

Kinetics of diclofenac adsorption from aqueous solution on commercial activated carbon

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This paper studies the possibility of using activated carbon as an adsorbent for diclofenac (DFC) from aqueous medium. Batch sorption experiments were performed, and the influence of different parameters was studied: adsorbent dose, contact time and temperature. The experimentally obtained results were fitted according to two linear theoretical models of isotherms: Freundlich and Langmuir and according to two different kinetic models: pseudo-first and pseudo-second order. The optimal adsorption parameters were found to be: dose of adsorbent 0,5 g; contact time 60 minutes and temperature 20°C, and the removal efficiency of diclofenac at these parameters was 92.8%. The results showed that the adsorption process follows a pseudo-second order kinetics and better matches the Freundlich isotherm model. The values of thermodynamic parameters indicate that adsorption process is spontaneous and exothermic. Based on the obtained data, it can be concluded that commercial activated carbon is an effective adsorbent for diclofenac from aqueous solution.

INTRODUCTION

Over the past decade, the emergence of pharmaceuticals in the environment and watercourses has been widely discussed and published. Pharmaceuticals are compounds used for the treatment and prevention of human and animal diseases, as well as growth promoters in veterinary medicine (Periša & Babić, 2016). The substances can reach the environment and watercourses in several different ways, through wastewater from the pharmaceutical industry, hospitals, agricultural farms and households, by direct disposal of unused pharmaceuticals or expired ones, etc. Even though these substances are present in small quantities in the wastewater (in µg/L or ng/L), they are biologically very active. Continuous release into the environment and watercourses leads to a long-term harmful impact on terrestrial and aquatic ecosystems, and that is the main reason for their removal.

Numerous studies showed that wastewater treatment plants are not designed for successful removal of pharmaceuticals, and as a result, they are present

in surface waters. There are currently numerous methods for pharmaceuticals removal from water, such as: chemical precipitation, flotation, advanced oxidation processes (Fenton's reagent, photocatalytic oxidation, ultrasonic oxidation, electrochemical oxidation, ozonation, etc.), membrane separation processes, microfilters osmosis, electrodialysis and biological treatment (Guo et al., 2017; Su et al., 2015). Main disadvantages of these methods are high cost and low efficiency (they are effective only in certain experimental conditions). Adsorption is a method that showed a considerable efficiency for pharmaceuticals removal from water, especially adsorption on activated carbon as adsorbent. In addition, this method is simple and has low operating costs.

Diclofenac belongs to a group of non-steroidal and anti-inflammatory drugs, and it has been widely used in medicine as an analgesic and anti-inflammatory agent. Due to its wide usage, diclofenac is one of the earliest discovered pharmaceuticals in the environment and wastewaters. Its presence could take place in a few different ways, such as direct disposal, through wastewater from hospitals and pharmaceutical industry, through discharges from wastewater treatment plants, etc. (De Oliveira et al., 2017). Even though concentrations are low, there are negative effects on the aquatic world and human beings (Fent et al., 2006).

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This paper studies adsorption of diclofenac from aqueous medium on commercial activated carbon as an adsorbent. Freundlich and Langmuir's adsorption isotherms and pseudo-first and pseudo-second order kinetic models were used to analyze the experimental data.

MATERIALS AND METHODS

Adsorbent

Powdered commercial activated carbon, product of ANALYTIKA®, spol s r.o., Czech Republic, was used for the experiments. A description of the basic physical, chemical and adsorption properties of material is given in Table 1.

Table 1. Physical and chemical properties of commercial activated carbon

Parameter	Value
Particle size	max. 0,1 mm
Ash	max. 10 %
Specific surface (BET, N ₂)	min. 1000 m ² /g
Iodine value	min. 1050 mg/g
Adsorption of methylene blue	min. 18%

Point of zero charge (pH_{pzc}) and pH of suspension (pH_{sus}) were determined according to the method described in the dissertation by Momčilović (2012).

