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# Synthesis, Characterization, and drug release study of polyacrylamide Hydrogels

**A Research**

**Submitted to the College of pharmacy Al-Qadisiya University in Partial Fulfillment of Requirements of B.Sc. Degree of Science in pharmaceutical**

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**بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ**

يَرْفَعِ اللَّهُ الَّذِينَ آمَنُوا مِنكُمْ

وَالَّذِينَ أُوتُوا الْعِلْمَ دَرَجَاتٍ

**صدق الله العلي العظيم**

**من سورة المجادلة (١١)**

# *Dedication*

To AL-Imam Al Mahdy

To my mother, my father

and all my family

To all the people who are

Sit in my heart.

# Abstract

This study is concerned with a significant application of surface chemistry in the fields of physical pharmacy and medical. It deals with adsorption-desorption systems of drug (Aspirin) on selected surfaces (polyacrylamide hydrogel) at variable conditions of pH, and temperature.

The polymeric hydrogel was used as an adsorbent for release Aspirin from aqueous solution. The adsorption experiments were carried out by using UV-Visible spectrophotometer. Hydrogels of polyacrylamide (AAm) was prepared by free radical polymerization. The chemical structures of polymer hydrogels were analyzed by Fourier transform infrared spectrometer (FTIR).

The adsorption phenomenon was examined as a function of temperature (15, 25 and 37$^{o}$C). The extent of adsorption of Aspirin on hydrogel was found to increase with increasing temperature (endothermic process).

The basic thermodynamic functions have also been calculated. The amount of drug adsorbed on the hydrogel surface at different pH values showed an increase in the following order: 7.2 < 4.0 < 1.2

# Contents

# Tables



# Scheme

# Figures

# CHAPTER ONE
# INTRODUCTION

## *1.1 General Introduction* [1-5]

Hydrogel are hydrophilic polymers that absorb water and are insoluble in water at physiologic temperature, pH, and ionic strength because of the presence of a three-dimensional network. The cross-links can be formed by covalent bonds, electrostatic, hydrophobic, or dipole–dipole interactions. The hydrophilicity is due to the presence of hydrophilic groups, such as hydroxyl, carboxyl and amide groups along the polymer chain. Hydrogels work well in the body because they mimic the natural structure of the body's cellular makeup.

Their porosity also permits loading of drugs into the gel matrix and subsequent drug release at a rate dependent on the diffusion coefficient of a small molecule or a macromolecule through the gel network.

The polymer cannot dissolve due to the covalent crosslink; water uptakes far in excess of those achievable with hydrophilic linear polymers can be obtained. Indeed, the benefits of hydrogels for drug delivery may be largely pharmacokinetic – specifically that a depot formulation is created from which drugs elute slowly, maintaining a high local concentration of drug in the surrounding tissues over an extended period of time, although they can also be used for systemic delivery. Hydrogels are also generally highly biocompatible, which may be attributed to the high water content of hydrogels. Biodegradability or dissolution of hydrogels may be brought about by enzymatic, hydrolytic, or environmental (e.g. pH, temperature, or electric field) pathways; however, degradation is not always desirable depending on the time frame and location of the drug delivery device.

Hydrogels can be prepared from natural or synthetic polymers, Table (1-1). Several techniques have been reported for the synthesis of biomedical hydrogels. Chemically cross-linked gels have ionic or covalent bonds between polymer chains.

**Table (1-1) Natural polymer and synthetic monomer used for hydrogel fabrication**

| Characteristics | Natural origin | Synthetic polymers |
|---|---|---|
| Preparation | By using natural polymer | By chemical polymerization |
| Advantages | -Biocompatible<br>-Biodegradable<br>-Supports cellular activities | -Inherent bioactive properties absent |
| Disadvantages | -Does not possess sufficient mechanical properties<br>-May contain pathogen<br>-Evoke immune and inflammatory responses | _____ |
| Examples | -Proteins like collagen and gelatin<br>-Polysaccharides like alginate and agarose | -Acrylic acid<br>-Hydroxyethyl - methacrylate (HEMA)<br>-Vinyl acetate<br>-Methacrylic acid(MAA) |

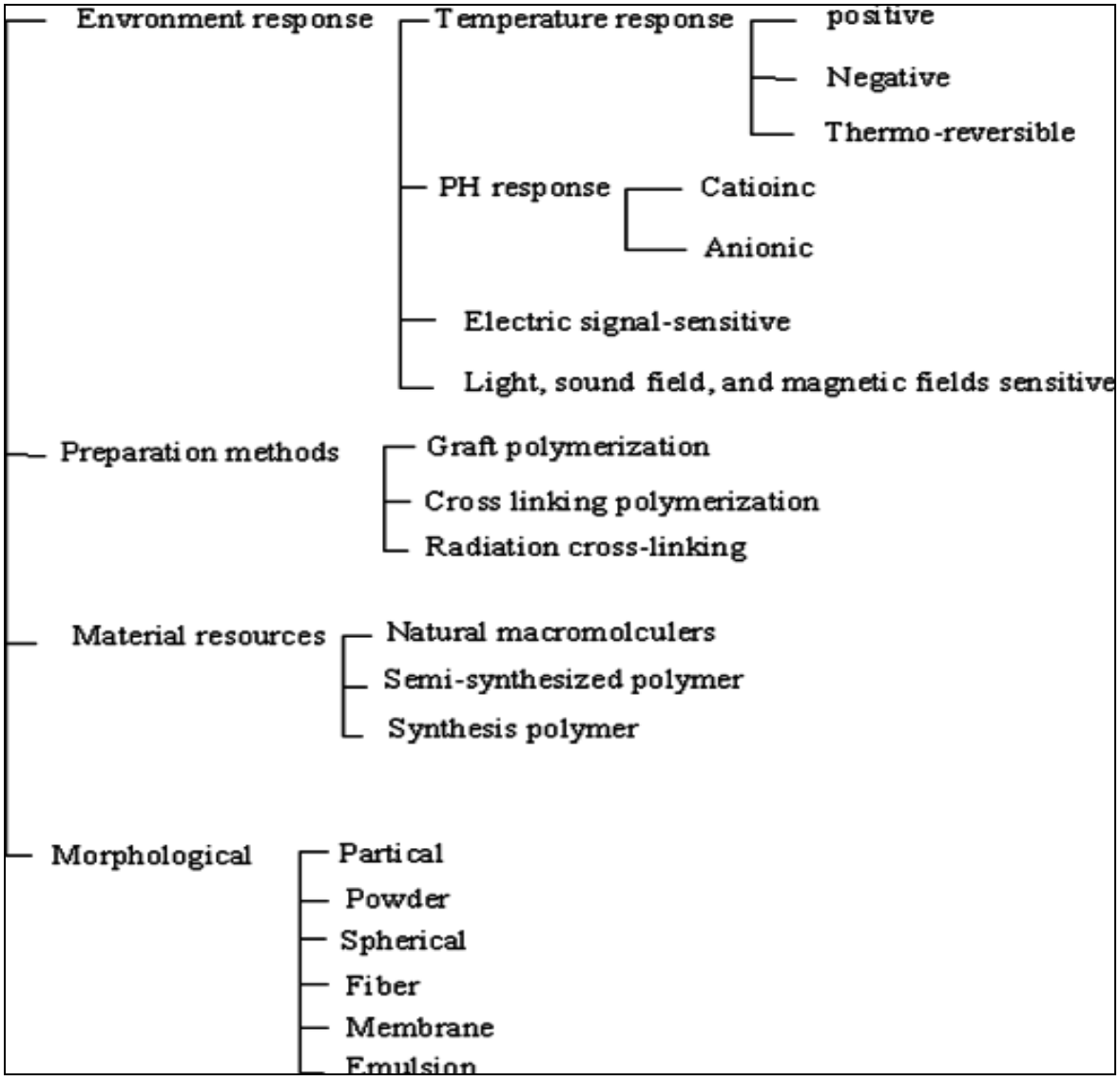
## *1.2 Classification of Hydrogels polymers* [6-11]

