

Article

The Use of Beech Bark (Latin: *Fagus sylvatica*) and Birch Bark (Latin: *Betula pendula* Roth) for the Removal of Cationic Dyes from Aqueous Solutions

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Abstract: The aim of this work was to determine the sorption capacity of the cationic dyes Basic Red 46 (BR46) and Basic Violet 10 (BV10) on the prepared sorbents: beech bark (BBE) and birch bark (BBI). Two fractions of bark were used in the research: fine (2–3 mm) and coarse (4–5 mm). The carried out tests made it possible to determine the influence of the pH value on the sorption efficiency, the sorption equilibrium time and the maximum sorption capacity of the two tested sorbents. The Langmuir model and the Freundlich model were used to describe the obtained experimental data. Beech and birch barks are effective sorbents for cationic dyes; however, the efficiency of dye sorption on both bark sorbents depends on the type of cationic dye. According to the obtained data, beech and birch bark sorbents showed higher sorption efficiency for Basic Red 46 than for Basic Violet 10. The pH correction was a necessary condition for sorption, and the sorption pH value for the cationic dyes Basic Red 46 and Basic Violet 10 was determined individually for each dye. The most favourable pH value for the sorption of the BR46 dye on the beech and birch bark sorbents was pH = 6, while for the dye BV10, it was pH = 3. The sorption equilibrium time for Basic Red 46 was 300 min and for Basic Violet 10–240 min. The fine fraction of beech bark had the highest sorption capacity for both BR46 (128.45 mg/g dry matter) and BV10 (18.07 mg/g dry matter).

Keywords: beech bark; birch bark; Basic Red 46 (BR46); Basic Violet 10 (BV10)



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1. Introduction

Colouring compounds in industrial wastewater pose a threat to the environment as they are not only very difficult to remove, but are also hazardous due to their toxic properties, low biodegradability and intense colour. Their presence in surface waters significantly affects the entire ecosystem by interfering with the process of photosynthesis, thus causing a direct, harmful effect on living organisms [1]. These compounds are also harmful to the human body and can cause various diseases. Cationic dyes can change the colour of water at concentrations as low as 0.1 mg/L, which impairs the transparency of water bodies [2].

Conventional biological wastewater treatment plants are not able to deal with this type of pollution with sufficient efficiency [3]. In addition, the degradation products of colourants are very toxic and mutagenic for fauna and flora. Therefore, new, more efficient systems for the removal of dyes from industrial wastewater are being sought.

Various biological, chemical and physical methods for the treatment of wastewater containing dyes, such as chemical coagulation [4,5], electrocoagulation [6–9], ion exchange [10,11], activated sludge [12,13], biodegradation [14–17], photocatalysis [18–20], advanced oxidation [21–24], UV/H₂O₂ process [25], membrane processes [26–29], osmosis [30] or nanofiltration [31–34], are widely described in the literature.

The advantages of adsorption in the abovementioned methods of dye removal are its low cost, which is often limited to the cost of the sorbent or its transport; the effec-

tive removal of toxic substances; and the fact that no additional reagents are required. In addition, adsorption does not cause sludge formation or salinisation of the wastewater. After the adsorption process, the colourants can be easily and quickly separated from the purified solution together with the adsorbent. This technology is considered environmentally friendly.

The efficiency of adsorption depends on the specific surface area of the sorbent, the pH value of the purified solution, the initial concentration of the solution, the process duration and the molar mass of the adsorbate. It is also important to choose the right adsorbent depending on the type of impurity.

Sorbents can be waste materials that are often a by-product of industrial processes and do not have a high commercial value. Wastes from which sorbents with a high efficiency of pollutant removal can be obtained are usually sought in the food industry, agriculture and wood processing. These industries produce large quantities of seeds, husks, sawdust, bark and pomace that can be used as sorbents. These by-products consist largely of polymers—cellulose and lignin as well as hemicellulose—which contain many functional groups that can form bonds with colourants.

Tree bark or sawdust is waste that is produced during wood processing. These products have recently become increasingly popular as sorbents due to their low cost, high availability and good sorption properties [35]. The cost of bark and sawdust from forestry waste is usually only related to the cost of transport from the place of storage to the place of use. The binding of pollutants by bark or sawdust can be achieved by physical or chemical adsorption [36,37]. The fundamental factor influencing the occurrence and efficiency of the sorption process is the specific chemical structure of the bark. The structure of the bark consists mainly of organic compounds, i.e., cellulose (about 45%), hemicellulose (about 30%) and lignin (approx. 20%), as well as proteins, starch and tannins [38]. Sawdust is characterised by the presence of functional hydroxyl (-OH) and aldehyde (-CHO) groups, which enable the binding of impurities (e.g., dyes) [39]. Data from the literature show that sawdust can be successfully used as a sorbent to remove dyes from industrial wastewater [40–46].

The aim of the research presented in this work was to determine the possibility of using bark waste from the wood industry as a sorbent. Two types of bark were used for the investigation: beech and birch. Two sizes of bark were used in the study, 1–2 mm and 3–4 mm, to determine whether it is justified to shred the bark to achieve higher sorption performance. This study was carried out with two cationic dyes with different chemical structures: Basic Violet 10 and Basic Red 46.

2. Materials and Methods

2.1. Sorbents

The bark of beech (lat. *Fagus sylvatica*) and birch (lat. *Betula pendula* Roth) was used in the study. Each type of bark was tested in fine fractions (1–2 mm) and coarse fractions (3–4 mm). The composition of the sorbents used in this study was analysed with the ANKOM 200 Fiber Analyser (ANKOM Technology, New York, NY, USA) using the “Acid Detergent Fiber Method (ADF Method 5)” (method for acid detergent fibres). The characteristics of the bark are shown in Table 1.

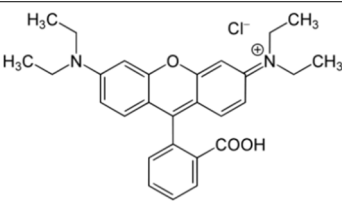
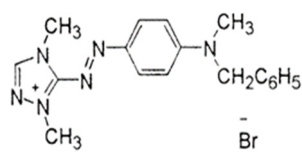
Table 1. Characteristics of sorbents used in this study.

Component	Beech Bark	Birch Bark
Lignin [%]	32.87	40.30
Cellulose [%]	30.49	25.20
Hemicellulose [%]	32.34	30.50
Ash; mineral substances; other ingredients [%]	4.30	4.00

2.2. Sorbates (Dyes)

Dyes of cationic class from ZPB “Boruta” SA were used in our research due to its widespread use in the industry. Table 2 shows the chemical characteristics of the dyes tested.

Table 2. Characteristics of the dyes tested.

Dye	Basic Violet 10—(BV10)	Basic Red 46—(BR46)
Structural formula		
Molar mass	479 g/mol	401 g/mol
Summaric formula	$C_{28}H_{31}ClN_2O_3$	$C_{18}H_{21}BrN_6$
λ_{max}	554 [nm]	530 [nm]
Type of dye	cationic	cationic
Application	dyeing paper, leather, cotton; paint production	dyeing of fibers and synthetic fibers; printing

2.3. Preparation of Sorbents

The bark was cleaned and ground in an electric mill into two fractions (fine 1–2 mm and coarse 3–4 mm). The sorbent was sieved through laboratory sieves and then rinsed with distilled water and kept in tightly closed containers at a temperature of 4 °C.

Four biosorbents were used in the study:

- Beech bark—fine fraction (BBeF);
- Beech bark—coarse fraction (BBeC);
- Birch bark—fine fraction (BBF);
- Birch bark—coarse fraction (BBcC).

2.4. Preparation of Dyes

A total amount of 1000 mg of dye was weighed into a beaker on an analytical balance. Distilled water was then poured to fill 60–70% of the volume of the beaker. After dissolving the dye, the contents of the beaker were quantitatively transferred to a volumetric flask with a capacity of 1000 mL and filled to the line. The procedure for preparing basic solutions was carried out identically for both of the tested dyes.

Working solutions with concentrations of 10–500 mg/L were produced from the prepared basic solutions. The pH correction of the working solutions was carried out with 0.1M NaOH and 0.1M HCl.

The determination of the dye concentration in the solution was carried out using the UV-3100 PC—UV/Visible spectrophotometer (VWR spectrophotometers, VWR International LLC., Mississauga, ON, Canada)

2.5. Effect of the pH Value on the Efficiency of Dye Sorption

Beech and birch barks were weighed and put into 80 Erlenmeyer flasks with a capacity of 250 mL in two fractions in an amount of 0.1 g DM (Table 3). Then, previously prepared dye working solutions (100 mL) with a pH of 2–11 were added to the Erlenmeyer flasks and placed on a laboratory shaker model SK71 with a mixing speed of 120 rpm for 120 min. After the specified time, samples of the solutions were taken with an automatic pipette (10 mL) into the previously prepared polypropylene tubes. The pH of the solutions and the concentration of the remaining dye were measured after the sorption process. A HI 221 pH meter (Hanna Instruments Woonsocket, RI, USA) was used to measure pH. The UV-3100 PC—UV/Visible spectrophotometer (VWR spectrophotometers, VWR International LLC., Mississauga, ON, Canada) was used to determine the dye concentration in the solutions.

Table 3. Test parameters—influence of pH on the efficiency of dye sorption.

