

Biosorption of styrene from synthetic wastewater by sugarcane waste (bagasse)

Narges Fallah^{1,*}, Mehdi hasanzadeh¹, Bahram Nasernejad¹, Rouein Halladj¹

¹ Chemical Engineering Department, Amirkabir University of Technology, Tehran, Iran

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ABSTRACT

In this work, styrene removal from wastewater by using sugarcane waste (bagasse) as an adsorbent was studied. Equilibrium isotherms and kinetics were determined; the effects of bagasse particle size and concentration, solutions pH, and temperature on the biosorption of styrene were studied in batch experiments. Adsorption equilibrium data was successfully fitted to Langmuir isotherms ($R^2=0.986$) and Freundlich isotherms ($R^2=0.96$). Also, the kinetics of biosorption was fitted to pseudo-second order equations ($K_2=0.00146 \text{ g mg}^{-1} \text{ min}^{-1}$, $q_e=24.5 \text{ mg g}^{-1}$ for particle size range of 88-105 μm).

According to the obtained results, an empirical equation was presented that could be used to calculate the percentage of styrene adsorption. The results showed that an increase in temperature caused a decrease in styrene removal. Moreover, maximum uptake was observed with NaOH-treated bagasse. It was found that an increase in average particle size decreased the biosorption rate. According to the calculated heat of adsorption, this sorption can be classified as a chemical biosorption. The optimum uptake was determined to be 88% at a pH equal to 12.1, a temperature of 35 °C, a particle size of 420-500 μm , and a bagasse concentration of 1 g L⁻¹.

1. Introduction

Styrene is a major chemical component which has many uses such as manufacturing polystyrene, plastics, and styrene-butadiene rubbers. It is a colorless, volatile, strong-smelling, and aromatic compound which is only slightly soluble in water (300 mg L⁻¹). The boiling point and vapor pressure of styrene is 145 °C and 10 mmHg, respectively. The annual production of this chemical by the petrochemical industry in Iran was 1.45×10^5 kg in 2008 [1]. The release of styrene, which is a highly toxic chemical, into the environment can occur through inappropriate disposal and handling. The increasing presence of styrene can be a great risk for the environment as well as a health concern. The effects from exposure to styrene may involve the central nervous system and include complaints of headache, fatigue, dizziness, confusion, drowsiness, malaise, difficulty in concentrating, and a feeling of intoxication. The International Agency for Research on Cancer (IARC) classifies styrene as a potential human carcinogen [2]. The United States Envi-

ronmental Protection Agency has limited the concentration of styrene in drinking water to 0.1 mg L⁻¹. The UK occupational exposure limit is 50 ppm over an 8 hour working day [3]. Therefore, the development of different methods to remove styrene from industrial wastes, like wastewater, has generated significant interest. Conventional treatment methods such as precipitation, activated sludge processes, membrane processes, etc. have some major disadvantages when styrene is a concern factor [4-6]. For example, since styrene is classified as a volatile organic compound (VOC), a significant quantity of it can exit these processes and pollute the air during the aeration of the activated sludge bioreactor [4,5,7]. Another point of concern is the toxic effect of styrene on biomass performance and properties [6]. Additionally, the industrial application of such processes is often restricted because of technical and economic constraints. Biofiltration is a commonly used process to remove VOCs such as styrene from air streams. It is particularly appropriate for applications with low inlet concentrations and high gas flows. The VOC is absorbed into a moist layer containing the micro-organisms which facilitates biodegradation. In

*Corresponding author. Tel: +98 21 64543199

E-mail address: nfallah2001@aut.ac.ir

unsteady state conditions, adsorption onto the inert solid bed is also significant [8]. Mofidi *et al.* investigated the adsorption of VOC vapors in a fluidized bed. The effects of parameters such as flow rate, particle size, concentration, and adsorption capacity were previously investigated [8].

The biosorption/bioaccumulation methodology involving pollution removal from wastewater or waste gas by adsorption on biological materials has recently attracted considerable attention due to its cost effectiveness, availability of large surface area, selective adsorption of pollution, capability of reducing the concentration of pollutants significantly below the permissible limit, and the possibility of material regeneration [9–13]. A number of studies dealing with metal ion removal were carried out using naturally available biomaterials such as eucalyptus bark, saw dust, sugarcane bagasse (SCB) and sugar beet pulp, coconut husk fibers, palm pressed fibers, wool and pine needles, orange waste, and palm flowers [14–17]. In recent years, microbial biomass has also been successfully employed in biosorption studies [18–20].

