1.0 Introduction

Pharmaceuticals have become chemicals of emerging concern to the public because of their potential to reach drinking-water. Therefore, it is necessary to develop an efficient method for the removal of drugs in waste waters [1]. During the last decade, there is a significant amount of research focusing on the removal of pharmaceuticals from wastewaters. Many investigations have studied the economic feasibility of using inexpensive alternative methods for the removal of pharmaceuticals such as chemical oxidation [2], photocatalytic degradation [3] and adsorption [4-6] from wastewaters [7]. In the present investigation adsorptive removal of ranitidine over nano talc has been studied. Ranitidine is classified as a drug of high environmental concern due to its occurrence in a variety of aquatic environments. Ranitidine inhibits the action of histamine on the H2-receptors of parietal cells and reduces the gastric acid secretion under daytime and nocturnal basal conditions. It is widely prescribed for the treatment of peptic ulcer, reflux oesophagitis and dyspepsia [8]. It has identified in effluents, in several water treatment plants with a mean concentration. Investigations demonstrate that even under ideal conditions, the ranitidine is only partially biodegradable with an efficiency of 71% of degradation within 28 days. As a consequence, ranitidine is not biodegradable in water treatment plants, with accumulation on water surfaces, where sunlight can change partially its structure, which can generate persistent and toxic photoproducts [9], in the present studies preliminary investigations were carried out by batch adsorption to examine the effects of pH, adsorbate concentration, adsorbent dosage, contact time, and temperature. A plausible mechanism for the ongoing adsorption process and thermodynamic parameters were also obtained from Langmuir, Freundlich, Dubinin-Radushkevich and Tempkin adsorption isotherm models. Thermodynamic parameters
Chapter 6: Adsorptive removal of ranitidine

showed that the sorption process of ranitidine onto Nano Talc was feasible, spontaneous and endothermic under studied experimental conditions.

2.0 Experimental

Ranitidine hydrochloride \([A]\) \(N\-\)2-[[5- ((dimethylamino)methyl)furan-2yl]methyl] sulphonyl] ethyl]- \(N\-'\)methyl-2-nitroethene-1,1-diamine hydrochloride) was purchased from Cadila pharmaceuticals pvt. ltd. with the brand name of aceloc. It is freely soluble in water. Adsorbent Nano talc (NT) was procured from M/s Innovation centre of applied nanotechnology, Pune.

\[ \text{[A]} \]

2.1 Reagents and Solutions

All reagents used in the present work were of analytical grade. PDAB (1%) solution was prepared in ethanol. The stock solution of ranitidine was prepared by dissolving 300 mg of ranitidine in 30 mL of distilled water in 50 mL of volumetric flask. Then 1 mL of concentrated HCL and 5 mL of 1% PDAB was added and the solution is heated at 80°C. A Red coloured solution was obtained and volume was made up to mark with double distilled water. Woking solution of ranitidine (0.25 mg/mL) was prepared from the stock solution with double distilled water.
2.2 Instrumentation

A Systronics model 166 digital spectrophotometer (Systronics Ltd, India) with matched 1-cm quartz cells was used to measure absorbance of the resulting solutions. Sartorius CP224S analytical balance (Gottingen, Germany) and ultra sonic cleaner (Frontline FS 4, Mumbai, India) were used during the study. Measurements of pH of the solutions were carried out on a digital pH meter (DB 1011 India). Scanning electron microscopy was performed using a Zeiss EVO 50 instrument. Powder X-ray diffraction (XRD) measurements were performed on diffractometer system XPERT-PRO X-ray powder diffract meter using a graphite monochromatic with Cu Ka radiation (k = 1.5406 Å).

