = E^{-1}$ $k_{2p} = E^2/KN$
		Type (II) $\frac{1}{q_t} = \left(\frac{1}{k_{2p}q_e^2}\right)\left(\frac{1}{t}\right) + \left(\frac{1}{q_e}\right)$	$1/q_t$ *and* $1/t$	$q_e = KN^{-1}$ $k_{2p} = KN^2/E$
		Type (III) $q_t = q_e - (1/k_{2p}q_e)q_t/t$	q_t *and* q_t/t	$q_e = KN$ k_{2p}=1/(E*KN)
		Type (IV) $\frac{q_t}{t} = k_{2p}q_e^2 - k_{2p}q_e q_t$	q_t/t *and* q_t	$q_e = -KN/E$ $k_{2p} = E^2/KN$

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$$q_t = \frac{(C_0 - C_t)xV}{W} \quad \text{(Equation 2)}$$

The term, q_t, expressed in Equation 1 is the amount of adsorbate (dyestuff) retained per unit adsorbent (mg/g), C_0 and C_t values are the concentrations of dyestuff in the solution at the beginning and measured at time t, respectively, V is the solution volume in the reactor, and W expresses the amount of adsorbent.[26]

3. RESULTS AND DISCUSSION

3.1. Equilibrium Time

The expression of the amount of substance removed over time (q_e) is a measure of the dyestuff capacity of the present material. The q_e values of the values determined as a result of the adsorption study are given in Figures 2 and 3 for the stationary and mobile phases, respectively.

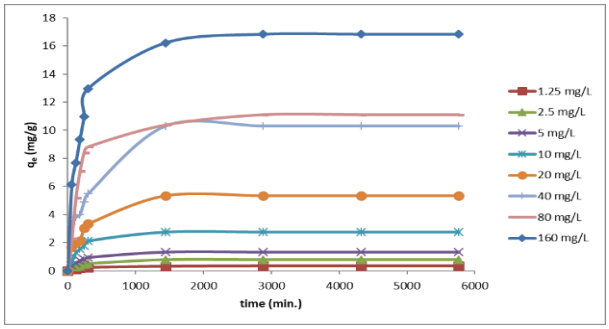

Figure 2. Stationary phase q_e plot.

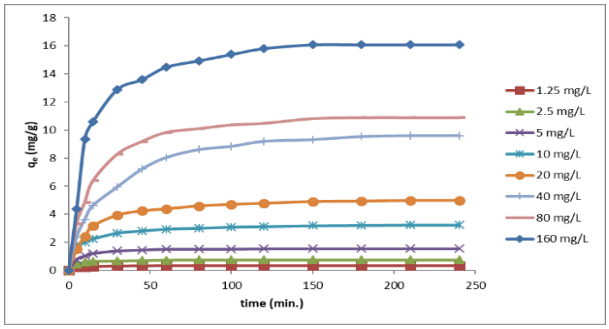

Figure 3. Mobile phase q_e plot.

Due to the empty surfaces of the material at the beginning of the adsorption and the high concentration of the dyestuff in the solution, the adhesion to the surface is fast at the beginning. As a result of the saturation of the surface with the dyestuff, the amount of the removed substance decreases as time progresses. In Figure 2 and Figure 3, it is observed that the dyestuff is removed more quickly at the beginning and it is understood that the amount of substance retained in the material decreases as time progresses. The equilibrium time for the highest initial adsorbate concentration (160 mg/L) was 2880 minutes (2 days) in stationary phase system while it was 180 minutes (3 hours) in mobile phase system. Sulyman et al. studied crystal violet removal with date palm (L.) Dead leaflets (*Phoenix dactylifera*) obtained an equilibrium capacity value of 65.55 mg/g using 500 mg/L initial crystal violet solution.[27] El-Sayed et al. studied crystal violet removal with palm kernel (*Phoenix dactylifera*) fibers. The researchers determined the adsorption equilibrium capacity to be 52.9 mg/g in the study they carried out with an initial dye concentration of 160 mg/L.[28] In this study, the capacity values reached at the moment of equilibrium in stationary and mobile phases (160 mg/L initial crystal violet solution) are 16.82 mg/g and 16.08 mg/g, respectively.