The selection of optimal physicochemical conditions such as optimum pH, temperature, particle size, and biomass concentration is an important step in the development of biosorption processes. The study of process kinetics and equilibrium is another fundamental step, giving important information about the uptake mechanism [19].

Bagasse is a by-product of sugarcane. Bagasse, like other woods, is composed of peel and pulp. The dominant components of these adsorbents are cellulose, lignin, and pentose, respectively. This material can be used in the production of medium density fiberboard (MDF) composites and good quality wood. Bagasse also has the potential to be used for biofuel production and is economically viable for bioethanol and biomethane production [21]. Recently, bagasse is found to be a valuable adsorbent in biosorption.

The biosorption of styrene from aqueous solutions with plant based adsorbents (bagasse) has not been previously reported.

Some published literature utilized Langmuir and Freundlich models (two-parameter models) for describing the biosorption isotherm due to their simplicity, physical significance, easy interpretation, and well-established nature [12]. In addition to their simplicity, the two-parameter models can be easily linearized and are thus preferred.

The optimization of pertinent parameters of a process is usually carried out by the design of experiments (DOE) [22]. Response surface methodology, such as central composite design (CCD), is employed [23–25].

The aim of this study was to investigate the possibility of the biosorption of styrene by means of bagasse. The biosorption kinetics of styrene was also examined. Additionally, the effects of four parameters, specifically temperature, solution pH, particles size, and bagasse concentration on biosorption, were determined using statistical design of experiments such as response surface methodology.

2. Materials and methods

2.1. Biosorbent preparation

Bagasse was supplied by the Hafttappe sugarcane factory in Khuzestan province, Iran. After washing it with deionized water and drying at 80 °C in a convection oven for 18 hr, the residues were ground and sieved into different fractions [26, 27]. The ranges of the size of the fractions are presented in Table 1.

Table 1. The coded forms of all parameters.

Parameters	-2	-1	0	1	2
Temperature (°C)	65	55	45	35	25
pH	13.6	12.1	7.5	2.2	1.3
Bagasse concentration (g L ⁻¹)	10	7	5	3	1
Bagasse particles size (μm)	610–700	420–500	177–210	88–105	55–76

2.2. Chemical treatment of bagasse

Twenty grams of dried bagasse was stirred for 24 hr with 800 ml of an aqueous solution of NaOH (0.5 M) or HCl (0.5 M) for base-treated or acid-treated, respectively. After filtration, the treated bagasse was washed with deionized water until the pH of the solution reached 7. Then it was dried at 80 °C in a convection oven for 18 h [26, 27].

2.3. Styrene solution preparation

Styrene (analytical grade) was purchased from Merck Co. Ltd. (Darmstadt, Germany) and deionized laboratory water was used for making the aqueous mixtures. The preparation of styrene was carried out using a special injector with a volume of 25 μl. The concentration of styrene in all experiments was 200 mg L⁻¹.

2.4. Analysis of styrene

The concentration of styrene in aqueous solutions was measured by an Agilent series 1200 HPLC equipped with a reverse phase Eclipse XDB C18 Agilent column (5 μm, 4.6×250 mm). In this measurement, the mobile phase was 75% acetonitrile and 25% water. The styrene concentration was determined using an injection volume of 10 μl of solution at a wavelength of 245 nm (UV detector) in a mobile phase with a flow rate of 1 ml min⁻¹ [28].

2.5. FTIR spectroscopy

FTIR spectroscopy was used to identify the chemical groups present in the structure of biosorbent. The spectra of the biosorbent for all normal bindings were recorded in a Fourier transform infrared spectrometer (Bruker, Tensor 27) with the sample prepared as KBr disc.

2.6. Central composite experimental design

In this work, the design of experiments (DOEs) was carried out using response surface methodology (RSM). For this purpose, Minitab software (V. 15) was employed.