2.3 Adsorption Studies

All adsorption measurements were carried out through batch technique at 30, 40 and 50℃ and desired pH. In each measurement, 30 mL of the working solution of drug of desired concentration and appropriate amount of adsorbent were taken in a 100mL graduated airtight conical flask and mechanically agitated intermittently, till the equilibrium was established. However, in case of kinetic measurements the flask was shaked only for the desired time period. Adsorbents was now removed from the solution after carefully filtering by Whatmann filter paper (no. 41) and the concentration of the drug was determined on spectrophotometer at $\lambda_{max}$ 470 nm. The percentage removal of drug was calculated using the following relationship:

$$\% \text{ Removal} = \left( \frac{C_o - C_e}{C_o} \right) \times 100$$

(i)

Where, $C_o$ and $C_e$ (both in mg/mL) are the initial drug concentration and the drug concentration at any time respectively.
The amount of the adsorbed drug onto NT was calculated by the initial concentration minus the equilibrium concentration as shown in Eq. (ii)

\[ q_e = (C_0 - C_e) \times \frac{V}{W} \]  (ii)

Where, V is the volume of the solution (L), W is the mass of the adsorbent used (g).

3.0 Results and discussion

3.1 Adsorbent: Nanotalc (NT)

SEM is widely used to study the morphological features and surface characteristics of the adsorbent materials. The NT was analyzed by scanning electron microscope (SEM) as shown in Fig.1. SEM photograph of NT reveals surface texture and porosity. The measured surface area of Nano Talc (NT) is 640 m\(^2\)/g. X-ray diffraction (XRD) pattern at \(2\theta\) ranges between 10°-70° was used to phase characterization. XRD pattern (Fig.2) of Nanotalc exhibits sharp diffraction peak at \(2\theta = 10^\circ\), which indicate that particles are crystalline in nature and the d-spacing 9.16263 and Rel. Int100%.

![Fig.1 Scanning Electron Microscope of Nano Talc](image-url)
3.2 Effect of adsorbent dose

The effect of adsorbent dosage for ranitidine adsorption onto NT has been studied by varying the dose from 0.1 to 0.7 g/L at initial drug concentration 0.25 mg/mL and results are shown in Fig. 3. Results showed a larger adsorption surface causes higher adsorption of drug. It is apparent from (Fig. 3) that the adsorption rate for ranitidine is increased as the amount of adsorbent is increased up to 0.4 g/L. Further increase in the amount of adsorbent shows an almost constant adsorption rate of drug. Therefore 0.4 g/L was taken as an optimum dose for all subsequent analysis. The increase in drug removal with the adsorbent dose can be attributed to increased surface area and the adsorption sites.
3.3 Effects of drug concentration

The uptake of the drug ranitidine was studied over NT in the concentration range 0.1 to 0.4 mg/mL at 30°C. It is apparent that the rate of adsorption was dependent on the concentration of the drug. The amount of adsorption of drug over NT was found to increase with increasing concentration of the adsorbate concentration to 0.25 mg/mL. The increase in the adsorption capacity is probably due to greater interaction between adsorbate and adsorbent. Fig.4 shows typical drug concentration versus amount adsorbed for NT adsorption. It is observed that with increasing concentration of the drug, the percentage removal increases from 30 to 82%. A further increase in drug concentration, adsorption rate of ranitidine is almost constant upto 0.4 mg/mL. Therefore 0.25 mg/mL has been taken as optimum concentration for this experiment.
3.4 Effect of temperature

Adsorption studies were also carried out at different temperatures i.e. 30, 40 and 50°C. The rate of uptake of drug increased with increase in temperature, thereby indicating process to be endothermic in nature. It is apparent that the maximum adsorption occurred at 50°C and adsorption follows the order 30°C<40°C<50°C. This is because the diffusion of drug molecules in the aqueous phase is gradually faster with an increased temperature of adsorption and this thereby promotes the exchange of interaction between the drug molecules and cations on the adsorbent surface. The influence of temperature on ranitidine removal by NT is presented in Fig. 5.
Fig. 5 Effect of temperature for the removal of ranitidine over NT at pH 2.5 and different temperature

3.5 Effect of contact time

The adsorption of the ranitidine at the fixed concentration on NT was studied as a function of the retention time in order to determine the equilibrium time. The extent of removal (in terms of $q_e$) of ranitidine by NT is shown in Fig.6. The adsorption of drug was very fast initially thereafter the adsorption rate levelled off gradually and then attained a more or less constant value (equilibrium). Based on these results, 30 min was taken as the equilibrium time in adsorption experiments.
3.6 Effect of pH