3.2. Results of Adsorption Experiments

In this study, the highest removal efficiencies obtained in stationary and mobile phase studies were determined as 75.17% and 88.73%, respectively. The removal efficiencies and initial solution concentrations determined in all study sets of the crystal violet removal study are given in Table 2 and Table 3 for stationary and mobile conditions, respectively. Sultana et al. studied crystal violet removal with powder adsorbent obtained from coconut shell. The researchers achieved 91% crystal violet removal after 150 minutes of contact time. They also found that the adsorption process slowed down after the 150th minute.[29] Rani et al., on the other hand, studied the removal of crystal violet dye from wastewater with adsorbent material prepared from citrus peel (*Citrus limetta*).

Table 2. Removal efficiencies and initial crystal violet concentrations under stationary operating conditions.

Time (t, minute)	Initial crystal violet concentration (C_0, mg/L)							
	1.25	2.50	5	10	20	40	80	160
	Removal, %							
60	17.08	24.19	20.16	18.35	20.84	20.14	7.39	9.42
120	20.10	25.82	28.55	34.56	24.30	23.19	16.77	11.79
180	31.39	32.04	38.47	42.22	26.36	24.34	22.96	14.32
240	39.64	46.26	42.33	47.95	37.12	29.79	27.24	16.79
300	46.46	48.86	49.46	57.76	41.04	33.47	28.61	19.87
1440	61.26	75.14	69.65	75.17	65.67	62.83	33.65	24.84
2880	67.23	75.14	69.65	75.17	65.67	62.83	36.01	25.77
4320	67.23	75.14	69.65	75.17	65.67	62.83	36.01	25.77
5760	67.23	75.14	69.65	75.17	65.67	62.83	36.01	25.77

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As a result of the study, they achieved 89.87% crystal violet removal.[30] Kumbhar et al. obtained 98.7% crystal violet removal with the composite adsorbent they synthesized using tea waste and iron oxide (Fe_3O_4). In addition, the found that the efficiency of crystal violet removal decreased when the pH value was more or less than 7.[31]

Table 3. Removal efficiencies and initial crystal violet concentrations under mobile operating conditions.

Time (t, minute)	Initial crystal violet concentration (C_0, mg/L)							
	1.25	2.50	5	10	20	40	80	160
	Removal, %							
5	51.72	47.81	43.34	47.59	20.11	15.67	11.39	7.12
10	54.31	66.67	57.79	55.36	31.97	23.85	16.60	15.24
15	57.76	71.49	68.17	61.38	42.23	30.41	21.87	17.30
3	67.24	74.56	78.56	72.87	52.60	39.13	28.35	21.06
45	68.97	77.63	81.94	77.13	56.61	47.47	31.41	22.19
60	72.41	81.14	85.55	80.63	58.58	52.95	33.63	23.66
80	72.41	81.58	85.78	82.60	61.36	56.69	34.55	24.40
100	72.41	81.58	86.00	84.68	62.86	58.21	35.45	25.13
120	72.41	82.46	87.13	85.78	63.93	60.56	35.85	25.83
150	72.41	82.46	87.13	87.31	65.53	61.37	36.99	26.26
180	72.41	82.46	87.58	87.96	65.96	62.82	37.23	26.26
210	72.41	82.46	87.58	88.73	66.60	63.22	37.23	26.26
240	72.41	82.46	87.58	88.73	66.60	63.22	37.23	26.26

As a result of their study for crystal violet removal with processed date palm *(Phoenix dactylifera)* at pH 6.5, Sulyman et al. determined the highest removal value as 96% .[27] Alshabanat et al., with a similar study, obtained approximately 98.5% removal in mobile medium and at pH value of 2.[32] El-Sayed performed a crystal violet removal study with non-processed (raw) palm kernel *(Phoenix dactylifera)* fibers and reached approximately 85% removal at pH 7.2 using 0.05 g adsorbent.[28]

In this study, 88.73% removal efficiency was obtained using 0.5 g *Washingtonia filifera* fibers without any physico-chemical treatment. The summary chart of related studies and this study are given in Table 4. In their study regarding crystal violet removal with *Carpobrotus edulis* plant, Dabagh et al., reported that the increase or decrease of the pH value did not have a significant effect on the dye removal.[33]

Table 4. Previous studies summarizing the highest crystal violet removal rates.

