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Batch biosorption studies of tetracycline hydrochloride onto unmodified rice straw: Equilibrium, Kinetic and Thermodynamic studies

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Abstract: Antibiotics are the most widely used products in healthcare sector, with tetracycline among the most commonly prescribed antibiotics, in both human and animal welfare. Due to unregulated use, resistance to these antibiotics is becoming widespread, which renders the antibiotics useless. Thus, it is necessary to treat the effluents from pharmaceutical industries efficiently. The objective of this work was to test rice straw (unmodified, URS) as a low-cost adsorbent for biosorption of tetracycline hydrochloride. Batch experiments were carried out to test the sorption process of tetracycline hydrochloride onto acid-treated rice straw from synthetic tetracycline hydrochloride solutions. The data was analyzed models that fit the data well, to find the kinetics, adsorption isotherms, and thermodynamic equations to find the biosorption capacity, reaction mechanism, rate of the reaction, heat of adsorption, etc. of the process. The results show that the adsorption of tetracycline hydrochloride onto rice straw was a chemisorption reaction, following first order reaction mechanism. The data fits Langmuir isotherm model. Thus, rice straw was found to be a good adsorbent for the biosorption of tetracycline hydrochloride.
Keywords: Tetracycline hydrochloride, biosorption, hospital effluent treatment, isotherm, rice straw, kinetic modelling ,thermodynamics.

1. Introduction

Pharmaceutical industries are involved in the production of various healthcare products- antibiotics, hormones, vitamins, vaccines, growth factors, proteins, cosmetic products, cell cultures etc. Antibiotics are compounds of natural (microbial), semi-synthetic or synthetic origin that kill or inhibit the growth of one or more microorganisms. Although substances with antimicrobial properties have been in use for over many centuries, the compound(s) that were responsible for the effect remained unknown till the early 20th century, when penicillin was accidentally discovered by Sir Alexander Fleming in 1928 [1-2]. Since the discovery of antibiotics, the medical field has seen astronomical developments and the quality as well as life-span of humans and animals has been greatly improved [3].

Tetracyclines (TETs) are a family of broad-spectrum antibiotics produced by some Streptomyces bacteria. The era of tetracyclines began with the discovery of Aueromycin (Chlortetracycline) by Benjamin Duggar in 1948 [4] and their general structure was first resolved by the Woodward group in 1953 [5] (Fig 1). Their antibiotic property may be either bacteriostatic (Bind to bacterial 30 S ribosome and inhibiting protein synthesis) [6] or bactericidal (by the disruption of cytoplasmic membrane) [7-9]

The antibiotic's effect was so overwhelming that even as early as 1949, several clinical studies were carried out to test the antibiotic capacity of aueromycin for the treatment of more than 25 different infections like Gonorrhoea, Typhus fever, etc. [10], and FDA approval was obtained in 1951. TETs were eventually used

to treat a number of microbial infections [11] as prophylactic agents [12-13], to control Mycoplasma contamination in tissue cultures, etc.

TETs are also known to possess non-antibiotic properties such as inhibition of inflammation, proteolysis, angiogenesis, apoptosis, metal ion chelation, bone metabolism, anti-cancer activity, regulation of gene expression etc. [14]. Sub-therapeutic doses of TETs are used as animal growth factors to improve feed efficiency and to enhance growth. [15-16]. TETs are some of the most commonly used antibiotics. A study revealed that more than 2500 tonnes of TET is used annually for veterinary purposes alone in Europe [17].Due to widespread and unregulated use; many susceptible microbes began showing increased resistance to the natural TETs [13]. Hence semi-synthetic and synthetic TETs have been developed with additional advantages like longer action and shelf-life [18] Antibiotics are some of the pharmaceutically active compounds that find their way into the environment, polluting water and soil. [19-21]. Most of the antibiotics used are not totally metabolized in living systems, and thus are excreted as active compounds [22] ,50-80 % of TETs are recoverable from patients as parent compound from urine [23].

TETs are frequently detected in wastewater in the concentration range of 0.1 to 1.0 µg/L [24-26]. The presence of TETs has been reported in wastewater treatment plant effluents and influents [27], ground water [28-29], drinking water [30] and soil [31].

