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Adsorption of ibuprofen sodium salt onto Amberlite resin IRN-78: Kinetics, isotherm and thermodynamic investigations

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Abstract–Amberlite resin IRN-78 was used for the adsorption of Ibuprofen sodium salt (IBP) from liquid phase. The effects of solvent, initial concentration, solution pH, temperature and contact time were investigated. Adsorption studies were carried out in water and in ethanol. It was found that the adsorption capacity was dependent on pH. The optimum pH range was between 6 and 10. The maximum adsorption capacities on the IRN-78 were 1.266 and 0.611 mmol/g for IBP in water and in ethanol, respectively. The equilibrium data of the adsorption of IBP onto IRN-78 fit well to the Langmuir model. The separation factor (R_L) values were in the range of 0-1, indicating that the adsorption was favorable. The values of thermodynamic parameters including ΔG^0, ΔH^0 and ΔS^0 demonstrated that the adsorption of IBP onto IRN-78 was spontaneous and endothermic within the temperature range of 288-308 K. The adsorption process was controlled by physical mechanism rather than chemical mechanism.

Keywords: Adsorption Isotherm, Pharmaceuticals Pollution, Ibuprofen Sodium Salt, Isotherm Modeling, IRN-78

INTRODUCTION

The usefulness of pharmaceuticals remains essential in our daily life. However, these products which are designed to be substances biologically active can also be a source of contamination, via their interactions with non-target organisms, not only for the environment but also for humans [1,2]. They are generally lipophilic and resistant to biodegradation, thus having the potential for accumulation and persistence in the environment [1].

Particularly, non-steroidal anti-inflammatory drugs such as Ibuprofen, diclofenac, and aspirin exert inhibition of certain functions in vertebrates and invertebrates [3]. These drugs have been detected in drinking water;,sewage effluent and groundwater [4,5]. In fact, concentrations measured in the environment are able to cause chronic toxicity [6].

Ibuprofen (2-(4-iso-butylphenyl)propionic acid) is one of the most consumed drugs worldwide [7]. It is a non-steroidal anti-inflammatory drug of the propionic acid, and it is an over-the-counter medicine indicated for the treatment of rheumatoid arthritis, osteoarthritis, but it is also used for the alleviation of mild to moderate pain, inflammation, and fever caused by diverse diseases [8]. Due to the widespread occurrence of ibuprofen in aqueous environments, its potential for ecological impact has received great attention [6,9]. Several works have been reported on the removal of organic pollutants such physical [10-13], biological [14,15] and electrochemical [12,16-18]. Among the advanced treatment processes that have been applied to pharmaceutical elimination we quote nanofiltration [13,19,20], ozonation [21], biodegradation and adsorption process [4,10,22-25].

The adsorption removal of pharmaceuticals has been investigated by activated carbon [26], soils [27], carbon nanotubes [28], etc. Nevertheless, the natural or engineering sorbents have disadvantages in terms of regeneration problems, effectiveness and applicability [29]. One of the possibilities for removing these molecules which are highly toxic, when accumulated in the environment, is the sorption onto an exchange resin. Polymeric resins have been widely used in wastewater treatment by dint of their strong adaptability to poor water quality, their easy regeneration and selectivity or affinity for ionic species exchange [30-32]. Several studies have highlighted the performance of commercial anion exchange resin to eliminate pharmaceuticals from water, such as Dowex 22 resins for ketoprofen, naproxen, paracetamol, diclophenac and ibuprofen removal [33]; Oasis Max resin for caffeine and metformin [34]; resin H103 for berberine [35]. Amberlite IRN-78 is a strong base anionic resin with ammonia functional groups. Its total exchange capacity was ≥1.7 meq/L as specified by the manufacturer. Traditionally, IRN-78 has been explored specially in the removal of heavy metals, pollutant ions and dyes from different water matrices and effluents (e.g., nitrates [36], phosphate [37], chromate IV, methyl orange forms [38], palladium [39], and Ruthenium [40]).

To the best of our knowledge, IRN-78 has not yet been studied for the removal of pharmaceutical pollutants. By taking advantage of what is reported in the literature, we attempted to generate new experiment data on IBP removal from water and ethanol using IRN-78. A modelization of isotherms, kinetic and thermodynamic investigation, was also discussed.

