Adsorption of Glimepiride on Activated Charcoal and Iraqi Kaolin from Aqueous Solution

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Abstract

Background	Treatment of acute poisoning due to drug overdose in general depends on the prevention of further absorption of the drug and acceleration of elimination, using specific antidotes. Drugs adsorption is of significant importance in physical pharmacy for the preparation of physical antidotes.
Objective	To investigate the adsorption of glimepiride from aqueous solution on two adsorbents (activated charcoal and Iraqi kaolin).
Method	UV-Spectrophotometric technique was used to obtain the quantitive adsorption data at different conditions of pH and temperature.
Results	The quantities of glimepiride adsorbed on activated charcoal and kaolin were increased with decreasing temperature. Adsorption isotherms of glimepiride on both surfaces were consistent with Freundlich adsorption isotherm. Thermodynamic functions (ΔG, ΔH and ΔS) were useful in describing the spontaneity of the adsorption process.
Conclusion	The quantity of the drug that is adsorbed on activated charcoal was higher than that adsorbed on kaolin surface therefore; the activated charcoal is a better antidote.
Keywords	Glimepiride, Adsorption, Activated charcoal, Iraqi kaolin

Introduction

Adsorption from solution is rather complicated in its theory due to the influence of solvent molecules and their competition with the solute species to be adsorbed. The porous and finely divided materials enhance adsorption due to their high surface area. Adsorption is usually accompanied by a decrease in free energy change and entropy of the system. This process is influenced by a number of factors such as concentration of adsorbate, surface area of adsorbent, temperature, ionic strength, pH solubility of adsorbate and adsorbent molecules [1].Through the citation of literature, it has been noticed that there are so many adsorption studies, some of these studies concentrated on the medical applications of the adsorption particularly in the treatment of poisoning and drug overdose [1-13]. These adsorption studies were carried out on different types of adsorbents such as kaolin, activated charcoal, attapulgite, talc, magnesium trisilicate and so many others. However the results of these studies indicated that the activated charcoal was the most active surface employed as adsorbent.

A number of studies were concentrated on the adsorption of heavy metals on clay minerals and oxides [14]. Recently an investigation was carried out on the adsorption of trimethoprim on cellulose acetate and attapulgite [15].

Kaolin was also used to adsorb toxic substances from the alimentary canal and is used in the treatment of diarrhea associated with food

poisoning [16]. Through the citation of literature it has been noticed also that no work has been done on the adsorption of the drug glimepiride, therefore it has been decided to investigate its adsorption on Iraqi kaolin and activated charcoal at different conditions.

Glimepiride is one of the third generation sulphonylurea, antidiabetic drug which stimulates insulin release. It is used for the treatment of non-insulin-dependent diabetes mellitus. Glimepiride is a constituent of an oral anti-diabetic medicine commercially available as Amaryl tablets. Over dosage of this drug may lead to sever and sometimes life-threatening hypoglycemia and require hospitalization even as a precautionary measure [17].

The aim of this investigation is to assess the abilities of both the Iraqi kaolin and the activated charcoal in adsorbing the over dosage of Glimepiride and to be used as antidote for such diabetic patients that may mistakenly ingest overdose of Amaryl or any other drug that contains Glimepiride.

If (x) mg of a drug is adsorbed from solution on (m) grams of an adsorbent, the extent of adsorption is given by (x/m) or (Qe). Two main theories have been adopted to describe the mechanism of adsorbate- adsorbent interaction.

1. The theory of Langmuir: Adsorption is limited to a monolayer of adsorbate molecules on a homogeneous adsorbent surface [18], (Equation 1):

$Ce/Qe = 1/ab + Ce/a$ …… (1), where (a) and (b) are constants.

(Ce) is the equilibrium concentration of the drug in solution.

Plotting Ce/Qe versus Ce produce a linear relationship if Langmuir's isotherm is valid for the system under investigation.