Once excreted from the organism, TETs are subjected to a number of natural and engineered processes, which result in the transformation of parent compounds to degradation products. Some processes include sorption, biotic and abiotic transformation reactions [22] .The presence of antibiotics in the environment can cause a number of complications, like the spread of bacterial antibiotic resistance, elimination of trophic levels of bacteria leading to a change in the microflora, damage to the aquatic life and plants, side effects of the antibiotic by accidental human consumption, etc. [32-36]. Bacterial resistance refers to the phenomenon where a previously susceptible microorganism becomes unaffected or resistant to an antibiotic. Although resistance can spread naturally, unrestricted-often unnecessary-use of antibiotics and improper effluent treatment contribute to rapid spread of bacterial resistance. The use of TETs in clinical practice has been responsible for the selection of resistant organisms, now rendering the drug useless [13] .The impact of antibiotic resistance is not yet fully appreciated [37]. If bacterial resistance renders an antibiotics useless for further treatment regimes, other antibiotics are used. This leads to the development of multiple-drug resistant forms, like the case of Methicillin resistant *Staphylococcus aureus* (MRSA), which are virtually resistant to almost all known antibiotics, and hence infections cannot be treated in the future. Also, other people around the infected individual are also likely to acquire resistant pathogens, especially in hospitals [38]. Recent surveys show that the number of casualties connected with drug-resistant microbes is on the rise [39]. The resistance to TET is also on the rise, severely curbing the effectiveness of these antibiotics. The genes responsible for TET resistance are designated *tet* genes. Currently over 40 *tet* genes have been discovered and characterized. The resistant genes can spread among bacteria in the environment, producing resistance in many species of bacteria of the locality [13].Bacterial resistance to antibiotics not only affects health but also renders antibiotics useless, extends the treatment period, increases the cost for cure and affects economy as well [40]. Proper effluent treatment can effectively remove antibiotics in effluents.

Conventional effluent treatment processes, except adsorption and degradation, do not successfully remove antibiotics. However, processes are economically taxing to the industries right now due to the cost of adsorbents and the non-feasibility of degradation process. Researches are being carried out to find alternative materials for adsorbents, and bio-materials have been found to have more potential in this aspect. Biosorption refers to the binding of adsorbates (solutes in a solution) to biomass [41]. The removal of TETs by adsorption has been tested by several groups of researchers [42-43], [25]. However the cost of adsorbent has prevented the implementation of these processes in real-time effluent treatment. Rice straw is a residue of the agricultural industry, with more than 620 million tonnes produced in Asia alone. It is used as a feed for cattle. It is also used in the production of activated charcoal, which is later used for adsorption in water treatment plants. Rice straw-derived charcoal has been shown to adsorb lead [44], 2-chlorophenol [45] phenol [46], etc. However the cost of activated charcoal is quite high due to the need for processing (at high temperature and pressure).

Recent research has been focussed to use straw directly for effluent treatment process, especially heavy metals [47]. This process will be economically feasible for industries, as it will cut down the processing cost of the adsorbent.

The current paper discusses the use of unmodified dried rice straw (from paddy crop) to adsorb tetracycline hydrochloride (TC-HCl) in batch mode under various conditions from synthetic effluents prepared in laboratory, and, the results and conclusions obtained from the experiments were discussed.

2. Materials and Methods

2.1. Chemicals

All reagents used were of analytical grade. Sodium molybdate ($NaMoO_4.2H_2O$, MW. 241.95), was purchased from SISCO research laboratories Pvt. Ltd., Mumbai and hydrochloric acid (HCl, MW. 36.45) from Merck ltd., Mumbai. Tetracycline hydrochloride (TC-HCl) was used from commercially available tetracycline hydrochloride capsules (Resteclin 250) obtained from Abbott healthcare Pvt. Ltd., Dilutions were done using distilled water.

2.2 Biosorbent: Collection and Processing

The biosorbent material used was unmodified rice straw (URS), collected from a paddy field near Chennai, Tamilnadu, India.The sample was ground using a blender and sieved to get uniform sized particles. The URS was first washed with water (to remove particulate impurities like dirt), then soaked in hydrochloric acid (3%) for 24 hours (for opening up the pores) rinsed with water and dried in hot air oven at 100^{o}C for 2 hours. After cooling, it was packed in zip-lock covers and stored in airtight containers.

2.3 Characterization of URS

URS was characterized by BET analysis using QuadraSorb analyzer with nitrogen gas as the adsorbate, to find the surface area, pore size and pore volume of the biosorbent.

2.4 Analysis of Tetracycline hydrochloride concentration in solution

TC-HCl concentration in solution was analyzed using UV-VIS spectrophotometer (Elico) by the method proposed by Salah M. Sultan [48]

2.5 Biosorption studies

Batch biosorption of TC-HCl were carried out using URS. All processes were carried out with a solution volume of 120 mL in Erlenmeyer flasks incubated in a shaker at a constant agitation speed of 150 rpm. The experiments were done in triplicates and the mean of the values were used for analysis. The data was analyzed to find the various properties like biosorption kinetics, adsorption isotherms, reaction mechanism, transport mechanism, adsorption capacity, etc. of the process, and the coefficient of linear regression (R^2) was used as a measure to compare the validity of each equation to fit the experimental data.