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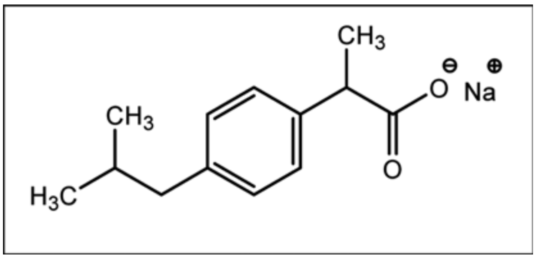

Fig. 1. Molecular structure of ibuprofen sodium salt.

Table 1. Calculation of molecule sizes

Molecule	IBP
Size (Å)	10.8×4.5
Occupied volume ($Å^3$)	211.53
Surface ($Å^2$)	264.97

EXPRIMENTAL

1. Chemicals and Equipment

Ibuprofen sodium salt (Fig. 1) was purchased from Sigma-Aldrich (Purity=98%) and used without any further treatment.

The solvents used are ethanol and ultra-pure water (resistivity of 18.2 MΩ). The sizes of the IBP were calculated and their arrangement in space was estimated using the software, Material Studio (Table 1).

A strong basic gel-type anion exchange resin, Amberlite IRN-78, supplied by Rohm and Haas, was used as the adsorbent. It is characterized by a particle size that varies between 0.58 and 0.68 nm, supplied in the hydroxide form.

Analyses were performed on a spectrophotometer "-670 UV-Vis Spectrophotometer - Jasco Inc. dual beam equipped with a single monochromator. The highest wavelengths were obtained directly by automatic scanning between 190 and 270 nm. Quartz cells with 1 cm optical path are used. The value of λ_{max} was found to be 222 nm for IBP.

Stock solution of ibuprofen sodium salt was prepared with concentrations of 9.73 and 4.8 mmol/L in water and in ethanol, respectively. Appropriate dilutions were carried out for concentrated solutions to maintain linearity.

2. Batch Adsorption Experiments

Adsorption experiments were performed by batch mode in 100 mL stoppered conical flasks. 0.3 g of Amberlite resin IRN-78 was added to 40 mL of the solution containing the desired quantity of IBP, ranging from 0.12 to 9.73 mmol/L for IBP in water, and from 0.10 to 4.8 mmol/L for IBP in ethanol (Table 2). Then, the solutions were stirred (100 rpm) for a certain time in an isothermal water-bath shaker at different controlled temperature (15-35 °C).

After the adsorption step, the solid phase was separated by centrifugation (1,000 tr/min; 15 min) and filtration through a 0.45 µm membrane filter. The final concentration of IBP in the solution was determined using a UV-Vis spectrometer and the pH of each sample was measured (Table 3). The adsorbed amount of IBP at equilibrium, Q_{ads} (mmol/g) was calculated by the following expression:

$$Q_{ads} = V\frac{(C_0 - C_e)}{m} \tag{1}$$

Table 3. Initial and equilibrium pHs

	Sample	Initial pH	Equilibrium pH
IBP/H_2O	1	8.26	10.21
	2	8.22	10.44
	3	8.70	10.54
	4	8.75	10.64
	5	8.90	10.82
	6	9.20	11.05
	7	9.25	11.18
	8	9.32	11.26
	9	9.41	11.33
	10	9.40	11.39
	11	9.45	11.44
	12	9.45	11.48
	13	9.49	11.53
	14	9.50	11.56
IBP/EtOH	1	9.41	12.52
	2	9.55	12.84
	3	9.55	12.97
	4	9.57	13.03
	5	9.87	13.23
	6	9.89	13.35
	7	10.00	13.39
	8	10.02	13.42
	9	10.05	13.44

Table 2. Table of initial concentrations performed by batch

IBP/H_2O				IBP/EtOH			
Sample	C_0 (mmol/L)	Sample	C_0 (mmol/L)	Sample	C_0 (mmol/L)	Sample	C_0 (mmol/L)
1	0.12	8	3.90	1	0.10	8	3.90
2	0.24	9	4.87	2	0.26	9	4.79
3	0.36	10	5.85	3	0.36		
4	0.49	11	6.76	4	0.49		
5	0.97	12	7.87	5	0.91		
6	1.93	13	8.81	6	1.92		
7	2.91	14	9.73	7	2.95		

where C_0 and C_e (mmol/L) are the initial and equilibrium concentration of IBP solution, respectively. V (L) is the volume of the solution, and m (g) is the mass of the used adsorbent. All the experiments were carried out in triplicate.

