Influence of salt on the decolourisation of Everzol Black B dye solution by adsorption process

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The textile industry produces considerable amounts of wastewater, which often contain high content of remained dyes from dyeing processes. Of the many decolourisation methods available, the adsorption has proven to be one of the most efficient and cost-effective. Namely, salts present in the wastewater due to its usage as auxiliaries in the dyeing process can increase the efficiency of the adsorption process. The aim of this paper was to investigate the adsorption efficiency of commercially available powdered activated carbon for the removal of the reactive dye Everzol Black B (c_0= 500 mg dm^{-3}) in the presence of sodium chloride at the different concentrations (c = 0.1 and 1.0 mol dm^{-3}). Isothermal batch adsorption studies were carried out at 45 (±1) °C with 0.1 g of activated carbon in the periods of 15 minutes to 16 hours when equilibrium was reached, and the results were compared with the adsorption process in a salt absence. Based on the results obtained, we determined that the adsorption process in a presence of sodium chloride results in increase in the decolourisation efficiency. Regardless of salt conecentration adsorption follows the pseudo-second-order kinetic model. Finally, determined thermodynamic parameters confirmed that the presence of sodium chloride leads to more energetically favourable process compared to the one in salt absence, and that higher sodium chloride concentration leads to the more spontaneous adsorption.

Keywords: *textile wastewater; Everzol Black B; isothermal adsorption; activated carbon; ionic strength; adsorption kinetics*

Izvorni znanstveni rad**

Utjecaj soli na obezbojavanje otopine bojila Everzol Black B procesom adsorpcije

Tekstilna industrija proizvodi znatne količine otpadnih voda, koje često sadrže i veliku količinu bojila zaostalih u procesu bojadisanja. Od mnogih dostupnih metoda za obezbojavanje, adsorpcija se pokazala jednom od najučinkovitijih i ekonomski najisplativijih. Naime, soli prisutne u otpadnoj vodi, koje se koriste i kao pomoćna sredstva u procesu bojadisanja, mogu povećati učinkovitost procesa adsorpcije. Cilj ovog rada bio je istražiti učinkovitost adsorpcije komercijalno dostupnog praškastog aktivnog ugljena za uklanjanje reaktivnog bojila Everzol Black B (c_0= 500 mg dm^{-3}) u prisutnosti natrijeva klorida u različitim koncentracijama (c = 0,1 i 1,0 mol dm^{-3}). Istraživanja izotermne šaržne adsorpcije provedena su na 45 (±1) °C s 0,1 g aktivnog ugljena u razdobljima od 15 minuta do 16 sati kada je postignuta ravnoteža, a rezultati su uspoređeni s postupkom adsorpcije u odsutnosti soli. Na temelju dobivenih rezultata utvrdili smo da proces adsorpcije u prisutnosti natrijeva klorida dovodi do povećanja učinkovitosti obezbojavanja. Neovisno o koncentraciji soli, adsorpcija slijedi kinetički model pseudo-drugog reda. Naposlijetku, određeni termodinamički parametri potvrdili su da prisutnost natrijeva klorida dovodi do energijski povoljnijeg procesa adsorpcije u odnosu na onaj u odsutnosti soli, te da veća koncentracija natrijeva klorida dovodi do spontanije adsorpcije.

Ključne riječi: *otpadne vode tekstilne industrije; Everzol Black B; izotermna adsorpcija; aktivni ugljen; ionska jakost; kinetika adsorpcije*

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1. Introduction

Textile industry as one of the main water consumers generates large quantities of wastewater, accounting for more than 20% of global water pollution [1]. Textile wastewater can be produced in a various stage of the textile materials production (cleaning of raw materials, starching, boiling, bleaching, mercerization, dyeing, printing, washing and wet cleaning). The particular characteristics of textile wastewater vary from one production unit to another depending on a type of raw material (plant-based, animal-based fibers or synthetic fibers) and applied technologies [2]. In terms of its environmental impact, almost all discharged textile industry wastewater is highly polluted. Very often, untreated wastewater exibit elevated temperature, high turbidity, pH values and conductivity accompanied with high-suspended solids content, chemical oxygen demand (COD) and biochemical oxygen demand (BOD) [2,3]. Such waters must be treated not only for technological processes so that the treatment effects show satisfactory results, but also before being discharged into a natural recipient without harmful consequences for the environment.