2. Freundlich theory: It is an empirical equation (2) based on the assumption that the surface possessing heterogeneous adsorption sites of different potential energies and different geometrical shapes. These sites exhibit different affinities towards the same adsorbate molecules [18]

$\log Qe = \log K + 1/n \log Ce$…..(2), where (n) and (k) represent empirical constants.

The study of the temperature effects on adsorption will help also in evaluating the basic thermo-dynamical functions (ΔH, ΔS, ΔG) of the adsorption process.

The importance of these functions is to see the feasibility and spontaneity of the adsorption process through the sign and value of the free energy change (ΔG). The motive behind the spontaneous reaction is the tendency to decrease its free energy to the minimum value.

The enthalpy function (ΔH) is directly related to the electrostatic interaction during the adsorption process, whereas the entropy (ΔS) is a function which can be linked to the mobility of the adsorbate in the adsorption media and can be determined from Gibbs equation [19].

Methods
The instruments used were UV - VIS Spectrophotometer (UV-1800) Shimadzu, thermostated Shaker bath/GFL (D-3006), Germany, pH Meter/HM -73, TDA Electronics Ltd., Centrifuge /eppendorf 5804 R, electronic Balance/Sartorius Lab. BP 3015. The materials used are HCl (GCC) and NaOH (Emscope laboratories Ltd). The drug used was Glimepiride that is obtained from (Zhejiang jiangbei pharmaceutical co., ltd.) Germany.

Glimepiride is a white to yellowish–white powder, crystalline, odorless. Molecular Formula: $C_{24}H_{34}N_4O_5S$, Molecular Weight: 490.62.
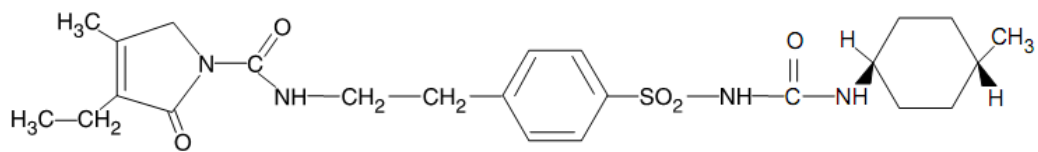
Figure 1. The structural formula of Glimepiride [20]

Adsorbents
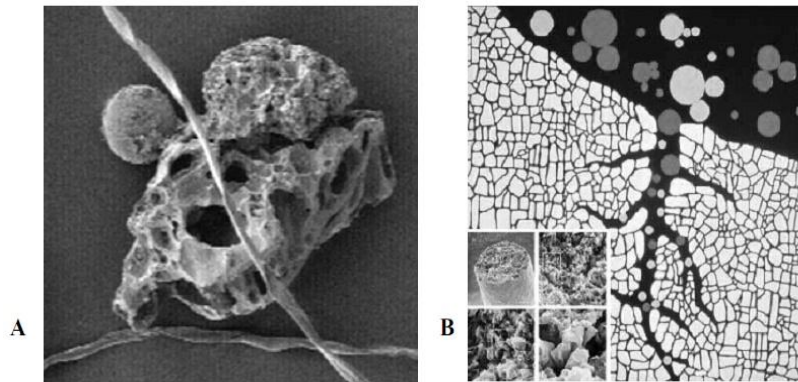*Activated charcoal (fluka)*

Figure 2. (A): Scanning electron micrograph of a particle of activated charcoal, (B): The pores that tunnel into the actual activated charcoal particles [21]