Dye	Conc. of Dye [mg/L]	pH of Dye Solutions	Sorbent Dose [g DM/L]	Mixing Speed [r.p.m]	Sorpt. Time [min]	Temp. [°C]
BV10	5	2/3/4/5/6/7/8/9/10/11	1	120	120	22
BR46	50	2/3/4/5/6/7/8	1	120	120	22

2.6. Research to Determine the Equilibrium Time

A total of 0.5 g dry mass of the sorbent was weighed and put into a series of beakers with a capacity of 600 mL. Dye solutions of 500 mL were then added and the laboratory beakers containing the material to be tested were placed on a multistage magnetic stirrer (M5 53M) with a stirring speed of 120 rpm. During the sorption process, samples (5 mL) were taken from the solutions at fixed intervals to determine the dye remaining in the solution. The parameters of the studies to determine the sorption equilibrium time are presented in Table 4.

Table 4. Test parameters—the sorption equilibrium time.

Sorbent	Dye	Conc. of Dye [mg/L]	pH of Dye Solutions	Sorbent Dose (for All Series) [g DM/L]	Sampling Time (for All Series) [min]	Mixing Speed [r.p.m.]	Temp. [°C]
BBeF	BV10	5	Optimal, determined for each dye in point 2.5	1	0, 5, 10, 20, 30, 45, 60, 90, 120, 150, 180, 240, 300, 360	120	22
BBeC	BR46	50					
BBiF	BV10	5					
BBiC	BR46	50					

2.7. Determination of the Maximum Sorption Capacity

A total of 0.5 g of sorbent (BBeF, BBeC, BBiF, BBiC) was weighed into Erlenmeyer flasks with a capacity of 250 mL. Then, dye solutions (100 mL) with concentrations of 10–500 mg/L and with the optimum pH determined in Section 2.5 were added to the flasks and the flasks were placed on the shaker for the sorption equilibrium time determined in Section 2.4. After completion of the sorption process, samples of 10 mL were taken from the solutions to determine the concentration of dye remaining in the solution. The most important parameters of the test series are listed in Table 5.

Table 5. Test parameters—determination maximum sorption capacity.

Sorbent	Sorbent Dose (for All Series) [g/L]	Dye	Dye Conc. [mg/L]	pH of the Solutions	Sampling Time [min]	Mixing Speed [r.p.m.]	Temp. [°C]
BBeF BBeC BBiF BBiC	1	BV10 BR46	10, 50, 75, 100, 200, 300, 400, 500	Optimal, determined for each dye in point 2.5	Equilibrium time determined for each dye in Section 2.6	120	22

2.8. Calculation Methods

The amount of sorbed dye on the sorbent calculated according to Formula (1):

$$Q_e = \frac{(C_o - C_s) \cdot V}{m} \quad (1)$$

Q_e —Mass of the sorbed dye [mg/g DM];

C_o —Initial dye concentration [mg/L];

C_s —Concentration of dye after sorption [mg/L];

V —Volume of solution [L];

M—Sorbent mass [g DM].

The kinetics of dye sorption onto tested sorbents was described using pseudo-first-order (2), pseudo-second-order (3) and intraparticle diffusion (4) models:

$$q = q_e \times \left(1 - e^{(-k_1 \times t)}\right) \quad (2)$$

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

$$q = k_{id} \times t^{0.5} \quad (4)$$

q—Instantaneous value of sorbed dye [mg/g];

q_e —The amount of dye sorbed at the equilibrium state [mg/g];

t—Time of sorption [min];

k_1 —Pseudo-first-order adsorption rate constant [1/min];

k_2 —Pseudo-second-order adsorption rate constant [g/(mg × min)];

k_{id} —Intraparticle diffusion model adsorption rate constant [mg/(g × min^{0.5})].

In this study, two sorption models were used to describe the data:

Langmuir's isotherm (5):

$$Q_e = \frac{Q_{\max} \cdot K_C \cdot C_e}{1 + K_C \cdot C_e} \quad (5)$$

Q_e —Equilibrium amount of sorbed dye [mg/g DM];

$Q_{\max}$ —Maximum sorption capacity [mg/g DM];

K_C —Constant used in the Langmuir's equation [L/mg];

C_e —Concentration of dye remaining in the solution [mg/L].

Freundlich's isotherm (6):

$$Q_e = K \cdot C_e^n \quad (6)$$

Q_e —Actual sorption of sorbate on the sorbent [mg/g DM];

K—Sorption equilibrium constant used in Freundlich's model;

C_e —Concentration of dye remaining in the solution [mg/L];

n—Heterogeneity parameter.

3. Results and Discussion

3.1. FTIR Analysis

The FTIR spectra of birch bark and beech bark are very similar, suggesting a similar chemical composition (Figure 1).

The spectra show bands that are characteristic of lignocellulosic materials. Peaks in the wavenumber range of 1440–850 cm^{−1} are typical for polysaccharides. The peaks at 1028 cm^{−1} and 1156 cm^{−1} are due to the glycosidic C-O-C bond between the pyranose and hemicellulose rings [47–49]. The peaks at 1100 cm^{−1} and 890 cm^{−1} indicate stretching of the saccharide skeletons of the holocellulose rings [50,51]. Additionally, specific to cellulose and hemicellulose are the peaks at 1440 cm^{−1} and 1368 cm^{−1}, which correspond to the bending vibrations -CH₂, and the peak at 1316 cm^{−1}, which corresponds to the wave vibrations -CH₂ [52].

Lignin is characterised by peaks at 1240 cm^{−1} and 1510 cm^{−1}, which are due to the presence of C-O and C=C bonds in the area of the lignin benzene rings [47,53] as well as the peak at 1604 cm^{−1}, which is related to the vibrations of these aromatic rings [51]. The content of lignin in the bark biomass is also indicated by the typical peak at 1734 cm^{−1}, indicating the presence of C=O carbonyl bonds in the structure [54].

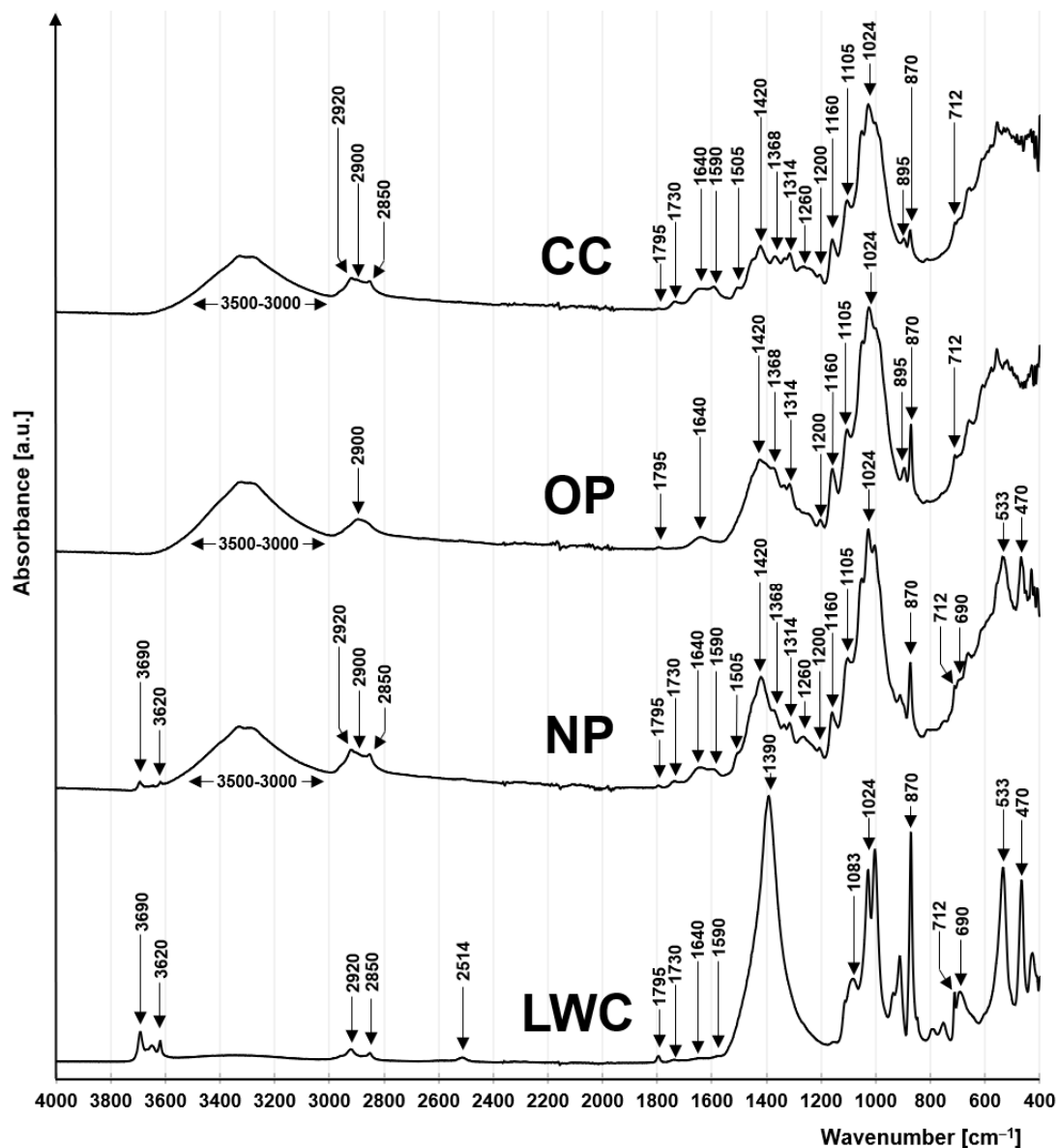


Figure 1. FTIR spectra for birch bark and beech bark.