Researchers	Adsorbant	Study Conditions	Removal, %
Sultana et al., 2022[29]	Coconut shell	200 rpm mixing speed 150 minute contact time 0,1 g amount of adsorbent pH 5 36 mg/L crystal violet initial concentration Synthetic wastewater	91
Rani et al., 2022[30]	Citrus peel *(Citrus limetta)*	200 rpm mixing speed 120 minute contact time 0.5 g amount of adsorbent pH 7 20 mg/L crystal violet initial concentration Synthetic wastewater	89.87
Kumbhar et al, 2022[31]	Tea waste /Fe_3O_4	Mobile reactor 90 minute contact time 2 g/L amount of adsorbent 100 mg/L crystal violet initial concentration pH 7 Synthetic wastewater	98.71
Sulyman et al, 2016[27]	Date palm (L.) dead leaflets *(Phoenix dactylifera)*	200 rpm mixing speed 30 minute contact time 50 mg/L amount of adsorbent 5 mg/L crystal violet initial concentration pH 6,5 Synthetic wastewater	96
Alshabanat et al., 2013[32]	Date palm fiber *(Phoenix dactylifera)*	100 rpm mixing speed 0,25 g amount of adsorbent $3*10^{-5}$ mol/L crystal violet initial concentration pH 2 Synthetic wastewater	≅ 98.5

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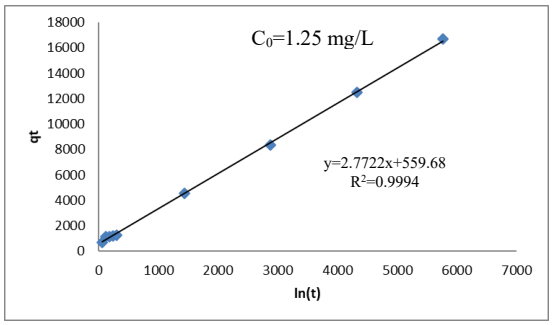
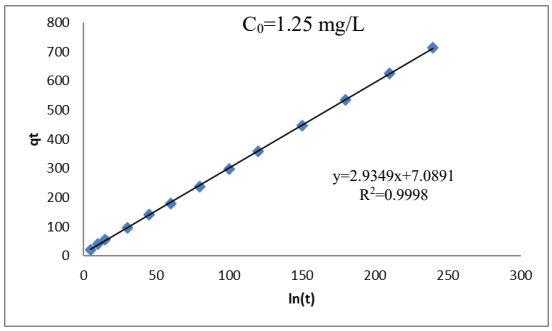
Table 4. Continued

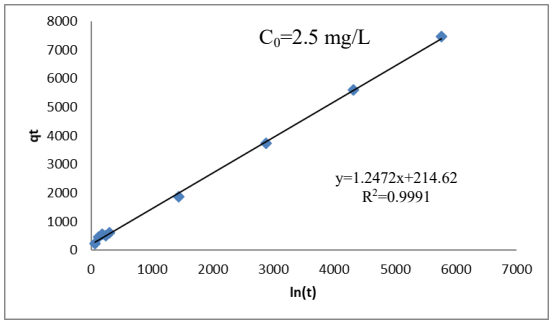
El-Sayed, 2011[28]	Palm kernel fiber *(Phoenix dactylifera)*	200 rpm mixing speed 60 minute contact time 0,05 g amount of adsorbent 0,15 mg/L crystal violet initial concentration pH 7.2 Synthetic wastewater	≅ 85
Current Study	**Palm fiber *(Washingtonia filifera)***	**300 rpm mixing speed** **210 minute contact time** **0.5 g adsorban miktarı** **pH 8.5** **10 mg/L crystal violet initial concentration** **synthetic wastewater**	**88.73**

