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SORPTION ISOTHERMS AND KINETICS OF CEFOTAXIME SODIUM SALT ON CHITOSAN-POLYBETAINE COMPLEXES

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The sorption kinetics and equilibrium studies of cefotaxime sodium salts (CF) onto chitosan microparticles and microparticles based on the complexes between chitosan (CH) and poly[1-vinyl-3-(2-carboxyethyl imidazolium) betaine] (CH-PCB) have been determined in a batch method. Equilibrium data were analyzed by the Langmuir, Freundlich and Dubinin-Radushkevich models by using linear regression technique. The kinetics was fitted with the pseudo-first order and pseudo-second order models and the best results were achieved with pseudo-second order kinetic model.

INTRODUCTION

Within the last decade the progress in polymer science and engineering has led to the creation of new polymeric materials that have been used in many fields, especially in medical and pharmaceutical field.[1,2] In this context, entrapping of drug molecules in a macromolecular support obtained by a combination between natural and synthetic polymers is a helpful strategy for protecting drugs against chemical and enzymatic degradation, reducing dissolution rate, enhancing aqueous solubility of drug and/or targeting drug release.[3-5]

In the literature, the sorption of certain β-lactam antibiotics (amoxicillin, ampicillin, cephalexin and cefadroxyl) has been studied using several polymeric sorbents to extraction and purification of these drugs but only a limited number of works have been focused on the kinetics, equilibrium and thermodynamic studies for the sorption of drugs onto different sorbents.[6-9]

Cefotaxime sodium salt (CF) is a third-generation cephalosporin antibiotic and is used for infections of the respiratory tract, skin, bones, joints, urogenital system, meningitis and septicemia.

In this work, the sorption equilibrium and kinetic studies of CF onto chitosan (CH) and chitosan-poly[1-vinyl-3-(2-carboxyethyl imidazolium) betaine] (CH-PCB) microparticles were investigated, as a necessary study prior to development of the products useful in the preparation of oral drug delivery system. In Fig. 1 are showed the chemical structures of CF, chitosan and polybetaine.

RESULTS AND DISCUSSION

The synthesis of the microparticles based onto CH and the CH-PCB complexes was described elsewhere.[10] The preparation conditions of the microparticles studied are presented in Table 1.

SORPTION ISOTHERMS

The equilibrium sorption isotherms are the most important in describing the interaction between the solution and the sorbent. Various mathematical models, fitted to the isotherm data have been reported in literature to optimize the effectiveness of sorbents. In the present study, three equilibrium models (Langmuir, Freundlich and Dubinin-Radushkevich) are analyzed and results are discussed below. The values of isotherm constants, sum of error square (SSE) and coefficient of determination (R^2) are presented in Table 2.

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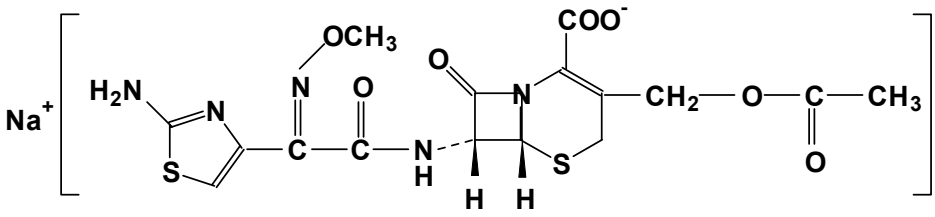

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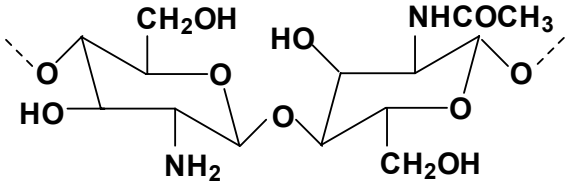