The classification of hydrogels depends on their physical properties, nature of swelling, method of preparation, origin, ionic charges, sources, rate of biodegradation and observed nature of cross linking.

In physical gels, the nature of the cross linking process is physical. This is normally achieved via physical processes such as crystallization, polymer chain complexion, and hydrogen bonding. On the other hand, a chemical process, i.e., chemical covalent cross linking (simultaneously or post polymerization) is utilized to prepare a chemical hydrogel. Physical

hydrogels are reversible due to the conformational changes where chemical hydrogels are permanent and irreversible because of configurational changes.

Another category is the dual-network hydrogel, formed by the combination of physical and chemical cross linked hydrogels due to an electrostatic interaction. It has recently been employed to overcome the disadvantages of solely using physical or chemical hydrogels with high liquid uptake capacity over a wide range of pH and a higher sensitivity towards changes in the pH as compared to chemical hydrogels.




**Scheme (1-1): Classification of hydrogel polymers materials**

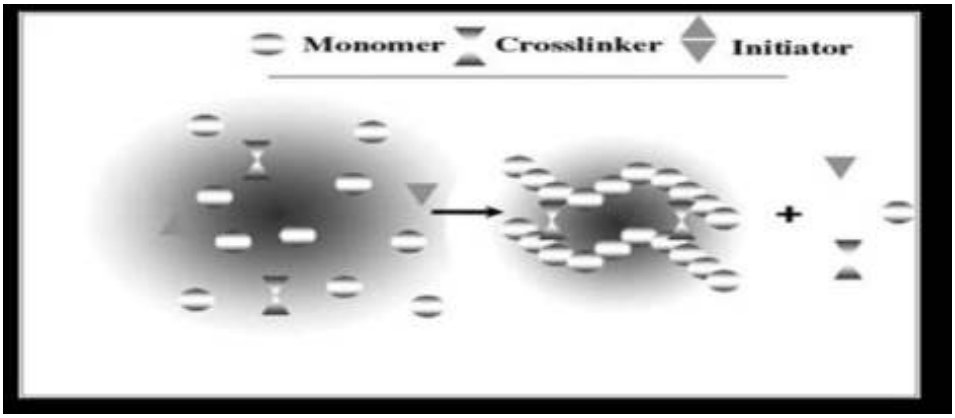
## *1.3 Preparation of hydrogel polymer* [12]

In general, hydrogels can be prepared from either synthetic polymers or natural polymers. The synthetic polymers are hydrophobic in nature and chemically stronger compared to natural polymers. Their mechanical strength results in slow degradation rate, but on the other hand, mechanical strength provides the durability as well. These two opposite properties should be balanced through optimal design. Water-soluble linear

polymers of both natural and synthetic origin are cross-linked to form Hydrogels in a number of ways

1. Linking polymer chains via chemical reaction.
2. Using ionizing radiation
3. Physical interactions such as entanglements, electrostatics, and crystallite formation.

In general, the three integral parts of the hydrogels preparation are monomer, initiator, and cross linker. To control the heat of polymerization and the final hydrogels properties, diluents can be used, such as water or other aqueous solutions.




**Scheme (1-2) Schematic diagram of hydrogel preparation**

### 1.3.1 Physical cross-linking Gel [13]

There has been an increased interest in physical gels due to relative ease of production and the advantage of not using cross-linking agents.

These agents affect the integrity of substances to be entrapped (e.g. cell, proteins) as well as the need for their removal before application. The various methods to obtain physically cross-linked hydrogels are:

### 1-3-2 -Chemically Cross linked Gel [18]

Chemically cross linked gels are mechanically quite stable due to the ionic and covalent bond which comprises these gels. However the addition of cross linking agent leads to adverse effects if the compound is toxic, which on liberation in the body becomes quite harmful.

#### 1-3-2-1: Radiation cross-linking [19]

Radiation cross-linking is widely used technique since it does not involve the use of chemical additives and therefore retaining the biocompatibility of the biopolymer. Also, the modification and sterilization can be achieved in single step and hence it is a cost effective process .The technique mainly relies on producing free radicals in the polymer following the exposure to the high energy source such as gamma ray, x-ray or electron beam. The action of radiation (direct or indirect) will depend on the polymer environment (i.e. dilute solution, concentrated solution, solid state).

#### 1-3-2-2: Copolymerization/Crosslinking Reactions [20]

Copolymerization reactions are used to produce polymer gels, many hydrogels are produced in this fashion, for example poly (hydroxyl alkyl methyl acrylates). Initiators used in these reactions are radical and anionic initiators. Solvents can be added during the reaction to decrease the viscosity of the solution.

## 1-4 Monomers Used for Fabrication of Hydrogel [21, 22]

The monomers used for fabrication of these biocompatible hydrogels have expanded from a handful of choices, to several novel materials with tailor-made properties suited to particular applications. The first synthesis of hydrogel was using PHEMA (poly hydroxyl ethyl meth acrylate) as the monomer. Depending upon the application, hydrogel monomers are chosen according to their properties, ease of delivery or encapsulations, as well as cost and availability. One of the most traditional monomers used for drug delivery of proteins is biodegradable PLGA (polymers of lactic and glycolic acid) .However these hydrophobic materials have a tendency to denature protein as well as cause inflammation due to degradation. These problems were overcome when researchers turned towards hydrophilic monomers. Monomers such as acrylic acid, polyethylene glycol, and meth acrylic acid are all materials used in therapeutic applications.