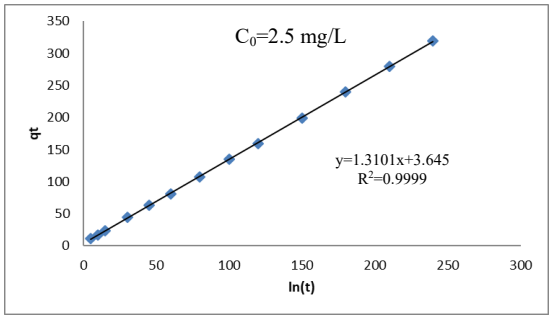
3.3. Kinetic Analysis

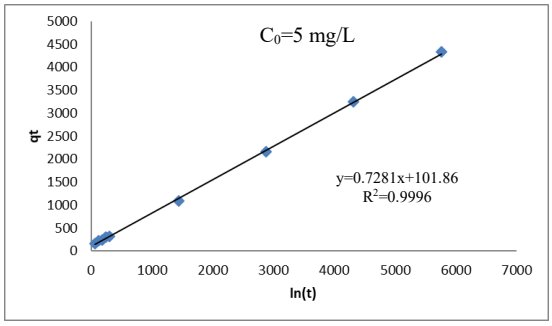
While performing the adsorption, the expression of speed is important in terms of understanding the relationship between the adsorbent and the adsorbate.[27,30,31] The removal data obtained under stationary and mobile test conditions were used as data in the kinetic models as shown in Table 1. As a result of the kinetic analyses, it was determined that the crystal violet removal was more suitable for the pseudo-second order kinetic equation type I for all study sets. In Table 5, the kinetic coefficients of all kinetic models are given, whereas in Figure 4, the graphs of pseudo-second-order kinetic equation type I are provided for stationary and mobile experimental sets.

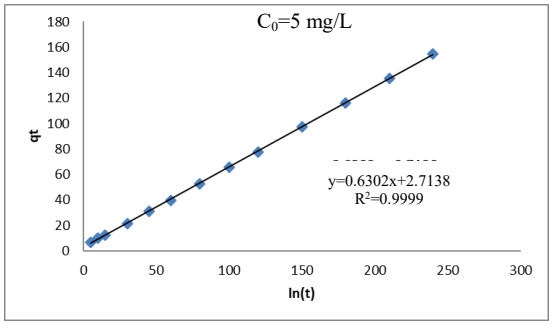












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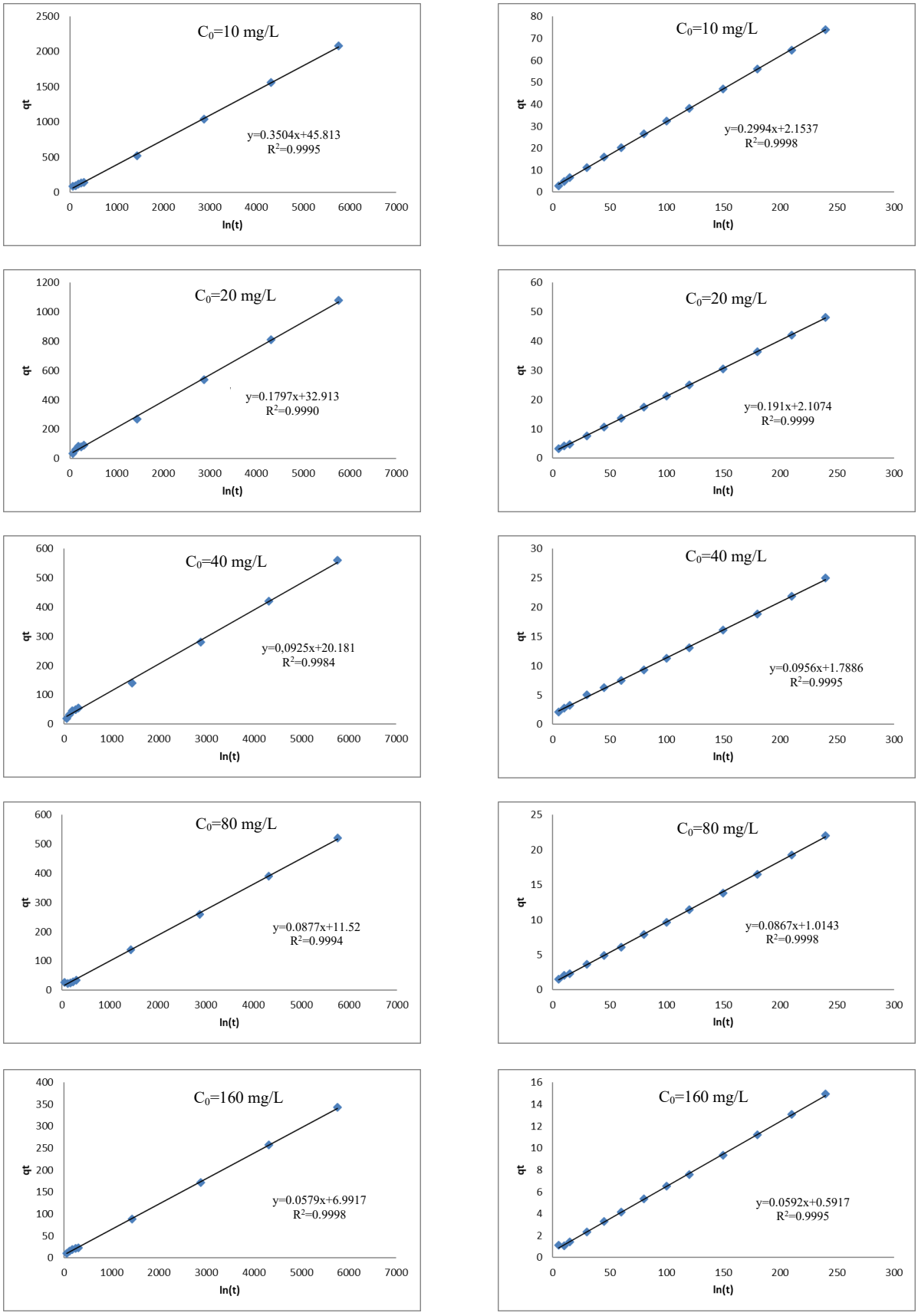

