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Adsorbent from Textile Waste for Removal of Textile Reactive Dye from Water – Equilibrium Adsorption and Kinetics

Adsorbent iz tekstilnih odpadkov za odstranjevanje tekstilnega reaktivnega barvila iz vode –adsorpcijsko ravnotežje in kinetika

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Abstract

The removal of textile reactive dye from an aqueous solution on a new adsorbent prepared from waste cotton knitted fabric was investigated in this study. Waste cotton textile, used for the production of adsorbents, is a by-product of the cutting of stacked parts of cotton knitwear planned for the production of women's T-shirts. The degree of efficiency of a paper pattern determines the amount of collected waste. The qualitative and quantitative characterization of the new adsorbent showed carbon and oxygen to be dominant in the chemical composition. A longer contact time means a greater amount of dye on the adsorbent, i.e. the dye concentration in the solution decreases with the duration of the adsorption process. The percentage of removed dye decreases with an increase in the initial dye concentration in the solution. However, the actual amount of adsorbed dye increases as the initial dye concentration increases. The results for equilibrium adsorption show that the Langmuir isotherm can be used for the interpretation of reactive dye adsorption on a new adsorbent. The pseudo-first order model can be fully used to describe the kinetics of dye adsorption on an adsorbent, with respect to valid results for statistical indicators. Based on the results, it can be concluded that the new adsorbent obtained from waste textiles has the potential to remove textile reactive dye from aqueous solutions.
Keywords: cotton knitted fabric, cutting, adsorbent, reactive dye, the Langmuir model, kinetics

Izvleček

V članku je bila raziskana odstranitev tekstilnega reaktivnega barvila iz vodne raztopine s pomočjo novega adsorbenta, pripravljenega iz odpadnega bombažnega pletiva. Uporabljena odpadna tekstilija je bila stranski proizvod krojenja bombažnega pletiva, položenega v plasti za izdelavo ženskih kratkih majic, pri čemer izkoristek papirnatega kroja določa količino zbranega odpadka. Kvalitativna in kvantitativna karakterizacija novega adsorbenta kažeta, da sta v kemični sestavi prevladujoča elementa ogljik in kisik. Daljši kontaktni čas pomeni večjo količino barvila na adsorbentu, torej se s časom trajanja procesa adsorpcije koncentracija barvila v raztopini zmanjšuje. Odstotek odstranjenega barvila se zmanjšuje s povečevanjem začetne koncentracije barvila v raztopini, vendar se dejanska količina adsorbiranega barvila

z naraščanjem začetne koncentracije barvila poveča. Rezultati adsorpcijskega ravnotežja kažejo, da se Langmuirjeva izoterma lahko uporabi za interpretacijo adsorpcije reaktivnega barvila na novem adsorbentu. Model psevdoprvega reda se lahko v celoti uporabi za opis kinetike adsorpcije barvila na adsorbentu glede na veljavne rezultate statističnih kazalnikov. Na podlagi rezultatov lahko sklepamo, da ima novi adsorbent, pridobljen iz odpadnega tekstila, potencial odstranjevanja tekstilnih reaktivnih barvil iz vodnih raztopin.
Ključne besede: bombažno pletivo, krojenje, adsorbent, reaktivno barvilo, Langmuirjev model, kinetika

1 Introduction

The textile industry consumes an extensive amount of synthetic dyes. The aim is to use dyes that are more exhausted from the bath during dyeing, as well as those that are more degradable and environmentally friendly, or that can be more easily removed from water after textile dyeing [1, 2].

Reactive dyes belong to the class of very successful modern synthetic dyes thanks to their wide range of shades, flexibility in application and excellent fastness properties, particularly when wool, silk and cotton, as well as regenerated cellulose fibres, are dyed. These dyes contain certain groups capable of forming covalent bonds with nucleophilic sites on the fibre, which is an assumption of the extraordinary properties of colour fastness in terms of washing. Reactive dyes for wool are considered alternatives to chrome dyes. Certain classes of reactive dyes have a positive effect on the amount of damage to wool during dyeing at the boiling point [3].

After textile dyeing of natural or artificial origin, waste water from the textile industry is inevitably dyed, as it contains a higher or lower amount of organic dye residues. One of the methods for removal of organic matters from dyed water is the use of porous solid sorbents. The properties of these substances that make them useful are high porosity and their surface, as well as the physical and chemical nature of the inner surface. Such and similar adsorbents, e.g. activated carbon, are most frequently used in separation and purification processes. Research aimed at finding alternative adsorbents that could replace expensive activated carbon have intensified recently.

Industrial waste materials are potentially inexpensive adsorbents for removing organic matter from water. To date, researchers have used various waste materials of cellulose origin, e.g. agricultural or agro-industrial waste of cellulose origin, such as barley straw, rice husks, cotton stalks, the pits of various fruits and vegetables, etc. There was no example of the use of waste from a garment plant for the production of active adsorbent that would be used for the adsorption of waste reactive dye from aqueous solutions [2, 4–6]. If other types of dye and a similar adsorbent are taken into account, there are studies that describe, for example, the adsorption processes of methylene blue (basic thiazine dye) on an adsorbent of cotton stalk, cotton waste fibres and cotton dust [7, 8]. It has been observed that these types of adsorbents can be successfully used to remove methylene blue from aqueous solutions using the sorption technique. Sorption increases by increasing the initial dye concentration, temperature, sorbent dose and solution pH. The time required for maximum dye removal was 90 minutes. Maximum dye removal of up to 97.50% was achieved in all tested experimental conditions [7, 8].