Iraqi kaolin: was obtained from (Dwaikhla) opened mine (north of Rutba) in the Iraqi Western desert supplied by the ''General Company for Geological Survey and Mining'', Baghdad, Iraq. The weight percentages of the Iraqi kaolin clay were:
SiO_2 (54.68%), Al_2O_3 (30.19%), Fe_2O_3 (1.02%), TiO_2 (1.00%) and loss on ignition (10.94%).
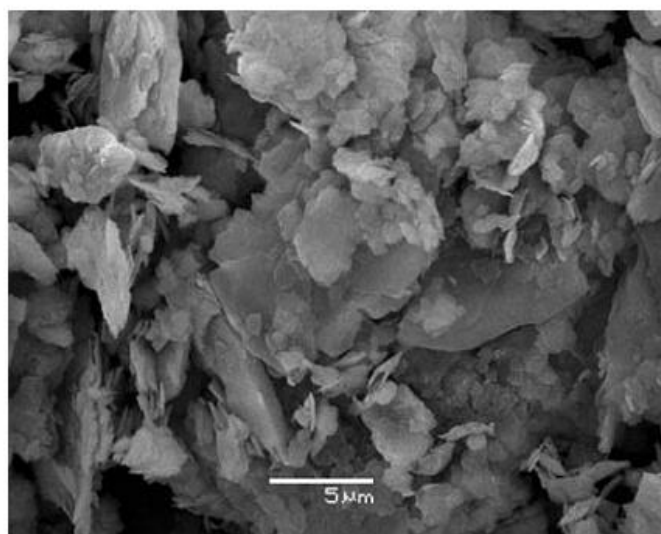

Figure 3. The shape characterization of kaolin [22]

Method

Kaolin and activated charcoal adsorbents were in powder form. Each of them was washed several times with excessive amounts of distilled water then dried at (170 °C) in the oven for three hours and kept in airtight containers. Each adsorbent was ground and sieved using Retsch test sieve 63μm.

A stock of (50 ml) aqueous solution of glimepiride drug (54 mg L^{-1}) was prepared and its (λmax) was determined. The maximum absorbance (λmax) was (200) nm. Various drug solutions with different concentrations were prepared by diluting the stock solution with distilled water (5.4, 16.2, 27, 37.8 and 48.6 mgL^{-1}).

In order to obtain the calibration curve for aqueous solutions of Glimepiride at pH =1 the absorbance values of these drug solutions were measured at the specific (λmax) using UV-Vis double beam Spectrophotometer and plotted versus the concentrations of these drug solutions (Figure 4).
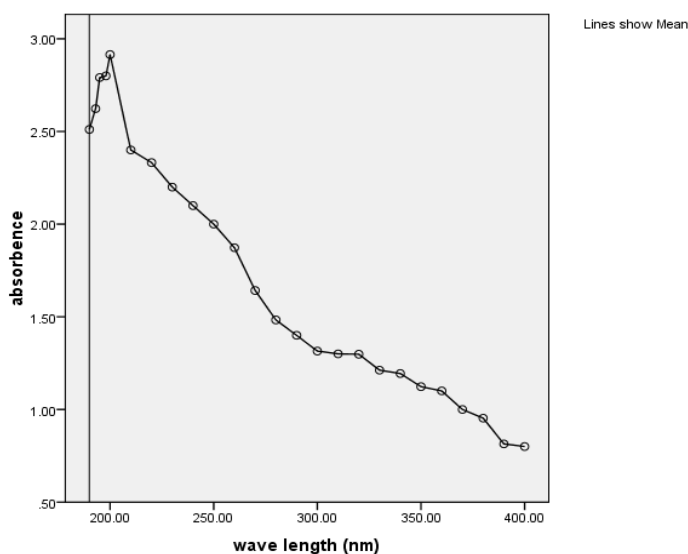

Figure 4. UV Spectra of aqueous solution of Glimepiride at pH=1

The time to reach equilibrium state, that is required for full saturation of adsorbent surface at 37 °C by the adsorbate has been determined by the following procedure: 50 ml initial concentration (54 mg/L) of adsorbate solution was shaken with (0.1 g) of each adsorbent. The absorbances of adsorbate solutions were measured by UV/Visible spectrophotometer at different intervals 10, 20, 30, 60, 90, 120......minutes until reaching equilibrium (no further uptake of adsorbate by adsorbent as the time proceeds).