2.6 Biosorption kinetics

20 mg of the biosorbent was kept in contact with TC-HCl solution (20 μg/mL concentration) and incubated. Samples were withdrawn at fixed time intervals and the residual TC-HCl concentration in the solution was determined. The experiment was carried out for 4 hours. The time required for the process to attain equilibrium was found from a plot of concentration of TC-HCl in solution versus time (effect of contact time). Equilibrium is said to occur when the concentration of the solution remains unchanged with respect to time due to saturation of adsorption sites or if the concentrations of TC-HCl in solution and adsorbent becomes equal.

2.7 Biosorption equilibrium studies

Biosorption equilibrium studies can be used to determine several properties of the biosorption process such as removal efficiency, isotherms and biosorption capacity. Seven different concentrations (0-120 μg/mL) of TC-HCl solution were mixed with 20 mg of biosorbent each and incubated in a shaker. The equilibrium solution concentrations were determined and plots were generated to show the effect of initial concentration on adsorption equilibrium (equilibrium time was found from kinetic experiments previously).

3. Data analysis

3.1 Removal efficiency

Removal percentage (also, biosorption percentage) is an indicator of efficiency of the biosorption process. It is given by the formula

$$Removal\ efficiency\ (\%) = \frac{C_0 - C_f}{C_0}\ x\ 100 \qquad \ldots(1)$$

3.2 Biosorption capacity

Biosorption capacity (q) is defined as the amount of adsorbate (TC-HCl) adsorbed per gram of biosorbent used. Equilibrium adsorption capacity, (q_e) is the adsorption capacity calculated under equilibrium conditions (i.e. when no further biosorption is possible). It was calculated using the initial and equilibrium concentrations of the solutions with the equation proposed by Vanderborght and Van Grieken [49]

$$q = \frac{(C_0 - C_f)V}{m} \qquad \ldots(2)$$

$$q_e = \frac{(C_0 - C_e)V}{m} \qquad \ldots(3)$$

i.e. ($q=q_e$ when $C_f=C_e$)

where V is the volume ,m is the mass and q_e can be used as a parameter to compare biosorption by different biosorbents and at varying process conditions.

3.3 Kinetic models for biosorption

3.3.1 Reaction Mechanisms

Reaction models give an insight into the kinetic mechanism of the process [50]. Some of the most common reaction models for adsorption as mentioned in Table 1 were used to analyze the data from the experiments, and the mechanism that fits best was determined.

Table 1 Reaction mechanisms for the kinetic analysis of the biosorption process

Reaction model	Linearized form	Plot
1st order	$-\ln(C/C_0)=k_1t$	$[-\ln(C/C_0)]$ versus t
Pseudo-1st order (Lagergren's equation)	$\log(q_e-q_t)=\log q_e - (k_{11}t/2.303)$	$\log(q_e-q_t)$ versus t
Pseudo 2nd order	$1/(q_e-q_t) = (1/q) + k_{12}t$	(t/q_t) versus t
Saturation model (mixed order)	$(1/t)\ln(C_0/C_t) = -(k_0/k_{sat}) - (1/k_{sat})(C_0-C_t)/t$	$(1/t)\ln(C_0/C_t)$ versus $(C_0-C_t)/t$

3.3.2 Diffusion models

Diffusion or transport models are also used to model the kinetics of adsorption involving mass transfer [51]. Some models include Elovich and Weber-Moris equations, as given in Table 2.

Table 2 Diffusion models for kinetic analysis of the biosorption process

Model	Linearized form	Plot
Elovich equation	$q_e = (1/\tau)\ln(a\tau) + (1/\tau)\ln t$	q_e versus ln t
Weber-Moris model	$q_e = R_{id}(t)^{(1/2)}$	q_e versus $(t)^{(1/2)}$

3.4 Biosorption isotherm experiment and modelling

Isotherms are empirical relationships used to predict the sorption mechanism, to estimate and compare the performance between different biosorbents, to predict various parameters and to find which model fits the experimental data well. These are generated from biosorption data that are specific to each system (even changes in any of the parameters such as temperature, time, pressure etc. Can affect the process) and must be estimated separately for each system [52-53]. The isotherm of the adsorption process was analyzed using the adsorption equilibrium data, with some isotherm models mentioned in Table 3.