The research presented in this paper uses precisely that waste material which thus far has typically been incinerated or disposed of in a landfill. This research proposes a new way of disposing of this waste, turning it into a useful product for the purification of coloured water. The aim is to use the resulting waste textile material, transform it into an adsorbent and use it for the removal of colour from water. Applying the equilibrium isotherm and the adsorption kinetics of textile dye has led to significant knowledge about the adsorption mechanism and feasibility of the decolorization process of aqueous solution.

2 Experimental

2.1 Materials

An adsorbent is made of the waste textiles from cotton knitted fabric after the cutting process in the manufacture of women's T-shirts. It is a by-product obtained from the cutting of the stacked parts of cotton knitted fabric during the clothing manufacture process. The raw material for the production of adsorbent was collected from a professional workshop. The amount of raw material waste was about

6 kg per one cutting of a multilayer stacked textile knitted fabric.

Since the waste cotton material was collected from the cutting of the cut parts of the future garment, the construction preparation of the women's T-shirt was monitored using a Gerber Technology computer software system. The optimal width of the basic material (140, 145 and 152 cm) was selected on the basis of the use of the paper pattern made using a CAD system during the production of the selected model of the women's T-shirt.

Knitted fabric made of 100% cotton fibres was used to make the selected model of a women's T-shirt with raglan sleeves. Table 1 shows the basic characteristics of the material (knitted fabric) that was used to make women's T-shirt as the by-product of cutting.

Table 1: Basic characteristics of knitted fabric for women's T-shirt production

Properties	Description/values
Raw material composition	Cotton, 100%
Colour	White
Weaving	Double knit plated
Horizontal density (1/cm)	14.6
Vertical density (1/cm)	20.5
Fineness of yarn (tex)	18
Surface mass (g/m^2)	165

The new adsorbent was obtained through the chemical and physical modification of cotton waste. After its collection, the waste was washed (distilled water, bath ratio 1 : 100, 60 minutes at 90 °C), dried and cut into pieces as small as possible. Such a prepared waste was treated with a solution of H_3PO_4 (Oleohemija, Serbia, 85%, ratio 1:4) for 48 hours at room temperature. After decantation, the samples were heated at 600 °C for 2 hours. Cooling and shredding followed, then rinsing with distilled water and neutralization with an aqueous solution of sodium carbonate (Tehnohemija, Serbia). Finally, the drying (100 °C) and grinding of the material was performed, and samples were prepared for adsorption.

2.2 Adsorption process

An adsorption model test was performed in reaction vessels in which the adsorbent was suspended in a reactive dye solution (adsorbate). The reaction vessels were placed on a shaker (130 rpm) at a temperature of 20 °C and maintained for some time. The amount of adsorbent was fixed at 2 g, whereas the solution in a constant amount of 0.1 dm^3 contained a reactive dye concentration of 30, 50, 75, 100, 125 and 150 mg/dm^3. Processing time was 5, 10, 20, 30, 40, 50 and 60 minutes. The pH for all dye solution was 3.

The reactive dye used, CI Reactive Red 84 (RR84), belongs to the group of monoazo dyes with two sulfo groups and one amino. The structure comprises sulfonyldibenzen, naphthalene and bromoacrylamide part. The dye is water-soluble, and is used for the dyeing and printing of wool and silk fabrics.

2.3 Analyses and measurements

Solution absorption was measured on a UV-VIS spectrophotometer (Cary 100 Conc UV-VIS, Varian) at λ = 490 nm (the maximum wavelength of the spectrum of the used dye solution). The moisture content in the sorbent was determined according to the SRPS EN ISO 18134 standard. The ash content in the sorbent was determined according

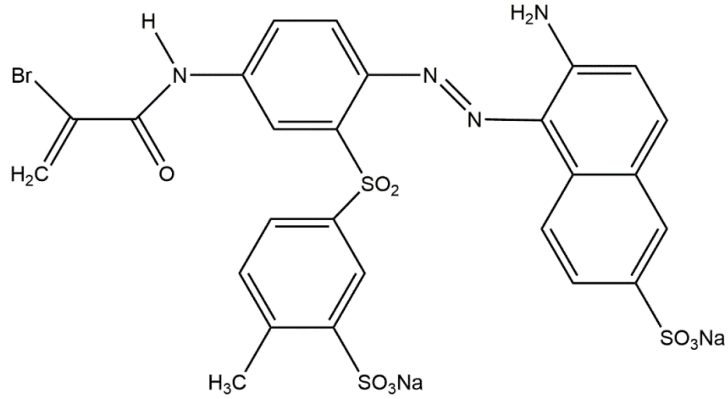

Figure 1: Structure of the used reactive RR84 dye

to the SRPS ISO 5984 standard. The density of the sorbent by pycnometer was determined according to the SRPS EN ISO 2811-1 standard. SEM and EDS measurements were performed on a TESCAN MIRA3 microscope. The samples were applied to an adhesive graphite strip and fixed to the supports, and then ion-coated with a thin layer of gold using a PO-LARON SC502 Sputter Coater.