The pH of the solution affects the nature and surface binding property of the adsorbent and is responsible for the interaction of the drug molecules with the adsorbent material. In addition, it has a significant effect on electrostatic charges that are imparted by ionized drug molecules between adsorbent and adsorbate. Experiments carried out at different pH show that there is a change in the percent removal of drug ranitidine over the entire pH range from 6.5 to 12 as shown in Fig.7. It exhibits maximum adsorption of ranitidine for NT at pH 2.5. Hence, all the following investigations were carried out at pH 2.5.
Fig. 7 Effect of pH for the removal of ranitidine over NT at pH 2.5 and 30°C temperature.

4.0 Adsorption isotherm

Successful application of the adsorption technique demands studies based on various adsorptions isotherm models [10]. The adsorption equilibrium indicates how the adsorbate molecules distribute between the liquid phase (solution) and the solid phase (adsorbent) when the adsorption process reaches an equilibrium state. To describe the adsorption equilibrium data of ranitidine on NT, Langmuir and Freundlich, Tempkin and D R isotherm models were used. In order to assess different isotherms and their ability to correlate with experimental results, the theoretical plots from each isotherm have been shown with the experimental data for adsorption of ranitidine on NT at various temperatures from 303 to 323 K.

4.1 Langmuir isotherm

Langmuir isotherm assumes that the surface of any adsorbent material contains a fixed number of active sites and saturation of these active sites stops the
adsorption of the adsorbate. This indicates that the adsorption occurs until a monolayer of adsorption is completed and after completion of adsorption no more interaction between the adsorbent and adsorbate molecules takes place [11]. Langmuir isotherm is expressed as:

$$\frac{1}{q_e} = \frac{1}{Q^\circ} + \frac{1}{bQ^\circ C_e}$$

(iii)

where $q_e$ is the amount adsorbed (mol/g) and $C_e$ is the equilibrium concentration of the adsorbate (mol/l). $Q^\circ$ and $b$ are the Langmuir constants related to maximum adsorption capacity and energy of adsorption, respectively. When $1/q_e$ was plotted against $1/C_e$, a straight line with slope $1/bQ^\circ$ was obtained (Fig. 8) which showed that the adsorption of ranitidine follows Langmuir isotherm. Langmuir constants are calculated and values of these constants at different temperatures are given in (Table 1).

![Langmuir adsorption isotherm for the adsorption of ranitidine over NT at pH 2.5 and different temperatures.](image-url)

**Fig. 8** Langmuir adsorption isotherm for the adsorption of ranitidine over NT at pH 2.5 and different temperatures.
4.2 Freundlich isotherm

Freundlich model is based on the assumption that adsorption occurs on a heterogeneous adsorption surface having unequally available sites with different energies of adsorption [12] and is given by the relation.

\[
\log q_e = \log K_f + \frac{1}{n} \log C_e
\]  

(iv)

Where \( q_e \) is the amount adsorbed (mol/g), \( C_e \) is the equilibrium concentration of adsorbate (mol/L) and \( K_f \) and \( n \) are Freundlich constants related to adsorption capacity and intensity respectively. When \( \log q_e \) is plotted against \( \log C_e \) at three different temperatures, (30, 40, and 50 °C), straight lines with slope \( 1/n \) are obtained (Fig. 9). Straight lines clearly verify the freundlich adsorption isotherm model for the adsorption of ranitidine over NT. Freundlich constants have been presented in Table 2.

---

**Table 1**

<table>
<thead>
<tr>
<th>Temp. (°C)</th>
<th>b (mol g(^{-1}))</th>
<th>( Q^0 ) (L mol(^{-1}))</th>
<th>b( Q^0 )</th>
<th>( R^2 )</th>
<th>%RSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 °C</td>
<td>23.256</td>
<td>0.0109</td>
<td>0.0005</td>
<td>0.963</td>
<td>0.96</td>
</tr>
<tr>
<td>40 °C</td>
<td>10.870</td>
<td>0.0113</td>
<td>0.0001</td>
<td>0.816</td>
<td>0.82</td>
</tr>
<tr>
<td>50 °C</td>
<td>7.092</td>
<td>0.0118</td>
<td>0.0017</td>
<td>0.828</td>
<td>0.92</td>
</tr>
</tbody>
</table>
Chapter 6: Adsorptive removal of ranitidine

**Fig. 9** Freundlich adsorption isotherms for adsorption of the ranitidine over NT at pH 2.5 and different temperatures.