The peaks at 2924 cm^{-1} and 2853 cm^{-1} can be traced back to the asymmetric and symmetric tensile vibrations of the $-\text{CH}_2$ groups, which originate from the aliphatic structures of holocellulose and lignin [55,56]. The broad band at $3500\text{--}3000\text{ cm}^{-1}$ is due to the stretching of the O-H bond of hydroxyl functional groups present in both saccharides and lignin.

3.2. Effect of pH on the Efficiency of Dye Sorption

Figure 2 shows the sorption efficiency of BR46 BV10 dyes on BBeF and BBiF sorbents as a function of the initial pH of the dye solution. In the case of BR46, the tests were performed in the pH range of 2–8, as discolouration of the solution was observed at an initial pH > 8. The study shows that an increase in the removal efficiency of Basic Red 46 was observed with increasing pH. The efficiency of sorption of BR46 pigment on both bark types increased with increasing pH = 5. A further increase in pH did not lead to an increase in the sorption efficiency of BR46 (Figure 2a).

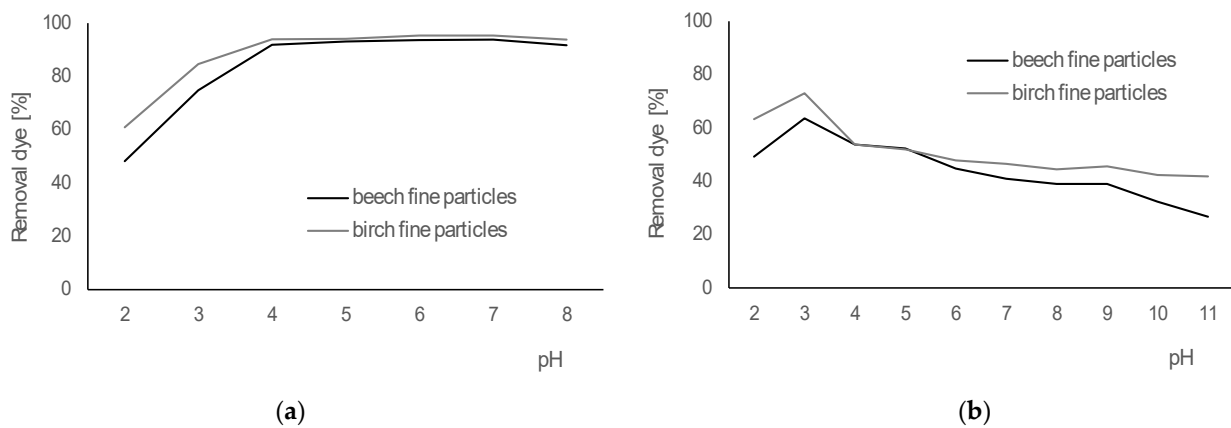


Figure 2. The influence of pH on the sorption efficiency of dyes (a) BR46 and (b) BV10.

The functional groups of the sorbent from beech bark and birch bark were protonated at low pH. This resulted in the sorbent acquiring a positive charge. The positively charged surface of the sorbent repelled molecules of the cationic dye Basic Red 46 electrostatically, which had a negative effect on sorption, explaining the lowest sorption efficiency of BR46 at pH 2.

A different process was observed with the second tested dye, BV10. It was also a cationic dye, but the highest sorption efficiency was observed at pH 3 (Figure 2b). As with BR46, the sorption efficiency of BV10 was compared for both sorbents.

Basic Red 46 and Basic Violet 10 are cationic dyes, but the effect of initial pH on the sorption efficiency of the two dyes was different. These differences may be due to the different chemical structure of the dyes.

One feature of Basic Violet 10 is the presence of an acidic carboxyl group, which could lead to electrostatic attraction of the functional carboxyl group (COO^-) of BV10 by the positively charged surface of the sorbent at low pH.

On the other hand, the lower sorption of the BV10 dye at higher pH could be due to the negative charge of the sorbent and the mutual repulsion of the dye molecules and the sorbent surface.

The pH_{PZC} values determined using the “drift” method for birch bark and beech bark were, respectively, $\text{pH}_{\text{PZC}} = 5.55$ and $\text{pH}_{\text{PZC}} = 5.77$ (Figure 3). The values obtained indicate the slightly acidic nature of the sorbents tested. This is probably due to the fact that these materials have a larger number of acidic functional groups (e.g., carboxyl, sulfonic acid) compared to basic groups (e.g., amino). The acidic nature of bark-based materials indicates potentially good sorption properties compared to cationic sorbates (including BR46 and BV10).

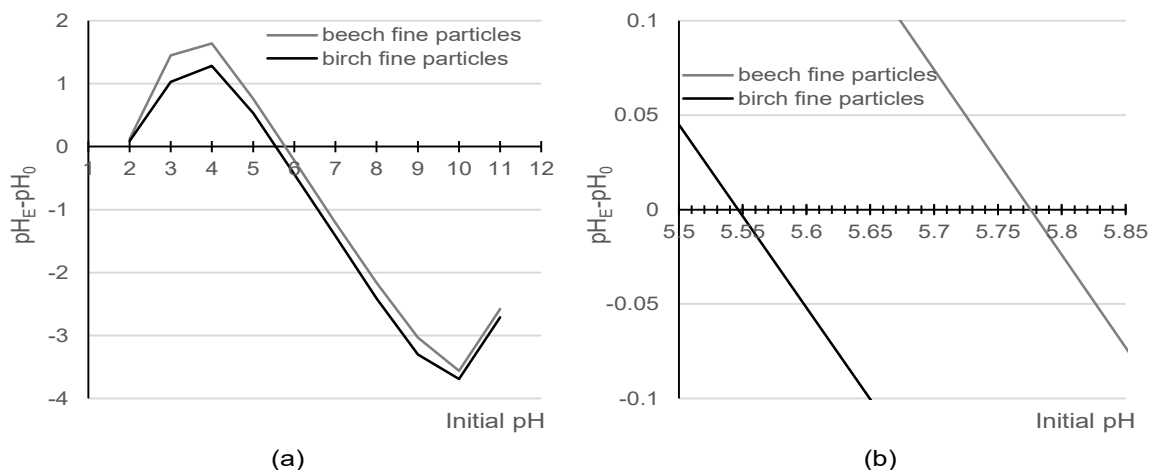


Figure 3. (a,b) pH_{PZC} of the tested sorbents determined with the “drift” method.

3.3. Kinetics of Dye Sorption

In the study, the equilibrium time of sorption of BR46 and BV10 dyes on the bark of beech and birch trees was determined as a function of the fraction. The sorption processes were carried out at an optimum pH value, which was pH = 5 for Basic Red 46 and pH = 3 for Basic Violet 10.

The studies to determine the sorption equilibrium time for both dyes were carried out for the BR46 solution at a concentration of 50 mg/L and for the BV10 solution at a concentration of 5 mg/L (Figure 4).

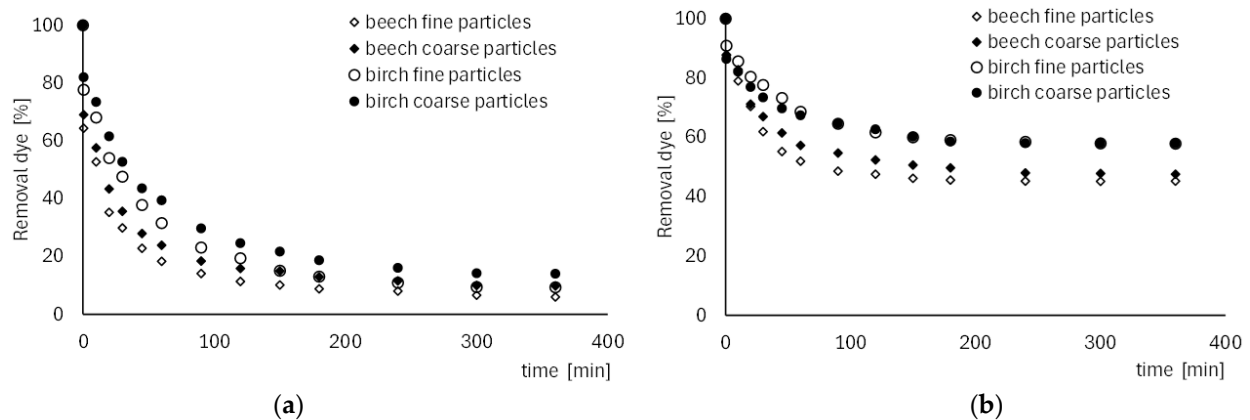


Figure 4. Sorption equilibrium time for (a) BR46 and (b) BV10.

Based on the studies carried out, the equilibrium time of 300 min for BR46 and 240 min for BV10 was assumed (Figure 4). The longer sorption time of the BR46 dye (300 min) may be due to its lower molar mass, which led to a longer time of filling the sorption centres by dye molecules. On the other hand, the shorter sorption time of the BV10 dye may indicate a higher molar mass, which had a limited ability to reach the sorption centres due to the size of the molecules.