Point of zero charge is the pH value at which adsorbent surface is not charged (pH_{pzc}). At pH values above pH_{pzc} , the adsorbent surface is negatively charged, while in cases when pH value is below pH_{pzc} , adsorbent surface is positively charged. 0,1 g of activated carbon was suspended in 30 mL of 0,1 M KNO₃ solution in a series of PVC containers, and different pH values were adjusted. The initial pH value of KNO₃ solution was adjusted by adding 0,1 M HNO₃ and 0,1 M KOH solutions in range from 3 to 12. The suspensions were left closed for 24 hours at room temperature, then they were filtered and pH value was measured. The pH value that did not change during 24 h was pH_{pzc} .

pH of the suspension (pH_{sus}) or contact pH is an indicator of the acid-alkali nature of activated carbon surface. The pH value of distilled water, which is around neutral, changes when it comes in contact with sorbent due to the reaction with acidic and alkali groups on its surface. A certain dose of activated carbon (0,2 g) was added to 30 mL of distilled water, and stayed in closed PVC containers for 72 hours, with occasional shaking. Then, pH was measured and this value represents the pH_{sus} .

Activated carbon suspended in water significantly increased the pH value of distilled water. Obtained results $pH_{sus}=10,80$ and $pH_{pzc}=10,43$ classify activated carbon as H-type. These types of activated carbons are activated at higher temperatures (800-1000°C) and increase the pH of neutral or acidic solutions. They have alkali surface structure, adsorb acid well, and are hydrophobic (Faust & Aly, 1998). The pH values were measured on a Jenway 3520 pH meter.

Adsorbate

The potassium salt of diclofenac ($M=334,23$ g/mol; C₁₄H₁₀Cl₂KNO₂), a product of Amoli Organics PVT LTD, India, was used as the emerging substance. The chemical structure of diclofenac is shown in Figure 1.

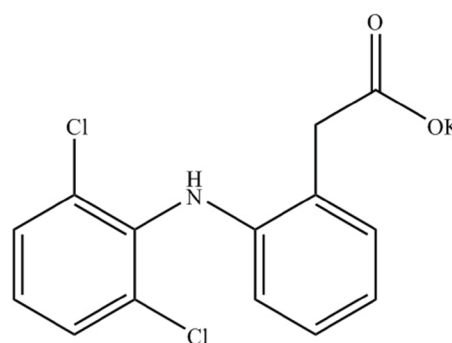


Figure 1. Chemical structure of diclofenac

Adsorption experiment

Adsorption experiments were performed in Erlenmeyer flasks in a thermostat (WiseCircu WCR, model WCR-P22, Witeg, Wertheim, Germany). In all experiments, the same volume of diclofenac solution (further in paper DFC) was used (50 mL), as well as the same concentration (0,005 mol/L) and temperature (20 °C), while the other parameters changed. Diclofenac solutions of the following concentrations: 0,001; 0,002; 0,003; 0,004 and 0,005 mol/L were prepared by diluting a stock solution ($c = 0,005$ mol/L), and used for a calibration curve. Distilled water was solvent for all prepared solutions. After the adsorption experiment, the suspensions were filtered (blue band filter paper) and diluted ($R = 50$). The concentration of DFC in all samples was determined by UV / Vis spectrophotometer (Perkin-Elmer Lambda 25) at 276 nm wavelength (da Silva et al., 2015).

The influence of adsorbent dose, contact time and temperature on the adsorption process was studied. Dose experiment was examined with different doses of activated carbon (0,1; 0,2; 0,3; 0,4; 0,5 and 1,0 g), contact time of 30 minutes, concentration $c = 0,005$ mol/L; volume $V = 50$ mL and temperature $t = 20$ °C. Adsorption equilibrium was studied through 90 minutes, dose of 0,5 g, concentration $c = 0,005$ mol/L; volume $V = 50$ mL and temperature $t = 20$ °C.