The dyeing is one of the most important finishing processes in textile industry. More than 700,000 tonnes of textile dyes are produced annually, out of which 15% of excess dyestuff is being discharged into water bodies due to incomplete dye exhaustion [4]. Even low amount of dye present in a water is noticeable as significant change in coloring. Such waters are not aesthetically pleasing and pose a serious ecological issue. Present dyes disrupt photosynthesis inhibiting light penetration, nutrients and oxygen production. Dyes can enter the food chain and bioaccumulate in human organism, causing a potential to induce mutagenic and carcinogenic effects [5]. In addition, some dying processes involve the usage of different auxiliaries such as carriers and inorganic salts [6]. Reactive dyes are characterised by numerous benefits, such as vibrant colours, high colourfastness and simplicity of application. Therefore, they are one of the most often used dyes in textile fibers dyeing process. The removal or mineralization of water-soluble reactive dyes are extremely challenging. As electron deficient, they are less susceptible to degradation in presence of light, heat, oxidant agents and microorganisms. Consequently, they tend to pass through conventional treatment systems unaffected. In addition, cleavage of azo bond can lead to the formation of toxic amines in the effluent [7,8]. Having that in mind, such wastewater poses a serious threat to the environment, if there not appropriately treated before discharge.

Various methods and technologies have been used for decolorization of textile wastewaters with varying efficacies. Adsorption stands out among other methods in a first place for their great decolorization efficiency of wastewater containing a variety of dyes. It is also economically suitable and eco-friendly, has the simplest operation and recyclability of the adsorbents. Activated carbon is still one of the most popular adsorbents used for wastewater treatment due to its low costs, easy accessibility, great adsorption efficiency and wide applicability [9].

The adsorption as time-dependent process is influenced by many factors such as temperature, optimal dosage of adsorbents, initial concentration of present dye and pH value, as well as and ionic strength of solution. It is very common that textile wastewater contains a large proportion of solvated inorganic salts. Therefore, the aim of this paper is to investigate the effect of presence of sodium chloride on the adsorption of reactive dye Everzol Black B (EBB) onto commercial powdered activated carbon. The experimental results are compared with the adsorption process in a salt absence [10]. Based on the results obtained, we determined the kinetic parameters of the adsorption process of Everzol Black B dye and proposed a suitable adsorption mechanism.

2. Experimental

2.1. Chemicals

Everzol Black B (EBB) dye, supplied by Evershine Enterprise Text-Tech Corporation (C.I. 20505, chemical formula: $C_{26}H_{21}N_5Na_4O_{19}S_6$, M_r = 991.82), was used for adsorption experiment. Chemical structure of the dye is shown in Fig.1. Powdered activated carbon was purchased from Kemika, Croatia (particles size: <40 µm 85%, >80 µm 5%). Adsorbent was dried in an oven at 105 ºC for 24 hours and stored in desiccator until it is used.

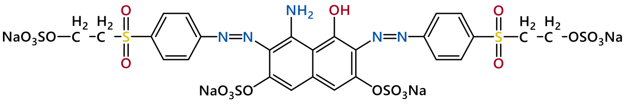

Fig.1 Chemical structure of Everzol Black B dye

2.2. Isothermal batch adsorption studies

Adsorption studies were conducted using 50 cm^3 of EBB dye solution of concentration c_0 = 500 mol dm^{-3} in presence of sodium chloride at different concentrations (c = 0.1 and 1.0 mol dm^{-3}). Isothermal batch adsorption studies were conducted with 0.1 g of powdered activated carbon in glass bottles.

Suspensions were shaken at different contact times (15, 30, 45, 60, 120 minutes and 16 hours) with impeller speed of 250 rpm at 45(±1) °C (Heidolph Unimax 1010 with Incubator 1000). Adsorption time of 16 hours as appropriate time to reach adsorption equilibrium we determined in our previous study [11]. All experiments were done in triplicates to confirm the repeatability of the experiments. Experimental data in tables and points presented in figures are the average values of three repetitions. After agitation, suspensions were filtered through filter-paper blue ribbon, and the residual liquid-phase dye concentration after adsorption was determined spectrophotometrically by monitoring the absorbance using UV–Vis spectrophotometer (Lambda 20, Perkin Elmer) at maximum absorbance wavelength (λ_{max} = 598 nm). For all filtrates, pH values after adsorption were also measured.