The central composite design (CCD), which is adequate for fitting a quadratic surface and usually is good for process optimization, was applied for the experimental design. In order to investigate the effect of operating parameters on the biosorption efficiency of styrene by bagasse, four independent variables were chosen: temperature, pH of the solution, bagasse concentration, and bagasse particle size. The coded values of process variables were obtained from Eq. (1):

$$X_i = \frac{x_i - x_{cp}}{\Delta x_i} \quad i = 1, 2, 3, \dots \quad (1)$$

Where x_i is the dimensionless coded value of an independent variable, X_i is the real (encoded) value of an independent variable, x_{cp} is the value of X_i at the center point, and Δx_i is the step change value. The second order equation response was used to correlate the dependent and independent variables that can be stated in the form of the following equation:

$$y = b_0 + \sum b_i X_i + \sum b_{ii} X_i^2 + \sum b_{ij} X_i X_j \quad (2)$$

where Y is the process response or output (dependent variable); b_0 is constant; b_1 , b_2 and b_3 are linear coefficients; b_{12} , b_{23} and b_{13} are cross product coefficients; b_{11} , b_{22} and b_{33} are quadratic coefficients; x_i is coded independent variables temperature (x_1); and pH (x_2), bagasse concentration (x_3), and bagasse particles size (x_4) that are represented in terms of coded factors (-2, -1, 0, +1 and +2). A positive sign in the equation indicates a synergistic effect of the variables, while a negative sign represents an opposite effect of the variables. The optimum values of the parameters were determined by solving the regression equation, analyzing the surface of the counter response surface plot. The coded forms of the parameters studied are listed in Table 1.

2.7. Desorption procedure

Desorption of the adsorbed styrene from the biosorbent was studied in a batch system. Sample mixtures were heated for three hours while stirring; then, the mixture was filtered using a vacuum pump and the solution was separated for analysis.

2.8. Experimental run

2.8.1. Kinetics studies

The experiments were conducted with five different bagasse particle size distributions, shown in Table 1, with an initial styrene concentration of 200 mg L⁻¹ and bagasse

concentration of 5 g L⁻¹. The mixture was agitated at 300 rpm. The solution was analyzed for the residual styrene concentration.

2.8.2. Biosorption isotherms

A number of batch experiments were conducted at a constant temperature (35 °C) using a 500 ml serum bottle. The concentration of dried bagasse added to each serum bottle was 3 g L⁻¹ and consisted of a total volume of 500 ml styrene solution with an initial concentration of 200 mg L⁻¹. All bottles were then sealed with Teflon coated silicone septa and aluminum crimps caps to minimize evaporation; they were mixed at 300 rpm on a magnetic mixer for 3 hr. The amount of styrene adsorbed was determined using the following equation:

$$q = \frac{(C - C_0) \times V}{m} \quad (3)$$

Where q is styrene uptake (mg g⁻¹), C_0 and C are the concentration of the styrene before and after biosorption (mg L⁻¹), V the volume of the aqueous phase (l), and m is the amount of biosorbent (g).

3. Results and discussion

3.1. Biosorption kinetics

Fig. 1 shows a styrene concentration profile versus an agitation time using dried bagasse with two different particle size distributions at an initial styrene concentration of 200 mg L⁻¹. It can be seen that biosorption consisted of two phases: A primary rapid phase and a secondary slow phase which is more apparent for small particle size diameter (88–105 µm). Equilibrium time was reached after 120 min for a particles size of 88–105 µm and 180 min for a particle size of 177–210 µm. Note that with a decrease in particle size, the rate of adsorption increases.

The equations for the determination of kinetics were:

$$\text{First order: } \ln(q_e - q_t) = \ln(q_e) - \left(\frac{K_f}{2.303}\right) \times t \quad (4)$$

$$\text{Second Order: } \frac{t}{q_t} = \frac{1}{K_2 \times q_e^2} + \frac{1}{q_e} (\times) t \quad (5)$$

Where q_t and q_e (mg g⁻¹) are biosorption capacity at time t and at equilibrium, respectively, K_2 (g mg⁻¹ min⁻¹) is the rate constant of pseudo-second order and K_f (min⁻¹) is the constant rate of first order equation.

Plots of (t/q_e) versus time for both particle sizes arshown in Fig. 2 and the variation of $\ln [(q_e - q_t)/q_e]$ time for both particle sizes is shown in Fig. 3.

As can be observed in Figs. 2(a, b) and Figs. 3(a, b), using a pseudo-second order equation is slightly better than a first order equation.