For the kinetic studies, 0.3 g of IRN-78 was added to IBP aqueous solution with different concentrations (0.25-9.73 mmol/L) and different concentration of IBP in ethanol solution (0.25-4.8 mmol/L). The samples were taken out at preset time intervals after being shaken (1,000 rpm) at 25 °C to determine the remaining concentrations of the adsorbate. The pH of the solution was maintained.

To determine the contact time necessary for establishment of adsorption equilibrium, the adsorbed quantity of ibuprofen on Amberlite resin IRN-78 was measured as a function of the contact time corresponding to adsorption equilibrium. Adsorption studies were carried out by using a batch adsorption approach as mentioned above. Initial concentrations of IBP were 9.73 mmol/L in water and 4.8 mmol/L in ethanol. 0.3 g of Amberlite resin IRN-78 was used and experiments were conducted at room temperature (25±2 °C). The amount of adsorbed ibuprofen was determined at different time intervals (0.25-30 h).

To explore the effect of solution pH on adsorption, batch adsorption procedure as mentioned overhead was performed. Using a Jenway Model 3510 pH meter different initial pHs were adjusted from 2 to 12 by addition of 0.1 M HCl or NaOH. After stirring for 24 h the concentration of IBP at equilibrium was determined and the uptake was calculated.

The regression coefficient (R^2), chi-square test (χ^2), and the residual root-mean-square error (RMSE) were used to evaluate the agreement between experimental data and predictions using models. The residual root-mean-square error (RMSE) was determined as follows:

$$\mathrm{RMSE}=\sqrt{\frac{\sum_{i=1}^{n}(Q_{exp}-Q_{cal})^2}{n}}$$

where Q_{exp} is the experimental results, Q_{cal} is the calculated values using the model and n is the number of experimental data.

RESULTS AND DISCUSSION

1. Effect of Initial pH

The adsorption of IBP on Amberlite resin IRN-78 at different equilibrium solution pH was investigated and the adsorption results were plotted in Fig. 2. As the pH decreased from 6 to 2, the IBP adsorption amounts decreased because of the inefficient ionization of carboxyl group of IBP at low pH condition. For pH less than the pKa of the ibuprofen (4.91), the molecule will be protonated (neutral charge). This result showed that IBP adsorption was probably controlled by ion exchange. However, the IBP adsorption was found to be favorable for a pH between 6 and 10 corresponding to the deprotonated form of hydroxylic group of IBP. In fact, H-bonding of the group decreased in presence of deprotonated form which restrained the interactions with the IRN-78 matrix. Similar results were found in the IBP removal on magnetic ion exchange resin (MIER) study [29]. At pH=12, a decrease of adsorption amount was observed. This can be explained by the competing effect of the increasing hydroxyl ion.

The same findings were observed for the adsorption of IBP in ethanol.

The same experiments were conducted without any pH adjustment. Initial and final pHs were measured and obtained results were mentioned in Table 3. The pH values found were in the range corresponding to the maximum of adsorption. Therefore, for further work, the adsorption experiments were conducted at medium pH.

2. Effect of Contact Time

The effect of the contact time on the adsorption of ibuprofen on Amberlite resin IRN-78 is shown in Fig. 3. The adsorbed amount of adsorbate increased with the increase of contact time. The adsorption of ibuprofen was rapid in the initial stage of contact time and gradually decreased with lapse of time until equilibrium. The fast adsorption at initial stage may be due to the availability of uncovered surface area and the remaining active sites on the Amberlite resin IRN-78. Optimum contact time was found to be 18 h. The equilibrium time considered for the further work was taken as 18 h to ensure steady state.