The amount of adsorbed dye at time (t), q_t (mg g^{-1}), and at equilibrium, q_e (mg g^{-1}), were calculated by using following equation:

$$q = \frac{V\,(c_0 - c_t)}{m} \qquad (1)$$

where c_0 is the initial dye concentration (c_0 = 500 mol dm^{-3}), c_t is its concentration in the liquid phase at time (t) and at equilibrium (t = 16 hours), V is the volume of liquid phase (dm^3), and m is mass of the adsorbent (g).

Efficiency of adsorption, *i.e.* efficiency of decoloration (E_d) is calculated by equation:

$$E_d = \frac{(c_0 - c_t)}{c_0} * 100 \qquad (2)$$

3. Results and discussion

3.1. Effect of salt addition on adsorption process

The aim of this research was to evaluate the influence of presence of salt on the treatment of dye-rich textile wastewaters by adsorption process. Concentration of c_0 = 500 mg dm^{-3} was chosen for EBB dye concentration, as this is expected dye concentration in wastewaters remained after dying process. Dye concentration in the liquid phase (c_t) and amount of adsorbed dye (q_t) after appropriate time (t) of adsorption for two sodium chloride concentrations are given in tab.1, while liquid phase concentrations of dye (c_t) during adsorption process are presented in Fig.2. Calculated values were compared with results obtained using the same procedure of adsorption experiment with the same experimental conditions (dye concentration, mass of adsorbent and temperature) in absence of a salt [10]. Fig.2 shows that the adsorbate concentration in the liquid phase (c_t) decreases exponentially with time (t), even in the absence of a salt. The diagram can be roughly divided into several areas: a very rapid initial adsorption, then a milder and gradual decrease in the dye concentration. Finally, the dye concentration reaches the equilibrium state.

Tab.1 Concentration of adsorbate in the liquid phase (c_t) and amount of adsorbate (q_t) after appropriate time of adsorption (t) for two NaCl concentrations (c = 0.1 and 1.0 mol dm^{-3}), and without NaCl [10].

t/min	**c (NaCl) = 0 mol dm^{-3}** [10]		**c (NaCl) = 0.1 mol dm^{-3}**		**c (NaCl) = 1.0 mol dm^{-3}**	
	c_t/ mg dm^{-3}	**q_t/ mg g^{-1}**	**c_t/ mg dm^{-3}**	**q_t/ mg g^{-1}**	**c_t/ mg dm^{-3}**	**q_t/ mg g^{-1}**
15	373.1	63.4	164.1	167.9	71.5	214.3
30	332.9	83.6	129.6	185.2	33.2	233.4
45	308.7	95.7	112.2	193.9	25.3	237.4
60	298.7	100.7	98.6	200.7	19.2	240.4
120	235.9	132.1	61.2	219.4	5.1	247.5
960	118.3	190.9	4.0	248.0	0.3	249.9

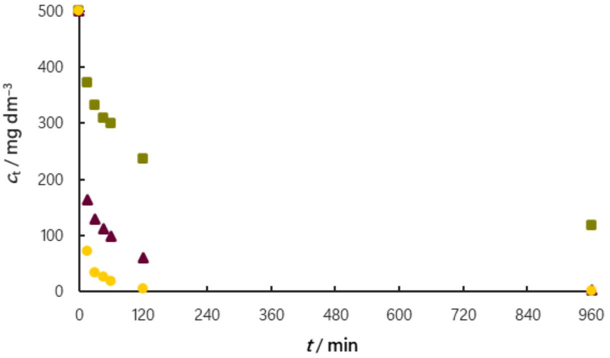

Fig.2 Effect of presence of sodium chloride at two concentrations (c = 0.1 and 1.0 mol dm^{-3}) compared to salt absence [10] on the adsorbate concentration in the liquid phase (c_t) after appropriate time of adsorption (t) (■ without NaCl; ▲ 0.1 mol dm^{-3} NaCl; ● 1.0 mol dm^{-3} NaCl)

The experimental data (tab.1 and Fig.2) show that the presence of sodium chloride substantially influences the adsorption process of the dye. This means that the adsorbate concentration in the liquid phase (c_t) decreases significantly in the presence of NaCl during the entire adsorption process compared to the absence of the salt. It is evident that substantially higher adsorption capacities (q_e) are achieved for both NaCl concentrations (q_e = 248.0 and 248.9 mg g^{-1}).