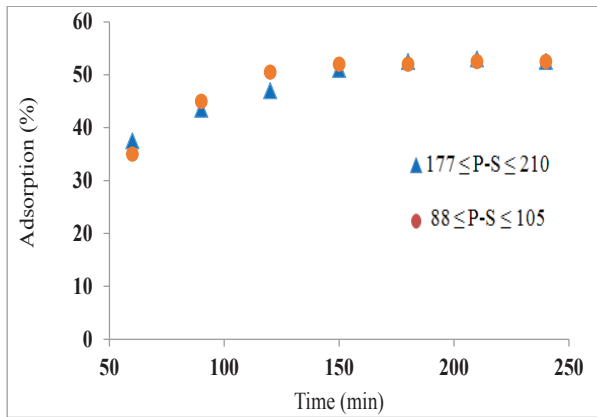


Fig. 1. Effect of contact time on styrene removal at two different particles size range ($C_0=200 \text{ mg L}^{-1}$, bagasse concentration 5 g L^{-1}).

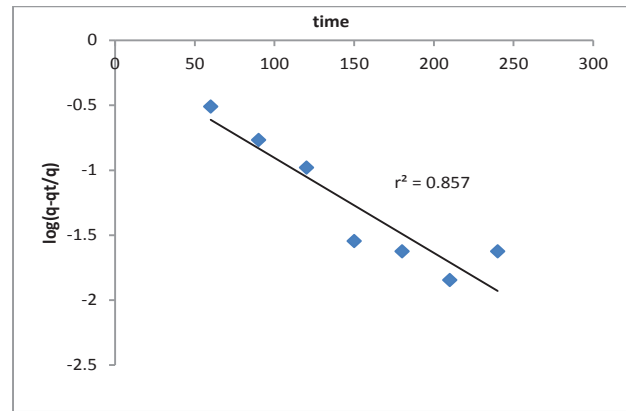


Fig. 3. Plot of $\log [(q_e - q_t)/q_e]$ vs. time (t) for the sorption kinetic of styrene on Bagasse and $177 \leq \text{particle size } (\mu\text{m}) \leq 210$ ($C_0=200 \text{ mg L}^{-1}$, bagasse concentration 5 g L^{-1})

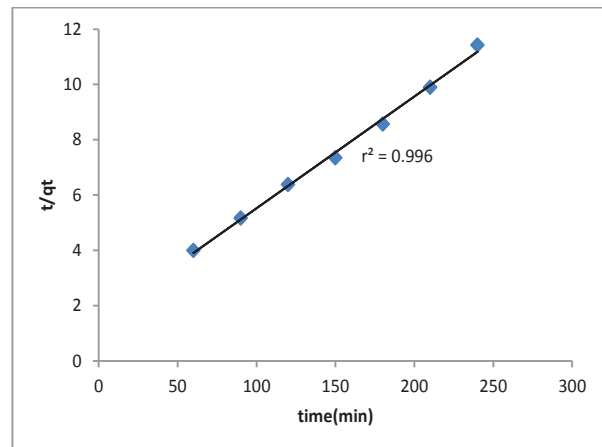
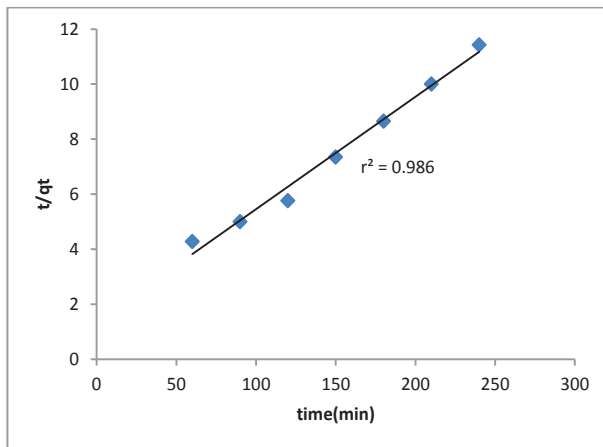


Fig. 2. Plot of t/q_t vs. time (t) for the sorption kinetic of styrene on Bagasse (a) $88 \leq \text{particle size } (\mu\text{m}) \leq 105$ (b) $177 \leq \text{particle size } (\mu\text{m}) \leq 210$ ($C_0=200 \text{ mg L}^{-1}$, bagasse concentration 5 g L^{-1}).