Experimental data from studies on the sorption kinetics of BR46 and BV10 on bark-based sorbents were described using pseudo-first- and pseudo-second-order models (Table 6, Figure 5). In each series of experiments, regardless of the type of sorbent and dye, the best agreement with the obtained data was demonstrated by the pseudo-second-order model, which is typical for the sorption of cationic dyes on plant biomass.

Table 6. Kinetic parameters of dye sorption onto BBeC, BBeF, BBiC and BBiF.

Dye (Initial Conc.)	Sorbent	Pseudo-First-Order Model			Pseudo-Second-Order Model			Exp. Data [mg/g]	Equil. Time [min]
		k_1	$q_{e,(cal.)}$	R^2	k_2	$q_{e,(cal.)}$	R^2		
		[1/min]	[mg/g]	-	[g/mg × min]	[mg/g]	-		
BR46 (50 mg/L)	BBeC	0.0564	42.55	0.9665	0.0018	46.19	0.9975	45.10	300
	BBeF	0.0678	44.33	0.9669	0.0021	47.80	0.9980	46.99	300
	BBiC	0.0277	40.89	0.9773	0.0008	46.45	0.9969	43.01	300
	BBiF	0.0328	43.12	0.9712	0.0009	48.24	0.9955	45.34	300
BV10 (5 mg/L)	BBeC	0.0373	2.50	0.9842	0.0899	2.79	0.9986	2.62	180
	BBeF	0.0418	2.69	0.9951	0.0195	2.97	0.9946	2.74	180
	BBiC	0.0409	1.98	0.9425	0.0271	2.18	0.9858	2.10	180
	BBiF	0.0277	2.04	0.9764	0.0159	2.30	0.9926	2.11	180

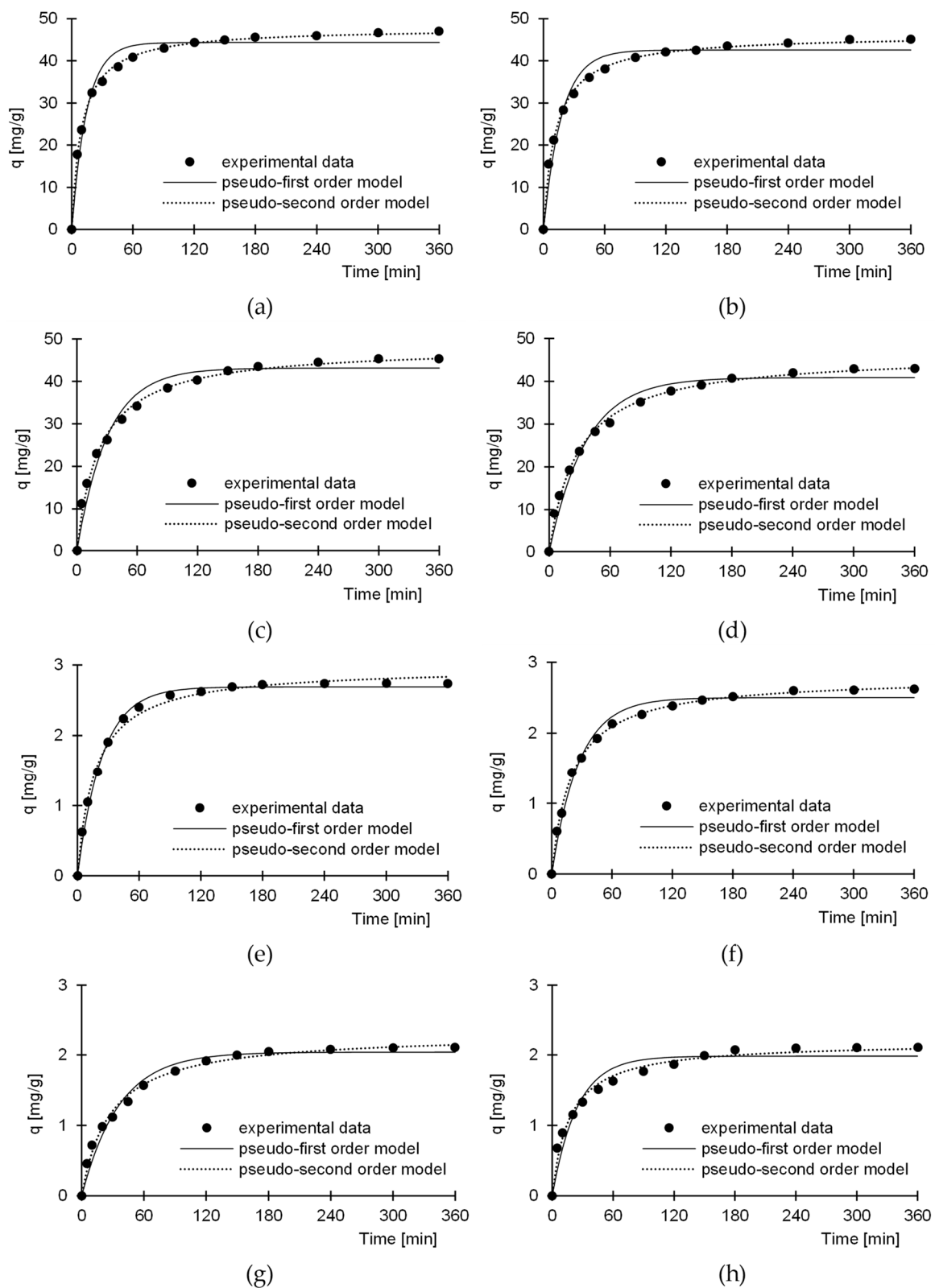


Figure 5. Sorption kinetics of BR46 onto (a) beech fine particles, (b) beech coarse particles, (c) birch fine particles and (d) birch coarse particles and sorption kinetics of BV10 onto (e) beech fine particles, (f) beech coarse particles, (g) birch fine particles and (h) birch coarse particles. Pseudo-first-order model and pseudo-second-order model.

The data from studies on the kinetics of dye sorption on BBeF, BBeC, BBiF and BBiC were also described using an intraparticle diffusion model. The analysis of the constants determined from a specific model showed that the sorption of dyes on the sorbents tested took place in three phases in each test series (Table 7, Figure 6).

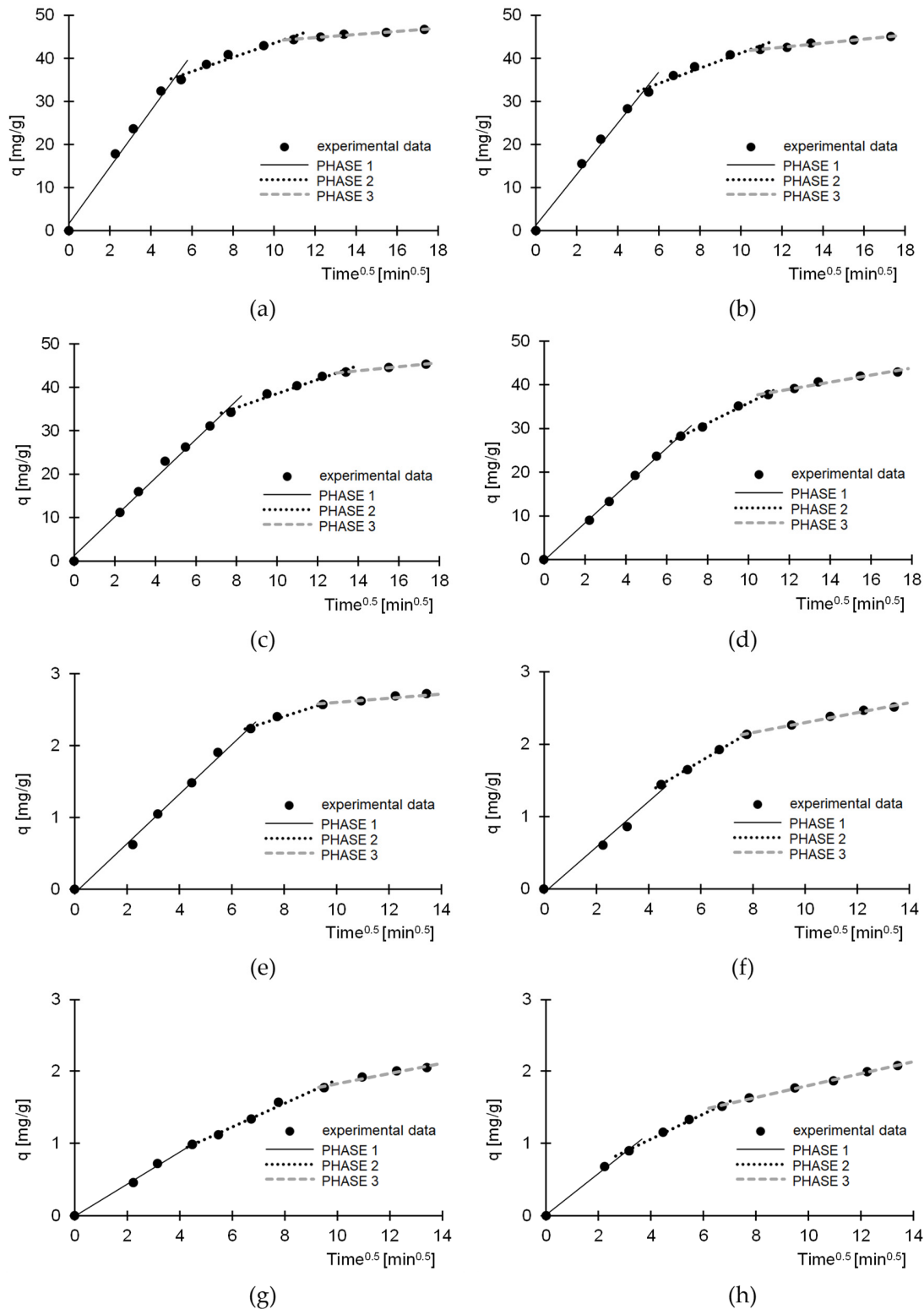


Figure 6. Intraparticle diffusion model of the sorption of BR46 onto (a) beech fine particles, (b) beech coarse particles, (c) birch fine particles and (d) birch coarse particles and sorption of BV10 onto (e) beech fine particles, (f) beech coarse particles, (g) birch fine particles and (h) birch coarse particles.