As already stated for the adsorption capacities, the results of E_d values show that the adsorption is much higher in the presence of salt (tab.2). At the higher salt concentration (c = 1.0 mol dm^{-3}), more than 90% of the dye is removed even at low time (t = 30 min). It can also be seen that the solutions are almost completely decolourised once equilibrium is reached, regardless of the salt concentration (E_d = 99.2 and 99.9%). On the contrary, in the salt absence almost 25% of EBB dye remains in solution [10].

Tab.2 Efficiency of decoloration (E_d) at appropriate time of adsorption (t) for adsorption in presence of sodium chloride at two concentrations (c = 0.1 and 1.0 mol dm^{-3}) compared to adsorption in sodium chloride absence [10]

t /min	E_d / %		
	c (NaCl) = 0 mol dm^{-3} [10]	c (NaCl) = 0.1 mol dm^{-3}	c (NaCl) = 1.0 mol dm^{-3}
15	25.4	67.2	85.7
30	33.4	74.1	93.4
45	38.3	77.6	94.9
60	40.3	80.3	96.2
120	52.8	87.8	99.0
960	76.3	99.2	99.9

Given the fact that adsorption depends on the pH value [12] and in order to determine whether the pH value changes significantly during the adsorption process, the pH values of all filtrates were measured. The pH value of the EBB dye solution (c_0 = 500 mg dm^{-3}) was also measured. The Fig.3 shows the measured pH values of the solutions before and after the adsorption process.

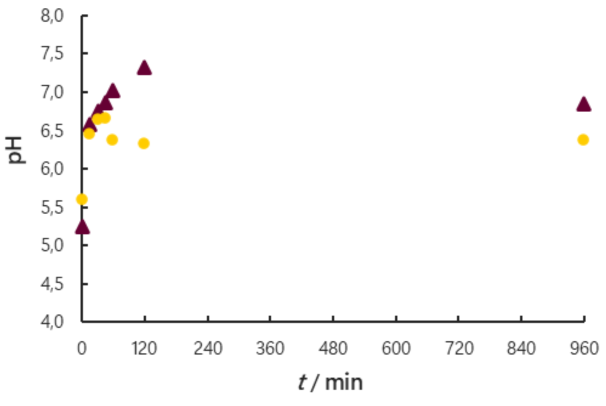

Fig.3 pH profiles of EBB dye after adsorption in presence of sodium chloride at two concentrations after appropriate time of adsorption (t) (▲ 0.1 mol dm^{-3} NaCl and ● 1.0 mol dm^{-3} NaCl)

It can be seen that the pH value of the solutions after adsorption are increased compared to the initial pH value for approximately 1.0 pH unit. The reactive dye Everzol Black B dissociates in water into the anion and sodium cations. The slightly increased pH values after adsorption can be explained by the fact that there is an attraction between the negative ion of the dye and the activated carbon. A certain amount of hydrogen ions will be also adsorbed onto the surface of the activated carbon. As a result, pH value of filtrate is increased [13]. However, you should bear in mind that this is not a significant change in the pH value. Namely, much larger differences in adsorption capacity are observed at much lower or higher pH values [12], what was not the case in this study.

3.2. Kinetics of adsorption

In order to determine the adsorption mechanism based on experimental data kinetic studies have been performed. Knowing the kinetic parameters, it is easy to calculate the uptake rate of adsorbate at any time and residual time of the whole adsorption process. Kinetic models can be divided into two groups:

- pseudo kinetic adsorption models
- mass transfer models.

In this work the obtained experimental data were analysed by three kinetic models: pseudo-first-order, pseudo-second-order and intraparticle diffusion model. The pseudo-first-order and pseudo-second-order are the most often used models for determination of kinetic parameters.