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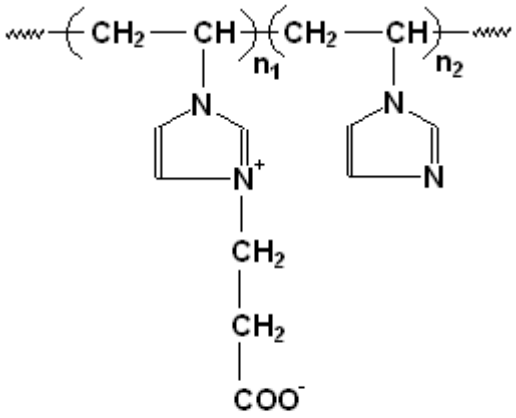


PCB

$n_1 = 94\%$

(c)

Fig. 1 – Chemical structures of: (a) cefotaxime sodium salt;
(b) chitosan and (c) poly[1-vinyl-3-(2-carboxyethyl imidazolium) betaine].

Table 1

Preparation conditions of microparticles based on CH and CH-PCB microparticles

Sample code	Concentration of chitosan (g/L)	Concentration of PCB (g/L)	Molar ratio CH : PCB	Chitosan solvent	T (^{0}C)	Reaction time (h)
C_1	15	-	-	0.1 N AcOH	25	24
B_1	15	1.5	1:1	0.1 N AcOH	25	24
B_3	15	1.5	1:2	0.1 N AcOH	25	24
B_4	15	1.5	1:1	0.1 N AcOH	50	24
B_5	15	1.5	1:1	0.1 N AcOH	25	3

Table 2

Isotherm constants for CF sorption onto CH and CH-PCB microparticles

	Sample code				
	C_1	B_1	B_3	B_4	B_5
Langmuir					
q_m (mg/g)	2095.3	373.13	515.46	438.60	323.62
K_L (x 10^2 L/mg)	0.0077	0.2836	0.6773	0.2946	0.2467
R_L	0.949-0.776	0.335-0.086	0.174-0.038	0.327-0.083	0.367-0.0975
R^2	0.973	0.971	0.984	0.986	0.980
SSE	0.091	0.084	0.093	0.097	0.086
Freundlich					
K_F (L/g)	0.248	19.71	114.27	31.87	14.80
1/n	0.926	0.383	0.198	0.333	0.394
R^2	0.999	0.998	0.998	0.996	0.996
SSE	0.002	0.004	0.003	0.005	0.004
Dubinin-Radushkevich					
q_m (mg/g)	238.77	273.14	444.06	331.14	241.32
E (kJ/mol)	2.78	9.53	12.07	10.48	8.31
R^2	0.989	0.981	0.987	0.983	0.984
SSE	0.016	0.021	0.018	0.020	0.020

1. Langmuir isotherm. The Langmuir model which is an indicative of monolayer sorption onto a surface is described by the following equation:

$$\frac{1}{q_e} = \frac{1}{q_m} + \frac{1}{K_L q_m C_e} \qquad (1)$$

where C_e is the equilibrium CF concentration (mg/L), q_e is the amount of CF sorbed at equilibrium (mg/g), q_m is the maximum sorption capacity (mg/g), K_L is the Langmuir constant (L/g) representing the affinity between the sorbent and sorbate. The values of q_m and K_L can be calculated from the slope and intercept of the linear plot of $1/q_e$ versus $1/C_e$.

The feasibility of the process is expressed by equilibrium parameter (R_L) defined as:

$$R_L = 1/(1 + K_L C_0)$$

where C_0 is the initial concentration of CF solution (mg/L). The values of R_L denote the unfavorable ($R_L > 1$), linear ($R_L = 1$), favorable ($R_L < 1$) or irreversible ($R_L = 0$) process.[11] Values of R_L calculated at 298K were between 0 and 1 (Table 2), indicating that the sorption of CF on the CH and CH-PCB complexes was favorable. However, as the initial concentration increased from 700 to 3750 mg/L, the R_L values decreased from all the sorbents studied. This indicated that sorption was more favorable at higher concentration.