**Table (1-2) Monomers used in synthesis of hydrogels for pharmaceutical applications**

| *Monomer abbreviation* | *Monomer* |
|---|---|
| HEMA | Hydroxy ethyl methacrylate |
| HEEMA | Hydroxy ethoxy ethyl methacrylate |
| HDEEMA | Hydroxy diethoxy ethyl methacrylate |
| MEMA | Methoxy ethyl methacrylate |
| MEEMA | Methoxy ethoxy ethyl methacrylate |
| MDEEMA | Methoxy diethoxy ethyl methacrylate |
| EGDMA | Ethylene glycol dimeth acrylate |
| NVP | N-vinyl-2-pyrrolidone |
| NIPAAM | N-isopropyl AAm |
| VAc | Vinyl acetate |
| AA | Acrylic acid |
| MAA | Methyl AA |
| HPMA | N-(2-hydroxypropyl)meth acryl amide |
| EG | Ethylene glycol |
| PEGA | PEG acrylate |
| PEGMA | PEG methacrylate |
| PEGDA | PEG diacrylate |
| PEGDMA | PEG dimeth acrylate |

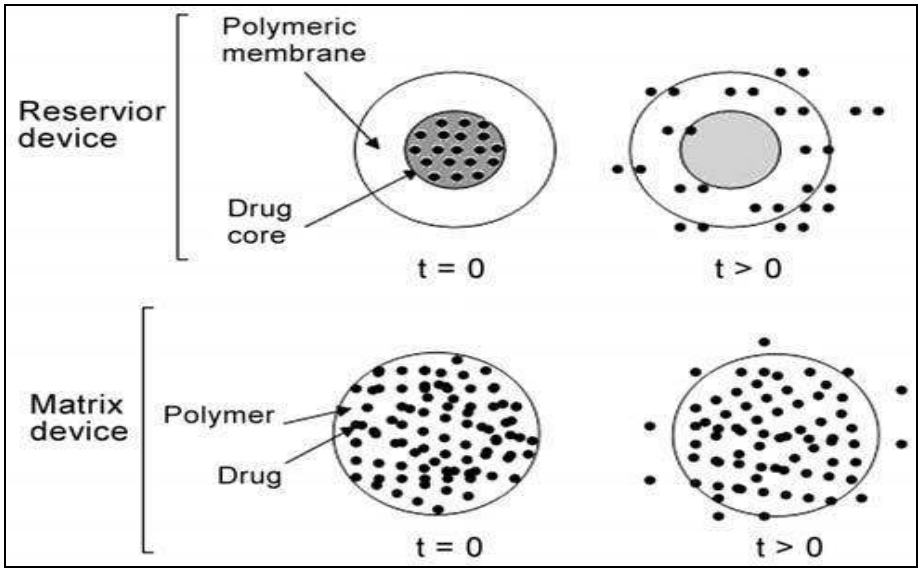
## 1-5 Drug release Mechanisms from hydrogels device [23]

Hydrogels imbibe more water than 90% of their weight due to hydrophilicity, thus differing in their release mechanisms from hydrophobic polymers. Various models have been developed to predict the release of an active agent from a hydrogel device as a function of time.

### 1-5-1-Diffusion-controlled Delivery Systems [23, 24]

Diffusion-controlled is the most widely applicable mechanism for describing drug release from hydrogels, dividing in two major types: reservoir devices and matrix devices.

Reservoir systems consist of a polymeric membrane surrounding a core containing the drug. In matrix devices, the drug is dispersed throughout the three-dimensional structure of the hydrogel. Drug release from each type of system occurs by diffusion through the macromolecular mesh or through the water filled pores. Fick's law of diffusion is commonly used in modeling diffusion controlled release systems. For a reservoir system where the drug depot is surrounded by a polymeric hydrogel membrane, Fick's first law of diffusion can be used to describe drug release through the membrane. For the case of a steady state diffusion process. To maintain a constant release rate or flux of drug from the reservoir, the concentration difference must remain constant. This can be achieved by designing a device with excess solid drug in the core. Under these conditions, the internal solution in the core will remain saturated. This type of device is an extremely useful device, allows for time-independent or zero-order release. For a matrix system where the drug is uniformly dispersed throughout the matrix, unsteady-state drug diffusion in a one-dimensional slap-shaped matrix can be described by the Fick’s second law**.**

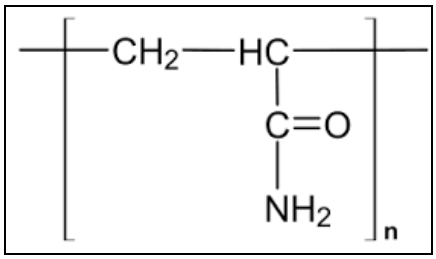



**Scheme (1-3) Schematic representation of diffusional controlled reservoir and matrix devices.**

## 1-6-Polyacrylamide (PAAm) [25]

Poly acryl amide (PAAm) is neutral hydrogel that are more suitable for drug delivery systems (DDS) as they are biocompatible and not very reactive. PAAm gel is chemically inert and nontoxic. PAM based hydrogels have already been used in several in vitro and in vivo studies to deliver various drugs.

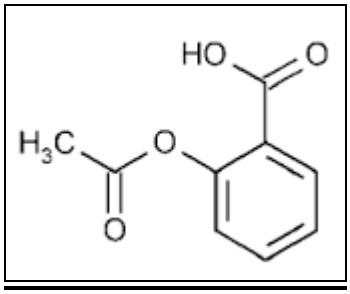
The formation of PAAm gels is dependent on several factors, including the concentration of acrylamide, the acrylamide: N,N'-Methylene bis acryl amide (MBA) weight ratio, and the presence of additives or solvents other than water used to prepare the gels. Thus, it is important to understand the physical properties of the gels and the influence of an additive such as a drug on the gel properties in considerations of PAAm gels as drug delivery systems.




**Scheme (1-4) Structure of polyacrylamide (PAAm)**

## 1-7-ASPIRIN [26]

Aspirin is the prototypical analgesic used in the treatment of mild to moderate pain. It has anti-inflammatory and antipyretic properties and acts as an inhibitor of cyclooxygenase which results in the inhibition of the biosynthesis of prostaglandins. Aspirin also inhibits platelet aggregation and is used in the prevention of arterial and venous thrombosis




**Scheme (1-5) Structure of Aspirin**

## Aim of the work

The aim of the work is summarized in following points:

1- Synthesis of the crosslinked poly acryl amide from acryl amide monomers.

2- Explore the feasibility utilizing Polymeric hydrogels as adsorbent for drug.

3- Characterization of the synthesized Polymeric hydrogels and adsorption studies by using FTIR and UV-Vis spectrophotometer.

4- Study the surface polymeric hydrogels capacity on adsorption of drug model.

5- The effect of the pH and the temperature on the release of the drug from the surface of the polymeric hydrogels.

6- Study the release of the drug from the surface of the polymeric hydrogels (desorption).

## [2-1] Chemicals

Table (2-1): shows the used chemicals in the experimental part .