3. Effect of Adsorbent Dose

Fig. 4 shows the influence of IRN-78 dosage on ibuprofen adsorption at initial concentrations of 9.73 mmol/L in water and 4.8 mmol/L in ethanol. Clearly, the amount of adsorbed ibuprofen onto IRN-78 increased along with increasing the adsorbent dose

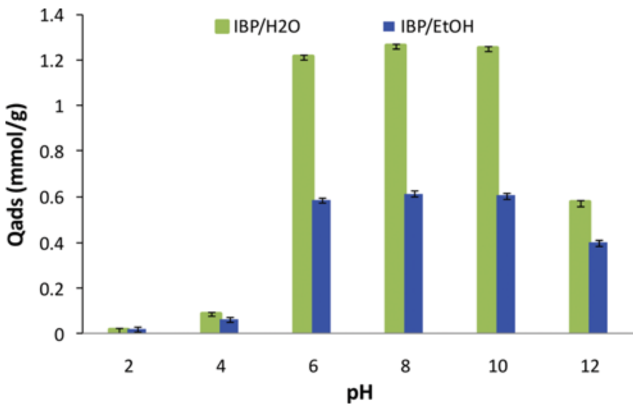

Fig. 2. Effect of initial pH for IBP adsorption.

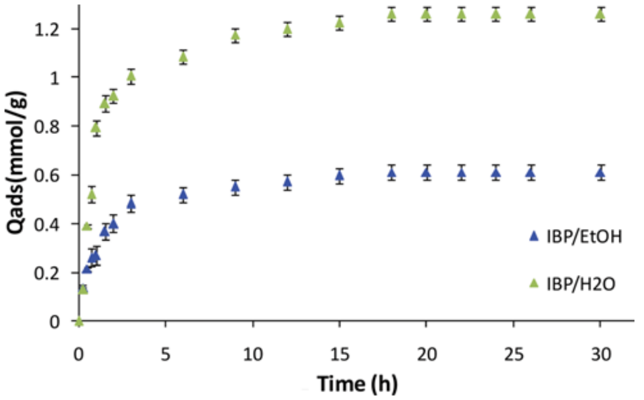

Fig. 3. Effect of contact time: IBP in water (9.73 mmol/L) and IBP in ethanol (4.8 mmol/L).

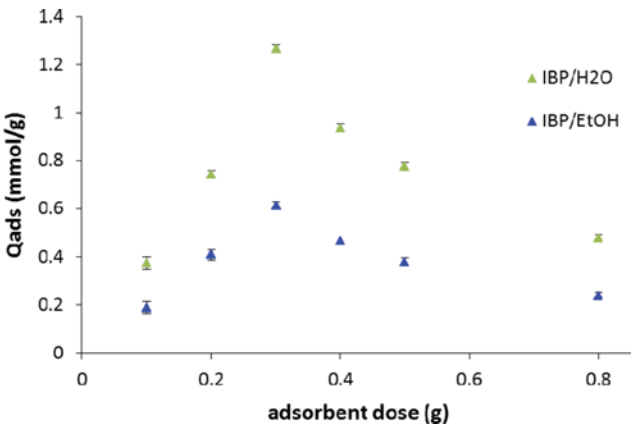

Fig. 4. Effect adsorbent dosage (contact time: 18 h).

from 0.1 to 0.3 g, and then decreased. 0.3 g of IRN-78 was considered as the optimum dose limit.

4. Adsorption Kinetics

The kinetics of ibuprofen adsorption onto Amberlite resin IRN-78 was studied with different initial adsorbate concentrations, and the results plotted in Fig. 5.

All the adsorption amounts typically increased with time and initial concentration. This can be explained by the broader channel for diffusion and more available active sites for interaction, which could improve both the kinetics and adsorption amount. The pseudo-first-order (Eq. (2)) and pseudo-second order (Eq. (3)) were applied to investigate the experimental data and the adsorption processes [41]. The goodness of fit of the equations to the data was evaluated based on the constant (R^2).

$$\ln(Q_{ads}-Q_t)=\ln Q_{ads}-k_1 t \qquad (2)$$

$$\frac{t}{Q_t}=\frac{1}{k_2 Q_{ads}^2}+\frac{t}{Q_{ads}} \qquad (3)$$

where Q_{ads} and Q_t (mg/g) are the adsorption capacity at equilibrium and at time "t", respectively, k_1 (1/min) and k_2 (g/(mmol h)) are the rate constant of pseudo-first order adsorption and pseudo-second order, respectively.