In order to determine the influence of temperature on the adsorption process, experiments were performed at three different temperatures: 20, 25 and 35 °C, under the following conditions: $m = 0,5$ g; $V = 50$ mL; $c = 0,005$ mol/L, $t = 60$ min.

The amount of adsorbed DFC on one gram of adsorbent, in the equilibrium state, q_e (mol/g), and the percentage of removed DFC, $E(\%)$, were calculated with equation (1) and equation (2), respectively:

$$q_e = \frac{(c_0 - c_e) \cdot V}{m} \quad (1)$$

$$E(\%) = \frac{(c_0 - c_e)}{c_0} \cdot 100 \quad (2)$$

where: c_0 and c_e are initial and equilibrium concentration of DFC in the solution (mol/L), respectively; V - volume of DFC solution used for adsorption experiments (L), m - dose of adsorbent (g).

Isotherm experiments were performed in concentration range from 0,001 to 0,005 mol/L, dose of 0,5 g, contact time of 60 minutes and temperature 20 °C.

Parameters for kinetics experiment were: time from 5 to 90 minutes, concentration 0,005 mol/L, dose of 0,5 g and temperature 20 °C. Adsorbed amount of DFC on one gram of activated carbon in different time intervals, q_t (mol/g), was calculated by using equation (3):

$$q_t = \frac{(c_0 - c_t) \cdot V}{m} \quad (3)$$

where: c_0 and c_t are initial and concentration of DFC in solution after time t (mol/L), V - volume of DFC solution used for adsorption experiments (L), m - dose of adsorbent (g).

pH value of the DFC solution in isotherm, kinetics and other experiments was not additionally adjusted, and was $\text{pH} \approx 10,35$.

Obtained results are the average value of three measurements. The data were analyzed and compared with two adsorption isotherm and two kinetics models.

Adsorption isotherms and kinetics models

Experimentally obtained data were analyzed with two equilibrium isotherm models: Freundlich and Langmuir. The mathematical expressions of linear forms of these models are given with equations (4) and (5), respectively:

$$\ln q_e = \ln K_F + \frac{1}{n} \ln c_e \quad (4)$$

$$\frac{c_e}{q_e} = \frac{1}{K_L q_m} + \frac{c_e}{q_m} \quad (5)$$

where: c_e - is equilibrium concentration of DFC in solution, (mol/L); q_e - adsorbed amount of DFC on 1 g of adsorbent, (mol/g); q_m - maximum adsorption capacity of adsorbent, (mol/L); K_F (mol/g)(mol/L)^{1/n} and $1/n$ are constant of Freundlich adsorption isotherm, while K_L is constant of Langmuir adsorption isotherm.

The obtained kinetics data are analyzed with two kinetic models, pseudo-first and pseudo-second order model. Linear forms of pseudo-first and pseudo-second order models are given with equations (6) and (7), respectively:

$$\ln(q_e - q_t) = \ln q_e - k_1 t \quad (6)$$

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \quad (7)$$

where: q_e - amount of adsorbed DFC on 1 g of adsorbent at equilibrium, (mol/g); q_t - amount of adsorbed DFC on 1 g of adsorbent at time t (mol/g); t - contact time (min.); k_1 - reaction rate constant for pseudo-first order (min⁻¹); k_2 - reaction rate constant for pseudo-second order (g mol⁻¹min⁻¹).

Thermodynamic study

Thermodynamic parameters, such as Gibbs energy (ΔG), enthalpy (ΔH) and entropy (ΔS), for the adsorption of DFC on commercial activated carbon, were calculated based on the equations:

$$\Delta G = -RT \ln \left(\frac{q_e}{c_e} \right) \quad (8)$$

$$\ln \left(\frac{q_e}{c_e} \right) = - \frac{\Delta H}{R} \cdot \frac{1}{T} + \frac{\Delta S}{R} \quad (9)$$

where R is universal gas constant (8,314 J/molK) and T is thermodynamic temperature (K).