The degree of dye removal [5] or degree of exhaustion was calculated on the basis of the dye concentration before and after this treatment:

$$E = \frac{C_0 - C_{t,e}}{C_o} \cdot 100 \quad (1)$$

where: C_0 and $C_{t,e}$ (mg/dm^3) represent the initial and final (equilibrium) concentration of the dye solution, respectively.

The amount of adsorbed dye (adsorbate) per unit mass of adsorbent [9] at time t, q_t (mg/g), or equilibrium time, q_e, (mg/g), was determined using the equation:

$$q_{t,e} = \frac{(C_0 - C_{t,e}) \cdot V}{M} \quad (2)$$

wherein: M (g) represents the mass of adsorbent and V (dm^3) represents the volume of solution from which the adsorption was performed.

The *Langmuir* isotherm [4] is presented using following equation:

$$\frac{1}{q_e} = \left[\frac{1}{b \cdot Q_0}\right] \cdot \frac{1}{C_e} + \frac{1}{Q_0} \quad (3)$$

where: Q_0 (mg/g) represents the maximum amount of adsorbate that can bind to the adsorbent and b (dm^3/mg) represents the ratio of the adsorption rate constant and the adsorbate desorption rate constant.

Adsorption kinetics data are described using the *Lagergren* model [9] of pseudo-first order:

$$\log(q_e - q_t) = \log(q_e) - \frac{k_1}{2.303} \cdot t \quad (4)$$

where k_1 (1/min) represents the rate constant of adsorption *pseudo-first* order.

The adsorption kinetics can also be described using the *pseudo-second* order model [9]:

$$\frac{t}{q_t} = \frac{1}{k_2 \cdot q_e^2} + \frac{1}{q_e} \cdot t \quad (5)$$

where k_2 (g/mgmin) represents the adsorption rate constant of the *pseudo-second* order.

3 Results and discussion

3.1 Origin of textile waste

Figure 2 is a graph showing the efficiency of paper patterns in the manufacture of women's T-shirts, resulting in waste used to create a new adsorbent for the adsorption of reactive dyes. All paper patterns show the expected efficiency obtained when fitting the cutting parts. On the basis of these results, the paper pattern with a width of 152 cm had the highest material efficiency (85.82%) in relation to the other widths, due to more suitable combinations of cutting parts.

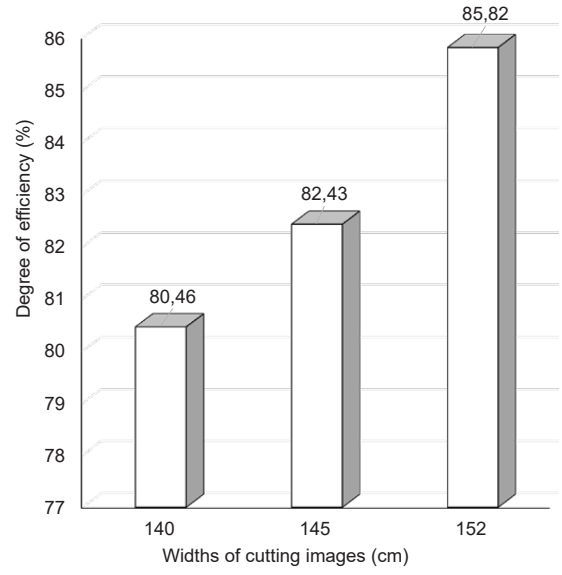

Figure 2: Graphic representation of the degree of efficiency of paper patterns with respect to their widths

3.2 Adsorbent characterization

The characterization of the absorbent was performed for the purposes of the representation of physical properties, as well as the introduction of morphological characteristics, or the actual chemical structure, as a very important factor for successful adsorption.

The determination of yield, density, ash content, moisture, etc. are techniques that provide information regarding the structure of the tested samples, but also regarding their reactivity and the possibility of application in appropriate conditions.

The loss after washing of raw cotton waste, before transformation into an adsorbent, was approximately 8% in relation to the sample of waste before washing. The yield of adsorbent from waste cotton textiles was approximately 42%.

The moisture content of the new adsorbent was 7.8%. The presence of moisture affected the activity in adsorption processes. Namely, the moisture that was largely adsorbed in the structure of the adsorbent obtained from waste textiles blocks the pores of the material, making them inaccessible to dye ions from the solution. The consequence of this effect was a decrease in the adsorption capacity towards the dye ions that were adsorbed from the solution into the porous structure of the adsorbent.

The ash content in the adsorbent may indicate a conversion pathway from the used precursor-waste cellulose textile. Typically, a powder adsorbent with high values of ash content show weaker adsorption power with respect to different adsorbates. The proportion of ash in the structure of the new adsorbent was 6%. The amount of ash was moderate, in this case, so there would be no obstacles to good sorption characteristics of the adsorbent in the processing of dyed water.

The determination of adsorbent particle density, including pore volume within the particles, was performed using a pycnometer. The new adsorbent had a density of 1.2 g/cm^3. Density values of the adsorbent were in a range typical for materials from cellulosic raw materials. Density is an important property of powder materials and illustrates porosity and the way the particles are packed in space. Porous materials with lower density have more air trapped in the structure.

The used adsorbent is a granular material with heterogeneous porous particles of divergent shape and form. Cracks, cavities and channels are present in the depth of the particles that are the basis of the porosity of the material. The micrograph in Figure 3 shows the appearance of adsorbent particles at a magnification of 2000x.