2. Freundlich isotherm. The Freundlich equation is an empirical equation used to describe the sorption on an energetically heterogeneous surface.[12] The linear form of the Freundlich expression can be represented as follows:

$$\ln q_e = \ln K_F + \frac{1}{n} \cdot \ln C_e \qquad (2)$$

where, K_F represents the quantity of CF sorbed per unit at equilibrium concentration (L/g), while $1/n$ is indicative of the energy or intensity of the reaction and suggests the favorability and capacity of the sorbent-sorbate system. A plot lnq_e versus lnC_e (Fig. 2) yields a straight line with slope $1/n$ and intercepts K_F.

The values of Freundlich isotherm constants are presented in Table 2. The Freundlich values of $1/n$ ($0.1 < 1/n < 1$) indicate that CF is sorbed favorably by all the sorbents studied. Also, is observed that the sorption capacity (K_F) is highest for B_3 and low for C_1.

3. Dubinin-Radushkevich isotherm. Dubinin-Radushkevich isotherm is applied to find out the sorption mechanism based on the adsorption potential theory assuming heterogeneous surface.[13] Also the model was chosen to estimate the apparent free energy of the sorption. The linear form of Dubinin-Radushkevich isotherm was given as:

$$\ln q_e = \ln q_m - K_{DR}\varepsilon^2 \qquad (3)$$

where q_m is the Dubinin-Radushkevich constant representing the theoretical monolayer saturation capacity (mg/g), K_{DR} is the constant of the sorption energy (mol^2/kJ^2) which is related to mean sorption energy (E) through $E = 1/\sqrt{2 \cdot K_{DR}}$ and ε is the Polanyi potential which is defined by:

$\varepsilon = RT\ln[1+(1/C_e)]$ where R is the gas constant (8.314 J/mol K) and T is the absolute temperature (K).

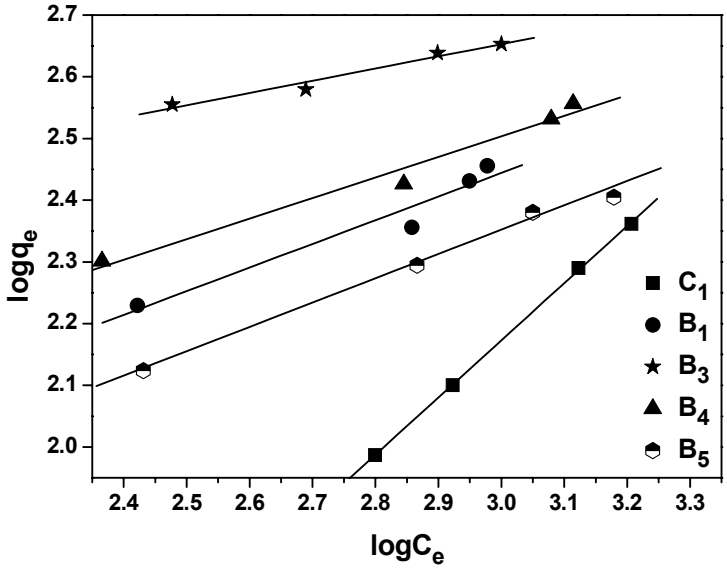


Fig. 2 – Freundlich equilibrium isotherms of CF sorbed onto CH and CH-PCB microparticles.

The values of the isotherm constants were obtained from the straight-line plot lnq_e versus ε^2. The values of Dubinin-Radushkevich constants and the mean free energy are given in Table 2. The constant q_m agreed well with experimental data and the maximum value of 444.06 mg/g was observed for B_3.

It is known that the magnitude of E is useful for estimating the type of sorption[14] and if this value is between 8 and 16 kJ/mol the sorption type can be explained by ion exchange reaction (case of B microparticles). The value of E found for C_1 microparticles is within the energy range of physical sorption (E < 8 kJ/mol). This indicates that sorption of CF on C_1 micropaticles is physical in nature.

Based on coefficient of determination (R^2) shown in Table 2 the results indicate that the Freundlich and Dubinin-Radushkevich models represent a better fit of experimental data than Langmuir model.