The linearity of the plots indicates the applicability of this kinetic model for styrene uptake. The values of K_2 , obtained from the plot, were $0.00135 \text{ g mg}^{-1} \text{ min}^{-1}$ for particle size of $177\text{--}210 \mu\text{m}$ and $0.00146 \text{ g mg}^{-1} \text{ min}^{-1}$ for particle size of $88\text{--}105 \mu\text{m}$. The value of q_e for both sizes was calculated as 22.2 mg g^{-1} , which is very close to experimental results (21 mg g^{-1}). Gerrad *et al.* have also shown that the kinetic adsorption of styrene by active carbon or perlite was fitted to the second order equation slightly better than first order [29].

3.1.1. Biosorption isotherms

Both the Langmuir and Freundlich models were used to describe biosorption isotherms. The Langmuir equation can be expressed as [30]:

$$q_e = \frac{q_m b C_e}{1 + b C_e} \quad (6)$$

Where q_e is the amount of styrene adsorbed (mg g^{-1}) at equilibrium condition, C_e is the equilibrium concentration (mg L^{-1}), b is a constant related to the energy of biosorption (l mg^{-1}), and q_m is the amount of styrene per unit weight of adsorbent to form a complete monolayer on the surface.

The constant b and q_m are the parameters of the Langmuir equation and can be determined from a linearized form of the Eq. (6):

$$\frac{C_e}{q_e} = \frac{1}{q_m b} + \frac{C_e}{q_m} \quad (7)$$

The Freundlich model can be written as [31]:

$$q_e = k C_e^{1/n} \quad (8)$$

Where k and n are empirically constants and were de-

terminated from linearized form of the Freundlich equation:

$$\ln(q_e) = \ln(k) + \frac{1}{n} C_e \quad (9)$$

Figs. 4(a) and 4(b) show the applicability of these models for styrene biosorption for bagasse. The model parameters and correlation coefficient value (R^2) are given in Table 2.

According to Table 2, very high regression correlation coefficients (>0.96) were found for both of the studied models. According to our results, both models are suitable for describing the biosorption equilibrium of styrene by the bagasse. Based on the Langmuir isotherm, the maximum capacity (q_m) of styrene was 25.64 mg g^{-1} . Khorramzadeh *et al.* studied biosorption of mercury ions (Hg(II)) on different biosorbents in which the results have shown good adsorption of mercury ions by sugarcane bagasse in comparison to other biosorbents [32]. Gerrad *et al.* have shown that the experimental data of adsorption of styrene from polluted air was fitted to the Freundlich model ($R^2=0.99$ to 1)

when perlite was used as an adsorbent medium [29].

3.2. The effect of temperature, solution pH, particles size, and bagasse concentration on biosorption efficiency of styrene

The various levels of adsorption efficiency for the combinations of the four pertinent factors in biosorption processes using the CCD design of experiments is presented in Table 3. The analysis of variance (Table 4), in which the second order polynomial regression model for the prediction of adsorption efficiency was tested for adequacy, showed that the regression model, as well as the linear and the square term, were highly significant. The refined regression model for the percentage of adsorption (P-A), as a function of terms in which according to the P-values present in Table 5 were significant, is presented below:

Table 3. CCD design matrix (in coded form) and observations for four factors (T: temperature ($^{\circ}\text{C}$), P-S: particle size of adsorbent (μm) c: concentration of adsorbent in solution (g L^{-1}) and P-A is percentage of adsorption).

pH	T($^{\circ}\text{C}$)	P-S(μm)	C(g L^{-1})	P-A(%)
0	0	0	0	60
-1	1	-1	1	62
1	1	-1	-1	68
1	-1	1	-1	48
-1	-1	-1	-1	81
-1	-1	1	1	76
-1	1	1	-1	89
0	0	0	0	52
1	-1	-1	1	48
1	1	1	1	72
1	-1	-1	-1	69
1	1	-1	1	70
0	0	0	0	63
-1	1	-1	-1	69
-1	1	1	1	61
0	0	0	0	53
-1	-1	1	-1	77
-1	-1	-1	1	83
1	-1	1	1	43
1	1	1	-1	92
0	0	0	-2	83
-2	0	0	0	85
0	2	0	0	65
0	0	0	2	50.5
0	0	0	0	49.5
0	0	2	0	55
0	0	-2	0	58
2	0	0	0	42
0	0	0	0	50
0	-2	0	0	45