The EDS system enables a quick assessment of the elementary composition of the sample. The following chemical elements were detected: C (41.87%), O (54.34%) and Na (3.79%). According to the EDS analysis, there was carbon, as expected, while the increased presence of oxygen related to the oxides of metals (Na), while an adsorbent might have reacted with oxygen from the air during the annealing process.

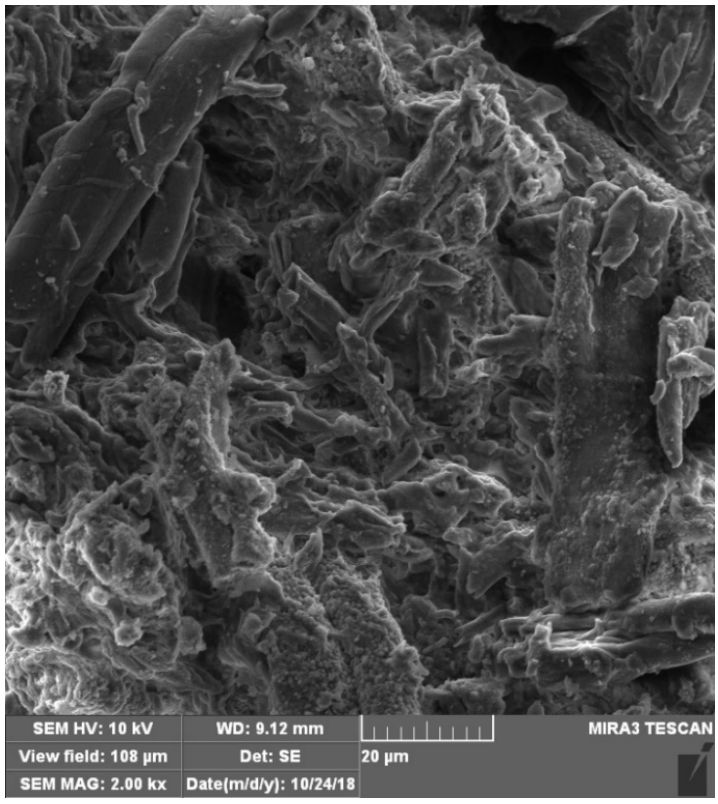

Figure 3: SEM micrograph of the applied adsorbent form textile waste

A similar morphology and chemical composition were seen in research [10] that deals with the preparation of cheaper and environmentally friendly adsorbents from biomass, with the use of phosphoric acid as the activator. Via SEM and EDXA spectra, the existence of the porous structure was asserted, as well as the presence of carbon and oxygen, which were dominant amongst chemical elements. The presence of potassium, sodium and phosphorus was negligible.

The selected RR84 dye has good solubility with respect to the existence of two sulfo groups, and shows a good affinity to the adsorbent in contact, given that there is no greater affinity towards the aqueous phase. The present sulfo groups represent a negative characteristic of this dye, whereas an amino group increases reactivity in the aromatic ring due to the electron donor [11].

It is known that adsorption from a solution towards a solid surface begins to occur when dipoles or charged types of adsorbent and adsorbate interact with each other. Also, the exchange of anions or cations occurs when the neutral molecules get close enough to each other. Similarly, an interaction occurs between the dissolved organic components (dyes), the molecule of the solvent (water) and the surface of the adsorbent [12].

3.3 Influence of certain factors on adsorption

The influence of the time of adsorption on the exhaustion of the RR84 dye was tested in a concentration range of 30–150 mg/dm^3 (Figure 4). As time increases, the initial dye concentration decreases in all cases. The initial dye concentration in the solution provides an important driving force for overcoming the mass transfer resistance between the aqueous and solid phases.

According to the curves in the graph presented in Figure 4, the higher initial dye concentrations of RR84 declined slightly more over time, while lower initial concentrations showed a more moderate change over time. All curves in the graph have a similar appearance of change over time, which shows similar or identical mechanisms of adsorption of dye molecules on the outer surfaces and inside the adsorbent particles.

Figure 5 presents a graph that explains the change in the level of exhaustion of RR84 dye relative to the duration of adsorption. The highest percentage of dye exhaustion occurs at the lowest initial dye