3.2.1. Pseudo-first-order kinetic model

The first model developed by Lagergren [14] is pseudo-first-order kinetic model. It describes a rate equation for the sorption of solute from a liquid solution based on the solid capacity. It can be said that the rate of adsorption is directly proportional to the number of free sites for the binding of adsorbate molecules on the surface of the adsorbent. Kinetic model is expressed by following equation:

$$\frac{dq_t}{dt}=k_1(q_e-q_t) \qquad (3)$$

where k_1 is the rate constant of pseudo-first-order (min^{-1}).
Integrating this equation for the boundary conditions t = 0 to t = t and q_t = q_t gives linear relationship expressed by equation:

$$\ln(q_e-q_t) = \ln q_e - k_1 t \qquad (4)$$

The pseudo-first-order kinetic constant k_1 can be determined by plotting $\ln(q_e-q_t)$ *vs*. time (t), and if the first-order equation is applicable, the plot should give a linear relationship with high value of correlation coefficient (R^2). Rate constant of pseudo-first-order (k_1) can be calculated from the slope of this plot, while amount of adsorbed dye at equilibrium ($q_{e,calc}$) from the intercept. The values of constants of the pseudo-first-order model (k_1) and amount of adsorbed dye at equilibrium ($q_{e,calc}$) for adsorption process of EBB dye on activated carbon in presence of 0.1 and 1.0 mol dm^{-3} sodium chloride are given in tab.3.

Tab.3 Kinetics parameters for the EBB dye adsorption on activated carbon in a presence of sodium chloride at two concentrations (c = 0.1 and 1.0 mol dm^{-3})

c (NaCl) / mol dm^{-3}	**$q_{e.exp.}$ / mg g^{-1}**	**pseudo–first order model**			**pseudo–second order model**			
		$q_{e.calc.}$ / mg g^{-1}	**R^2 / %**	**k_1 / min^{-1}**	**$q_{e.calc.}$ / mg g^{-1}**	**R^2 / %**	**k_2 / g mg^{-1}min^{-1}**	**h / mg g^{-1} min^{-1}**
0.1	248.0	85.8	98.4	0.0094	250.0	99.9	3.18 * 10^{-4}	19.88
1.0	249.9	40.6	97.5	0.024	250.0	100%	1.78 * 10^{-3}	111.1

According to calculated data shown in tab.3 correlation coefficients (R^2) for pseudo-first order kinetic model is relatively high (97.5 and 98.4 %). However, there is a great disagreement between experimental ($q_{e,exp.}$) and calculated ($q_{e,calc.}$) values of amount of adsorbed EBB dye at equilibrium. This implies that adsorption system can not be described by a pseudo-first-order kinetics model. Therefore, we preformed experimental data fitting into pseudo-second-order model.

3.2.2. *Pseudo-second-order kinetic model*

Ho and McKay [15,16] developed a second-order equation based on adsorption capacity. This kinetic model is given by equation:

$$\frac{dq_t}{dt}=k_2(q_e-q_t) \qquad (5)$$

where k_2 is the rate constant of pseudo-second-order (g mg^{-1} min^{-1}).

Integrating this equation for the same boundary conditions as for the first-order gives equation, which in the linear form is presented as:

$$\frac{t}{q_t}=\frac{1}{k_2 q_e^2}+\frac{1}{q_e}t \qquad (6)$$

If the pseudo-second-order equation is applicable, the plot of t/q_t against time (t) should give a linear relationship. The amount of adsorbate adsorbed at equilibrium ($q_{e,calc}$) from the slope and the rate constant of pseudo-second-order (k_2) from the intercept are calculated. Based on this model, calculated q_e values ($q_{e,calc}$) show much better agreement with experimental equilibrium values ($q_{e,exp}$), while values of the correlation coefficients are approximately 100 % (tab.3). The calculated values for the amount of adsorbate adsorbed at equilibrium ($q_{e,calc}$) are also practically identical for both salt concentrations.

As expected, maximum k_2 value was obtained for the 1.0 mol dm^{-3} sodium chloride solution. Fig.4 shows much better agreement of the data with the pseudo-second-order equation, compared to pseudo-first-order equation. The experimental points are shown together with the theoretically generated ones for both kinetic models, and they well fit to pseudo-second order kinetic model. Therefore, it can be concluded that adsorption of EBB dye on commercial activated carbon is kinetically controlled assuming a pseudo-second order. The pseudo-second-order model considers chemical sorption (chemisorption) as the rate-limiting adsorption process [17].