Table 7. Rate constants of BR46 and BV10 diffusion determined from a simplified intraparticle diffusion model (sorbent dose = 5 g/L); * [mg/(g·min^{0.5})].

Dye (Initial Conc.)	Sorbent	PHASE 1			PHASE 2			PHASE 3		
		k _{d1}	Time	R ²	k _{d2}	Time	R ²	k _{d3}	Time	R ²
		*	[min]	-	*	[min]	-	*	[min]	-
BR46 (50 mg/L)	BBeC	5.940	30	0.9895	1.758	60	0.9501	0.472	210	0.9804
	BBeF	6.553	30	0.9811	1.638	90	0.9449	0.353	180	0.9724
	BBiC	4.278	45	0.9990	2.308	75	0.9923	0.810	180	0.9634
	BBiF	4.461	60	0.9908	1.621	120	0.9721	0.467	120	0.9973
BV10 (5 mg/L)	BBeC	0.314	20	0.9823	0.213	40	0.9997	0.069	120	0.9901
	BBeF	0.344	45	0.9949	0.118	45	0.9824	0.029	90	0.9044
	BBiC	0.287	10	0.997	0.174	35	0.9955	0.082	135	0.9964
	BBiF	0.222	20	0.9967	0.164	70	0.9889	0.071	90	0.9652

The first phase of sorption was the shortest but was characterised by the highest efficiency. In this phase, the dye cations diffused from the solution onto the surface of the sorbent and the most accessible active sites were occupied by the sorbate. When most of the sorption centres on the surface of the sorbent material were already saturated, phase 2 began, in which the dye ions competed for the remaining free active sites. Due to the very limited number of remaining sorption sites, phase 2 showed a much lower sorption intensity than phase 1. When the sorbent only had free active sites in its deeper layers, phase 3 began. Due to the difficult access to the last few active sites, this phase was characterised by the longest duration and the lowest intensity. Once all available sorption centres were saturated, the system entered a state of equilibrium.

The values of q_e (Table 6) and k_{d1} (Table 7) determined from kinetic models suggest that the finer cortical fraction (BBeF, BBiF) has a much better availability of sorption centres for dyes than the coarse fraction (BBeC, BBiC).

3.4. Sorption Capacity of Beech and Birch Barks

Two sorption models such as the Langmuir and Freundlich isotherms were used to describe the sorption capacity of beech and birch barks. The experimental data and sorption isotherms as well as the constants determined from both models are shown in Figures 7 and 8 and Table 8.

The Langmuir isotherm, which describes the single-layer adsorption of sorbate on the sorbent, clearly better describes the obtained experimental data. The R^2 values presented in Table 8 show that regardless of the type of sorbent, its fineness or the type of dye, the R^2 values obtained for the Langmuir isotherm were higher and ranged from 0.999 (BBiC–BR46) to 0.991 (BBiC–BV10), while for the Freundlich isotherm, the R^2 values ranged from 0.896 (BBiC–BR46) to 0.7761 (BBeF–BV10). This suggests that bark-based sorbents, regardless of their type, adsorb dyes in a single layer.

Table 8. Test parameters—sorption capacity of the sorbents.

Isotherm		Basic Red 46				Basic Violet 10			
		BBeF	BBeC	BBiF	BBiC	BBeF	BBeC	BBiF	BBiC
Langmuir	$Q_{\max}$ [mg/g DM]	131.5	123.0	111.7	111.2	18.0	17.3	16.5	15.9
	K_C [L/g DM]	0.088	0.066	0.091	0.056	0.286	0.229	0.145	0.130
	R^2	0.998	0.995	0.994	0.999	0.994	0.998	0.994	0.991
	n [-]	0.265	0.267	0.230	0.282	0.144	0.154	0.170	0.174
Freundlich	K [(mg·g DM ⁻¹)/(L/g DM) ⁿ]	30.07	26.9	29.3	22.1	8.27	7.48	6.36	5.99
	R^2	0.879	0.894	0.855	0.896	0.761	0.800	0.786	0.768

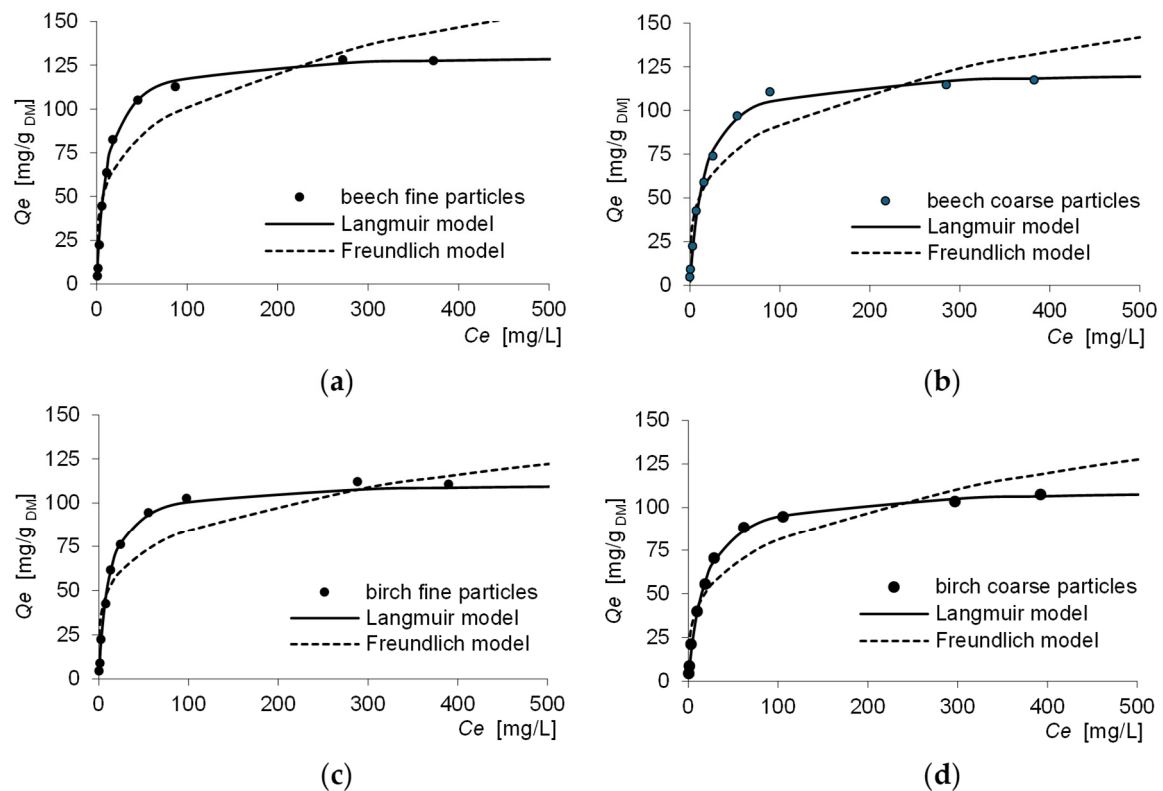


Figure 7. Experimental data and isotherms determined from the Langmuir and Freundlich equations for dye BR46: (a) beech fine particles, (b) beech coarse particles, (c) birch fine particles and (d) birch coarse particles.