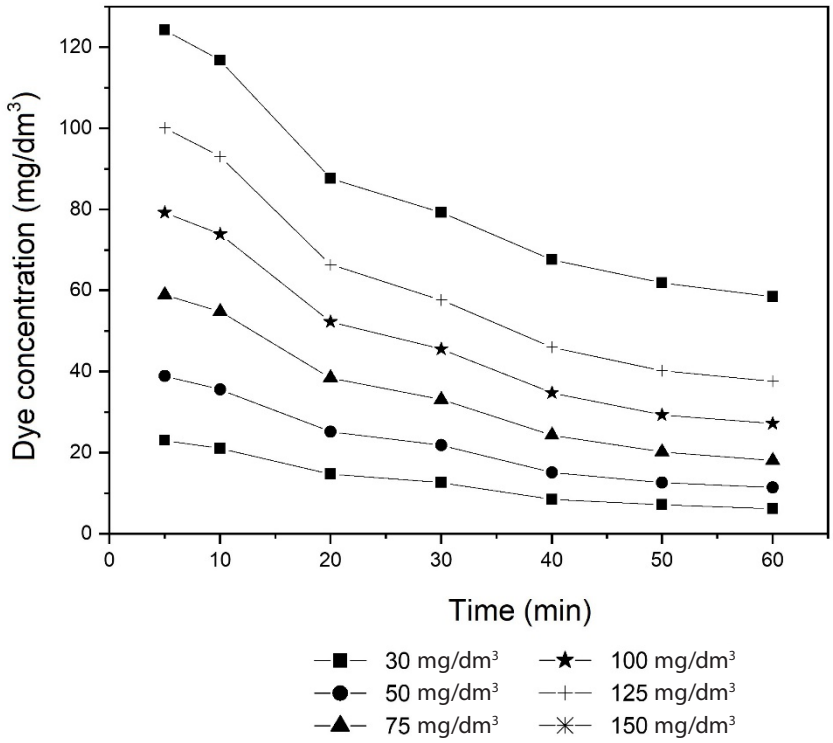

Figure 4: Change of the initial dye concentration of RR84 during adsorption to a new adsorbent for different initial concentrations

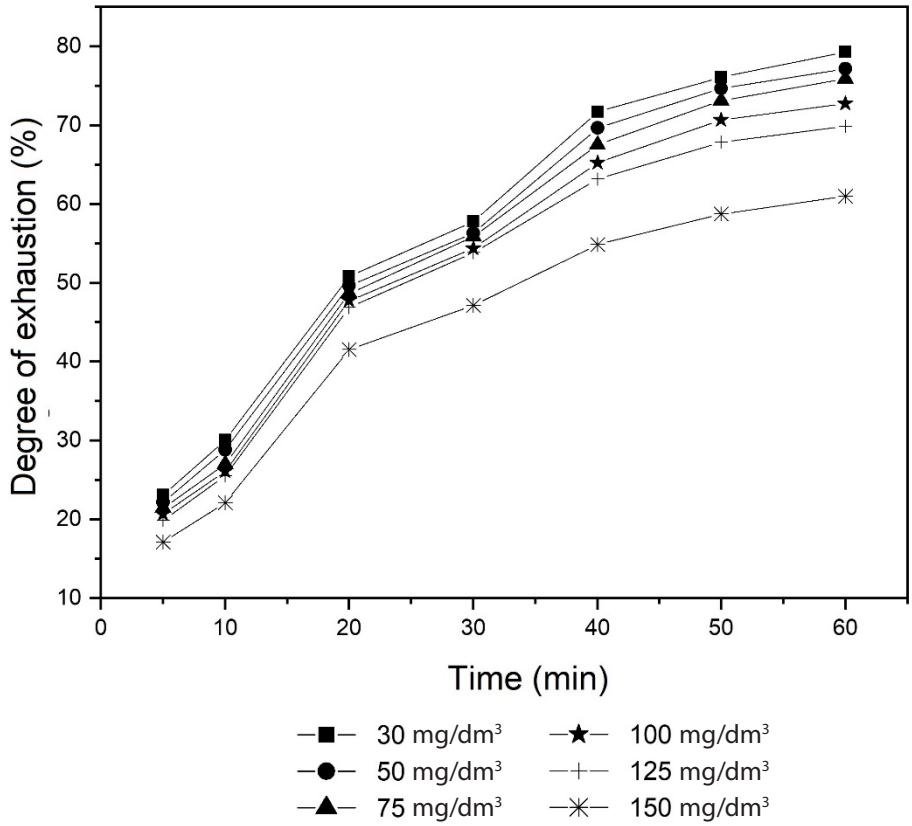

Figure 5: Degree of exhaustion of RR84 dye during adsorption to a new adsorbent for different initial concentrations

concentrations, while the lowest percentage is present at the highest initial concentrations. All curves demonstrate an upward trend. On the other hand, the largest amount of the adsorbed dye from the aqueous solution in absolute terms, is found with the highest initial concentrations.

Thus, for example, in equilibrium (after 60 minutes):

- at the highest initial concentration (150 mg/dm^3), the degree of exhaustion was 61% or 91.5 mg in absolute terms; and
- at the lowest initial concentration (30 mg/dm^3), the degree of exhaustion was 79.33% or 23.8 mg in absolute terms.
- There was thus almost four times more of the adsorbed dye to the new sorbent (91.5 mg >> 23.8 mg) at the highest initial concentration, although a lower percentage of the degree of exhaustion occurred here (61% < 79.33%).

Similar results are shown by a study of the adsorption potential of rice husk and alkali-treated rice husk to remove yellow reactive dye from an aqueous solution. The highest adsorption was achieved after 40 minutes and did not change after that time. The first adsorbent was found to remove 65% of the dye within 40 minutes compared to the second which removed 92% [5].

The graph in Figure 6 shows the change in the adsorbed amount of dye per unit mass of adsorbent during adsorption (adsorption capacity) for different initial dye concentrations of RR84. The graph confirms that the amount of adsorbed dye increases relative to the duration of adsorption, and that the highest adsorption was observed at the highest initial concentrations. Since the curves have a similar appearance in the graph, it is assumed that the mechanism of adsorption at all initial concentrations is identical.