A systematic procedure was followed to determine the adsorption isotherms for each pair of adsorbent -adsorbate systems. A volume of (50ml) of five different concentrations of drug solution (5.4, 16.2, 27, 37.8 and 48.6 mg/L) was shaken with (0.1 g) of adsorbent at a certain temperature in a thermostatic shaker. The speed of shaking was 60 cycles per minute. After the equilibrium time (30 min) elapsed, the mixtures were allowed to settle and the clear liquids were either centrifuged at 4000 round per minute (rpm) for 20 minutes or filtered using double filter papers T (whatman No. 42 Germany). The two methods of separation gave identical results. The absorbencies of the filtrate solutions were measured at (λmax). The equilibrium concentrations of the prepared solutions can be determined from the calibration curve using their absorbencies.

The adsorbed amount of the drug was calculated at certain conditions from the concentration of solution before and after adsorption according to equation (3):

$X_m = (C_o-C_e)$ V / m................(3), where C_o and C_e are the initial and equilibrium concentrations of drug solution (mg/L) respectively, V is the volume of solution in liter, X_m= the maximum quantity of adsorbate (in mg) that is adsorbed on the adsorbent at certain value of C_e that was fixed for all temperatures used in the study, (m) is the weight of adsorbent in grams.

X_m can be determined from equation (4):

$Q_e = X_m$ / m........................(4), where $Q_{e=}$ is the quantity of adsorbate (in mg) held by (0.1 g) of adsorbent.

The equilibrium constant (k) for the adsorption process at each temperature is calculated from equation (5):

K = (Qe) (0.1 g)/(Ce) (0.05 L)...........(5), where (0.1 g) represents the weight of the clay that has

been used, (0.05 liter) represents the volume of the drug solution used in the adsorption process. The change in free energy (ΔG) could be determined from equation (6):

$\Delta G = - R T \ln k$................(6), where R is the gas constant (8.314 J/mol. deg) and T is the absolute temperature.

The heat of adsorption (ΔH) may be obtained from equation (7):

$\ln X_m = -\Delta H/RT + constant$ ....(7)

The change in entropy (ΔS) can be determined from equation (8):

$\Delta G = \Delta H - T\Delta S$.........(8)

Results

Adsorption isotherms

The adsorption isotherms of glimepiride on activated charcoal and kaolin at pH=1 and different temperatures are shown in figures 5 and 7. Figures 6 and 8 show a linear relationship between (log Qe) and (log Ce).
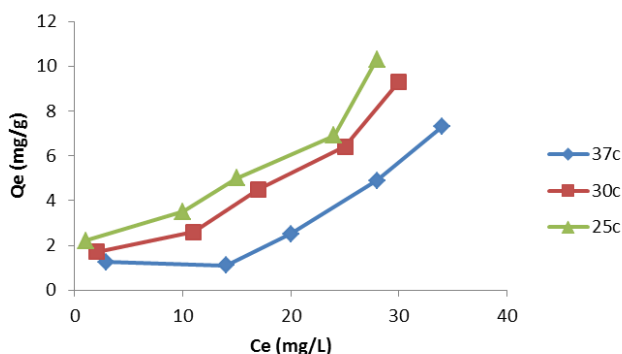

Figure 5. Adsorption isotherms of Glimepiride on activated charcoal at pH=1 and different temperatures (25, 30, 37 ^{o}C).

Effect of pH

The adsorption extent of glimepiride on activated charcoal and kaolin investigated at different pH values (1, 4 and 7). It was found that the drug quantity adsorbed increased with increasing pH of the solution. It is clear from figures 9 and 10 that pH does play an important role in the adsorption of glimepiride on activated charcoal and kaolin.
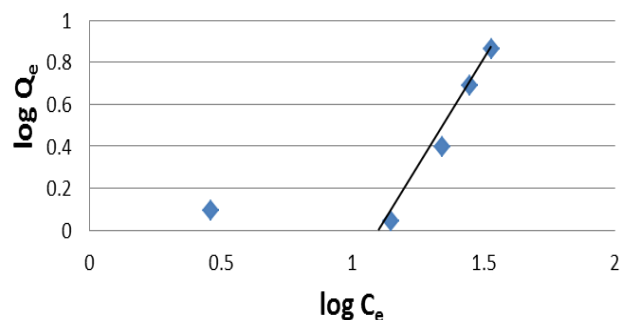