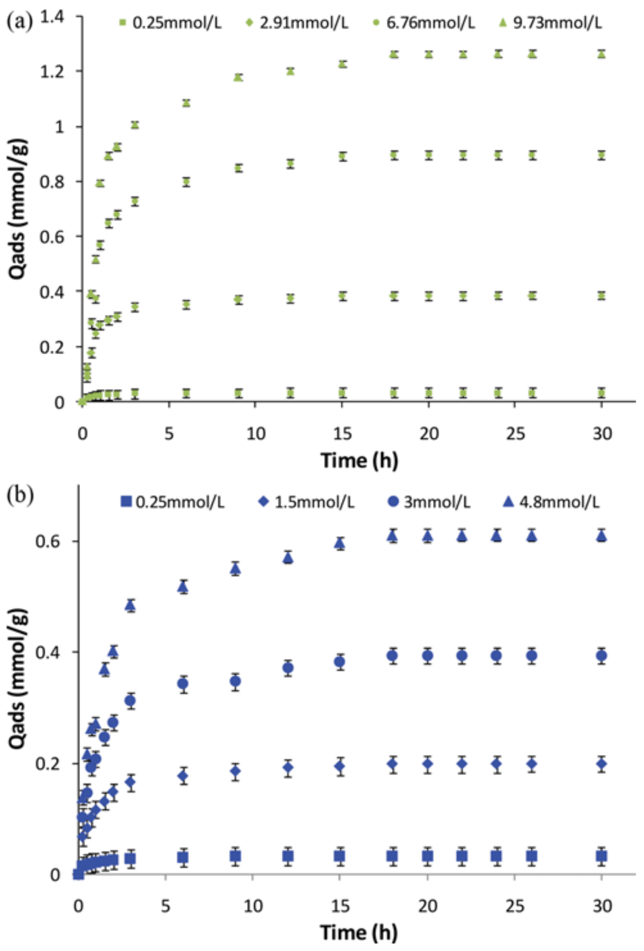

Fig. 5. Effect of initial concentration: (a) Ibuprofen in water and (b) Ibuprofen in ethanol.

Table 4 lists the values of kinetic parameters for pseudo-first order kinetic model and pseudo-second order kinetic model in IBP

Table 4. Kinetic parameters for adsorption

IBP-water							
		Pseudo-first order			Pseudo-second order		
Concentration (mmol/L)	$Q_{ads\cdot\, exp}$ (mmol/g)	$Q_{ads\cdot\, cal}$ (mmol/g)	k_1 (h^{-1})	R^2	$Q_{ads\cdot\, cal}$ (mmol/g)	k_2 (g $mmol^{-1}$ h^{-1})	R^2
9.73	1.265	1.165	0.376	0.943	1.326	0.664	0.998
6.76	0.897	0.895	0.440	0.952	0.936	1.076	0.999
2.91	0.386	0.359	0.506	0.940	0.395	4.506	0.999
0.25	0.033	0.027	0.519	0.956	0.033	67.318	0.999
IBP-ethanol							
		Pseudo-first order			Pseudo-second order		
Concentration (mmol/L)	$Q_{ads\cdot\, exp}$ (mmol/g)	$Q_{ads\cdot\, cal}$ (mmol/g)	k_1 (h^{-1})	R^2	$Q_{ads\cdot\, cal}$ (mmol/g)	k_2 (g $mmol^{-1}$ h^{-1})	R^2
4.80	0.611	0.571	0.332	0.964	0.638	1.389	0.999
3.00	0.394	0.353	0.339	0.948	0.409	2.477	0.999
1.50	0.198	0.141	0.296	0.928	0.204	6.496	0.999
0.25	0.033	0.016	0.265	0.983	0.033	55.593	0.999

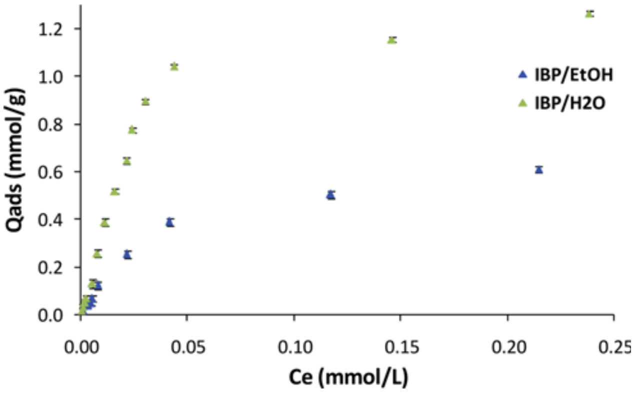

Fig. 6. Adsorption isotherm of IBP onto IRN-78.

adsorptions. The pseudo-second order described well the adsorption kinetics with regression coefficient (R^2) higher than 0.998. So, this suggests that IBP uptake is followed by chemisorption [42,43].