RESULTS AND DISCUSSION

Influence of adsorbent dose on DFC adsorption

The effect of the adsorbent dose on the adsorption process was determined by a series of experiments, with different adsorbent masses (0,1; 0,2; 0,3; 0,4; 0,5 and 1,0 g), while the adsorption parameters were: DFC concentration 0,005 mol/L, temperature 298 K and contact time 30 minutes. Efficiency of DCF removal in function of adsorbent dose was shown in Figure 2. According to the obtained results shown in Figure 2, it can be concluded that the increase in the adsorbent dose positively affects the removal efficiency. With an

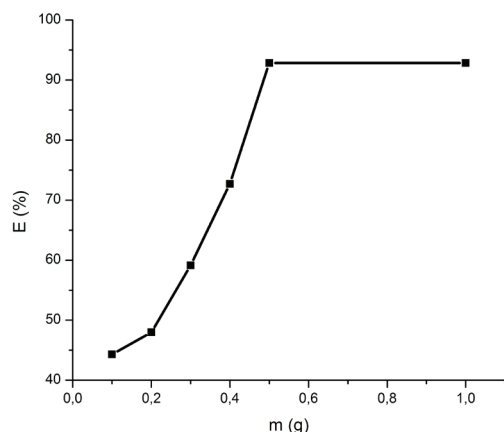


Figure 2. Influence of adsorbent dose on efficiency of DFC adsorption (conditions: $c=0,005$ mol/L; $V=50$ mL; $T=298$ K; $t=30$ min.)

adsorbent dose of 0,5 g, a maximum removal efficiency of 92,8% was achieved. Further increasing of adsorbent dose practically does not change the efficiency of adsorption. Similar results were obtained earlier (Thi Minh Tam et al., 2019). This increasing in DFC removal efficiency with dose is associated with higher specific surface area and greater number of active sites.

Influence of contact time on DFC adsorption

The influence of the contact time on the DFC adsorption process onto activated carbon was studied under the following experimental conditions: $m = 0,5$ g; $c = 0,005$ mol / L; $V = 50$ mL and $T = 298$ K for 90 minutes. Activated carbon has been proved to be a very effective adsorbent for DFC removal. As the contact time increases, the efficiency of DFC removal increases, (Figure 3). For the first 30 minutes ($E = 89,6\%$), the adsorption process found to be very fast, but later, as the saturation process started, equilibrium state was achieved. A great driving force (initial concentration of DFC) and a large number of active sites are the main reasons for efficient and rapid adsorption of DFC at the beginning of the process, (Larous & Meniai, 2016; Wahab et al., 2010). The efficiency of DFC removal practically did not change after 60 minutes, and that time was chosen to be optimal for further experiments.

Influence of temperature on DFC adsorption

The influence of temperature on the efficiency of DFC removal was examined at three different temperatures: 20, 25 and 35 °C, and other experimental conditions were: $m = 0,5$ g; $V = 50$ mL; $c = 0,005$ mol/L, $t = 60$ minutes. The obtained results are shown in Figure 4, which shows that the efficiency of DFC removal is the highest at 20 °C, the lowest temperature at which the experiment was performed. As the temperature

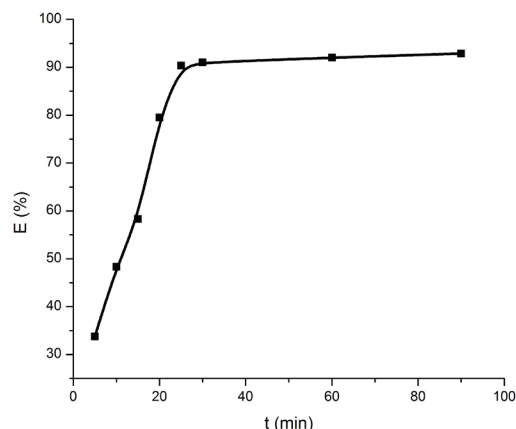


Figure 3. Influence of contact time on efficiency of DFC adsorption (conditions: $c=0,005$ mol/L; $V=50$ mL; $T=298$ K)