Similar behaviour in terms of the degree of exhaustion of the reactive dye (Bezaktiv Red S-Maks) was seen in a study [6] that estimated the different activated carbon prepared from by-products from agricultural waste. It was observed that adsorption was more rapid during the initial phase of the adsorption process, followed by a slower stage until equilibrium was reached. This phenomenon was due a large number of free positions exposed to

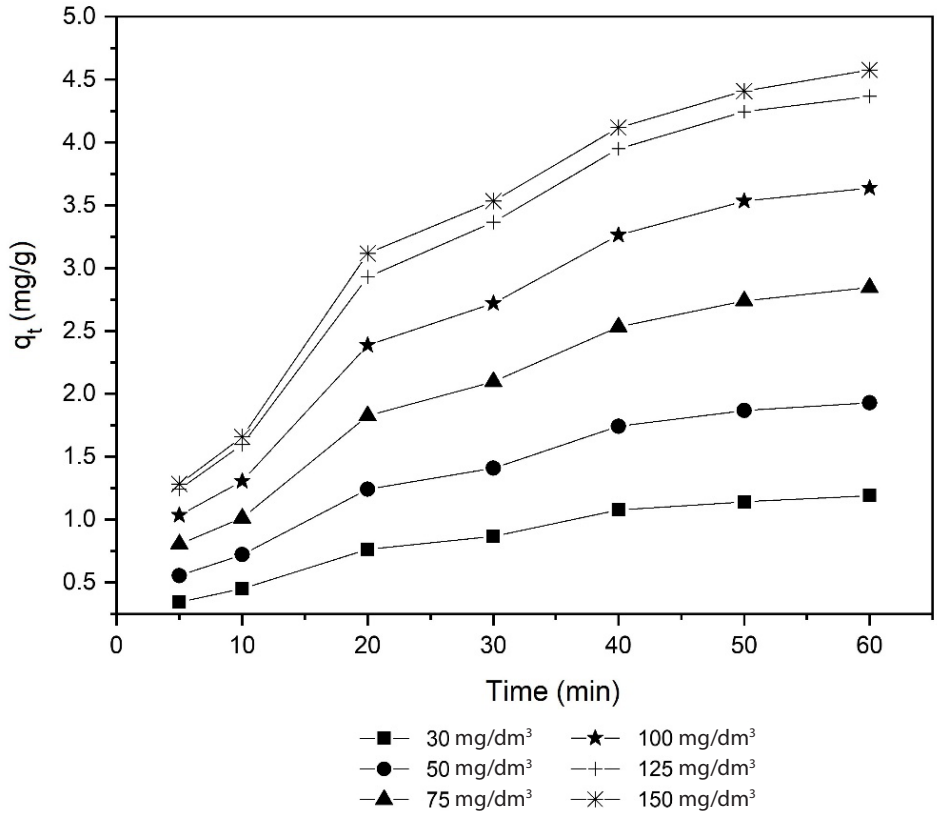

Figure 6: Change of adsorption capacity of RR84 dye during adsorption on a new adsorbent for different initial concentrations

adsorption in the initial phase, which made the taking of the remaining places on the surface harder because of the refusal between the adsorbate and adsorbent.

3.4 Adsorption izotherms

The graph in Figure 7 represents the linear interpretation of the *Langmuir* adsorption isotherm, showing the dependency of the parameter ($1/q_s$) in relation to the equilibrium dye concentration ($1/C_s$). The values of the *Langmuir* constants were determined from this graph, i.e. the slope and cut of the functional line.

The significant functionality of this parameter was observed from this graph, i.e. the fitting curve perfectly covers the experimental points. It can thus be concluded that the *Langmuir* adsorption isotherm can be used for the analysis of this specific case of RR84 dye adsorption onto the adsorbent.

The Langmuir constants Q_0 and b represent to the maximum amount of adsorbate that can bind to the adsorbent and the free adsorption energy, respectively. The values of these constants were 8.35 mg/g and 0.027 dm³/mg, respectively. In this particular case, the *Langmuir* model had a very high value of R^2, which was 0.997.

The features of the *Langmuir* isotherm can be expressed in dimensionless constant, equilibrium parameter R_L. In the specific case of R_L= 0.2, it was confirmed that the applied *Langmuir* isotherm was suitable since the equilibrium parameter was between 0 and 1.

Similarly, in other research, [10] the application of cheaper and more environmentally friendly adsorbents from biomass for the needs of purification of reactive dye (Reactive red 23) from aqueous solution confirmed the dominance of the *Langmuir* model after comparison with the four most frequently used equilibrium adsorption models.

3.5 Adsorption kinetics

According to the linear forms of kinetic model in Figure 8, it can be concluded that the rate of adsorption, in the presented experimental conditions, can be functionally described in full by the *pseudo-first* order.