5. Solvent Effect

The adsorption of IBP on the IRN-78 was performed by batch experiments in water and in ethanol. These solvents were selected because of their capacity of dissolvation of IBP molecule which has a low solubility [44]. Comparing both adsorption isotherms (Fig. 6), we found that the affinity of the IRN-78 for IBP was low. Yet, the amount removed by the IRN-78 of IBP in ultra-pure water solution (1.266 mmol/g) was higher than that removed in ethanol solution (0.611 mmol/g). Based on the difference in solubility, the IBP molecule is more soluble in ethanol than in water and finally does not interact with the material, which may explain the larger amount of adsorbed IBP in water solution compared to that observed in the presence of ethanol [45].

Moreover, at pH values higher than pKa (4.91) [46], the IBP molecule may proceed to the deprotonated form. Therefore, adsorption of IBP becomes more favorable because of the electrostatic interaction between the cationic surface of the resin (trimethylammonium functional group) and the negatively charged anionic molecule. This result is confirmed by Mestre et al. [47] in the sorption of IBP onto two activated carbons where the adsorption becomes less favorable for pH>pKa of IBP, due to electrostatic repulsions between the deprotonated IBP and the anionic surface of activated carbon.

6. Modeling of Isotherms

Modeling the non-linear isotherm was conducted to elucidate the selectivity and the adsorption capacity of IRN-78. Selectivity is defined as the equilibrium of the solid phase concentration ratio (Q_{ads}) to the concentration in the pharmaceutical liquid phase (C_e) as a higher selectivity of pharmaceutical shows that the amount present in solid phase (adsorbed) is greater than that in solution. The experimental data were applied to the Langmuir and Freundlich models (Table 5).

In recent decades, linear regression was one of the most viable tools to define the best fitting [50] to quantify the distribution of the adsorbates, analyze mathematically the adsorption systems [51] and check the consistency of theoretical assumptions of a model isothermal [52].

In this study, a nonlinear analysis chi-square test (χ^2) is also

Table 5. The models of Langmuir and Freundlich and linearized forms

Isotherm	Non-linear form	Linear form	Plot
Langmuir [48]	$Q_{ads}=\frac{C_e \cdot Q_{max} \cdot K_L}{1+(K_L \cdot C_e)}$	$\frac{1}{Q_{ads}}=\frac{1}{K_L \cdot Q_{max}}\frac{1}{C_e}+\frac{1}{Q_{max}}$	$\frac{1}{Q_{ads}}$ *vs* $\frac{1}{C_e}$
Freundlich [49]	$Q_{ads}=K_F C_e^{1/n}$	$\ln(Q_{ads})=\ln(K_F)+\frac{1}{n}\ln C_e$	$\ln(Q_{ads})$ *vs* $\ln(C_e)$

Langmuir parameters: Q_{ads} - The amount adsorbed at equilibrium (mmol/g), K_L - Langmuir constant (L/mmol), Q_{max} - adsorption capacity to the monolayer (mmol/g), C_e - The concentration of the solution at equilibrium (mmol/L)
Freundlich parameters: Q_{ads} - The amount adsorbed at equilibrium (mmol/g), K_F - Freundlich constant ($\text{mmol}^{(1-1/n)}\text{L}^{(1/n)}$/g), C_e - The concentration of the solution at equilibrium (mmol/L), 1/n: Freundlich coefficient

Table 6. Langmuir and Freundlich parameters for the adsorption of IBP onto amberlite IRN-78

System		Ibuprofen sodium salt/Water	Ibuprofen sodium salt/Ethanol
Freundlich model	K_F ($\text{mmol}^{(1-1/n)}\text{L}^{(1/n)}$/g)	9.061	2.829
	1/n	0.783	0.732
	R^2	0.917	0.945
	χ^2	2.003	0.223
	RMSE	0.526	0.116
Langmuir model	K_L (L/mmol)	25.700	25.123
	Q_{max} (mmol/g)	1.297	0.545
	R^2	0.993	0.988
	R_L	0.00397-0.24216	0.00822-0.26948
	χ^2	0.767	0.150
	RMSE	0.175	0.074

presented (Table 6). Several authors [52-55] applied this analysis. The benefits of using this analysis were discussed by Ho [55] to verify the agreement between the experimental data and theoretical modeling of isotherms. χ^2 was determined according to the following equation:

$$\chi^2 = \sum \frac{(Q_{exp} - Q_{mod})^2}{Q_{mod}} \qquad (4)$$

where Q_{exp} is the experimental amount adsorbed at equilibrium and Q_{mod} is the amount adsorbed calculated from the model.