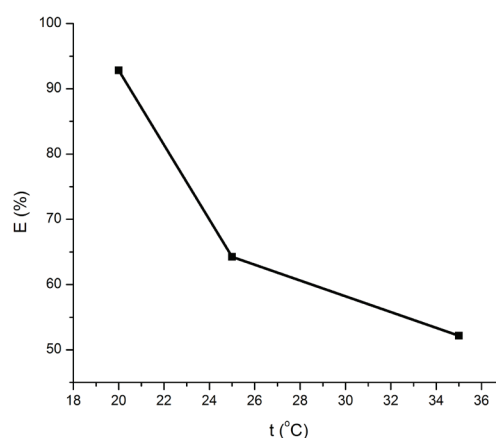


Figure 4. Influence of temperature on efficiency of DFC adsorption (conditions: $m=0,5$ g; $V=50$ mL; $c=0,005$ mol/L, $t=60$ min.)

increases, the efficiency of DFC removal decreases. At 20 °C, the removal efficiency was 92,77%, at 25 °C was 63,20% and at 35 °C it was 50,77%. It can be assumed that with increasing temperature, the mobility of DFC molecules increases, due to weak attraction forces between molecules and/or species of DFC in solution and functional groups on the surface of activated carbon, and the opposite process-desorption is favored. This trend indicates that activated carbon is not a suitable adsorbent of DFC in a wide temperature range and that the process of adsorption of DFC on activated carbon is exothermic. Similar results of the influence of temperature on the DFC adsorption on activated carbon, were obtained from the tuber *Cyclamen persicum* L, and published by Jodeh et al. (2016).

The possible adsorption mechanism

Adsorption mechanism is important for understanding adsorption process and the surface of porous adsorbent. Parameters, like pH value of medium, pH_{pzc} and pKa of adsorbate help to define adsorption mechanism. Earlier studies (Ayati et al., 2016; Bhadra et al., 2017) showed that adsorption of pharmaceuticals onto carbon adsorbents surface can be described through electrostatic interactions, hydrogen bonds, π - π interactions and Van der Waals forces. DFC is acidic pharmaceuticals with $\text{pKa}=4,15$. At pH below pKa ($\text{pH}<4,15$), molecules of DFC are mostly neutral ($-\text{COOH}$), and its solubility in water decreases (Larous & Meniai, 2016). For pH values above pKa ($\text{pH}>4,15$), DFC molecules are negatively charged ($-\text{COO}^-$) due to ionization process. Point of zero charge determined for activated carbon was $\text{pH}_{\text{pzc}}=10,43$, which means that activated carbon surface is positively charged at pH values below pH_{pzc} , while at pH above pH_{pzc} surface is negatively charged. According to literature data (An et al., 2018; Bhadra et al., 2017; Ersan et al., 2017; Thi Minh Tam et al., 2019; Wu et al., 2020) and based on DFC molecules structure, pH_{pzc} of activated carbon, experiments are studied at pH around 10,35, and possible adsorption mechanism could be electrostatic interactions, hydrogen bonds and π - π interactions. The main mechanisms responsible for adsorption of DFC onto activated carbon are π - π interactions, donor-acceptor interactions of π - π electrons between aromatic rings of DFC (acceptor of π -electrons) and active carbon (donor of π -electrons), as well as electrostatic interactions and hydrogen bonds.