Table 3 Isotherm modelling for biosorption process

Isotherm	Empirical form	Linearized form	Plot
Freundlich	$(x/m)=k_F C_e^{(1/n)}$	$\log (x/m) = \log k_F + (1/n) \log C_e$	$\log (x/m)$ versus $\log C_e$
Langmuir	$q_e=(q_m k_L C_e)/[1+(k_L C_e)]$	$(C_e/q_e)=(1/q_m k_L)+(C_e/q_m)$	(C_e/q_e) versus C_e
Temkin	$q_e=(RT/b) \ln (A_T C_e)$	$q_e = B \ln A_T + B \ln C_e$ with $B=(RT/b)$	q_e versus $\ln C_e$
Dubinin-Radushkevich	$q_e=q_{DR} \exp\{-B_D[RT\ln (1+(1/C_e))]^2\}$	$q_e=q_{DR} \exp(-\gamma\varepsilon^2)$ with $\varepsilon = RT\ln(1+(1/C_e))$	$\ln q_e$ versus $\ln \varepsilon^2$

3.4.1 Freundlich adsorption isotherm

Freundlich adsorption isotherm is an empirical relationship between the amount of an adsorbate adsorbed per unit weight of adsorbent (x/m) and the adsorbate equilibrium concentration (C_e) [54]. It is used to describe adsorpion onto heterogeneous surfaces as well as multilayer adsorption [55-56]. It assumes an exponentially decaying sorption site energy distribution and is applicable for physical adsorption [57].

The constants k_F and n are constants that are characteristic of the particular adsorbent-adsorbate system. The constant k_F is an approximate indicator of adsorption capacity while (1/n) is an indicator of adsorption strength or intensity. Table 4 shows the significance of n value [56].

Table 4 Significance of n value in Freundlich isotherm

Value	Indicates following conditions
(1/n)=1	Partition between the 2 phases is independent
(1/n)>1	Cooperative adsorption
(1/n)<1	Normal adsorption
1 < n <10	Favourable adsorption process

3.4.2 Langmuir adsorption isotherm

Langmuir adsorption isotherm is considered the most common isotherm in any type of adsorption system with monolayer adsorption [55, 58]. It describes quantitatively the formation of a monolayer adsorption on the adsorbent surface, after which no further adsorption can take place. Hence, Langmuir adsorption isotherm describes equilibrium distribution of adsorbate between the solution and adsorbent [56]. The essential features of Langmuir can be represented by separation factor (R_L), a dimensionless constant derived from Langmuir adsorption isotherm that can be used to predict whether a batch adsorption process is favourable or not [59]. It is calculated using the formula

$$R_L=1/(1+k_L C_0) \quad \ldots(4)$$

Where, k_L is the Langmuir constant (mL/mg) and C_0 is the initial concentration (μg/mL). The Table 5 shows the type of isotherm with respect to R_L values.

Table 5 R_L value and its significance

Value	Type of isotherm
$R_L=0$	Irreversible
$R_L=1$	Linear
$R_L>1$	Unfavourable
$0<R_L<1$	Favourable

3.4.3 Temkin adsorption isotherm

Temkin isotherm assumes that the fall in heat of adsorption is linear rather than logarithmic [60-61].

3.4.4 Dubinin-Radushkevich isotherm

This is an empirical model applied to express adsorption mechanism with a Gaussian energy distribution onto a heterogeneous surface. It is temperature dependent [62-64].This model is generally applied to distinguish physical and chemical adsorption process with the mean free energy (E) which is energy required to remove a molecule of adsorbate from its sorption site to infinity [65-66]. It is given by the formula

$$E = 1/(2B_D)^{(1/2)} \quad \ldots(5)$$

3.5 Thermodynamics studies

3.5.1 Effect of temperature

The effect of temperature on biosorption process can be used to find out whether the process is physical or chemical sorption. If an adsorption process decreases with increase in temperature, it is physical in nature; if it increases with increase in temperature, it is a chemical process. The biosorption experiments for solutions with initial TC-HCl concentration of 120 µg/mL were carried out at three different temperatures (283, 301 and 333 K) and the final concentrations were determined. A plot of adsorption capacity versus time was plotted to demonstrate the effect of temperature on the current adsorption process.

3.5.2 Heat of adsorption

Heat of adsorption is a thermodynamic parameter used to determine if a reaction is exothermic or endothermic in nature (Table 6). The thermodynamic parameters change in Gibb's free energy (ΔG^o), change in enthalpy ΔH^o, and change in entropy ΔS^o for the adsorption process was determined by using the following equation 6 [67].

$$\Delta G^o = \Delta H^o - t\Delta S^o \quad \ldots(6)$$

The values of ΔH^o and ΔS^o are calculated from the slope and intercepts of the linear plot of ln C_e vs 1/T

Table 6 Heat of adsorption

Value of ΔH^o	Nature of reaction
Negative	Exothermic
Positive	Endothermic

3.6 Calculations and plots

All calculations and plots were done using Microsoft Office Excel 2010.