**Table (2-1): Chemicals and their Sources**

| Chemicals | Purity (%) | Supplied from |
|---|---|---|
| Acrylamide | 99 | Merck |
| N,N'-Methylene bis acryl amide | 97 | BDH |
| Potassium Persulfate | 98 | Merck |
| N,N,N',N'-tetra methyl ethylene diamine | 99 | Merck |
| Sodium Hydroxide | 99 | BDH |
| Acetyl salicylic acid | 99 | HIMEDIA |
| Hydrochloride Acid | 37 | BDH |
| Deionized Water | - | Iraqi local product |

## [2-2] INSTRUMENTS

1- UV-Visible spectrophotometer, Double Beam, Shimadzu. PC 1650, Japan.

2- Dunboff metabolic shaking Incubater GCA/ precision Scientific.

3- Centrifuge tubes ., Hettich Universal (D-7200).

4- Electronic Balance, Sartorius Lab. L420 B, +0.0001.

5- pH meter, HANNA, Romania.

6- FTIR 8400S, Fourier Transform infrared spectrophotometer, SHIMADZU, Japan.

7- Fume Hood, K &K Scientific suppler, Korea.

8- Hot plate stir, Lap TECH CO. LTD , Korea.

9- Oven, Lap TECH CO. LTD, Korea.

## [2-3] Methodology

### 2.3.1 - Preparation of hydrogels

5 g of Acryl amide (AAm) was dissolved in 5 ml distilled water and then the solution was added into in a three necked 250ml round bottom flask .Which was equipped with a stirring apparatus and a reflux condenser. When the mixture is heated up to 45°C under nitrogen protection, and 1.25 ml of 1% concentration of MBA was added to the aqueous solutions. Then 1 ml of APS (5 g/100 ml water) was added this solution as initiator, and finally, 1.25 ml of TEMED (1 ml/100 mL water) was added onto solution. Polymerization process after 60 min .The reaction was stopped after 2 h. The prepared crosslinked polyacrylamide hydrogel was poured into a Petri dish and was then dried in the oven of 50 °C for 24 h. The hydrogels were soaked in distilled water for one day to remove any possible residual monomers and dried in vacuum at 80 ◦C for 5 h. to form crosslinked polyacrylamide hydrogels with constant weights.

### 2.3.2 - Preparation of Calibration curve

Wavelength of maximum absorbency ($\lambda_{max}$) was recorded for model drug aspirin dissolved in aqueous media and found 275nm.Figure (1).

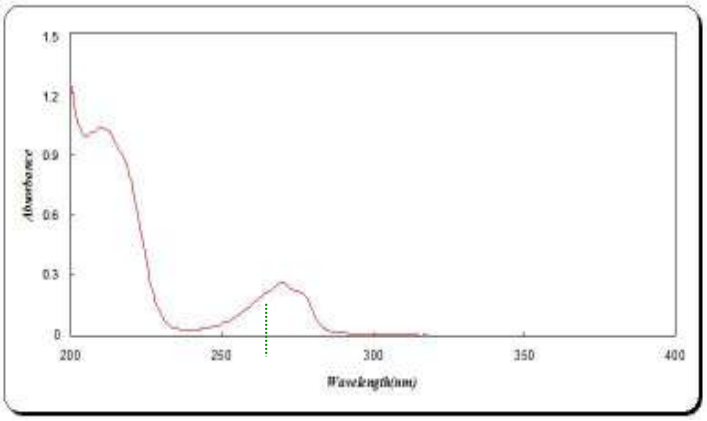



**Figure (2-1): UV spectrum of Aspirin (Conc.)**

This value was utilized for estimation of quantity of drug adsorbed. A standard curve for aspirin was constructed in the range of 10 to 250 ppm. The Solutions were prepared from 250 ppm stock solution was prepared by dissolving 250 mg of aspirin in 1000 ml deionized water. Solutions of different concentrations were prepared by serial dilution at wavelength of maximum and plotted against concentration values.

The calibration curve in the concentration range that falls in the region of applicability of Beer-Lambert's law was employed.

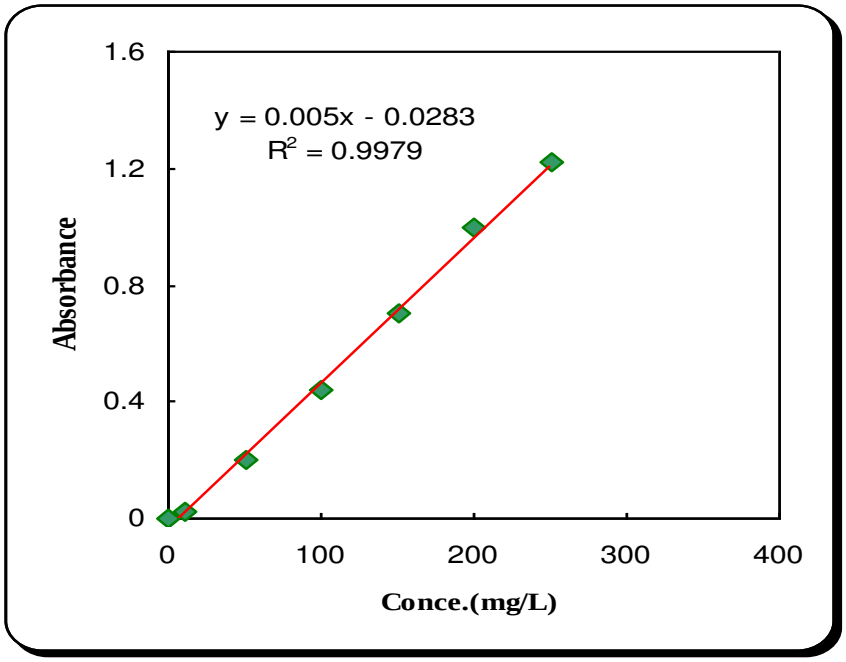



**Figure (2-2): The working calibration curve for the data of Aspirin (the absorbance in *1cm cell ) at* $\lambda$ max 275 nm**

### 2.3.3- Fourier Transform IR Measurements

Hydrogel sample was prepared by grinding the dry hydrogel with KBr and compressing the mixture to form disk by recording Fourier transform infrared (FTIR) spectra on a model 8400S SHIMADZU. The spectra were recorded both before and after the adsorption of drug on hydrogel (**Figure (2-2) and Table (2-2)**).