The essential characteristics of Langmuir adsorption isotherm can be expressed in terms of a dimensionless equilibrium constant R_L, defined by Webber and Chakkravorti [56] expressed as follows:

$$R_L = \frac{1}{1+(K_L \times C_0)} \qquad (5)$$

The R_L contributes to predict whether the adsorption process is favorable ($0<R_L<1$), unfavorable ($R_L>1$) or linear ($R_L=1$) [57]. The values of R_L, were all between 0 and 1 (Table 6), indicating favorable adsorption process of IBP onto Amberlite IRN-78. The R_L values for IBP in water are lower than those in ethanol, which indicates that adsorption of IBP on Amberlite IRN-78 is more favorable in aqueous media.

Recently, only few studies have investigated the IBP removal onto anion exchange resin such as Dowex [33] and magnetic ion-exchange resin (MIER), both synthetic and commercial one [29]. Results about the removal percentage are summarized in Table 8 and compared with data from literature. It is noteworthy that using IRN-78 presents the higher adsorption rate of IBP whether in ethanol or aqueous medium compared to other strongly basic anion-exchange resins cited. This fact proves the performance of IRN-78 as anionic strongly basic resin for IBP sorption.

To determine a suitable model for adsorption isotherms, experimental data were evaluated by using the regression coefficient (R^2) and non-linear analysis chi-square test (χ^2).

Table 7. Thermodynamic parameters for the adsorption of IBP onto Amberlite IRN-78

	Temperature (K)	ΔG^0 (kJ/mol)	ΔH^0 (kJ/mol)	ΔS^0 (J/mol K)
IBP in water	288	−7.21	21.59	99.85
	298	−8.04		
	308	−9.21		
IBP in ethanol	288	−6.57	27.09	117.14
	298	−7.98		
	308	−8.91		

Table 8. Removal percentage of IBP onto IRN-78 compared to those in previous studies

Resins	Solvents	% Removal
IRN-78 (this work)	Water	97
	Ethanol	95
Dowex 22 [33]	Synthetic ureolyzed urine	93
MIER1 [29]	Water	44
MIER2 [29]	Water	40

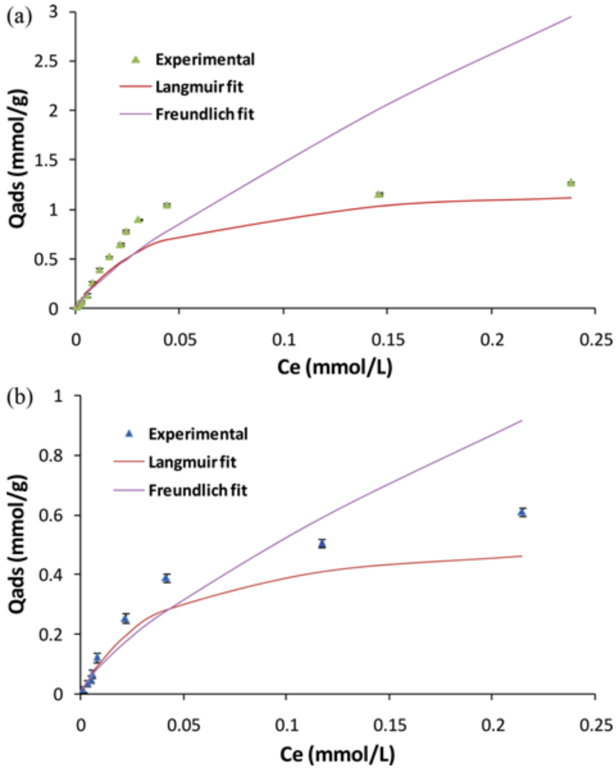

Fig. 7. Fitting of Langmuir and Freundlich models to the experimental adsorption isotherms of IBP in water (a) and in ethanol solution (b).