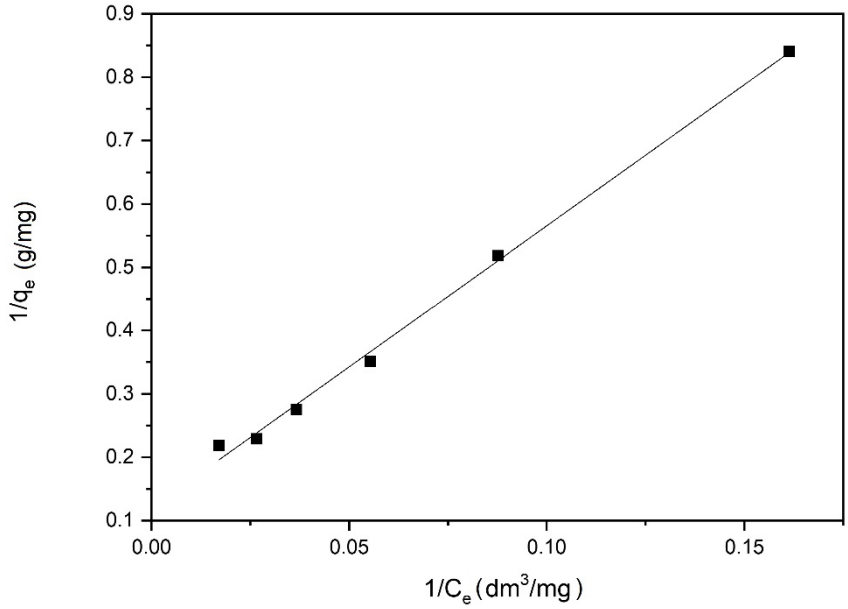

Figure 7: Modelling of RR84 dye adsorption on new adsorbent using the Langmuir model

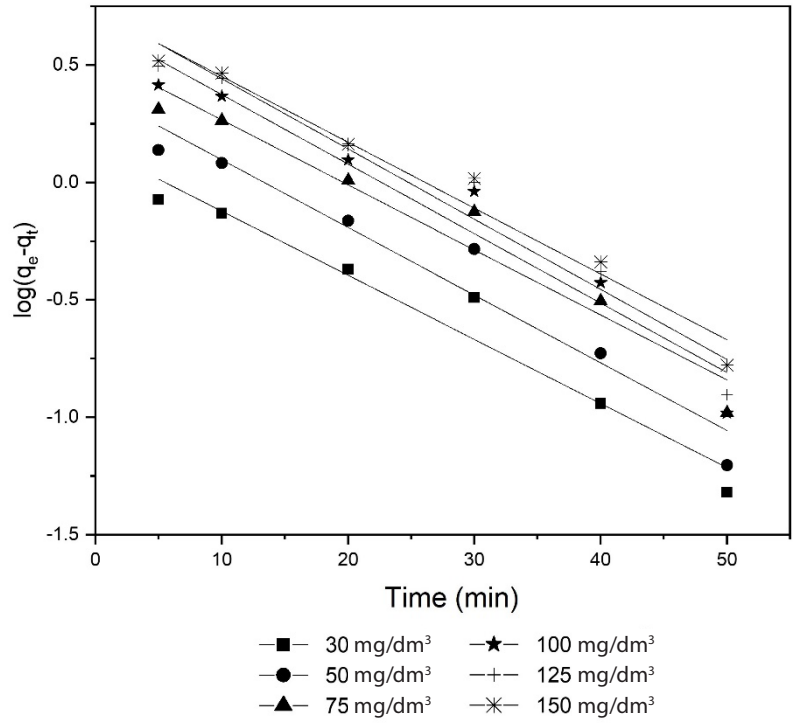

Figure 8: Kinetic curves of RR84 dye adsorption on a new adsorbent according to the pseudo-first order model

Thus, according to the appearance of curves on this graph, as well as the positions of the experimental points around the ideal fitting curves, it was determined that the kinetic adsorption of RR84 dye on the adsorbent from cotton textiles, obtained from waste after cutting of cotton knitted fabric, is perfectly described by the *pseudo-first* order model.

Table 2 presents the value of the kinetic parameter of the RR84 dye adsorption process on the adsorbent from the waste cotton (equilibrium constant rate of the *pseudo-first* order) for all of the initial

dye concentrations, values for the parameter q_e (calculated, $q_{e,izr}$ and experimental, $q_{e,exp}$) and statistical indicators of validity. The *pseudo-first* order model has, in all cases, a coefficient of determination greater than 0.940 (0.945-0.971), resulting in a high functionality, where the model can be accurately used to describe the process of dye adsorption on the adsorbent. Also, according to the statistical parameter *residual sum of squares (RSS)*, whose values are approximately zero, the validity of the results of the modelling of kinetics using the *pseudo-first* order model can be confirmed.

The differences between parameters $q_{e,izr}$ and $q_{e,exp}$ are approximate for this model, but again not completely identical.

According to the data presented in Table 2, the rate constant of *pseudo-first* order is not dependent on the initial dye concentration in the solution, which in turn confirms the validity of the results of that model.

The adsorption kinetics according to the *pseudo-second* order model (Figure 9) are presented using the graph of the dependence of t/q_t on time. By fitting the data to a graph, functional straight lines for all the initial dye concentrations were obtained. This model includes all phases of adsorption, such as external diffusion, adsorption and internal diffusion in particles, since it is *pseudo* model. It was established by comparing the curves from the graph, as well as the appearance and the dispersion of the

Table 2: Kinetic parameters of the RR84 dye adsorption process on new adsorbent (pseudo-first order, 20°C)

Dye concentration (mg/dm³)	$q_{t,exp}$ (mg/g)	$q_{t,izr}$ (mg/g)	k_1 (g/mg×min)	R^2	*RSS*
30	1.19	1.41	0.063	0.957	0.05
50	1.93	2.42	0.066	0.945	0.07
75	2.85	3.49	0.064	0.952	0.06
100	3.64	4.67	0.068	0.942	0.08
125	4.37	5.50	0.069	0.956	0.06
150	4.57	5.39	0.064	0.971	0.04