**Table (2-2): The FTIR of assignment groups of adsorbents**

| Wave number ($cm^{-1}$) | Assignment groups |
|---|---|
| 3494 | N-H Stretching of amide |
| 3178 | Hydrogen bonded |
| 2947 | C-H ($-CH_2$) Stretching |
| 2792 | N-H Stretching |
| 1697 | C=O carbonyl group of acrylamide |
| 1589 | N-H bending |
| 1404 | C-N Stretching |
| 1319 | C-O Stretching in Carbonyl group of amide |
| 1195 | C-C Stretching |
| 1118 | C-H bending alkanes |
| 972 | C-H bending |

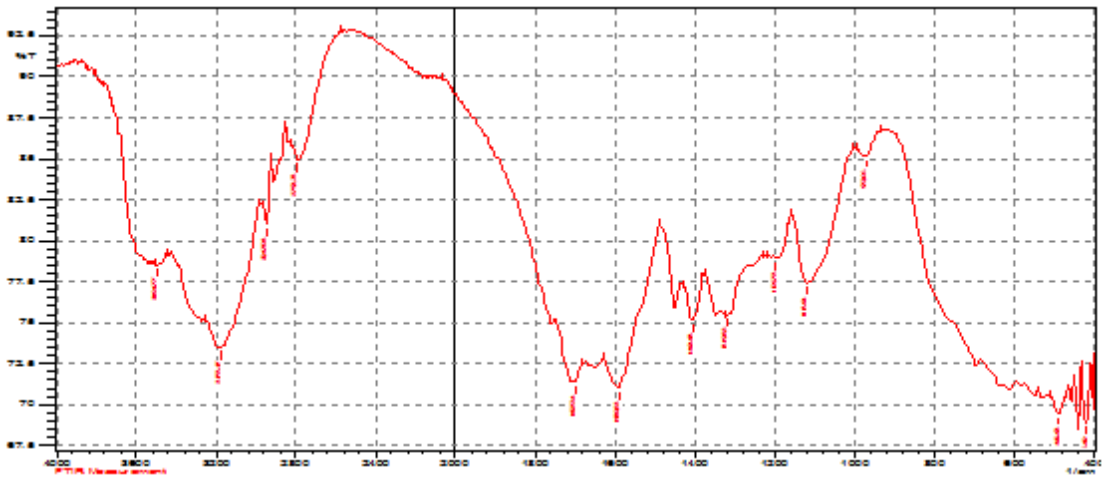


**Figure (2-3): FTIR spectra of adsorbents**

### 2.3.4- Adsorption Isotherm

The adsorption isotherms were determined by shaking 0.05 g of hydrogel into 10 ml drug solutions, having concentrations ranging from 10-250 ppm. After 45 min. of shaking, the suspensions were centrifuged at 3000 rpm for 10 min. The drug concentration was determined spectrophotometrically.

The quantity of Drug adsorbed was calculated according to the following equation [2-1]:-

$$q_e \text{ or } \frac{x}{m} = \frac{V(C_o - C_e)}{m} \quad \text{..... (2-1)}$$

Where:

x : the quantity adsorbed (mg).

m : weight of adsorbent (g).

$C_o$ : initial concentration (mg/L).

$C_e$: equilibrium concentration (mg/ L).

V : volume of solution (L).

### 2.3.5- Effect of Temperature

Adsorption experiment was repeated in the same manner at temperatures of 15, 25 and 37$^o$C to estimate the basic thermodynamic functions.

### 2.3.6- Effect of pH

Adsorption experiment was carried out as mentioned previously as a function of pH (1.2, 4.0, 7.1) using a fixed concentration of Drug. Sodium hydroxide and hydrochloric acid were used to adjust the pH. The pH of the

suspensions at the commencement of the adsorption was measured as well as at the end of experiment using pH-meter.

### 2.3.7- Desorption Experiments

The elution extent of the adsorbate was determined using distilled water as elution media. Solutions of different concentrations of each adsorbate (10 mL) were added to flasks containing 0.05 g of surface. The flasks were placed in a constant temperature bath at $37^{o}$C. After equilibration, the suspensions were centrifuged, and the supernate was decanted carefully and set a side for assay. A 10 ml portion of distilled water was added; after shaking for 60 min, the suspensions were centrifuged. The clear supernate was again decanted and the adsorbate content was determined.

## Results and Discussion

### 3-1- Adsorption Isotherm

The adsorption of Drug from aqueous solution onto hydrogel has been studies at different temperature (15 , 25 and 37$^{o}$C). The adsorption isotherm of drug is given in Figure (3-1).

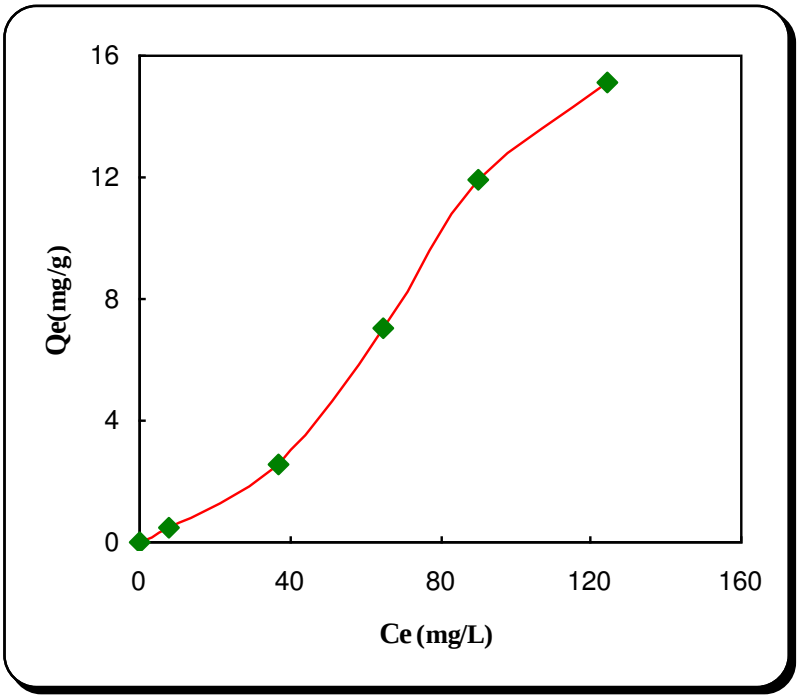



**Figure (3-1): Adsorption isotherm of Aspirin onto hydrogel at 15 $^{o}$C**

The adsorption efficiency and effectiveness of hydrogel surface increase with increasing initial drug concentration [27]. The capacity of adsorption depends on several parameters such as the specific surface area, the expansible character [28]. The shape of drug isotherm can be considered as S-type according to Giles classification [29]. The S-type isotherm depends upon the Freundlich

assumption about the heterogeneity of the surface. The presence of various planes leads to heterogeneous adsorption behaviour. Heterogeneity is a usual and a general feature of surface properties due to different unsaturated adsorption sites of different energetic behaviour [30] .