The χ^2 value should be as small as possible so that the values calculated by the model are similar to the experimental data and vice versa. χ^2 values calculated (Table 6) are consistent with Ho's [55] conclusions, since this analysis is much clearer than that observed when the R^2 values are considered. Indeed, with regard to the Langmuir model, it is best suited for IBP isotherms obtained when the values of χ^2 are considered (χ^2 Langmuir<χ^2 Freundlich). According to RMSE, the Langmuir model exhibited lower errors than the Freundlich model. As can be seen from Fig. 7, the Langmuir model agrees well with the experimental data. This result suggests that the adsorption process of IBP by IRN-78 was monolayer adsorption. The results agreed with previous research which reported that the adsorption of IBP fit to Langmuir model using different adsorbents such as activated carbon [58,59], *Parthenium hysterophorus* derived biochar [10] and ion exchange [33].

Although, based on the concept of Freundlich, the exponent 1/n is related to the energetic heterogeneity of adsorbent surface, all 1/n values for IBP sorption were less than unity, indicating that the adsorption was favorable (Fig. 7).

7. Thermodynamics

To evaluate the effect of temperature on the IBP adsorption in water, experiments were carried out for the initial concentration of 9.73 mmol/L in water and 4.8 mmol/L in ethanol, at different temperatures (15, 25 and 35 °C). Thermodynamic constants, standard free energy (ΔG^0), standard enthalpy (ΔH^0), and standard entropy

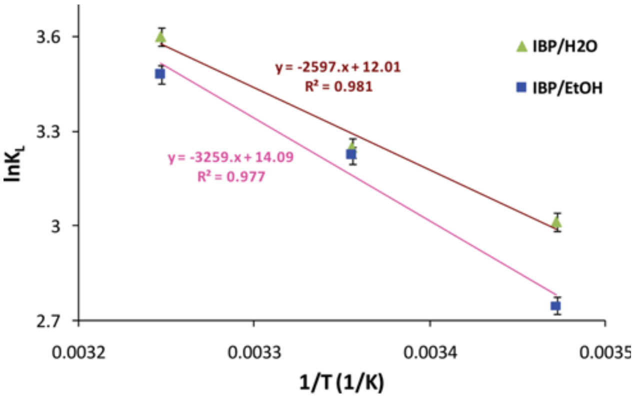

Fig. 8. Plot of $\ln K_L$ versus (1/T) for estimation of thermodynamic parameters.

(ΔS^0) were calculated by the following equations [60]:

$$\Delta G^0 = -RT\ln K_L \tag{6}$$

$$\ln K_L = -\frac{\Delta H^0}{RT} + \frac{\Delta S^0}{R} \tag{7}$$

where T is absolute temperature in Kelvin; R (8.314 J/mol K) is the universal gas constant; K_L (L mol^{-1}) is Langmuir constant.

The ΔH^0 and ΔS^0 are calculated from the slope and intercept of the linear plot of $\ln K_L$ versus 1/T (Fig. 8). The calculated values of ΔG^0, ΔH^0 and ΔS^0 for adsorption of IBP onto IRN-78 are shown in Table 7. The negative ΔG^0 values indicate the feasibility and spontaneity of the adsorption process. The ΔG^0 values are in the range of 0 to −20 kJ/mol, indicating that the adsorptions are physical [61]. The positive ΔH^0 value (22.38 kJ/mol) indicated an endothermic process, which is in agreement with the experimental observation. Hence, ΔS^0 was more than zero so that the adsorption led to increasing the standard entropy of the system.

CONCLUSION

IRN-78 was used effectively as adsorbent for the removal of IBP as a pharmaceutical pollutant in aqueous medium. Adsorption capacity of the studied resin for IBP in water (1.266 mmol/g) was higher than in ethanol (0.611 mmol/g) with an important removal rate of 97 and 95%, respectively. The equilibrium data of IBP sorption were best described by the Langmuir isotherm model. Kinetic study showed that the pseudo second-order described better than the pseudo first-order the adsorption kinetics of IBP suggesting that the uptake is followed by chemisorption. Thermodynamic parameters revealed that adsorption process was endothermic. The negative values of ΔG^0 indicate the spontaneity of the adsorption process. The ΔG^0 values are in the range of 0 to −20 kJ/mol, indicating, that the adsorption was controlled by physical mechanism. Besides its relatively high cost, the results indicate that the IRN-78 can be a promising adsorbent material used for the removal of pharmaceuticals pollutants such as IBP from wastewater.

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