Figure 6. Linear form of freundlich isotherm of glimepiride adsorbed on activated charcoal at 37 ^{o}C and pH=1

Temperature effects and thermodynamic parameters

The general shapes of the adsorption of glimepiride on kaolin and activated charcoal at three different temperatures 37, 30 and 25ºc are given in figures 5 and 7. Figures 5 and 7 show also that the adsorption of Glimepiride decreases with increasing temperature.
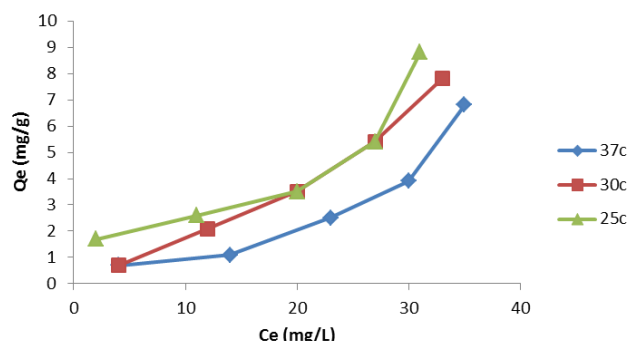

Figure 7. Adsorption isotherms of Glimepiride on kaolin at pH=1 and different temperatures (25, 30, 37 ^{o}C)

Table 1 gives X_m values at different temperatures at pH=1. Plotting ($\ln X_m$) versus 1000/T produced a straight line with a slope = $- \Delta H/R$ as shown in figures 11 and 12). Table 2 shows the basic thermodynamical values of adsorption of Glimepiride on kaolin and activated charcoal.
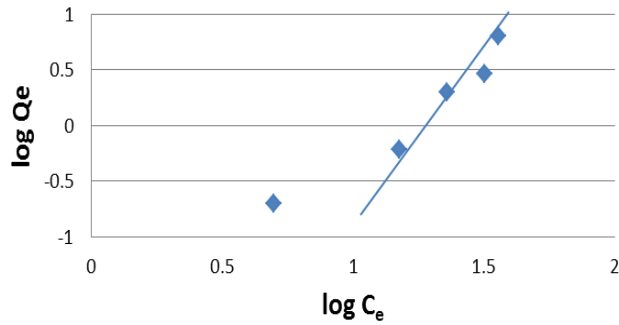
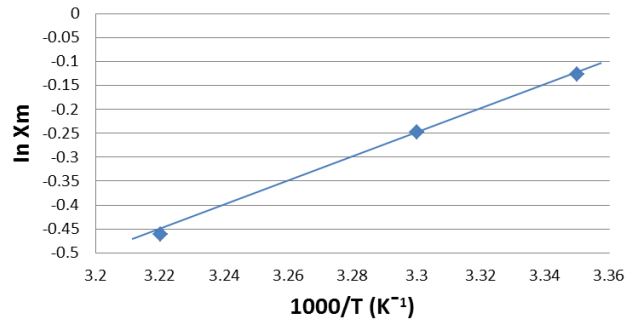**Figure 8. Linear form of freundlich isotherm of glimepiride adsorbed on kaolin at 37 ^{o}C and pH=1**

Figure 9. Adsorption isotherms of Glimepiride on activated charcoal at 37 ^{o}C and different pH (1,4,7)
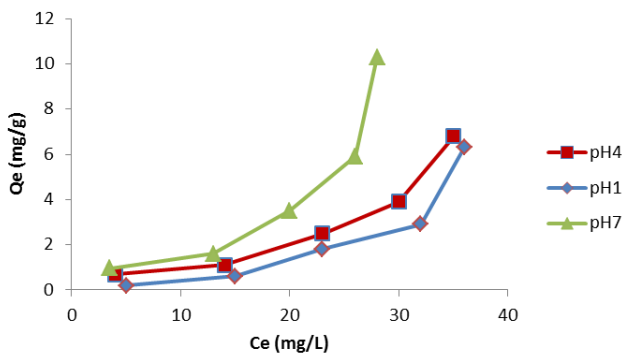
Figure 10. Adsorption isotherms of Glimepiride on kaolin at 37 ^{o}C and different pH (1,4,7)