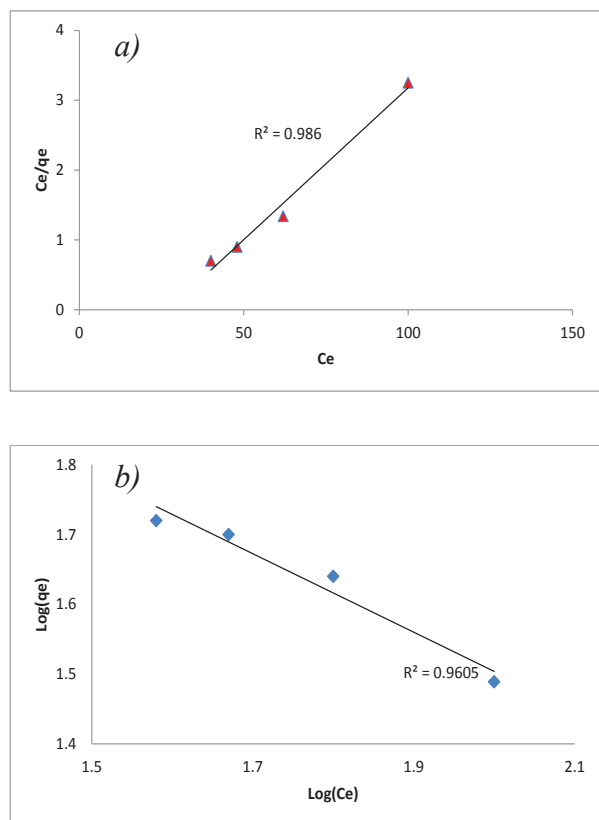


Fig. 4. Styrene biosorption isotherms (a) Langmuir isotherm (b) Freundlich isotherm.

Table 2. Langmuir and Freundlich model parameters for biomass.

	Langmuir isotherm			Freundlich isotherm		
	$q_m(\text{mg g}^{-1})$	$b(\text{l mg}^{-1})$	R^2	k	n	R^2
Biomass	25.64	0.0438	0.986	363	1.92	0.96

Table 4. ANOVA of the second order polynomial model for adsorption efficiency of styrene obtained from the CCD results.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Blocks	2	0.076380	0.076380	0.038190	8.54	0.002
Regression	8	0.392311	0.392311	0.049039	10.96	0.000
Linear	4	0.174854	0.174854	0.043714	9.77	0.000
Square	2	0.069807	0.069807	0.034903	7.80	0.003
Interaction	2	0.147650	0.147650	0.073825	16.50	0.000
Residual Error	19	0.084989	0.084989	0.004473		
Lack-of-Fit	16	0.076777	0.076777	0.004799	1.75	0.358
Pure Error	3	0.008212	0.008212	0.002737		
Total	29	0.553680				

Table 5. Estimated regression coefficients, t-statistics and significance probability of the second order polynomial model for biosorption of styrene results of CCD runs.

Term	Coeff SE	Coeff	T	P
Constant	0.545833	0.02789	19.574	0.000
Block 1	0.047000	0.01764	2.665	0.019
Block 2	0.023000	0.01764	1.304	0.215
PH	-0.044167	0.01394	-3.168	0.007
T	0.040833	0.01394	2.929	0.012
P-S	0.010833	0.01394	0.777	0.041
C	-0.059583	0.01394	-4.273	0.001
PH*PH	0.028646	0.01304	2.196	0.047
T*T	0.019896	0.01304	1.526	0.151
P-S*P-S	0.011146	0.01304	0.855	0.408
C*C	0.049271	0.01304	3.778	0.002
PH*T	0.081250	0.01708	4.758	0.000
PH*P-S	-0.005000	0.01708	-0.293	0.774
PH*C	-0.006250	0.01708	-0.366	0.720
T*P-S	0.051250	0.01708	3.001	0.010
T*C	-0.017500	0.01708	-1.025	0.324
P-S*C	-0.018750	0.01708	-1.098	0.292

$$P-A = 0.576875 - 0.0441667(\text{pH}) - 0.0408333(\text{T}) - 0.0108333(\text{P-S}) + 0.0595833(\text{C}) + 0.0247656(\text{pH})^2 + 0.0453906(\text{C})^2 + 0.0812500(\text{pH} \times \text{T}) + 0.0512500(\text{T} \times \text{P-S}) \quad (10)$$

In this equation T, P-A, P-S, and C are temperature (°C), percentage of adsorption, particle size (μm), and concen-

tration of adsorbent in solution (g L⁻¹), respectively.

The coefficient of determination, R², for the above model was calculated to be 0.84913 which shows that the regression model is suitable for describing adsorption efficiency.