(a) **(b)**

Figure 4. Pseudo-second order type I plots of stationary (a) and mobile (b) test sets removal of crystal violate using palm (*Washingtonia filifera*) fibers from synthetic dye solition.

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Table 5. Coefficients of all kinetic models.

Kinetic Model		Parameter	C_0, mg/L							
			1.25	2.5	5	10	20	40	80	160
Stationary Phase										
Zero Order		q_e, mg/g	0.1708	0.3982	0.7379	1.5863	2.6818	4.8133	6.6301	9.9593
		k, mg/g.min	-0.00004	-0.00009	-0.0001	-0.0003	-0.0006	-0.0013	-0.001	-0.0016
		R^2	0.6537	0.638	0.6106	0.5621	0.6607	0.6975	0.5053	0.6219
First Order		q_e, mg/g	-1.8528	-0.9881	0.3697	0.3784	0.9245	1.5163	1.7863	2.2544
		k, mg/g.min	-0.0002	-0.0002	-0.0002	-0.0001	-0.0002	0.0002	0.0001	-0.0001
		R^2	0.5345	0.5709	0.517	0.4392	0.6046	0.668	0.3481	0.544
Second Order		q_e, mg/g	0.1435	0.3505	0.6452	1.3220	2.3906	4.3706	5.1466	9.1157
		k, mg/g.min	-0.0009	-0.0004	-0.0002	-0.00009	-0.00005	-0.00003	0.00002	-0.00001
		R^2	0.4072	0.4873	0.3976	0.2981	0.5268	0.6148	0.2148	0.4532
Pseudo Second Order	**Type I**	Q, mg/g	0.3607	0.8017	1.3734	2.8538	5.5648	10.8108	11.4025	17.2711
		k, mg/g.min	0.0137	0.0072	0.0052	0.0026	0.0009	0.0004	0.0006	0.0004
		R^2	0.9994	0.9991	0.9996	0.9995	0.999	0.9984	0.9994	0.9998
	Type II	q_e, mg/g	0.3475	0.7129	1.3852	3.2637	4.8239	8.6206	15.5038	16.5562
		k, mg/g.min	0.0146	0.0103	0.0044	0.0014	0.0015	0.0009	0.0002	0.0005
		R^2	0.9288	0.8587	0.9904	0.982	0.8715	0.8195	0.9306	0.9602
	Type III	q_e, mg/g	0.3584	1.2934	1.4054	2.9803	5.3151	9.8538	11.599	17.116
		k, mg/g.min	0.0138	-0.0037	0.0042	0.0019	0.0011	0.0006	0.0005	0.0004
		R^2	0.8916	0.8213	0.9764	0.9322	0.8275	0.7456	0.7121	0.9384
	Type IV	q_e, mg/g	0.3636	0.8269	1.4067	3.0363	5.6470	10.9565	12.9183	17.4545
		k, mg/g.min	0.0121	0.0062	0.0041	0.0018	0.0009	0.0004	0.0003	0.0004
		R^2	0.8916	0.8213	0.9764	0.9322	0.8275	0.7456	0.7121	0.9384
Elovich		β, g/mg	0.0602	1.2472	0.2134	0.4377	0.9216	1.847	-1.6575	-0.0077
		α, mg/g.min	1.4693	4.35E+74	0.7437	12.5035	0.1037	0.0392	-2.3090	0.0000034
		R^2	0.9375	0.9252	0.9276	0.8963	0.9361	0.9389	0.8341	0.9267
Mobile Phase										
Zero Order		q_e, mg/g	0.2835	0.6256	1.1907	2.3202	3.0884	4.9113	6.5859	10.344
		k, mg/g.min	-0.0003	-0.0008	-0.0021	-0.0052	-0.0107	-0.0263	-0.0248	-0.0332
		R^2	0.4919	0.4275	0.4697	0.6568	0.5906	0.6947	0.6003	0.5559
First Order		q_e, mg/g	-1.2687	-0.4839	0.1479	0.8275	1.0663	1.5219	1.8214	2.2664
		k, mg/g.min	-0.0011	-0.0012	-0.0017	-0.002	-0.0031	-0.0043	-0.0033	-0.003
		R^2	0.478	0.3767	0.4181	0.5991	0.4779	0.577	0.5017	0.4197
Second Order		q_e, mg/g	0.2789	0.6059	1.1254	2.2527	2.6939	4.2194	5.7438	8.7565
		k, mg/g.min	-0.0037	-0.0019	-0.0015	-0.0008	-0.001	-0.0008	-0.0005	-0.0003
		R^2	0.4638	0.3274	0.3648	0.5397	0.3656	0.4422	0.3989	0.2929
Pseudo Second Order	**Type I**	q_e, mg/g	-0.3407	0.7633	1.5867	3.3400	5.2356	10.4602	11.5340	16.8918
		k, mg/g.min	1.2150	0.4708	0.1463	0.0416	0.0173	0.0051	0.0074	0.0059
		R^2	0.9998	0.9999	0.9999	0.9998	0.9999	0.9995	0.9998	0.9995
	Type II	q_e, mg/g	0.3377	2.3359	1.6168	3.1826	5.3879	10.0704	11.6550	18.3823
		k, mg/g.min	1.2262	2.7559	0.1120	0.0679	0.0147	0.0059	0.0067	0.0037
		R^2	0.8883	0.8064	0.9968	0.9509	0.9954	0.9947	0.9966	0.9512
	Type III	q_e, mg/g	0.339	0.7712	1.6137	3.219	5.2926	10.3390	11.688	17.039
		k, mg/g.min	1.1856	0.3824	0.1139	-0.0628	0.0160	0.0053	0.0066	0.0055
		R^2	0.8732	0.952	0.991	0.9313	0.9837	0.9819	0.9920	0.8782
	Type IV	q_e, mg/g	0.3441	0.7749	1.6158	3.2484	5.2990	10.3923	0.9137	17.5151
		k, mg/g.min	1.0198	0.3623	0.1127	0.0579	0.0157	0.0052	13.9980	0.0047
		R^2	0.8732	0.952	0.991	0.9313	0.9837	0.9819	0.992	0.8782
Elovich		β, g/mg	0.0271	0.0665	0.1865	0.4023	0.868	2.0007	-0.776	2.7242
		α, mg/g.min	68337.01	9397.015	165.4741	47.0353	2.2891	0.3544	-0.0001	0.9089
		R^2	0.8714		0.8628	0.9685	0.9368	0.9779	0.9448	0.9108