Figure 11. In Xm plotted against reciprocal absolute temperature for the adsorption of glimepiride on kaolin at pH=1

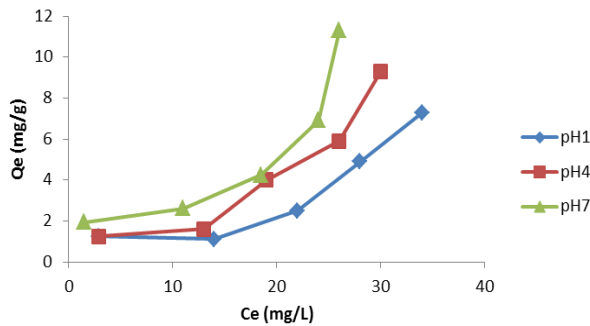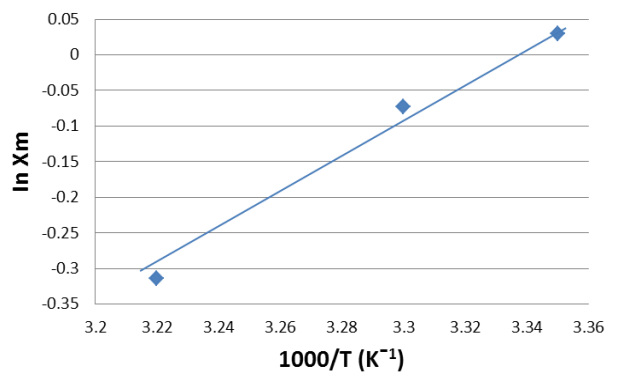**Figure 12. In Xm plotted against reciprocal absolute temperature for the adsorption of glimepiride on activated charcoal at pH=1**

Discussion

Adsorption isotherm

The adsorption isotherms describe how adsorbates interact with adsorbents [23]. The relationship between the amount of substance adsorbed at constant temperature and its equilibrium concentration is called the adsorption isotherm [24]. The shape of the adsorption isotherms of Glimepiride on kaolin and activated charcoal was S type of Giles classification as shown in figures 5 and 7. This type of adsorption isotherm indicates a good applicability of freundlich assumptions. This indication can be seen clearly from the linear relationships between (log Qe) and (log Ce), Figures 6 and 8.

Surface imperfection and the presence of impurities can play an important role in the heterogeneity of the surface.

Table 1. Effect of temperature on the maximum adsorbed quantity for adsorption of glimepiride on activated charcoal and kaolin in pH=1

Adsorbent	T. ^oC	T. ^oK	1000/T $^oK^{-1}$	Xm (mg)	In Xm
Kaolin	25	298	3.35	0. 88	-0.1278
	30	303	3.30	0. 78	-0.2484
	37	310	3.22	0.63	-0.4620
Activated charcoal	25	298	3.35	1.03	0.0295
	30	303	3.30	0. 93	-0.0725
	37	310	3.22	0.73	-0.3147

Effect of pH

According to the concept that is known as "diffuse double-layer" the clay particles in aqueous solution are charged and can attract molecules either by electrostatic forces or by inducing dipole formation in the neutral molecule.

In general the pH of the solution affects the degree of ionization of the adsorbate molecules and the extent of dissociation of functional groups on the active sites of the adsorbent [25].

The maximum quantities of the drug adsorbed on both adsorbents followed the order: pH 7 > pH 4 > pH 1 (figures 9 and 10). This behavior can be attributed to the changes that may take place in the nature of adsorbent and the changes in the interactions between solvent-surface, solvent-solute and solute-surface species. The changes in these interactions are due to the changes in the degree of dissociation of acidic or basic functional groups of the solute, the solvent and the surface. This in turn affects the polarization of these species and subsequently affects the adsorption extent [1]. In addition, the solubility of Glimepiride may increase with decreasing pH because of the increase in the positive charges on the nitrogen atoms of the drug molecules which makes them more soluble and hence decrease the adsorption affinity toward kaolin or activated charcoal surface.