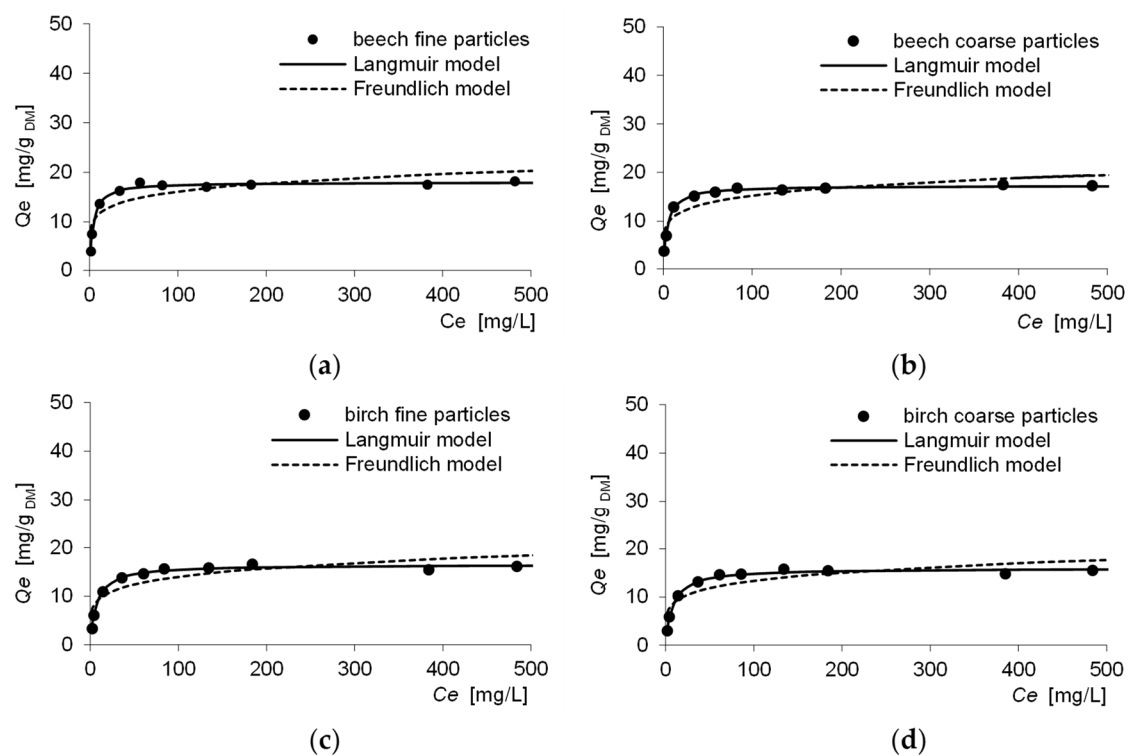


Figure 8. Experimental data and isotherms determined from the Langmuir and Freundlich equations for dye BV10: (a) beech fine particles, (b) beech coarse particles, (c) birch fine particles and (d) birch coarse particles.

As far as sorption capacity is concerned, such general conclusions cannot be drawn. The research carried out showed a clear dependence of the sorption capacity obtained on the type of dye, which is much weaker than the type of sorbent. The highest sorption capacities were obtained for the beech bark sorbent and BR46 dye. The sorption capacity of fine fraction of the beech bark in relation to the BR46 dye was 131.5 mg/g DM, and for the coarse fraction of the beech bark was 123.0 mg/g DM. The sorption capacities of the birch bark sorbent were slightly lower: 111.7 mg/g DM for the fine fraction and 111.2 mg/g DM for the coarse fraction.

The sorption capacity in relation to the Basic Violet 10 dye was significantly lower regardless of the type of bark used and ranged from 18.0 mg/g DM for the fine fraction of beech bark to 15.9 mg/g DM for the coarse fraction of birch bark (Table 8). The values of the K_c constants, which describe the affinity of the sorbate for the sorbent, were an order of magnitude higher for BV10 compared to BR46. It can be seen that in case of BR46, the K_c value was influenced by the fraction of the sorbent. For the bark with a fraction of 1–2 mm, the value of the K_c coefficient describing the affinity was higher than the value of K_c for the fraction of 3–4 mm and was 0.088 L/g DM and 0.066 L/g DM and 0.091 L/g DM and 0.056 L/g DM, respectively.

Table 9 presented below summarises the sorption properties of various unconventional biosorbents in relation to the tested cationic dyes BR46 and BV10. The obtained data show that cationic dyes are not absorbed with high efficiency, especially on organic or mineral sorbents. The sorption capacities determined in the study for two types of beech and birch barks proved to be satisfactory. The application advantage of the proposed sorbents is of course the possibility of further utilisation of the bark, e.g., for energy purposes.

Table 9. Summary of sorption properties of various unconventional biosorbents.

Dye	Sorbent	Sorption Capacity [mg/g DM]	Time Sorption [min]	pH	Source
BR46	beech tree bark	131.5	300	5	own research
	birch tree bark	111.7	300	5	own research
	ceramic clay	28.05	120	6	[57]
	rapeseed husks	49.00	60	8	[58]
	bone meal	24.56	90	6	[59]
	biochar prepared from Chrysanthemum morifolium Ramat straw	32.26 (180 °C) 49.5 (200 °C) 53.19 (220 °C)	60	10	[60]
	clay–wood sawdust mixture	30.12	30	7	[61]
	pyrolyzed by-product biomass	135.0	5	7.5	[62]
	carbon and silica-based composite	41.3 (293 K)	120	4.7	[1]
		87.31 (313 K)			
		176.1 (333 K)			
	raw and purified clay	54.0 (raw) 72.0 (purified)	10 (raw) 20 (purified)	6	[63]
BV10	beech tree bark	18.0	240	3	own research
	birch tree bark	17.3	240	3	own research
	cedar cone	17.2	480	5	[64]
	exhausted coffee ground	2.5	180	2	[65]
	fly ash	1.9	4320		[66]
	sugarcane bagasse	88.7	-	4	[67]
	pine bark–compost	126	-		[68]
	compost	41.7	1440	5.3	[69]
	banana peels	9.5	60	2	[70]

4. Conclusions

The effectiveness of sorption of dyes on the bark of beech and birch sorbent depends on the type of cationic dye. The tested sorbents showed a higher sorption efficiency of Basic

Red 46 than Basic Violet 10. The bark of beech and birch trees has proven to be an effective sorbent for cationic dyes.

The pH correction is a prerequisite for sorption. The pH value of sorption for the cationic dyes Basic Red 46 and Basic Violet 10 should be determined individually.

The time of equilibrium for sorption of dyes on the beech and birch bark sorbent depends on the type of dye and must be redetermined each time. This is due to differences in the type of dye and its molar mass.

The adsorption of cationic pigments on beech and birch barks occurs in a single layer, as evidenced by a better fit of the experimental data to the Langmuir isotherm.

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References

- Wiśniewska, M.; Chibowski, S.; Wawrzekiewicz, M.; Onyszko, M.; Bogatyrov, V. CI Basic Red 46 Removal from Sewage by Carbon and Silica Based Composite: Equilibrium, Kinetic and Electrokinetic Studies. *Molecules* **2022**, *27*, 1043. [\[CrossRef\]](#) [\[PubMed\]](#)
- Nigam, P.; Armour, G.; Banat, I.M.; Singh, D.; Marchant, R. Physical Removal of Textile Dyes from Effluents and Solid-State Fermentation of Dye-Adsorbed Agricultural Residues. *Bioresour. Technol.* **2000**, *72*, 219–226. [\[CrossRef\]](#)
- Robinson, T.; McMullan, G.; Marchant, R.; Nigam, P. Remediation of Dyes in Textile Effluent: A Critical Review on Current Treatment Technologies with a Proposed Alternative. *Bioresour. Technol.* **2001**, *77*, 247–255. [\[CrossRef\]](#) [\[PubMed\]](#)
- Ihaddaden, S.; Aberkane, D.; Boukerroui, A.; Robert, D. Removal of Methylene Blue (Basic Dye) by Coagulation-Flocculation with Biomaterials Bentonite and Opuntia Ficus Indica. *J. Water Process Eng.* **2022**, *49*, 102952. [\[CrossRef\]](#)
- Klimiuk, E.; Filipkowska, U.; Korzeniowska, A. Effects of PH and Coagulant Dosage on Effectiveness of Coagulation of Reactive Dyes from Model Wastewater by Polyaluminium Chloride (PAC). *Pol. J. Environ. Stud.* **1999**, *8*, 73–80.
- Ghalwa, N.M.; Saqer, A.M.; Farhat, N.B. Removal of Reactive Red 24 Dye by Clean Electrocoagulation Process Using Iron and Aluminum Electrodes. *J. Chem. Eng. Process Technol.* **2015**, *7*, 269. [\[CrossRef\]](#)
- Nandi, B.K.; Patel, S. Effects of Operational Parameters on the Removal of Brilliant Green Dye from Aqueous Solutions by Electrocoagulation. *Arab. J. Chem.* **2017**, *10*, S2961–S2968. [\[CrossRef\]](#)
- Ahangarnokolaie, M.A.; Ganjidoust, H.; Ayati, B. Optimization of Parameters of Electrocoagulation/Flotation Process for Removal of Acid Red 14 with Mesh Stainless Steel Electrodes. *J. Water Reuse Desalination* **2018**, *8*, 278–292. [\[CrossRef\]](#)
- Janoš, P.; Buchtová, H.; Rýznarová, M. Sorption of Dyes from Aqueous Solutions onto Fly Ash. *Water Res.* **2003**, *37*, 4938–4944. [\[CrossRef\]](#)
- Yang, Z.; Asoh, T.A.; Uyama, H. Removal of Cationic or Anionic Dyes from Water Using Ion Exchange Cellulose Monoliths as Adsorbents. *Bull. Chem. Soc. Jpn.* **2019**, *92*, 1453–1461. [\[CrossRef\]](#)
- Hassan, M.M.; Carr, C.M. A Critical Review on Recent Advancements of the Removal of Reactive Dyes from Dyehouse Effluent by Ion-Exchange Adsorbents. *Chemosphere* **2018**, *209*, 201–219. [\[CrossRef\]](#) [\[PubMed\]](#)
- Raut, P.; Pal, D.; Singh, V.K. Dye Removal Using Activated Sludge. *Biol. Approaches Dye. Contain. Wastewater* **2022**, *2*, 1–16. [\[CrossRef\]](#)
- Widajarno, R.L.; Kardena, E.; Arifianingsih, N.N.; Helmy, Q. Activated sludge: Conventional dye treatment technique. In *Biological Approaches in Dye-Containing Wastewater*; Springer: Singapore, 2022; Volume 1, pp. 119–153. [\[CrossRef\]](#)
- Rane, A.; Joshi, S.J. Biodecolorization and Biodegradation of Dyes: A Review. *Open Biotechnol. J.* **2021**, *15*, 97–108. [\[CrossRef\]](#)
- Bustamante-Torres, M.; Romero-Fierro, D.; Estrella-Núñez, J.; Pardo, S.; Bucio, E. Interaction of Dye Molecules with Fungi: Operational Parameters and Mechanisms. In *Dye Biodegradation, Mechanisms and Techniques. Sustainable Textiles: Production, Processing, Manufacturing & Chemistry*; Muthu, S.S., Khadir, A., Eds.; Springer: Singapore, 2022. [\[CrossRef\]](#)