The equilibrium removal of drug can be mathematically expressed in terms of adsorption isotherm. The Langmuir and Freundlich models are the most frequently employed models to describe the experimental data of adsorption isotherms. The Freundlich equation was developed mainly to allow for an empirical account of the variation in adsorption heat with concentration of an adsorbate (vapor or solute) on an energetically heterogeneous surface **[31]**. It has the general form:

$Q_e$ or $\frac{x}{m} = kC_e^{1/n}$ ……. (3-1)

Where $Q_e$ is the amount adsorbed per unit mass of the solid (adsorbent), $C_e$ is the vapor or solute concentration at equilibrium, k is the Freundlich constant, equal to adsorption capacity at $C_e = 1$; and n is an exponent related to the intrinsic heat of solute adsorption [32].

The drug sorption isotherm followed the linearized Freundlich model as shown in Figure (3-2).

$$\log Q_e = \log k + \frac{1}{n}\log C_e \quad \text{……..} \quad (3\text{-}2)$$

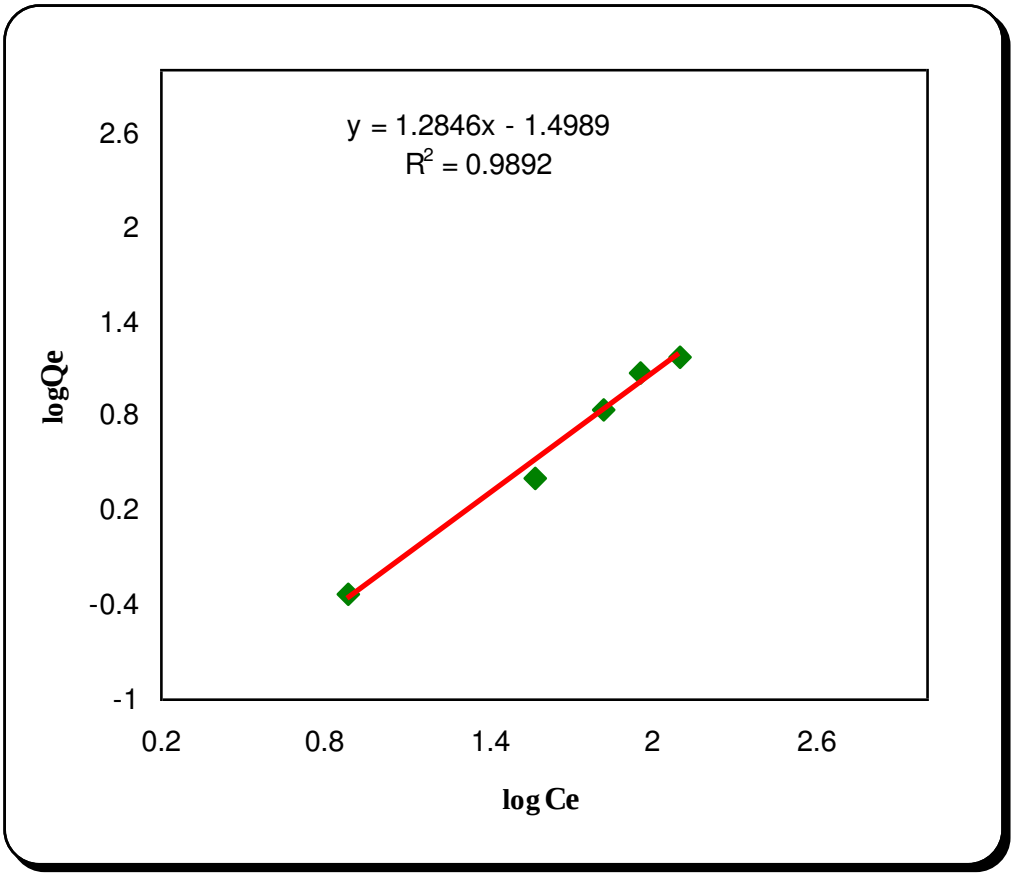



**Figure (3-2) linear form of Freundlich isotherm of Aspirin on Hydrogel**

Figure (3-2) shows the linear relationship of **$\log Q_e$** versus **$\log C_e$**. The values of Freundlich constants as well as the correlation coefficient are presented in Table (3-1). The isotherm data fit the Freundlich model well as indicated from the value of correlation coefficient [33].

**Table (3-1): Freundlich constants for the adsorption of Aspirin on hydrogel**

| n | $K_f$ | r |
|---|---|---|
| 0.8656 | 0.4457 | 0.9892 |

### 3-2- Effect of Temperature

Figure (3-3) shows the effect of temperature on the adsorption of drug, in the range of (15, 25 and 37) $^{o}$C.

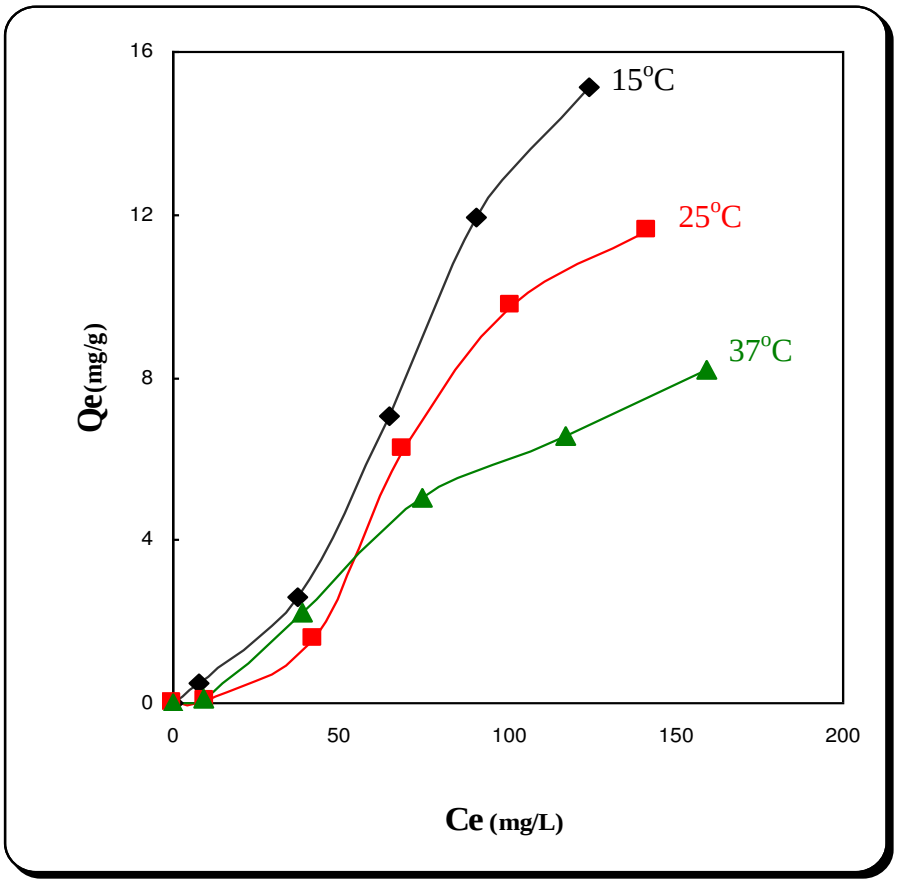



**Figure (3-3): Adsorption isotherms of Aspirin on hydrogel at different temperatures**

The adsorption capacity of the hydrogel increased with increasing of the temperature from 15 to 37$^{o}$C. It is found that the higher temperature is to the advantage of adsorption and that the adsorption is an endothermic reaction.