Equilibrium study

Adsorption isotherms describe adsorbate molecules distribution between the liquid and solid phases, in the equilibrium state. Adsorption experiments are studied in these experimental conditions: $m=0,5$ g; $V=50$ mL; $c=0,001-0,005$ mol/L; $T=293$ K and $t=60$ minutes. The obtained data are analyzed by two adsorption models: Freundlich and Langmuir. The parameters of these two isotherm models are shown in Table 2. Langmuir adsorption isotherm describes adsorption onto energetic uniform surface with a defined number of active sites. Every adsorption site can adsorb one molecule, and maximum of adsorption is achieved with formation of a monolayer. Linear form of Langmuir isotherm is described with equation (5). The graphical dependence c_e/q_e vs c_e gives a straight line with a slope equal to $1/q_m$, and intercept is $1/K_L q_m$. q_m (mmol/g) is maximum adsorption capacity of adsorbent, and K_L (L/mmol) is constant correlated to adsorption energy. Negative value for adsorption capacity and Langmuir constant, even though correlation coefficient value is high, showed that this isotherm model could not

Table 2. Parameters of Freundlich and Langmuir isotherm models for adsorption of DFC on activated carbon

Isotherm	T (K)	Constants		
		K_F (mmol/g)(mmol/L) ^{1/n}	n	R ²
Freundlich	293	3,3730	0,3544	0,8729
		Constants		
Langmuir	293	q_m (mmol/g)	K_L (L/mmol)	R ²
		-0,0869	-1,8066	0,8851

describe the adsorption process in this study, and it is not applicable in this case.

Freundlich adsorption isotherm is the most used isotherm for describing adsorption from solution. This adsorption model is empirical and can be used for adsorption on inhomogeneous adsorbent surface, while adsorbed molecules are in the interactions. Linear form of this isotherm was described with equation (4). The constants of Freundlich adsorption isotherm K_F and n were calculated from diagram $\ln q_e$ vs $\ln c_e$. Slope form linear equation is $1/n$, while intercept is equal to $\ln K_F$ value. Constant K_F ((mmol/g)(mmol/L)^{1/n}) is equal to equilibrium adsorption capacity of adsorbent, while constant $1/n$ is equal to intensity of adsorption and/or heterogeneity of surface. In case when $n=1$, adsorption is linear, for $n>1$ adsorption is a favorable process, while $n<1$ describes cooperative adsorption (Güzel et al., 2012). In this study, $n=0,3544$ showed that adsorption was cooperative.

Based on literature data, Langmuir and Freundlich isotherms equally well describe the adsorption of sodium salt of diclofenac on carbon adsorbents.

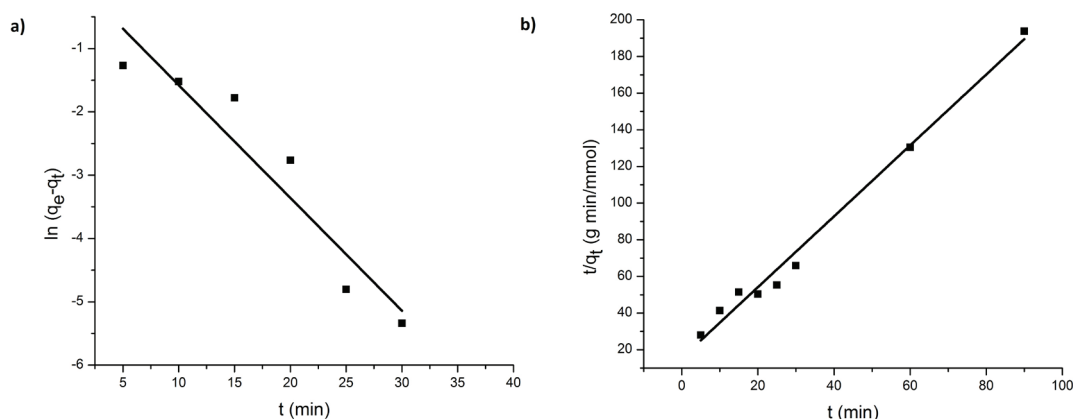
For example, Freundlich isotherm better describes adsorption of DFC on commercial activated carbon (De Franco et al., 2018), and activated carbon synthesized from cocoa bean shell (De Luna et al., 2017), while Langmuir model better describes adsorption on carbon synthesized from coconut shell (Vedenyapina et al., 2016).