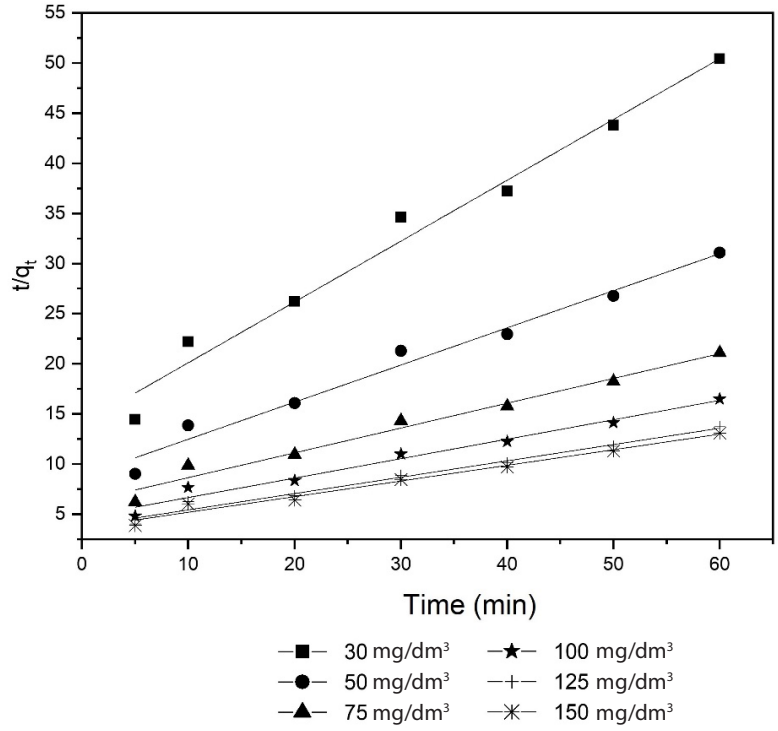

Figure 9: Kinetic curves of RR84 dye adsorption on a new adsorbent according to the pseudo-second order model

points around the ideal curve fitting, that the kinetics of RR84 dye adsorption to the adsorbent are sufficiently described by the *pseudo-second* order model.

Table 3 shows the value of the kinetic parameters of the adsorption process of the reactive dye on the adsorbent (the equilibrium rate constant for the *pseudo-second* order) for all the initial dye concentrations, values for parameter qe (calculated, $q_{e,calc}$ and experimental, $q_{e,exp}$) and statistical indicators of validity. In all cases, the kinetic *pseudo-second* order model had a coefficient of determination of $R^2>0.97$, thereby achieving a high degree of functionality (better than that of the pseudo-first order model), when the model can be used to describe the dye adsorption process on the adsorbent with sufficient certainty.

On the other hand, the differences between parameters $q_{e,izr}$ and $q_{e,exp}$ are more significant for this model than in the *pseudo-first* order model. Also, a greater variation of the rate of constant k_2 with a change in the initial dye concentration, as well as a very high number of values for the *residual sum of square* far greater than zero, push the *pseudo-second* order model into the background and give preference to the *pseudo-first* order model.

It can be concluded that the adsorption of RR84 dye on an adsorbent is of a physical nature, although it can be supported at any time by chemisorption, given the results of kinetic analysis, as well as the fact that the rate of equilibrium is rapid, which characterizes physisorption and activated chemisorption [13]. A similar observation was made in the study of the adsorption kinetics of reactive yellow and blue dyes on an adsorbent made by modifying agricultural residues from sugar cane processing. Dye adsorption is well described by the kinetic pseudo-first order model for reactive yellow and pseudo-second order for reactive blue dye [14].

4 Conclusion

With phosphoric acid as an activating agent, the thermochemical conversion of waste cotton textile into a powder adsorbent was performed. The obtained adsorbent was tested for physical and chemical properties. The element composition of the produced adsorbent was dominated by carbon and oxygen, while the surface morphology shows porosity.

The removal of reactive azo-dye with the help of the adsorbent was tested under different conditions. It was found that the adsorption depended on contact time and initial dye concentration.

The *Langmuir* equilibrium model perfectly describes the process of adsorption of reactive dye on the adsorbent from waste cotton textiles from the cutting of knitted fabric during the production of women's T-shirts.

The kinetic *pseudo-first and pseudo-second* order models excellently described the change in the adsorption rate of the reactive dye on the adsorbent, but preference was still given to the *pseudo-first* order model.

Based on these results, it can be concluded that the adsorbent obtained from the waste cotton textile may be an effective adsorbent for the removal of the reactive azo-dyes from an aqueous solution, with a reasonable tendency of application in industrial conditions, as well.

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Table 3: Kinetic parameters of RR84 dye adsorption process on new adsorbent (pseudo-second order, 20°C)

Dye concentration (mg/dm³)	$q_{t,exp}$ (mg/g)	$q_{t,izr}$ (mg/g)	k_2 (g/mg×min)	R^2	*RSS*
30	1.19	1.65	0.026	0.980	18.47
50	1.93	2.70	0.015	0.980	7.18
75	2.85	4.04	0.010	0.977	3.65
100	3.64	5.16	0.008	0.978	2.16
125	4.37	6.14	0.007	0.982	1.24
150	4.57	6.41	0.006	0.981	1.16

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