The thermodynamic treatment of adsorption enables interesting information to be obtained about the magnitude of the bond strength, randomity and spontaneity of the adsorption process. The thermodynamic functions which characteristics adsorption from solution may be determined by measuring

adsorption isotherms at different temperatures in systems exhibiting reversible behavior. An essential prerequisite of adsorption studies at different temperatures (which results in calculation of thermodynamic data and their interpretation) is obviously the consideration of variations of solution density, variations of the solubility of substances with temperature, etc. [34].

One of the foremost tasks of adsorption thermodynamics is the analysis of heat effects which accompany adsorption. The heat change which occurs when a solution is brought into contact with a solid is not as simple to consider as the heat of adsorption evolved when a single gas is adsorbed by a solid. The heat of adsorption from solution is usually several times smaller than that on the same adsorbent from a gaseous phase [35,36], it can be obtained from the measurements of the concentrations required to produce a given amount of adsorption at different temperatures. So, the heat of adsorption ($\Delta H$) could be determined from the equation:

$$\ln X_m = \frac{-\Delta H}{RT} + \text{Constant} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (3\text{-}3)$$

Where $X_m$ is the maximum uptake of adsorption at a certain value of the equilibrium concentration ($C_e$) that was taken identical for all temperatures of study.

Thus, a plot $\ln X_m$ against 1/T gives a straight line with slope equal to $-\Delta H/R$.

In adsorption from solutions, equilibrium is established more slowly than in adsorption from the gas phase. The equilibrium constant (K) for the adsorption process at each temperature was calculated from the equation [37]:

$$K = \frac{Q_e \times m(g)}{C_e \times V(L)} \quad \text{…… (3-4)}$$

Where:

$q_e$: amount adsorbed in $mg.g^{-1}$.

$C_e$: equilibrium concentration of the adsorbate expressed in $mg.L^{-1}$.

m: weight of adsorbent (g)

V: volume of adsorbate solution (L).

The change in free energy (ΔG) can be calculated from the equation [58]:

$$\Delta G = -RT\ln K \quad \text{…… (3-5)}$$

Where R is the gas constant (8.314 $J.mol^{-1}.K^{-1}$) and T is the absolute temperature.

The change in entropy (ΔS) may be obtained from Gibbs equation:

$$\Delta G = \Delta H - T.\Delta S \quad \text{…… (3-6)}$$

$$\therefore \Delta S = \frac{\Delta H - \Delta G}{T} \quad \text{…… (3-7)}$$

Alternatively, ΔH and ΔS can be calculated according to the following considerations:

$$\ln K = -\frac{\Delta G}{RT} \qquad \text{…… (3-8)}$$

Substituting ΔG from equation (3-6), then:

$$\ln K = -\frac{\Delta H - T.\Delta S}{RT}$$

$$\ln K = -\frac{\Delta H}{RT} + \frac{\Delta S}{R} \qquad \text{…… (3-9)}$$

Thus, plotting ln K versus 1/T a straight line is obtained with a slope of $-\Delta H / R$ and an intercept $\Delta S / R$, $\Delta G$ can be estimated from Gibbs equation.

Table (**3-2**) and Figure (**3-4**) demonstrate these calculations. Table (**3-3**) shows the calculated values of the thermodynamic parameters for the Drug adsorption onto hydrogel [38].

**Table (3-2): Effect of temperature on the maximum adsorbed quantity for adsorption of Aspirin on hydrogel**

| **T**(k) | $10^3$/**T**($k^{-1}$) | $\mathbf{X_m}$(mg/g) | $\mathbf{ln_{(}X_{m)}}$ |
|---|---|---|---|
| | | **Ce = 124.4** | |
| 288 | 3.472 | 15.1 | 2.715 |
| 298 | 3.355 | 10.9 | 2.389 |
| 310 | 3.225 | 6.9 | 1,932 |

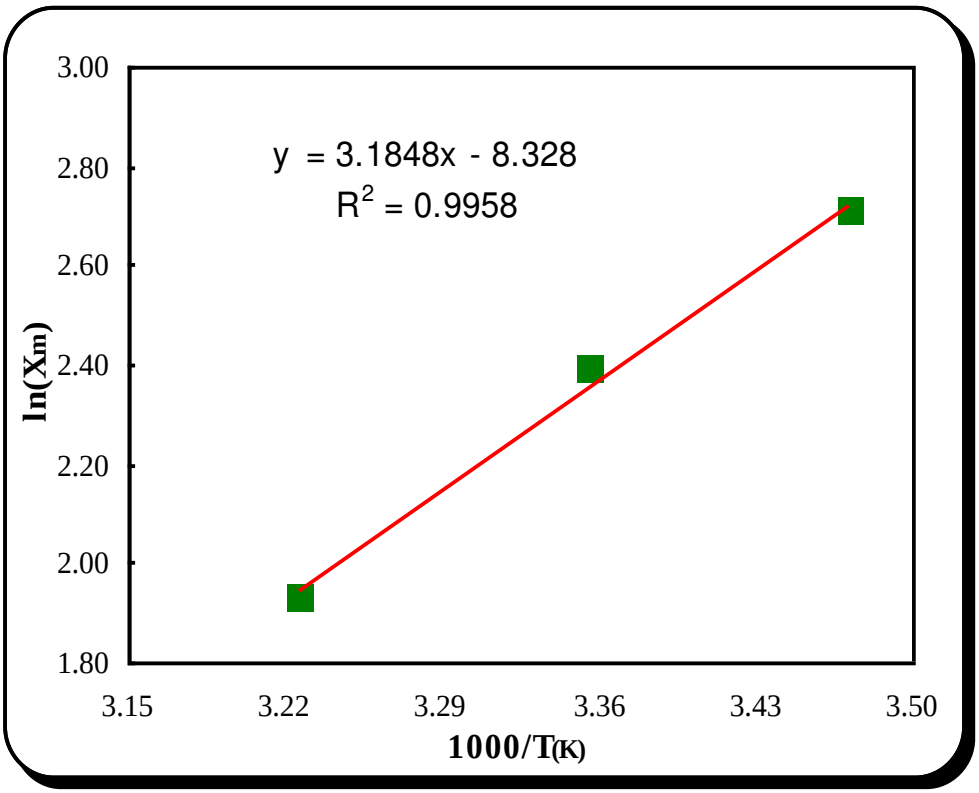



**Figure (3-4): Plot of ln Xm against reciprocal absolute temperature for adsorption of Aspirin onto hydrogel**

The value of ΔH indicates endothermic adsorption process. One possible explanation of the exothermicity of heats of adsorption is that drugs and the surface are both solvated in water. In order for the drugs to be adsorbed, they have to lose part of their hydration shell. The dehydration processes of the drugs and the adsorbent surface require energy [39]. So, the dehydration processes supersede the exothermicity of the adsorption processes. The negative ΔS values, as well as the very small negative ΔG values have also been considered as the consequence of the diffusion of the drug into the chemical structure of the adsorbent.