Effect of temperature & pH on thermodynamic parameters

The quantities of Glimepiride adsorbed on activated charcoal and kaolin were decreased with increasing temperature (figures 5 and 7). The increase in temperature may increase the solubility of the solute, hence decreasing its adsorption affinity towards the surface, in addition, to the increase in the kinetic energy of the species. Consequently, there is an increase in the entropy of the system, which results in a decrease of aggregate organization on the surface of the adsorbent.

The negative values of the ΔG for the adsorption of Glimepiride on activated charcoal and kaolin at pH=4 and pH=7 indicated that the adsorption process of Glimepiride is spontaneous, but the positive values of the ΔG at pH=1 in 37, 30 and 25 ^oC indicates that the adsorption process is nonspontaneous due to the small values (< 1) of the equilibrium constant. However, even with positive (ΔG) values there were some interactions.

The negative values of the ΔH for the adsorption of Glimepiride on activated charcoal and kaolin at pH=1, pH=4 and pH=7 at 25 ^oC indicated that the adsorption was an exothermic process. The positive values of ΔH at pH=1, pH=4 and at 37, 30^oC indicated an endothermic reaction, which could be attributed to the enlargement of pore size and/or activation of the adsorbent surface, creating some sort of interactions [23].

Table 2. Values of thermodynamic functions for the adsorption of glimepiride on activated charcoal and kaolin at different pH and temperatures

Adsorbent	ΔH (J/ mol)	ΔG (J/ mol)	ΔS(J/ mol k)	pH	Temperature
Activated charcoal	+811.50	+2178.72	-4.41	1	37 °C
Kaolin	+1191.08	+2705.74	-4.88	1	37 °C
Activated charcoal	+183.25	+1204.24	-3.36	1	30 °C
Kaolin	+626.22	+1887.43	-4.16	1	30 °C
Activated charcoal	-72.35	+760.40	-2.79	1	25 °C
Kaolin	+317.27	+1402.52	-3.64	1	25 °C
Activated charcoal	+187.47	+1232.06	-3.36	4	37 °C
Kaolin	+994.21	+2436.30	-4.65	4	37 °C
Activated charcoal	-809.85	-688.46	0.40-	4	30 °C
Kaolin	-985.95	-1116.82	+0.43	4	30 °C
Activated charcoal	-1355.47	-2241.69	+2.97	4	25 °C
Kaolin	-1051.76	-1314.66	+0.88	4	25 °C
Activated charcoal	-314.08	+361.20	-2.17	7	37 °C
Kaolin	-75.42	+791.02	-2.79	7	37 °C
Activated charcoal	-306.97	+353.04	-2.17	7	30 °C
Kaolin	-73.70	+773.15	-2.79	7	30 °C
Activated charcoal	-491.52	-51.08	-1.47	7	25 °C

The negative values of ΔS for the adsorption of Glimepiride on activated charcoal and kaolin at pH=1, pH=4 and pH=7 at 37 °C indicated a decrease in the degree of freedom of the adsorbed species [26]. The positive values of ΔS at pH=4 and at the temperatures 30 and 25 °C might be attributed to the more freedom of motion of the ions in the solution than that attached to the surface [27].

We conclude that Iraqi kaolin showed a moderate ability to adsorb the Glimepiride drug from its aqueous media, however, the activated charcoal showed a better performance, therefore, both adsorbents can be used as antidotes for dealing with a case of drug overdose. Moreover, adsorption isotherms of the drug Glimepiride on Iraqi kaolin and activated charcoal obeyed Freundlich isotherm model. These results indicated the surface heterogeneity of the adsorbents leading to different adsorption strengths from site to site and different affinities towards drug molecules. Furthermore, the drug quantities adsorbed on Iraqi kaolin and activated charcoal at 37 °C showed an increase in adsorption of the drug uptake with increasing pH of the solution. Finally, adsorption of Glimepiride on Iraqi kaolin and activated charcoal decreases with increasing temperature.

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