The response surface plots for adsorption efficiency are shown in Fig. 5. Referring to Fig. 5(a), it could be inferred that an increase in pH causes an increase in efficiency and this effect is more pronounced at high levels of P-S. As well, this effect is confirmed at different levels of bagasse in Fig. 5(b).

Totally, it was observed that treating bagasse with NaOH or HCl increase biosorption efficiency. However, the maximum biosorption efficiency was by NaOH-treated bagasse and the minimum was by untreated bagasse. (Fig. 5(a))

Referring to Figs. 5(b) and 5(c), it is obvious that increasing the bagasse concentration increased the styrene biosorption efficiency. Esfandiar *et al.* also showed that an increase in adsorbent dosage resulted in an increase of biosorption efficiency [27].

It could be inferred by Fig. 5(d) that at a low level of P-S, biosorption efficiency is decreased as the temperature increased; furthermore, Fig. 5(c) indicates that with a high concentration of bagasse, the effect of temperature on biosorption efficiency is approximately negligible. Mofidi *et al.* also noted that with a decrease in particle size of activated carbon, the adsorption of styrene from polluted air increased [8].

In order to estimate the heat of biosorption (ΔH), a new set of experiments at four different temperatures were carried out and the Langmuir parameters were calculated. Since b is equilibrium constant, its dependence on temperature can be used to estimate enthalpy changes of biosorption [33, 34]:

$$\ln(b) = -\frac{\Delta G^\circ}{RT} + \frac{\Delta H}{RT} - \frac{\Delta S^\circ}{R} \quad (11)$$

The plot of Ln (b) versus $\frac{1}{T}$ is a straight line and is depicted in Fig. 6. By considering universal gas constant (R) as 1.987 cal mol⁻¹ K⁻¹, the value of ΔH was found to be -6.135 kcal mol⁻¹, which indicated that the reaction was exothermic.

The magnitude of ΔH may give an idea about the type of sorption. The two main types of adsorption are physical adsorption and chemical adsorption. The enthalpy for physical adsorption is usually no more than 1 kcal mol⁻¹; and the enthalpy for chemical adsorption is more than 5 kcal mol⁻¹ [33, 34]. We may conclude that styrene biosorption on bagasse is a chemical process.

3.3 FTIR analysis

Figs. 7(a), (b), and (c) show the FTIR spectra of the untreated, NaOH-treated, and HCl-treated bagasse after styrene biosorption, respectively. As it could be seen from the FTIR spectra, many functional groups are presented on the bagasse surfaces [35].