16. Benkhaya, S.; M'rabet, S.; Lgaz, H.; El Bachiri, A.; El Harfi, A. Dyes: Classification, Pollution, and Environmental Effects. Muthu, S.S., Khadir, A., Eds.; In *Dye Biodegradation, Mechanisms and Techniques. Sustainable Textiles: Production, Processing, Manufacturing & Chemistry*; Springer: Singapore, 2022. [\[CrossRef\]](#)
17. Kamal, I.M.; Abdeltawab, N.F.; Ragab, Y.M.; Farag, M.A.; Ramadan, M.A. Biodegradation, Decolorization, and Detoxification of Di-Azo Dye Direct Red 81 by Halotolerant, Alkali-Thermo-Tolerant Bacterial Mixed Cultures. *Microorganisms* **2022**, *10*, 994. [\[CrossRef\]](#) [\[PubMed\]](#)
18. Rafiq, A.; Ikram, M.; Ali, S.; Niaz, F.; Khan, M.; Khan, Q.; Maqbool, M. Photocatalytic Degradation of Dyes Using Semiconductor Photocatalysts to Clean Industrial Water Pollution. *J. Ind. Eng. Chem.* **2021**, *97*, 111–128. [\[CrossRef\]](#)
19. Panchal, D.; Sharma, A.; Pal, S. Novel Photocatalytic Techniques for Organic Dye Degradation in Water. In *Photocatalytic Degradation of Dyes: Current Trends and Future Perspectives*; Elsevier: Amsterdam, The Netherlands, 2021; pp. 1–22. [\[CrossRef\]](#)
20. Nazri, M.K.H.M.; Sapawe, N. A Short Review on Photocatalytic toward Dye Degradation. *Mater. Today Proc.* **2020**, *31*, A42–A47. [\[CrossRef\]](#)
21. Negarestani, M.; Etemadifar, P.; Kheradmand, A. *Advanced Oxidation Processes for Dye Removal*; Springer: Berlin/Heidelberg, Germany, 2021; pp. 71–128. [\[CrossRef\]](#)
22. Thanavel, M.; Bankole, P.O.; Selvam, R.; Govindwar, S.P.; Sadasivam, S.K. Synergistic Effect of Biological and Advanced Oxidation Process Treatment in the Biodegradation of Remazol Yellow RR Dye. *Sci. Rep.* **2020**, *10*, 20234. [\[CrossRef\]](#)
23. Buthiyappan, A.; Abdul Aziz, A.R.; Wan Daud, W.M.A. Recent Advances and Prospects of Catalytic Advanced Oxidation Process in Treating Textile Effluents. *Rev. Chem. Eng.* **2016**, *32*, 1–47. [\[CrossRef\]](#)
24. Cuiping, B.; Xianfeng, X.; Wenqi, G.; Dexin, F.; Mo, X.; Zhongxue, G.; Nian, X. Removal of Rhodamine B by Ozone-Based Advanced Oxidation Process. *Desalination* **2011**, *278*, 84–90. [\[CrossRef\]](#)
25. Basturk, E.; Karatas, M. Decolorization of anthraquinone dye Reactive Blue 181 solution by UV/H₂O₂ process. *J. Photochem. Photobiol. A Chem.* **2015**, *299*, 67–72. [\[CrossRef\]](#)
26. Hidalgo, A.M.; León, G.; Gómez, M.; Murcia, M.D.; Gómez, E.; Macario, J.A. Removal of Different Dye Solutions: A Comparison Study Using a Polyamide NF Membrane. *Membranes* **2020**, *10*, 408. [\[CrossRef\]](#) [\[PubMed\]](#)
27. Moradihamedani, P. Recent Advances in Dye Removal from Wastewater by Membrane Technology: A Review. *Polym. Bull.* **2022**, *79*, 2603–2631. [\[CrossRef\]](#)
28. Dasgupta, J.; Sikder, J.; Chakraborty, S.; Curcio, S.; Drioli, E. Remediation of Textile Effluents by Membrane Based Treatment Techniques: A State of the Art Review. *J. Environ. Manag.* **2015**, *147*, 55–72. [\[CrossRef\]](#) [\[PubMed\]](#)
29. Cevallos-Mendoza, J.; Amorim, C.G.; Rodríguez-Díaz, J.M.; Montenegro, M.d.C.B.S.M. Removal of Contaminants from Water by Membrane Filtration: A Review. *Membranes* **2022**, *12*, 570. [\[CrossRef\]](#) [\[PubMed\]](#)
30. Gubari, M.Q.; Zwain, H.M.; Hassan, W.H.; Vakili, M.; Majdi, A. Desalination of Pigment Industry Wastewater by Reverse Osmosis Using OPM-K Membrane. *Case Stud. Chem. Environ. Eng.* **2023**, *8*, 100401. [\[CrossRef\]](#)
31. Mulyanti, R.; Susanto, H. Wastewater Treatment by Nanofiltration Membranes. *IOP Conf. Ser. Earth Environ. Sci.* **2018**, *142*, 012017. [\[CrossRef\]](#)
32. Desiriani, R.; Susanto, H.; Aryanti, N. Performance Evaluation of Nanofiltration Membranes for Dye Removal of Synthetic Hand-Drawn Batik Industry Wastewater. *Environ. Prot. Eng.* **2022**, *48*, 51–68. [\[CrossRef\]](#)
33. Abdi, G.; Alizadeh, A.; Zinadini, S.; Moradi, G. Removal of Dye and Heavy Metal Ion Using a Novel Synthetic Polyethersulfone Nanofiltration Membrane Modified by Magnetic Graphene Oxide/Metformin Hybrid. *J. Memb. Sci.* **2018**, *552*, 326–335. [\[CrossRef\]](#)
34. Aouni, A.; Fersi, C.; Cuartas-Urbe, B.; Bes-Pía, A.; Alcaina-Miranda, M.I.; Dhahbi, M. Reactive Dyes Rejection and Textile Effluent Treatment Study Using Ultrafiltration and Nanofiltration Processes. *Desalination* **2012**, *297*, 87–96. [\[CrossRef\]](#)
35. Meez, E.; Rahdar, A.; Kyzas, G.Z. Sawdust for the Removal of Heavy Metals from Water: A Review. *Molecules* **2021**, *26*, 4318. [\[CrossRef\]](#)
36. Gupta, V.K. Suhas Application of Low-Cost Adsorbents for Dye Removal—A Review. *J. Environ. Manag.* **2009**, *90*, 2313–2342. [\[CrossRef\]](#) [\[PubMed\]](#)
37. Dutta, S.; Gupta, B.; Srivastava, S.K.; Gupta, A.K. Recent Advances on the Removal of Dyes from Wastewater Using Various Adsorbents: A Critical Review. *Mater. Adv.* **2021**, *2*, 4497–4531. [\[CrossRef\]](#)
38. Shukla, A.; Zhang, Y.H.; Dubey, P.; Margrave, J.L.; Shukla, S.S. The Role of Sawdust in the Removal of Unwanted Materials from Water. *J. Hazard. Mater.* **2002**, *95*, 137–152. [\[CrossRef\]](#) [\[PubMed\]](#)
39. Shukla, S.R.; Pai, R.S. Adsorption of Cu(II), Ni(II) and Zn(II) on Modified Jute Fibres. *Bioresour. Technol.* **2005**, *96*, 1430–1438. [\[CrossRef\]](#)
40. Rubio, A.J.; Silva, I.Z.; Gasparotto, F.; Paccola, E.A.S.; Silva, C.N.; Emanuelli, I.P.; Bergamasco, R.; Yamaguchi, N.U. Removal of Methylene Blue Using Cassava Bark Residue. *Chem. Eng. Trans.* **2018**, *65*, 751–756. [\[CrossRef\]](#)
41. Shamsheer, H.B.; Mughal, T.A.; Ishaq, A.; Zaheer, S.; Zahid, K. Extraction of Ecofriendly Leather Dyes from Plants Bark. *Pak. J. Sci. Ind. Res. Ser. A Phys. Sci.* **2017**, *60*, 96–100. [\[CrossRef\]](#)
42. Dawood, S.; Sen, T.K. Removal of Anionic Dye Congo Red from Aqueous Solution by Raw Pine and Acid-Treated Pine Cone Powder as Adsorbent: Equilibrium, Thermodynamic, Kinetics, Mechanism and Process Design. *Water Res.* **2012**, *46*, 1933–1946. [\[CrossRef\]](#) [\[PubMed\]](#)