SORPTION KINETIC STUDY

Kinetic study is important in determining the rate of sorbate uptake at the solid-phase interface. Two kinetic models: pseudo-first-order and pseudo-second-order models were applied to evaluate sorption dynamics and to describe the sorption rate of CF onto CH and CH-PCB complexes.

1. Pseudo-first order kinetic model. The pseudo-first order equation developed by the Lagergren[15] was used to describe the sorption of a sorbate from the liquid phase on a solid phase. The linear form of pseudo-first-order equation is given by:

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

where k_1 is the rate constant of the pseudo-first order sorption process (min^{-1}). The plot $log(q_e - q_t)$ versus t gave the slope of k_1 and the intercept q_e. The values of k_1 and coefficient of determination R^2 are given in Table 3.

It is seen from Table 3 that the coefficient of determination value obtained was relatively small and the theoretical $q_{e(calc)}$ values calculated from the pseudo-first-order model did not give reasonable values with regard to the experimental uptake ones, $q_{e(exp)}$. This shows that the sorption of CF onto CH and CH-PCB microparticles is not a first-order reaction.

2. Pseudo-second order kinetic model. The pseudo-second order model[16] can be represented in the following form:

$$\frac{t}{q_t} = \frac{1}{h} + \frac{1}{q_e}t \qquad (5)$$

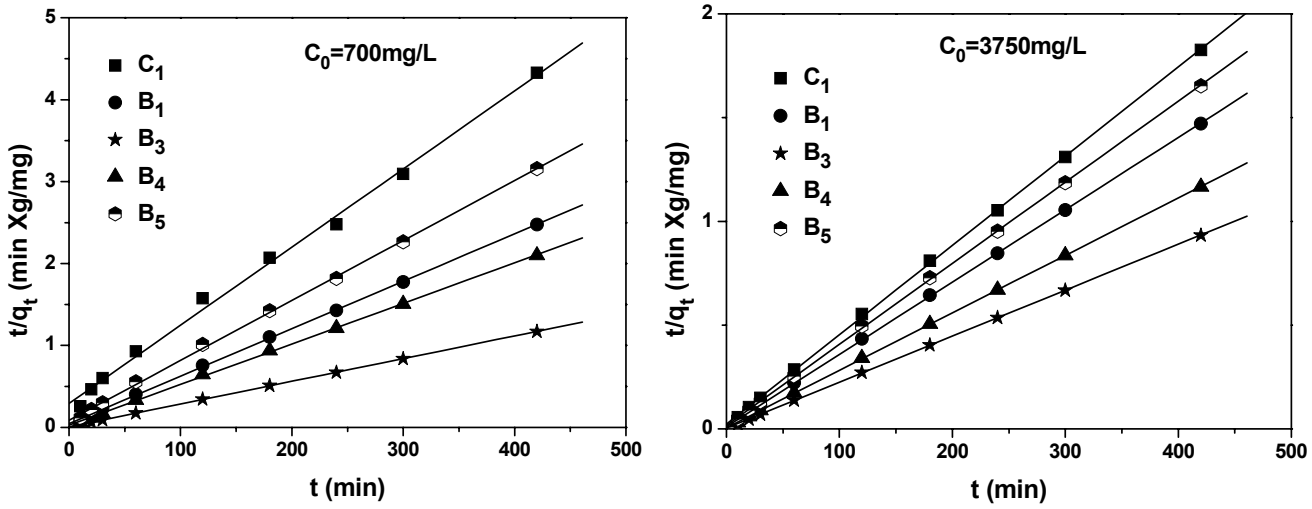
where $h = k_2 \cdot q_e^2$ is the initial sorption rate (mg/g·min) and k_2 is the rate constant of pseudo-

second order sorption (g /mg·min). The linear plot t/q_t versus t (Fig. 3) can be used to determine q_e and h from slope and intercept of the plot.