4. Results and Discussions

4.1 Characterization of URS

Results of BET analysis with nitrogen gas as adsorbate gave the following results:

Total surface area = 0.424 m^2/g,
Total pore volume = $1.569e^{-03}$ cc/g
Average pore radius = $7.40569e^{+01}$ A^0

4.2 Effect of contact time

Fig. 1 & 2 show the effect of contact time on biosorption capacity (q) and removal efficiency values, which were found to increase with time until equilibrium (which occurs between 90 and 120 minutes), after which they remain constant. Thus, contact time is an important factor which influences the biosorption capacity and efficiency. The time for the biosorption process to attain equilibrium was fixed as 120 minutes. The q_e was found to be 81.07 µg/mg, and the maximum removal efficiency was 68.08%.

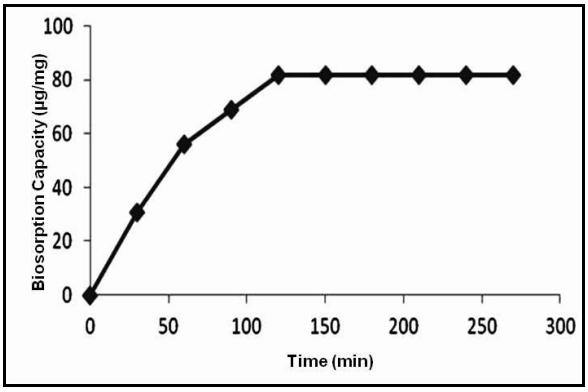

Figure 1 Effect of contact time on adsorption capacity

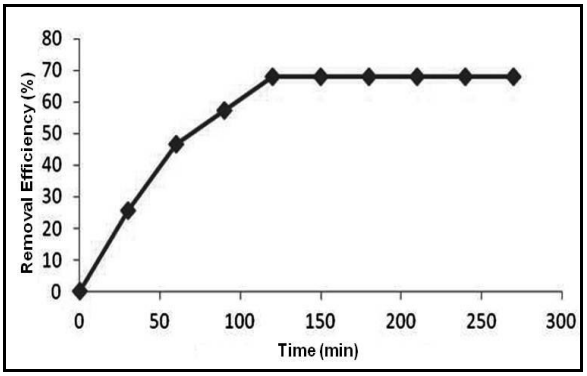

Figure 2 Effect of contact time on removal efficiency

4.3 Effect of initial concentration

The effect of initial concentration of TC-HCl (20, 40, 60, 80 and 100 µg/mL) on adsorption was estimated. The amount of TC-HCl adsorbed was found to increase with increase in initial concentration, which can be attributed to a shift in the equilibrium conditions. There was an increase in q_e and removal % values with increase in initial concentration (Fig.3). Thus initial concentration of the solution also influences biosorption capacity and equilibrium conditions.

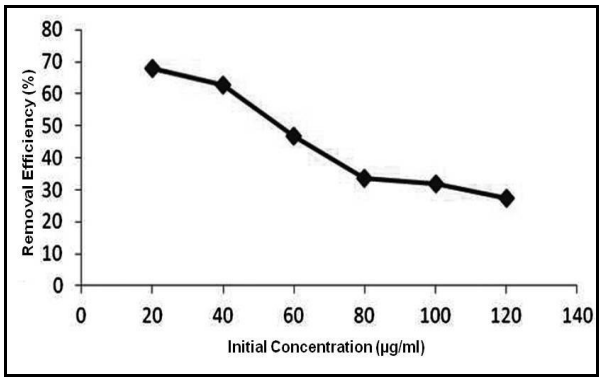

Figure 3 Effect of initial concentration on removal efficiency

4.4 Reaction mechanisms

The kinetic profiles of biosorption of TC-HCl onto URS was modelled using first order, pseudo first order, pseudo second order , saturation(mixed order) kinetic models (Fig. 4) and the results were tabulated in Table 7. Table 7 shows that the experimental data fits first order kinetics well. Thus the reaction mechanism was found to be of first order and the rate constant was 0.009 per minute.