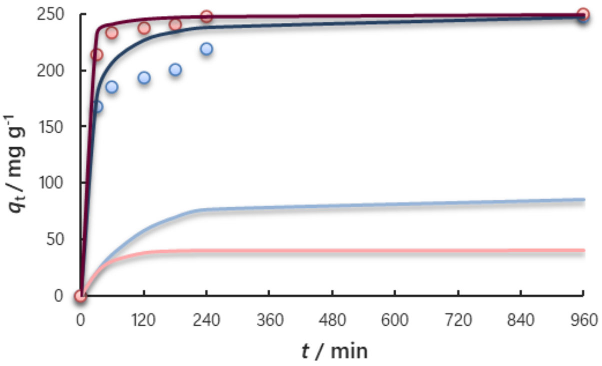

Fig. 4. Fitting of experimental data for the adsorption of the Everzol Black B dye (c_0 = 500 mg dm^{-3}) with two sodium chloride concentrations on activated carbon (○ 0.1 and ○ 1.0 mol dm^{-3} NaCl) into pseudo-first (— 0.1 and — 1.0 mol dm^{-3} NaCl) and pseudo-second (— 0.1 and — 1.0 mol dm^{-3} NaCl) kinetic models

According to pseudo-second-order model, as time approaches zero the initial adsorption rate h (mg g^{-1} min^{-1}) can be calculated using following eq. [16,18]:

$$h = k_2 * q^2_{e,\ calc.} \qquad (7)$$

and the calculated h values are also presented in Tab.3. Initial adsorption rate for the sodium chloride concentration od 1.0 mol dm^{-3} is ca. 5.6 times higher than for the concentration of 0.1 mol dm^{-3}.

3.2.3. *Intraparticle diffusion model*

For evaluation of the diffusion mechanism, we also used intraparticle diffusion model. Most adsorption processes involve three steps:

I. mass transfer of adsorbate from the solution to adsorbent surface,
II. adsorption of adsorbate at a site on the surface of the adsorbent, and
III. intraparticle diffusion of the adsorbate in the pores of adsorbent and adsorption at the site.

Step (II) is usually assumed to be very fast and therefore cannot be treated as a rate-limiting step. In contrast, adsorption of large molecules, which requires a longer contact time to reach equilibrium, is almost always considered to be diffusion controlled by external film resistance and/or internal diffusional mass transport or intraparticle diffusion [13].

Theoretical treatments of intraparticle diffusion yield complex mathematical relationships, which differ in form as functions of the geometry of the adsorbent particle, and the intraparticle diffusion model could be based on the following equation [13,18]:

$$q_t = k_i * t^{0.5} \tag{8}$$

where k_i is the intraparticle diffusion rate constant (mg g^{-1} $min^{-0.5}$).

If intraparticle diffusion is rate limiting step of adsorption, *i.e.* if intraparticle diffusion controls the rate of adsorption, then plot q_t *vs*. $t^{0.5}$ should be linear and pass through the origin. If plot presents multi-linearity this indicates that intraparticle diffusion is not the only rate-controlling step and that two or more rate controlling steps occur in the adsorption process [13,19].

Fig.5 shows the root time plots for the adsorption of EBB onto commercial activated carbon for both sodium chloride concentrations.

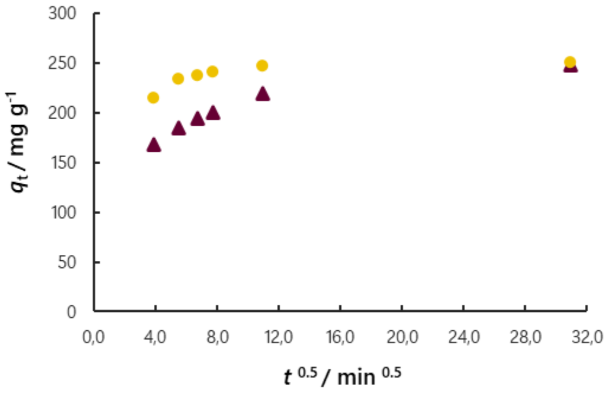

Fig. 5. Root time plot for the adsorption of EBB on activated carbon in presence of sodium chloride at two concentrations (▲ 0.1 mol dm^{-3} NaCl and ● 1.0 mol dm^{-3} NaCl)

All plots on this figure are non-linear, *i.e.* they exhibit multilinearity. From this figure, one could conclude that intraparticle diffusion is not the decisive process influencing the adsorption rate. This means that the adsorption process of the dye Everzol Black B on activated carbon consists of several different steps with different rates.