Kinetics study

Kinetics parameters are important to design the adsorption system in industry. Adsorption rate is strongly influenced by several parameters, such as

Table 3. Kinetics parameters for adsorption of DFC on activated carbon at 293 K

Pseudo-first order kinetics model			Pseudo-second order kinetics model		
k_1 (min^{-1})	q_e (mmol/g)	R^2	k_2 ($\text{g mmol}^{-1} \text{min}^{-1}$)	q_e (mmol/g)	R^2
0,0056	1,2279	0,9016	0,0002	0,5172	0,9881

Figure 5. Kinetics models: a) pseudo-first order and b) pseudo-second order for adsorption of DFC on activated carbon at 293 K (conditions: $m=0,5$ g; $V=50$ mL; $c=0,005$ mol/L; $t=5-90$ min)

solid state of adsorbent, with heterogeneous reactive surface, as well as physicochemical conditions of adsorption. Kinetics experiments were studied under the following conditions: $m = 0,5$ g; $V = 50$ mL; $t = 5-90$ min; $c = 0,005$ mol / L. The experimentally obtained data were analyzed by using two kinetics models: pseudo-first and pseudo-second order. Table 3. gives the parameters of these two kinetics models. The linear forms for the pseudo-first order and pseudo-second order kinetics models are given by equations (6) and (7), respectively.

The parameters for pseudo-first kinetic model are determined from diagram $\ln(q_e - q_t)$ vs t (Figure 5a.). Slope value from linear equation is equal to rate constant, $k_1(\text{min}^{-1})$, while intercept gives the value for $\ln q_e$. Diagram for pseudo-second order is t/q_t vs t , and constants $k_2(\text{g mmol}^{-1} \text{min}^{-1})$ and q_e (mmol/g) are determined from intercept and slope, respectively (Figure 5b.).

The obtained data showed that above 50% adsorption process is completed in the first 30 minutes (Figure 3.), because over the half of initial concentration is removed. After 60 minutes, the DFC concentration changes slightly and an equilibrium value of the adsorption capacity q_e (exp.) = $0,4644$ mmol/g is reached. Experimental result and the calculated adsorption capacity, $q_e = 0,5172$ mmol/g, are in good correlation. From Table 3., it can be seen that the kinetics model of the pseudo-second order, with a correlation coefficient $R^2 = 0,9881$, describes the experimental kinetics data well. Similar results were obtained by De Luna et al. (2017).

Thermodynamic study

The change in Gibbs energy (ΔG), enthalpy (ΔH) and entropy (ΔS) for the adsorption of DFC on commercial activated carbon were calculated by using equations (8) and (9) and van't Hoff diagram ($\ln(q_e/c_e)$ vs. $1/T$), and the obtained data are presented in Table 4.

Table 4. Thermodynamic parameters for adsorption of DFC on activated carbon at different temperatures

T(K)	ΔG (kJ/mol)	ΔH (kJ/mol)	ΔS (J/mol K)
293	-1,57	-10,98	-32,11
298	-0,75		
308	-0,14		

Negative value of the Gibbs energy change (ΔG), in observed temperature interval, indicates that adsorption of DFC on commercial activated carbon is a spontaneous process, while negative change of enthalpy (ΔH) indicates the exothermic nature of the process. The obtained negative change of entropy (ΔS) confirms the reduction of disorder at liquid/solid phase boundary during the adsorption process on carbon particles. It may indicate some structural changes of the adsorbent, and a system possessing a more orderly state. Similar results were obtained by Jodeh et al. (2016).