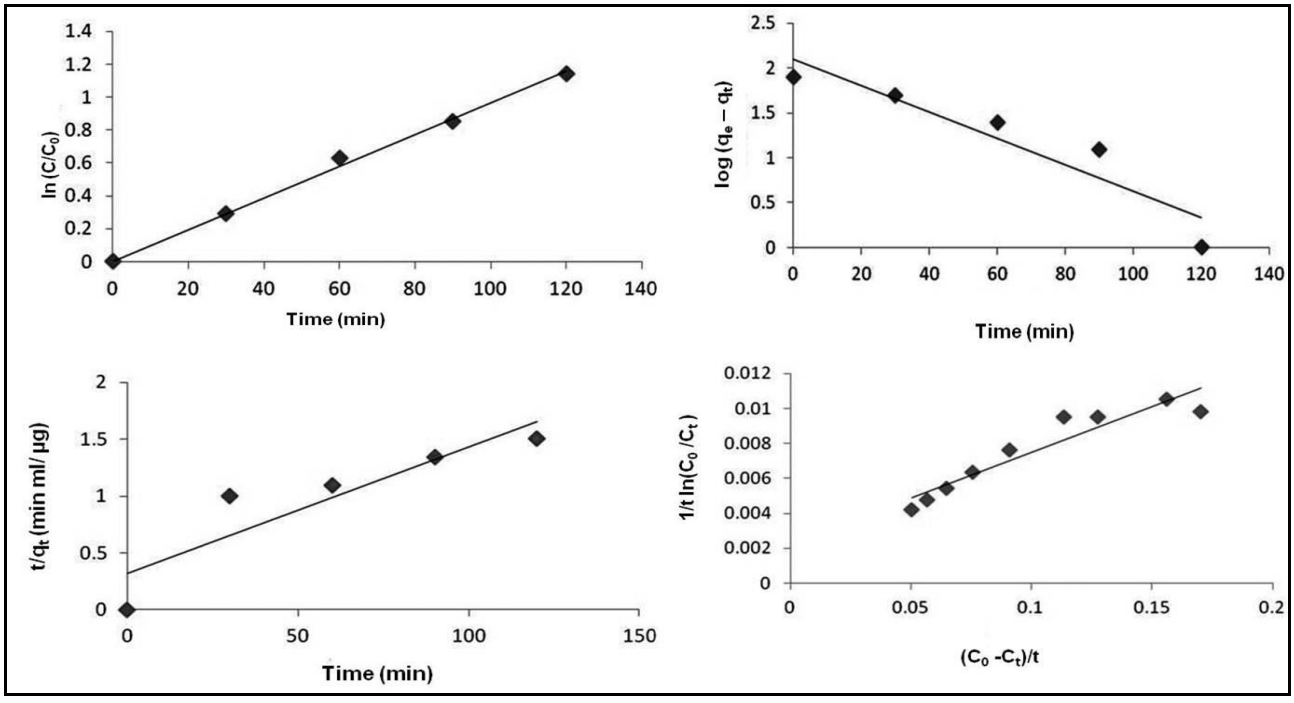

Figure 4 Kinetic profiles of biosorption of TC-HCl onto URS using first , pseudo first order ,pseudo second order and mixed order

Table 7 Reaction mechanisms for biosorption of TC-HCl onto URS

Kinetic model		Parameter	Theoretical value
1st order		k_1	0.009
		R^2	0.996
Pseudo order	1st	k_{11}	0.0322
		q_e	125.3141
		R^2	0.871
Pseudo order	2nd	q_e	90.90909
		k_{12}	0.000379
		R^2	0.812

4.4.1 Diffusion models

Fig.5 depicts the diffusion models for adsorption of TC-HCl onto URS, and the results are tabulated in Table 8. It can be seen that the data fits Weber-Morris model.Weber-Morris model is used for modelling intraparticle mass transfer in a competitive system [68] and the adsorption rate is influenced by several factors including:

(i) Diffusion of the solute from the solution to the film surrounding the particle,

(ii) Diffusion from the film to the particle surface (external diffusion),

(iii) Diffusion from the surface to the internal sites (surface diffusion or pore diffusion) and

(iv) Uptake of the solute into the sites, due to physico-chemical sorption, ion exchange, precipitation or complexation

Weber-Morris model considers step (iii) as the rate-limiting step. Higher values of R_{id} illustrate an enhancement in the rate of adsorption, whereas larger 'a' values illustrate a better adsorption mechanism. This means that the sorption process is particle diffusion controlled and that the intraparticle mass transfer resistance is the rate limiting step [69].