<table>
<thead>
<tr>
<th>Temp (°C)</th>
<th>K\textsubscript{f}</th>
<th>N</th>
<th>R\textsuperscript{2}</th>
<th>%RSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 °C</td>
<td>447.71</td>
<td>8.771</td>
<td>0.881</td>
<td>1.06</td>
</tr>
<tr>
<td>40 °C</td>
<td>641.20</td>
<td>16.393</td>
<td>0.861</td>
<td>0.97</td>
</tr>
<tr>
<td>50 °C</td>
<td>1353.22</td>
<td>8.474</td>
<td>0.854</td>
<td>0.91</td>
</tr>
</tbody>
</table>

**4.3 Tempkin isotherm**

Tempkin isotherm assumes that the heat of adsorption of all the molecules increases linearly with coverage of the adsorbate molecules over adsorbent surface [13]. The linear form of this isotherm can be given by following equation:

\[
q_e = B \ln A + B \ln C_e \tag{v}
\]
where \( RT/bT = B \) (J mol\(^{-1}\)), which is the Tempkin constant related to heat of sorption whereas \( A \) (L g\(^{-1}\)) is the equilibrium binding constant corresponding to the maximum binding energy, \( R \) (8.314 J mol\(^{-1}\) K\(^{-1}\)) is the universal gas constant and \( T \) (K) is the absolute solution temperature.

**Fig. 10** Tempkin adsorption isotherms for adsorption of the ranitidine over NT at pH 2.5 and 30° C.

<table>
<thead>
<tr>
<th>Temp.(°C)</th>
<th>B(J mol(^{-1}))</th>
<th>A (L g(^{-1}))</th>
<th>b</th>
<th>( R^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 °C</td>
<td>3.125</td>
<td>1333.5</td>
<td>314893.0</td>
<td>0.915</td>
</tr>
</tbody>
</table>

**4.4 Dubinin- Radushkevich isotherm**

D-R isotherm is more general because it does not assume a homogenous surface or constant adsorption potential [14]. It was applied to estimate the porosity
apparent free energy and the characteristics of adsorption. The linear form can be represented as:

\[ \ln q_e = \ln q_D - B \varepsilon^2 \]  

(vi)

where, \( B \) is a constant related to the mean free energy of adsorption (mol\(^2\)(kJ\(^2\))\(^{-1}\)), \( q_D \) is the theoretical saturation capacity (mg g\(^{-1}\)), \( \varepsilon \) is the polyani potential, and calculated as follows:

\[ \varepsilon = RT \ln (1+1/C_e) \]  

(vii)

The slope of the plot of \( \ln q_e \) versus \( \varepsilon^2 \) gives \( B \) and the intercept yields the adsorption capacity, \( q_D \). Fig.11 shows D-R plot and the results are given in Table 4. The mean free energy of adsorption (\( E \) (KJmol\(^{-1}\)) is calculated from the equation (viii):

\[ E = \frac{1}{2B}^{0.5} \]  

(viii)

Fig. 11 Dubinin- Radushkevich (D-R) isotherm of ranitidine adsorption over NT at pH 2.5 and different temperatures.
Table 4

D-R constants for the ranitidine over NT

<table>
<thead>
<tr>
<th>Temp. (°C)</th>
<th>B_D</th>
<th>E</th>
<th>q_D</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 °C</td>
<td>467.7</td>
<td>30.87</td>
<td>7.324</td>
<td>0.887</td>
</tr>
<tr>
<td>40 °C</td>
<td>616.0</td>
<td>35.09</td>
<td>5.795</td>
<td>0.846</td>
</tr>
<tr>
<td>50 °C</td>
<td>629.2</td>
<td>35.47</td>
<td>7.710</td>
<td>0.850</td>
</tr>
</tbody>
</table>