3.3. Adsorption thermodynamics

Thermodynamic adsorption parameters were calculated for the adsorption process of EBB dye on activated carbon in presence of 0.1 and 1.0 mol dm^{-3} sodium chloride. Standard Gibbs free energy value of adsorption process (ΔG° kJ mol^{-1}) can be calculated from the equation:

$$\Delta G^\circ = R * T * \ln(K_c) \tag{9}$$

where R is the universal gas constant, T is the temperature (T = 318.15 K) and K_c is equilibrium constant. Equilibrium constant K_c could be calculated from ratio [20]:

$$K_c = \frac{(c_0 - c_e)}{c_0} \tag{10}$$

where c_0 is the initial dye concentration (c_0 = 500 mol dm^{-3}) and c_e (mg dm^{-3}) is the concentration after adsorption at equilibrium.

Tab.4 shows the calculated equilibrium constant K_c and standard Gibbs free energy changes (ΔG°) for the adsorption of EBB dye on activated carbon in presence of 0.1 and 1.0 mol dm^{-3} sodium chloride.

Tab.4 Standard Gibbs free energy changes (ΔG°) for the adsorption of EBB dye on activated carbon in presence of 0.1 and 1.0 mol dm^{-3} sodium chloride

c **(NaCl) / mol dm^{-3}**	***c_e*** **/ mg dm^{-3}**	***c_0 - c_e*** **/ mg dm^{-3}**	***K_c***	**ΔG^0 / kJ mol^{-1}**
0.1	4.0	496.0	124.0	-12.8
1.0	0.3	499.7	1665.7	-19.6

The negative value of ΔG^0 indicates that the adsorption process is spontaneous. This means that the adsorption process does not require any energy input from outside the system. In comparison, the value of ΔG° in absence of sodium chloride is −3.1 kJ mol^{-1} [10]. Even the addition of 0.1 mol NaCl significantly lowers the standard Gibbs free energy of adsorption (more than 4 times). Since the higher negative value reflects an energetically more favorable adsorption, it can be concluded that the presence of sodium chloride results in a more favorable process.

4. Conclusions

The textile industry is one of the greatest environmental polluters, as among other things produces large quantities of wastewater. The dyeing process is one of the most important finishing processes in the textile industry. Even small amounts of dye in a water result in noticeable change in colour, which is aesthetically unpleasant and ecologically unacceptable. It must therefore be treated before being discharged into recipients. The adsorption process has proven to be one of the most efficient and cost-effective process for the colorants removal. It is influenced by the physico-chemical properties of adsorbent as well as the temperature, pH value and the presence of other substances in the wastewater, like salts that can increase the efficiency of the adsorption process. Therefore, in this study we carried out isothermal adsorption of the reactive dye Everzol Black B (c_0 = 500 mg dm^{-3}) on activated carbon in the presence of sodium chloride at different concentrations (c = 0.1 and 1.0 mol dm^{-3}).

The results of this study showed that the addition of sodium chloride significantly increases the adsorption of the dye on activated carbon. Even at a concentration of 0.1 mol dm^{-3} NaCl, a significant increase in the decolourisation efficiency of the EBB dye solution is achieved compared to that in the absence of sodium chloride. We also found that the pH value of the solution slightly changes after adsorption, but not to the extent that affects adsorption. The increase is approximately the same regardless of the sodium chloride concentration. Kinetics studies revealed that the adsorption process in a presence of sodium chloride follows the pseudo-second-order kinetic model. In addition, intraparticle diffusion is not the only process that influences on the adsorption rate. Finally, calculated standard Gibbs free energy of adsorption of Everzol Black B dye on activated carbon confirmed that the presence of sodium chloride leads to more energetically favourable process compared to the one in salt absence, and that higher sodium chloride concentration leads to the more spontaneous adsorption.

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