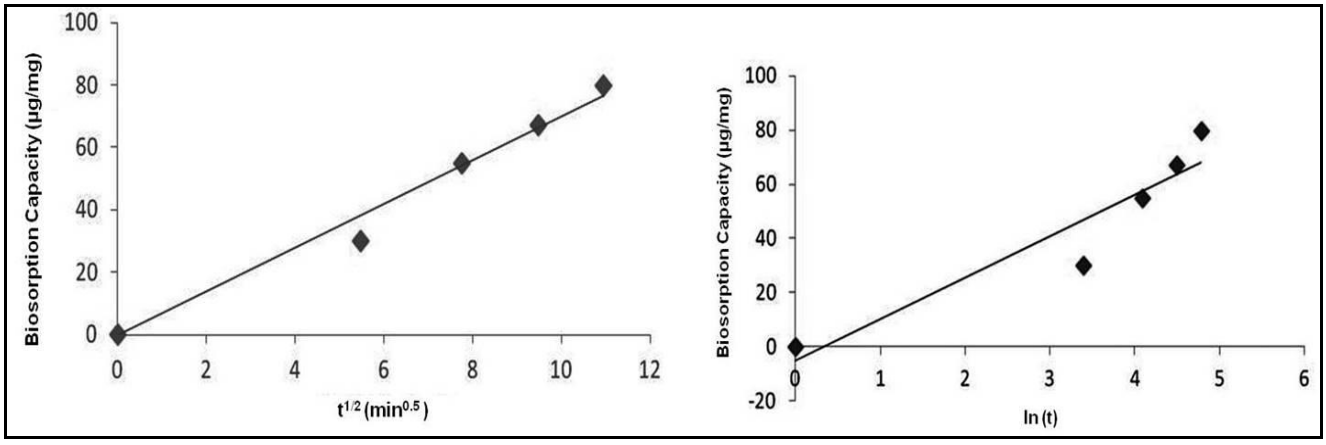

Figure 5 Diffusion Models (Weber-Moris and Elovich) for adsorption of TC-HCl onto URS

Table 8 Parameter of diffusion mechanism model for biosorption of TC-HCl onto URS

Kinetic model	Parameter	Theoretical value
Weber-Moris	R_{id}	6.993
	R^2	0.979
Elovich	τ	0.065232
	a	10.9458
	R^2	0.883

4.4.2 Biosorption equilibrium studies

The equilibrium isotherms were plotted to find theoretical values for various parameters of adsorption. Fig.6 show the isotherm modelling of biosorption of TC-HCl by URS using linear isotherm plots of Freundlich, Langmuir, Temkin and Dubinin-Radushkevich. The results were tabulated in Table 9.

A comparison of the various models shows that the experimental data fits Langmuir adsorption isotherm. The experimental q_m value and those calculated using Langmuir isotherm equations are similar. Thus the assumptions of Langmuir adsorption isotherm hold good for this process. The Langmuir isotherm model assumes that the surface of an adsorbent material contains a number of active sites where the adsorbate attaches itself (by physical interactions or chemical bonds), and there is not much interaction between the adsorbate molecules. Once the active sites are saturated, no further adsorption would take place [70] analysis of separation factor shows that the adsorption process is favourable (all values lie between 0 and 1).

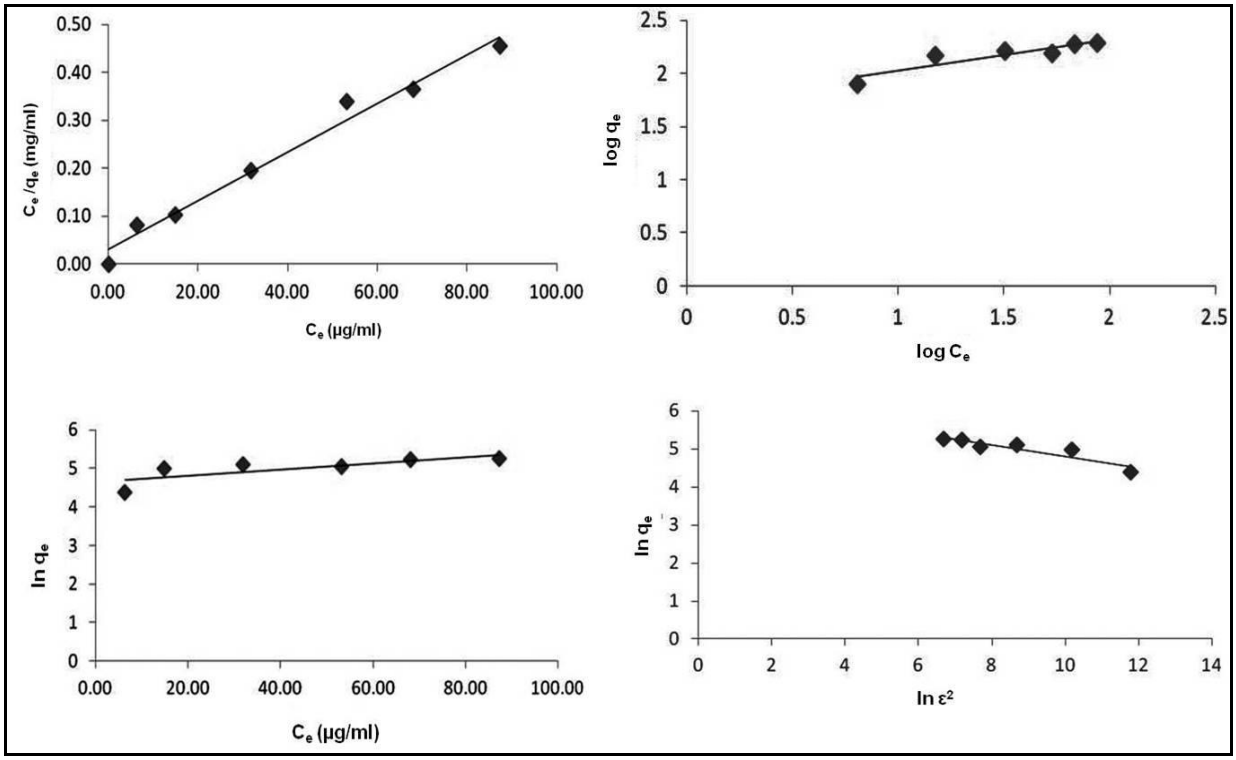

Figure 6 Isotherm profiles of biosorption of TC-HCl onto URS using Langmuir , Freundlich , Temkin and Dubinin –Raduskevich models