5.0 Thermodynamic Studies

To study the thermodynamic aspect of the adsorption process, the studies were carried out at different temperatures from 30° to 50°C. Thermodynamic parameters (ΔH°, ΔS°, and ΔG°) were evaluated by using the following equations:

\[ ΔG° = -RT \ln b \]  
\[ ΔH° = -R \frac{(T_2T_1)}{(T_2 - T_1)} \ln \left( \frac{b_2}{b_1} \right) \]  
\[ ΔS° = \frac{ΔH° - ΔG°}{T} \]

Where, b, b₁, b₂ are the equilibrium constants at different temperatures, which are obtained from the slopes of straight lines from Langmuir adsorption isotherms at different temperatures, R (8.314 JK⁻¹ mol⁻¹) is the universal gas constant and T (K) is the absolute solution temperature. Negative value of ΔG° indicates feasible and spontaneous nature of the ongoing adsorption process. It is also observed that in each case, ΔG° value decreases with the increasing temperature, indicating thereby greater adsorption at higher temperature. Endothermic nature of the process was once again confirmed by the positive values of ΔH° (Table 5).
Chapter 6: Adsorptive removal of ranitidine

Table 5
Thermodynamic parameters of ranitidine over NT

<table>
<thead>
<tr>
<th>Adsorbent</th>
<th>$\Delta G^\circ (\text{kJ mol}^{-1})$</th>
<th>$\Delta H^\circ (\text{kJ mol}^{-1})$</th>
<th>$\Delta S^\circ (\text{J} \text{k}^{-1} \text{mol}^{-1})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>NT</td>
<td>$-18.115 \times 10^3$</td>
<td>$-20.002 \times 10^3$</td>
<td>$-21.772 \times 10^3$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$42.932 \times 10^3$</td>
<td>$42.871$</td>
</tr>
</tbody>
</table>

6.0 Adsorption kinetic studies

6.1 Lagergren kinetic model

Adsorption kinetics relates the adsorption capacity and process time. The kinetic study of the adsorption process was studied with the Lagergren’s pseudo-first order. The first order equation was used under the assumption that the rate of change of solute uptake with time is directly proportional to difference in saturation concentration and the amount of solid uptake with time. The Lagergren’s rate equation is one of the most widely used rate equations to describe the adsorption of adsorbate from the liquid phase. Pseudo-first order rate equation is commonly used to the adsorption of liquid/solid system based on adsorbent capacity. According to this model, one adsorbate species reacts with one active site on surface. The linear form of pseudo first-order rate expression of Lagergren is given as [15]:

$$\log (q_e - q_t) = \log q_e - k_{ad} \times t/2.303$$  \hspace{1cm} (xii)

Where, $q_e$ and $q_t$ are the amounts of ranitidine adsorbed on adsorbent (mg/g) at equilibrium and at time $t$ (min), respectively, and $k_{ad}$ is the rate constant of pseudo first-order kinetics. The plot of $\ln(q_e - q_t)$ versus $t$ as shown in Fig.12, gave the slope of $k_{ad}$.
and intercept of log \( q_e \). Values of \( k_{ad} \) and correlation coefficient, \( R^2 \) obtained from the plots for adsorption of ranitidine on the NT at 30\(^0\)C are given in Table 6. The slope of each straight line gave value of the rate constant, \( k_{ad} \) at that temperature. An increase in values of \( k_{ad} \) further confirms the increase in uptake of drug at increasing temperature. The \( k_{ad} \) values evaluated, for each system, from the respective Lagergren plot are presented in Table 6. The correlation coefficients for the pseudo second order kinetic model are < 0.95, indicating a poor pseudo second order fit to the experimental data.

**Fig. 12** Lagergren pseudo first order plots for adsorption of ranitidine over NT at pH 2.5 and different temperatures.