CONCLUSIONS

This paper studied the ability for potassium diclofenac salt removal from aqueous solution by using commercial activated carbon. Adsorption equilibrium is reached in 60 minutes. Pseudo-second order kinetics model better described the rate of the adsorption than pseudo-first model. The efficiency of DFC removal with activated carbon increases with decreasing temperature. It is assumed that the decrease in adsorption with increasing temperature is a consequence of the weakening of intermolecular forces, due to the increase in adsorbate energy, and the opposite process-desorption is favored. This trend of dependence on the removal efficiency with temperature indicates that the process of DFC adsorption on activated carbon is exothermic. Based on structure of the DFC molecule and the pH_{pzc} value of activated carbon, the experiments were performed at $pH \approx 10,35$, and possible mechanisms of DFC adsorption on activated carbon could be electrostatic interactions, hydrogen bond interactions and π - π interactions. Freundlich adsorption isotherm better describes adsorption of DFC on activated carbon, and the value of the Freundlich parameter $n = 0,3544$ indicates cooperative adsorption. Thermodynamic study showed that adsorption of DFC on activated carbon is spontaneous and exothermic process.

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Kinetika adsorpcije diklofenaka iz vodenog rastvora na komercijalnom aktivnom uglju

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U ovoj studiji ispitana je mogućnost primjene komercijalnog aktivnog uglja kao adsorbensa za uklanjanje diklofenaka (DKF) iz vodenog rastvora. Izvedeni su eksperimenti šaržne sorpcije a ispitivan je uticaj mase adsorbensa, vremena kontakta i temperature na proces adsorpcije. pH vrijednost rastvora DKF pri ispitivanju izoterme adsorpcije i kinetike adsorpcije, kao i pri izvođenju drugih eksperimenata nije posebno podešavana i iznosila je $\text{pH} \approx 10,35$. Nađeni optimalni parametri adsorpcije su masa adsorbensa 0,5 g; vrijeme kontakta 60 minuta i temperatura 20°C.

Rezultati su pokazali da se adsorpcija DKF na aktivnom uglju odvija veoma brzo, u dvije faze, pri čemu se u prvoj fazi uklanja $\approx 90\%$ DKF, nakon čega sledi sporija faza uspostavljanja ravnoteže. Sa porastom temperature opada efikasnost uklanjanja DKF, što ukazuje na egzotermnu prirodu procesa. Adsorpcija DKF na aktivnom uglju je pod značajnim uticajem temperature, vjerovatno zbog slabljenja međumolekulskih sila usled povećanja energije adsorbata.

Eksperimentalni rezultati analizirani su upotrebom kinetičkog modela pseudo-prvog i pseudo-drugog reda i upotrebom dvije adsorpcione izoterme: Langmuir-ove i Freundlich-ove. Kinetičke podatke dobro opisuje kinetički model pseudo-drugog reda a izračunati adsorpcioni kapacitet kod 293 K iznosi $q_e = 0,5172$ mmol/g, i približno je jednak eksperimentalno određenom adsorpcionom kapacitetu koji iznosi $q_e = 0,4644$ mmol/g. Parametri izoterme procijenjeni su linearnom regresijom. Freundlich-ova izoterma pokazuje bolje slaganje sa eksperimentalnim rezultatima adsorpcije. Freundlich-ov parameter n ima vrijednost $n = 0,3544$ i ukazuje na kooperativnu adsorpciju. Negativna vrijednost promjene Gibsove energije (ΔG) ukazuje da je proces adsorpcije spontan, a negativna vrijednost promjene entalpije (ΔH) označava egzotermnu prirodu procesa.

Saglasno literaturi mehanizam koji diktira adsorpciju DFK na aktivnom uglju su π - π interakcije, to je interakcija donor-akceptor π - π elektrona između aromatskih prstenova DFK (akceptor π -elektrona) i aktivnog uglja (donor π -elektrona), a u manjoj mjeri zastupljene su i elektrostatske interakcije i interakcije putem vodonične veze.

Rezultati ovog istraživanja pokazuju da je komercijalni aktivni ugalj efikasan adsorbens za uklanjanje DKF iz vodenog rastvora.