Table 9 Biosorption isotherm parameters of various models

Equilibrium models	Parameters	Theoretical value
Freundlich	k_F	54.07543229
	n	3.424657534
	R^2	0.829
Langmuir	q_m	200
	k_L	5.8
	R_L	0.00172117
	R^2	0.981
Temkin	B	0.008
	A_T	$3.4853E^{252}$
	R^2	0.691
Dubinin	γ	0.149
Radushkevich	q_{DR}	546.7545602
	E	-3.355704698
	R^2	0.823

4.5 Thermodynamic studies

4.5.1 Effect of temperature

The effect of temperature on the adsorption process was analyzed using a plot of temperature vs. biosorption capacity (Fig 7, Table 10). It could be seen that increase in the temperature leads to an increase in biosorption capacity at an equilibrium time, which indicates the endothermic nature and the chemical nature of the adsorption process (i.e. Chemisorption). For any reaction to occur, the molecules must possess certain energy, called activation energy (also called energy barrier because the reaction will not occur unless the reacting molecules have this energy). Increase in temperature increases the kinetic energy of the molecules, thereby decreasing the activation energy barrier, which in turn increases the rate of adsorption [71]. The enhancement in the biosorption capacity might be due to the chemical interaction between biosorbate and biosorbent, creation of

some new adsorption sites or the increased rate of intraparticle diffusion of molecules into adsorbent at higher temperatures [72].

Table 10 Effect of temperature on biosorption of TC-HCl onto URS

Temperature(K)	C_i (µg/mL)	C_e (µg/mL)	q (µg/mg)
283	120	72.34	285.95
301	120	53.19	400.85
333	120	42.55	464.68

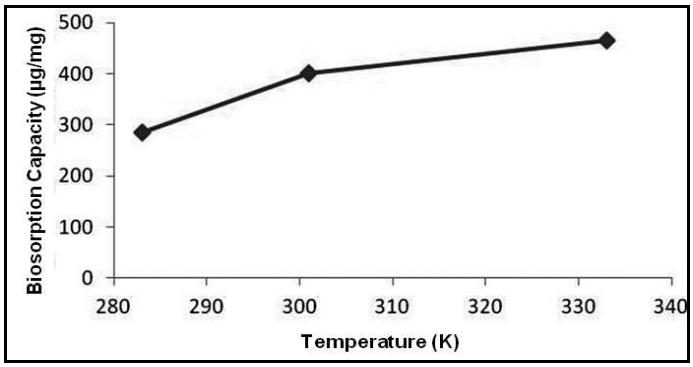

Figure 7 Effect of temperature on the adsorption of TC-HCl onto URS

4.5.2 Heat of adsorption

Heat of adsorption was found using a plot of ln Ce vs. (1/T) to be 975.87 J/mol (Fig 8). Thus the process is endothermic in nature. The higher heat of adsorption obtained in this work indicates that chemisorption rather than the physisorption are prevalent in this case.

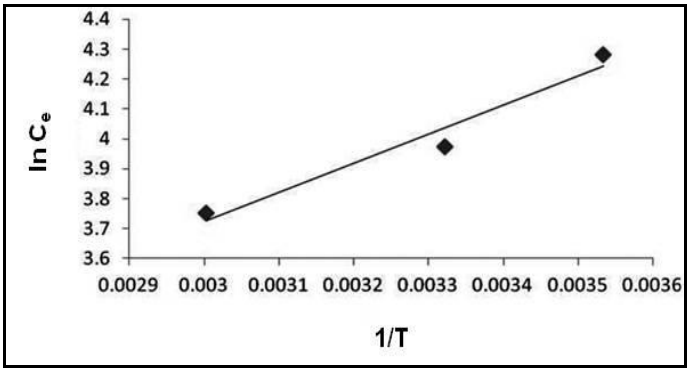

Figure 8 Heat of adsorption plot on the adsorption of TC-HCl onto URS

5. Conclusions

The experimental data proves that rice straw can be used to effectively adsorb tetracycline hydrochloride from solutions in batch process. Thus, incorporation of rice straw into adsorption process in hospital and pharmaceutical effluent treatment plants can be used as a measure against the release of tetracycline hydrochloride into the environment, thus serving as a means of controlling microbial resistance to tetracycline. Future work will involve the continuous column studies for the same.

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