**Table – 6**

<table>
<thead>
<tr>
<th>Temp ((^\circ)C)</th>
<th>( k_{ad} )</th>
<th>% RSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 (^\circ)C</td>
<td>0.0852</td>
<td>0.988</td>
</tr>
<tr>
<td>40 (^\circ)C</td>
<td>0.0829</td>
<td>0.985</td>
</tr>
<tr>
<td>50 (^\circ)C</td>
<td>0.0713</td>
<td>0.986</td>
</tr>
</tbody>
</table>

# Average of three replicates measurement
6.2 Elovich kinetic model

The Elovich equation was developed to describe the kinetics of chemisorption of gases onto solids [16] and it is expressed as:

\[ q_t = \frac{1}{\beta} \ln(\alpha \beta) + \frac{1}{\beta} \ln(t) \]  

(xiii)

Where \( \alpha \) (mg g\(^{-1}\) min\(^{-1}\)) is the initial sorption rate and the parameter \( \beta \) (g mg\(^{-1}\)) is related to the extent of surface coverage and activation energy for chemisorption. The kinetic results are linear on a \( q_t \) versus \( \ln(t) \) plot (Fig. 13), Elovich plot of \( \ln(t) \) vs \( q_t \) gives a linear relationship. The high correlation coefficient shows the effectiveness of the Elovich model. The Elovich equation data obtained in this study for ranitidine adsorption with NT are given in Table 7.

**Fig. 13** Elovich model plot for ranitidine adsorption over NT at pH 2.5 and 30° C temperature.

<table>
<thead>
<tr>
<th>Temp. (°C)</th>
<th>( \alpha ) (mg g(^{-1}) min(^{-1}))</th>
<th>( \beta ) (gmg(^{-1}))</th>
<th>( R^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>0.615</td>
<td>4.694</td>
<td>0.943</td>
</tr>
</tbody>
</table>
7.0 Adsorption diffusion model

7.1 Intraparticle diffusion model

Kinetic data were further analyzed using the intraparticle diffusion model [17]. The above kinetic models were not able to identify the diffusion mechanism, thus this model was proposed. It is an empirical model that describes drug uptake and varies almost proportionally with $t^{1/2}$ rather than with the contact time, $t$:

$$q_t = k_{id}t^{1/2} + C$$

Where $k_{id}$ (mg g$^{-1}$ min$^{1/2}$), the rate parameter of stage i, is obtained from the slope of the straight line of $q_t$ versus $t^{1/2}$. $C$ is the intercept which is proportional to the extent of boundary layer thickness.

![Fig.14 Intraparticle diffusion plots of adsorption the ranitidine over NT at different temperatures](image)

Fig.14 Intraparticle diffusion plots of adsorption the ranitidine over NT at different temperatures
Chapter 6: Adsorptive removal of ranitidine

Table 8

Intraparticle diffusion coefficients and intercept values for adsorption of the ranitidine over NT at different temperatures

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>k_{dif}</th>
<th>C</th>
<th>R^2</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>0.004</td>
<td>0.007</td>
<td>0.986</td>
</tr>
<tr>
<td>40</td>
<td>0.005</td>
<td>0.08</td>
<td>0.990</td>
</tr>
<tr>
<td>50</td>
<td>0.005</td>
<td>0.010</td>
<td>0.985</td>
</tr>
</tbody>
</table>

8.0 Conclusion

The present work is an attempt to develop a versatile and reliable method for the removal of drug ranitidine from waste water. The present study offer major advantage where Nano talc (NT) was used without any previous activation treatment which decreases adsorption coast. In view of all findings, it may be concluded that the adsorbent is very useful for the removal of ranitidine. This system can be used for the removal of ranitidine from waste water and any other effluent. The adsorption characteristics of ranitidine onto NT were evaluated in terms of equilibrium, kinetics, and thermodynamic parameters. A pseudo first order kinetic model agreed well with the dynamic behaviour of adsorption of ranitidine onto the NT under different temperature, consist with chemisorptions being rate limiting step. The adsorption data also confirm the validity of Langmuir, Freundlich, Dubinin-Radushkevich and Tempkin adsorption isotherm models.
9.0 Reference