Table 3

Kinetic parameters for the sorption of CF onto CH and CH-PCB microparticles

Sample code	C_{CF} (mg/L)	$q_{e,exp}$ (mg/g)	Pseudo-first-order model				Pseudo-second-order model				
			q_e (mg/g)	$k_1 \cdot 10^2$ (min^{-1})	R^2	SSE	q_e (mg/g)	$k_2 \cdot 10^4$ (g/mg·min)	h (mg/g·min)	R^2	SSE
C_1	700	97	116.90	2.26	0.885	0.027	104.82	3.11	3.41	0.997	0.020
	1500	126	52.62	1.32	0.989	0.018	129.20	6.77	11.29	0.999	0.010
	3000	195	55.21	1.31	0.988	0.017	198.02	7.14	28.00	0.999	0.010
	3750	230	52.04	1.28	0.989	0.017	232.56	7.82	42.32	0.999	0.010
B_1	700	170	58.67	1.46	0.992	0.012	172.71	7.14	21.30	0.999	0.010
	1500	227	47.97	1.25	0.988	0.016	229.36	8.41	44.25	0.999	0.020
	3000	270	44.86	1.23	0.991	0.007	271.74	9.04	66.76	0.999	0.020
	3750	286	35.92	1.16	0.990	0.009	287.56	11.24	92.94	0.999	0.010
B_3	700	359	42.31	1.22	0.992	0.008	361.01	9.94	129.55	0.999	0.010
	1500	380	38.34	1.18	0.990	0.010	381.68	10.63	154.86	0.999	0.020
	3000	435	33.54	1.15	0.989	0.017	436.68	12.22	233.02	0.999	0.010
	3750	450	30.13	1.10	0.990	0.010	451.47	13.01	265.25	0.999	0.010
B_4	700	200	41.82	1.18	0.981	0.015	202.02	8.79	35.92	0.999	0.020
	1500	267	41.06	1.17	0.985	0.016	268.82	9.81	70.92	0.999	0.020
	3000	340	35.88	1.16	0.990	0.011	341.30	11.00	128.21	0.999	0.010
	3750	360	30.56	1.13	0.991	0.011	361.01	13.50	175.94	0.999	0.010
B_5	700	133	63.20	1.56	0.983	0.018	136.61	6.24	11.65	0.999	0.010
	1500	197	53.98	1.30	0.990	0.011	200	7.25	29	0.999	0.020
	3000	240	49.51	1.26	0.991	0.010	242.13	8.15	47.78	0.999	0.020
	3750	254	43.89	1.22	0.988	0.017	255.75	9.28	60.68	0.999	0.010



(a) (b)

Fig. 3 – The fitting of pseudo-second-order model for CF onto CH and CH-PCB microparticles (initial CF concentration was 700mg/L (a) and 3750mg/L (b)).

The data presented in Table 3 show a good agreement between the experimental and calculated q_e values. The coefficient of determination for the second-order-kinetic model approaches 1, indicating the applicability of second-order kinetic model to describe the sorption of CF onto all five samples. Moreover, it can be observed that for the same kind of sorbent the values of h increase with increasing of CF concentration.

EXPERIMENTAL

1. Materials

Chitosan with high molecular weight (600,000 g/mol) and degree of acetylation 13.5%, acetic acid, Na_2CO_3 and cefotaxime sodium salt with molar mass 477.40 g/mol were purchased from Fluka Chemical Co. Poly(carboxybetaine) based on poly(N-vinylimidazole) was prepared as described elsewhere.[17]

2. Methods

Preparation of microparticles based on CH-PCB complexes and chitosan. The synthesis of the microparticles based on CH-PCB complexes and chitosan was previously shown.[10]