When Table 5 is examined, it is seen that the R^2 values obtained among all kinetic models are closest to the R^2=1 value in pseudo-second-order type 1. Therefore, it was determined that the removal of crystal violet from palm fibers was suitable for pseudo-second-order type 1. Various researchers who have studied crystal violet removal have reported that adsorption is suitable for pseudo-second-order type 1 as a result of their research studies.[28-34] The pseudo-second order kinetic model expresses chemical adsorption and indicates the electron sharing between the adsorbate.[35]

Conflict of interests

I declare that there is no a conflict of interest with any person, institute, company, etc.

4. CONCLUSION

In this study, it is understood that the adsorbent material synthesized from palm fibers can be prepared without requiring any heat treatment and can be used for dyestuff removal. In the study, the highest crystal violet removal

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efficiency was obtained with 88.73% in the experiment with stirring. The capacity values reached at the moment of equilibrium in stationary and mobile phases (with 160 mg/L initial crystal violet concentration) are 16.82 mg/g and 16.08 mg/g, respectively. As the ultimate result, dye removal can be achieved with this natural adsorbent material obtained from palm trees, which are widely grown in the Mediterranean region. Palm fiber, which is a natural and inexpensive material, can be disposed of by burning after its use for dystuff removal or can be used as raw materials in various industries such as the construction industry.

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