43. Litefti, K.; Freire, M.S.; Stitou, M.; González-Álvarez, J. Adsorption of an Anionic Dye (Congo Red) from Aqueous Solutions by Pine Bark. *Sci. Rep.* **2019**, *9*, 16530. [\[CrossRef\]](#)
44. Annadurai, G.; Juang, R.S.; Lee, D.J. Use of Cellulose-Based Wastes for Adsorption of Dyes from Aqueous Solutions. *J. Hazard. Mater.* **2002**, *92*, 263–274. [\[CrossRef\]](#)
45. Gul, S.; Kanwal, M.; Qazi, R.A.; Gul, H.; Khattak, R.; Khan, M.S.; Khitab, F.; Krauklis, A.E. Efficient Removal of Methyl Red Dye by Using Bark of Hopbush. *Water* **2022**, *14*, 2831. [\[CrossRef\]](#)
46. Al-Zawahreh, K.; Barral, M.T.; Al-Degs, Y.; Paradelo, R. Competitive Removal of Textile Dyes from Solution by Pine Bark-Compost in Batch and Fixed Bed Column Experiments. *Environ. Technol. Innov.* **2022**, *27*, 102421. [\[CrossRef\]](#)
47. Mohamed, M.A.; Salleh, W.N.W.; Jaafar, J.; Asri, S.E.A.M.; Ismail, A.F. Physicochemical Properties of “Green” Nanocrystalline Cellulose Isolated from Recycled Newspaper. *RSC Adv.* **2015**, *5*, 29842–29849. [\[CrossRef\]](#)
48. Pavithra, R.; Gunasekaran, S.; Sailatha, E.S.; Kamatchi, S. Investigations on Paper Making Raw Materials and Determination of Paper Quality by FTIR-UATR and UV-Vis DRS Spectroscopy. *Int. J. Curr. Res. Acad. Rev.* **2015**, *3*, 42–59.
49. Woźniak, M.; Ratajczak, I.; Szentner, K.; Kwaśniewska, P.; Mazela, B. Propolis and Organosilanes in Wood Protection. Part I: FTIR Analysis and Biological Tests. *Ann. Wars. Univ. Life Sci. SGGW* **2015**, *91*, 218–224.
50. Kaya, M.; Sargin, I.; Aylanc, V.; Tomruk, M.N.; Gevrek, S.; Karatoprak, I.; Colak, N.; Sak, Y.G.; Bulut, E. Comparison of Bovine Serum Albumin Adsorption Capacities of α -Chitin Isolated from an Insect and β -Chitin from Cuttlebone. *J. Ind. Eng. Chem.* **2016**, *38*, 146–156. [\[CrossRef\]](#)
51. Bhavsar, P.S.; Dalla Fontana, G.; Zoccola, M. Sustainable Superheated Water Hydrolysis of Black Soldier Fly Exuviae for Chitin Extraction and Use of the Obtained Chitosan in the Textile Field. *ACS Omega* **2021**, *6*, 8884–8896. [\[CrossRef\]](#) [\[PubMed\]](#)
52. Halib, N.; Amin, M.C.I.M.; Ahmad, I. Physicochemical Properties and Characterization of Nata de Coco from Local Food Industries as a Source of Cellulose. *Sains Malays.* **2012**, *41*, 205–211.
53. Vârban, R.; Cris, I.; Vârban, D.; Ona, A.; Olar, L.; Stoe, A.; Tefan, R.S.; Cavaco, A.M.; Marques Da Silva, J.; Guerra, R.; et al. Comparative FT-IR Prospecting for Cellulose in Stems of Some Fiber Plants: Flax, Velvet Leaf, Hemp and Jute. *Appl. Sci.* **2021**, *11*, 8570. [\[CrossRef\]](#)
54. Popescu, M.C.; Popescu, C.M.; Lisa, G.; Sakata, Y. Evaluation of Morphological and Chemical Aspects of Different Wood Species by Spectroscopy and Thermal Methods. *J. Mol. Struct.* **2011**, *988*, 65–72. [\[CrossRef\]](#)
55. Md Salim, R.; Asik, J.; Sani Sarjadi, M. Chemical Functional Groups of Extractives, Cellulose and Lignin Extracted from Native *Leucaena Leucocephala* Bark. *Wood Sci. Technol.* **2021**, *55*, 295–313. [\[CrossRef\]](#)
56. Rao, H.; Yang, Y.; Hu, X.; Yu, J.; Jiang, H. Identification of an Ancient Birch Bark Quiver from a Tang Dynasty (A.D. 618–907) Tomb in Xinjiang, Northwest China. *Econ. Bot.* **2017**, *71*, 32–44. [\[CrossRef\]](#)
57. Bouatay, F.; Dridi-Dhaouadi, S.M.F.; Mhenni, M.F. Valorization of Tunisian Pottery Clay onto Basic Dyes Adsorption. *Int. J. Environ. Res.* **2014**, *8*, 1053–1066.
58. Mahmoodi, N.M.; Arami, M.; Bahrami, H.; Khorramfar, S. Novel Biosorbent (Canola Hull): Surface Characterization and Dye Removal Ability at Different Cationic Dye Concentrations. *Desalination* **2010**, *264*, 134–142. [\[CrossRef\]](#)
59. El Haddad, M.; Mamouni, R.; Saffaj, N.; Lazar, S.; Saïd Lazar, S. Removal of a Cationic Dye-Basic Red 12-from Aqueous Solution by Adsorption onto Animal Bone Meal Removal of a Cationic Dye-Basic Red 12-from Aqueous Solution by Adsorption onto Animal Bone Meal. *J. Assoc. Arab. Univ. Basic. Appl. Sci.* **2018**, *12*, 48–54. [\[CrossRef\]](#)
60. Yang, X.; Zhu, W.; Song, Y.; Zhuang, H.; Tang, H. Removal of Cationic Dye BR46 by Biochar Prepared from *Chrysanthemum Morifolium* Ramat Straw: A Study on Adsorption Equilibrium, Kinetics and Isotherm. *J. Mol. Liq.* **2021**, *340*, 116617. [\[CrossRef\]](#)
61. Yeddou, N.; Bensmaili, A. Kinetic Models for the Sorption of Dye from Aqueous Solution by Clay-Wood Sawdust Mixture. *Desalination* **2005**, *185*, 499–508. [\[CrossRef\]](#)
62. Sahnoun, A.Y.; Selatnia, A.; Mitu, L.; Ayeche, R.; Daoud, N.; Dahoun-Tchoulak, Y. Basic Red 46 Adsorption Studies onto Pyrolyzed By-Product Biomass. *Appl. Water Sci.* **2024**, *14*, 111. [\[CrossRef\]](#)
63. Karim, A.B.; Mounir, B.; Hachkar, M.; Bakasse, M.; Rais, Z.; Yaacoubi, A. Adsorption of BR46 Dye Using Raw and Purified Clay. *J. Water Sci. Environ. Technol.* **2017**, *2*, 233–240.
64. Zamouche, M.; Hamdaoui, O. Sorption of Rhodamine B by Cedar Cone: Effect of Ph and Ionic Strength. *Energy Procedia* **2012**, *18*, 1228–1239. [\[CrossRef\]](#)
65. Shen, K.; Gondal, M.A. Removal of Hazardous Rhodamine Dye from Water by Adsorption onto Exhausted Coffee Ground. *J. Saudi Chem. Soc.* **2017**, *21*, S120–S127. [\[CrossRef\]](#)
66. Pengthamkeerati, P.; Satapanajaru, T.; Chatsatapatayakul, N.; Chairattananamanokorn, P.; Sananwai, N. Alkaline Treatment of Biomass Fly Ash for Reactive Dye Removal from Aqueous Solution. *Desalination* **2010**, *261*, 34–40. [\[CrossRef\]](#)
67. Alivio, R.K.O.; Go, A.W.; Angkawijaya, A.E.; Santoso, S.P.; Gunarto, C.; Soetaredjo, F.E. Extractives-Free Sugarcane Bagasse as Adsorbent for the Removal of Rhodamine B (Basic Violet 10) with High Capacity and Reusability. *J. Ind. Eng. Chem.* **2023**, *124*, 175–200. [\[CrossRef\]](#)
68. Al-Zawahreh, K.; Barral, M.T.; Al-Degs, Y.; Paradelo, R. Comparison of the Sorption Capacity of Basic, Acid, Direct and Reactive Dyes by Compost in Batch Conditions. *J. Environ. Manag.* **2021**, *294*, 113005. [\[CrossRef\]](#) [\[PubMed\]](#)

69. Otero, M.; Paradelo, R.; García, P.; González, A.; Al-Zawahreh, K.; Barral, M.T. Influence of Zinc and Humic Acids on Dye Adsorption from Water by Two Composts. *Int. J. Environ. Res. Public Health* **2023**, *20*, 5353. [[CrossRef](#)]
70. Oyekanmi, A.A.; Ahmad, A.; Hossain, K.; Rafatullah, M. Adsorption of Rhodamine B Dye from Aqueous Solution onto Acid Treated Banana Peel: Response Surface Methodology, Kinetics and Isotherm Studies. *PLoS ONE* **2019**, *14*, e0216878. [[CrossRef](#)] [[PubMed](#)]

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