**Table (3-3): Values of thermodynamic functions of adsorption process of Aspirin on Hydrogel**

| T($^{o}$C) | K | ΔS (J.mol$^{-1}$.k$^{-1}$) | ΔG (kJ.mol$^{-1}$) | ΔH (KJ.mol$^{-1}$) |
|---|---|---|---|---|
| 15 | 1.752 | -84.598 | -0.253 | -26.478 |

## 3-3-Effect of pH

The effect of the initial pH of the Drug solution on the amount of drug adsorbed was studied by varying the initial pH (1.2, 4.0 and 7.2) at constant process parameters. An increase in initial pH increase the amount of drug adsorbed as indicated form results in Figure (**3-5**).

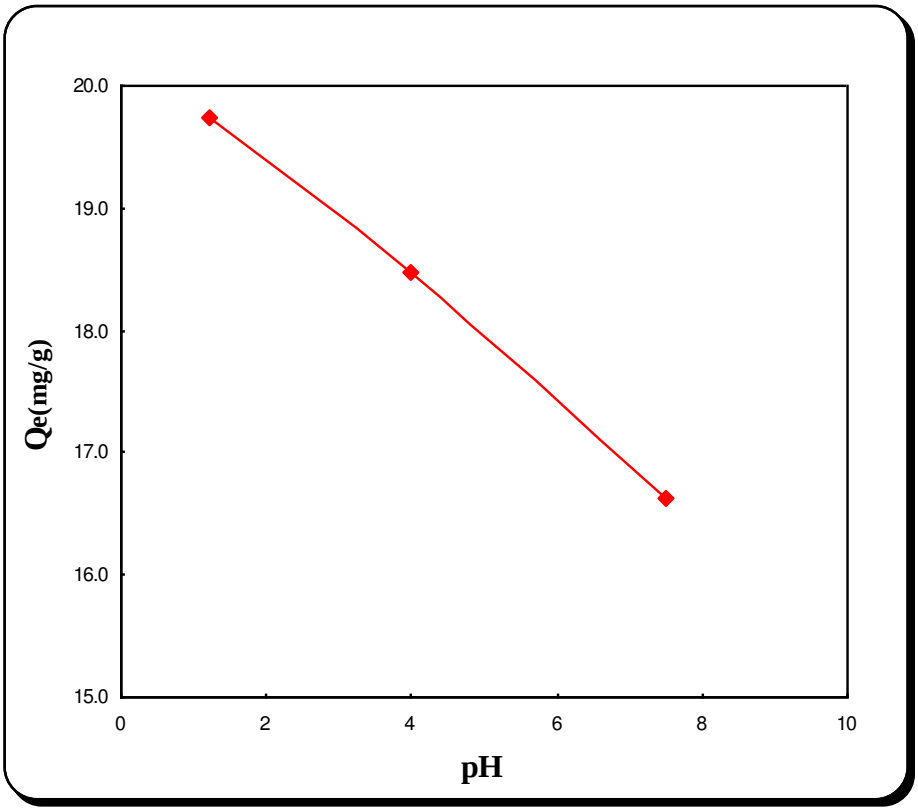



**Figure (3-5): Effect of pH in adsorption uptake of Aspirin on hydrogel at 20$^{o}$C**

The nature of the solid surface as well as that of the solute and solvent may be altered by change in pH. The solution pH affects the surface charge of the adsorbent and, therefore, the adsorption process through dissociation of functional groups, via, surface oxygen complexes of basic character ( such as carbonyl and phenolic groups) or of basic character on the active sites of the adsorbent [40].

### *3-4-Releasing Process*

An adsorbed species present on a surface at low temperatures may remain almost indefinitely in that state. As the temperature of the substrate is increased, however, there will come a point at which the thermal energy of the adsorbed species is such that one of several things may occur:

1- A molecular species may decompose to yield either gas phase products or other surface species.

2- An atomic adsorbate may react with the substrate to yield a specific surface compound or diffuse into the bulk of the underlying solid.

3- The species may desorb from the surface and return into the original state.

The last of these options is the desorption process. In the absence of decomposition, the desorbing species will generally be the same as that originally adsorbed but this is not necessarily always the case [41].

The desorption process in solution may be affected by several factors such as the nature of adsorbate and adsorbent surface, temperature, pH of solution, and the nature of solvent [42] . If a better solvent is used, or a strongly competitive adsorbate, then desorption can be rapid and complete [43]. Desorption process is important in surface area determination of solid surfaces [44].

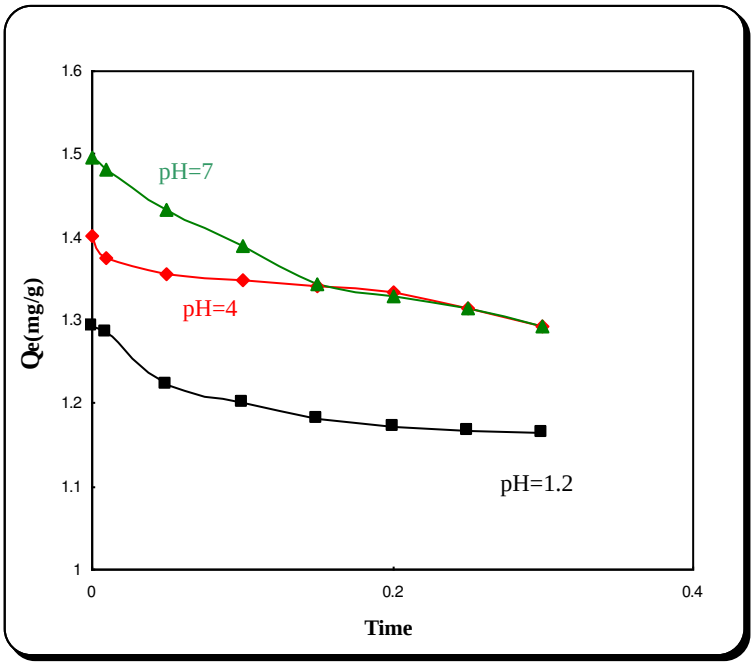



**Figure (3-6): Releasing of drug from hydrogel as a function of amount adsorbed at 37°C**

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