Batch sorption studies. The sorption of CF onto CH and CH-PCB complexes was investigated in a batch system at 298K with various concentrations ranging from 700 to 3750 mg/L. Batch sorption experiments were carried out by adding a known amount of CH and CH-PCB complexes (0.5g) to a set of 100 mL conical flasks filled with 20 mL CF solution. The conical flasks were placed in a thermostated shaker bath (Memmert M00/M01, Germany) and shaken at 160 stroke per minute (horizontal back/forth movement) and 298K for different contact time ranging between 10 min and 7 h until equilibrium was reached. The flasks were than removed from the shaker and the samples were centrifuged at 1000 rpm for 10 min. The concentration of CF was measured using a UV-VIS Spectrophotometer (UV-VIS SPEKOL 1300, Analytik Jena) at a wavelength of 236 nm. The amounts of CF at equilibrium, q_e (mg/g) and at any time, q_t (mg/g) were calculated from the following equations[18]:

$$q_e = (C_0 - C_e) \cdot V / W$$

and (6)

$$q_t = (C_0 - C_t) \cdot V / W$$

where, C_t is the concentration of CF solution at any time (mg/L), V is the volume of CF solution (L) and W is the amount of microparticles (g). All the sorption data were achieved in duplicate and the average values were plotted.

CONCLUSIONS

The following conclusions can be drawn from this study:

Drug sorption capacity increased in the following order: $C_1 < B_5 < B_1 < B_4 < B_3$. Also, the batch studies indicated that the CF sorption onto CH and CH-PCB microparticles increased with increase of CF solution concentration.

The equilibrium sorption data were tested with three isotherm models and were best fitted with the Freundlich isotherm and Dubinin-Radushkevich isotherms.

The sorption energy obtained by Dubinin-Radushkevich isotherm suggested the physical process in cases of C_1 microparticles and ion-exchange process for CH-PCB microparticles.

The sorption kinetic was found to follow pseudo-second order rather than pseudo-first order model.

REFERENCES

1. A.T. Florance and N. Hussain, *Adv. Drug Deliv. Rev.*, **2001**, *50*, S69-S89.
2. H. Ringsdorf, *J. Polym. Sci. Polym. Symp.*, **1975**, *51*, 135-153.
3. T. C. Chang, J. W. Wang and M. H. Hon, *Macromol. Biosci.*, **2004**, *4*, 416-420.
4. Y. Hu, X. Jiang, Y. Ding, H. Ge, Y. Yuan and C Yang, *Biomaterials*, **2002**, *23*, 3193-3201.
5. S. Vasiliu, I. Bunia, S Racovita and V. Neagu, *Carbohydr. Polym*., **2011**, *85*, 376-387.
6. M. J. Abdekhodaie and X. Y. Wu, *Biomaterials*, **2006**, *27*, 3652-3662.
7. F.R.C. Silva, J.A.M. Pereria, M.O.D. Araújo and C.C. Santana, *Hungarian J. Ind. Chem*., **1999**, *27*, 183-187.
8. W.S. Adriano, V. Veredas, C. C. Santana and L. R. B. Goncalvers, *Bioochem. Eng. J*., **2005**, *27*, 132-137.
9. V. Neagu, S. Vasiliu and S Racovita, *Chem. Eng. J*., **2010**, *162*, 965-973.
10. S Racovita, S. Vasiliu and C. D. Vlad, *Rev. Roum. Chim.*, **2010**, *55*, 661-667.
11. G. McKay, H. S. Blair and J. R. Gardner, *J. Appl. Polym. Sci*., **1982**, *27*, 3043-3057.
12. H. M. F. Freundlich, *J. Phys. Chem.*, **1906**, *57*, 385-470.
13. A. Dabrowski, *Adv. Colloid Interface Sci*., **2001**, *93*, 135-224.
14. M. Chabani, A. Amrane and A. Bensmaili, *Chem. Eng. J*., **2006**, *125*, 111-117.
15. S. Lagergren, *Kungliga Svenska Vetenskapsakademiens Handlingar Band*, **1898**, *24*, 1-39.
16. Y. S. Ho and G. McKay, *Can. J. Chem. Eng.*, **1998**, *76*, 822-827.
17. C. Luca, V. Neagu and S. Vasiliu, "Focus in Ionic Polymers", Research Singpost, India, 2005, p. 117.
18. K. Kosutic, L. Furac, L. Sipos and B. Kunst, *Sep. Purif. Technol.,* **2005**, *42*, 137-144.