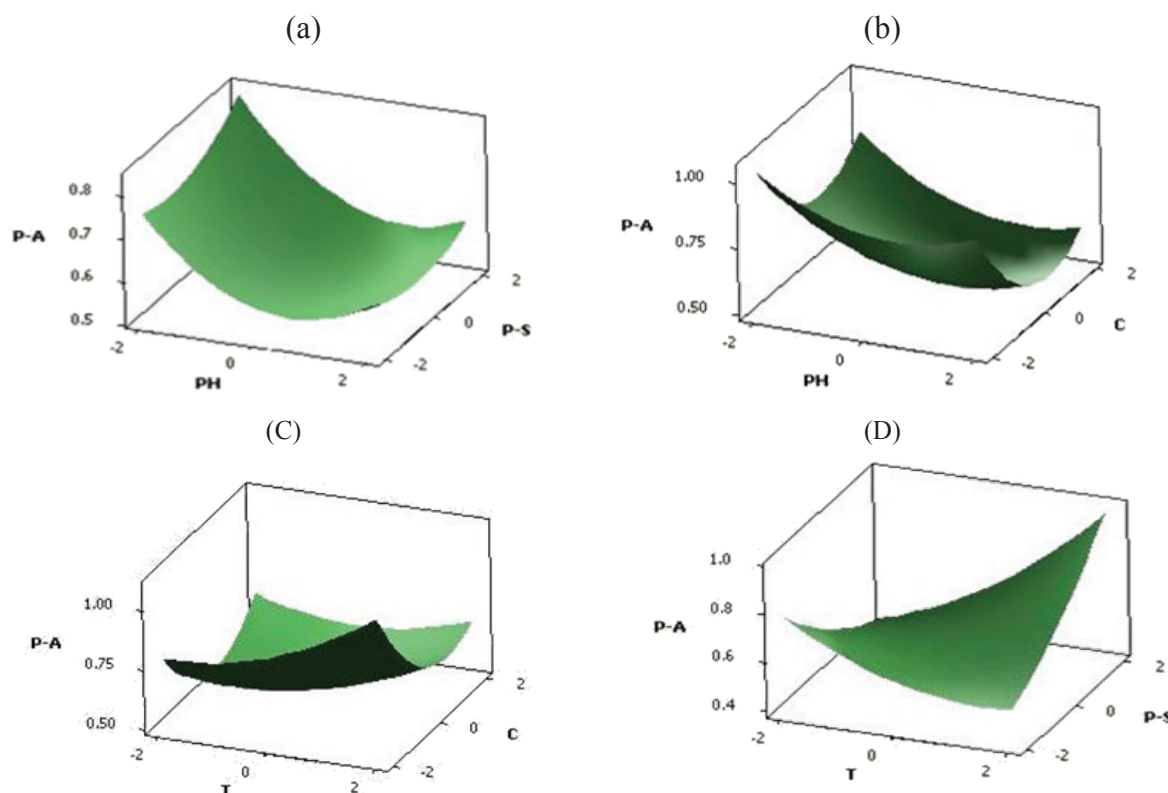


Fig. 5. Effects of all parameters on the percentage of adsorption. (a) effect of pH and P-S on P-A ($T = 45\text{ }^{\circ}\text{C}$, $C = 5\text{ g L}^{-1}$). (b) Effect of pH and C on P-A ($T = 45\text{ }^{\circ}\text{C}$, $P-S = 177\text{--}210\text{ }\mu\text{m}$). (c) Effect of T and C on P-A ($\text{pH} = 7.5$, $P-S = 177\text{--}210\text{ }\mu\text{m}$). (d) Effect of T and P-S on P-A ($C = 5\text{ g L}^{-1}$, $\text{pH} = 7.5$).

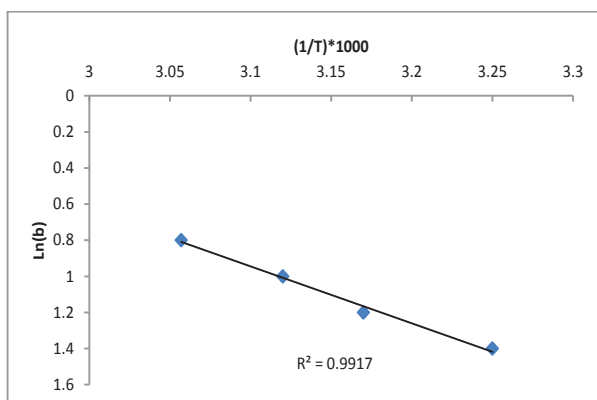


Fig. 6. Plot of $\ln(b)$ versus $1/T$

As can be noted, the main difference between the presented spectra in Fig. 7 is in C=C stretching bands. The two first shoulders in Fig. 7(a), $1600\text{--}1650\text{ cm}^{-1}$, can be attributed to C=C bands in the lignin structure; the third peak, $1700\text{--}1750\text{ cm}^{-1}$, is attributed to S=O in the pentosan structure.

The comparison of the spectra showed that during treatment with NaOH, lignin C=C stretching peaks disappeared due to its removal of lignin. After the biosorption process, a peak was observed at $1600\text{--}1650\text{ cm}^{-1}$ and is attributed to the presence of styrene [Fig. 7 (c)].

FTIR spectra were used to explain the effect of the adsorbent's pH on the efficiency of the biosorption process. When HCl was added to the bagasse, the structure of cellulose was exploded. The alkaline treatment removed hemicelluloses and lignin mainly from the surface of bagasse fibers. As a result, a surface with more roughness and a higher surface area was generated [36]. The results revealed that the treated bagasse had a higher adsorption capacity and between these two kinds of treatments, the NaOH-treated bagasse showed a higher capacity than the HCl-treated. It is known that a C=C band exists in both styrene and lignin structures. However, because of the destruction of lignin, this band does not exist in NaOH-treated bagasse.

4. Conclusion

The removal of styrene from polluted aquatic systems was carried out by using bagasse as the adsorbent medium. The pseudo-second order kinetic model gives a better view of describing the adsorption process. The parameters of both isotherms, Langmuir and Freundlich, were determined. Also, it was found that as particle size increased, the rate of biosorption decreased. The biosorption efficiency was decreased by increasing the adsorption temperature, and it

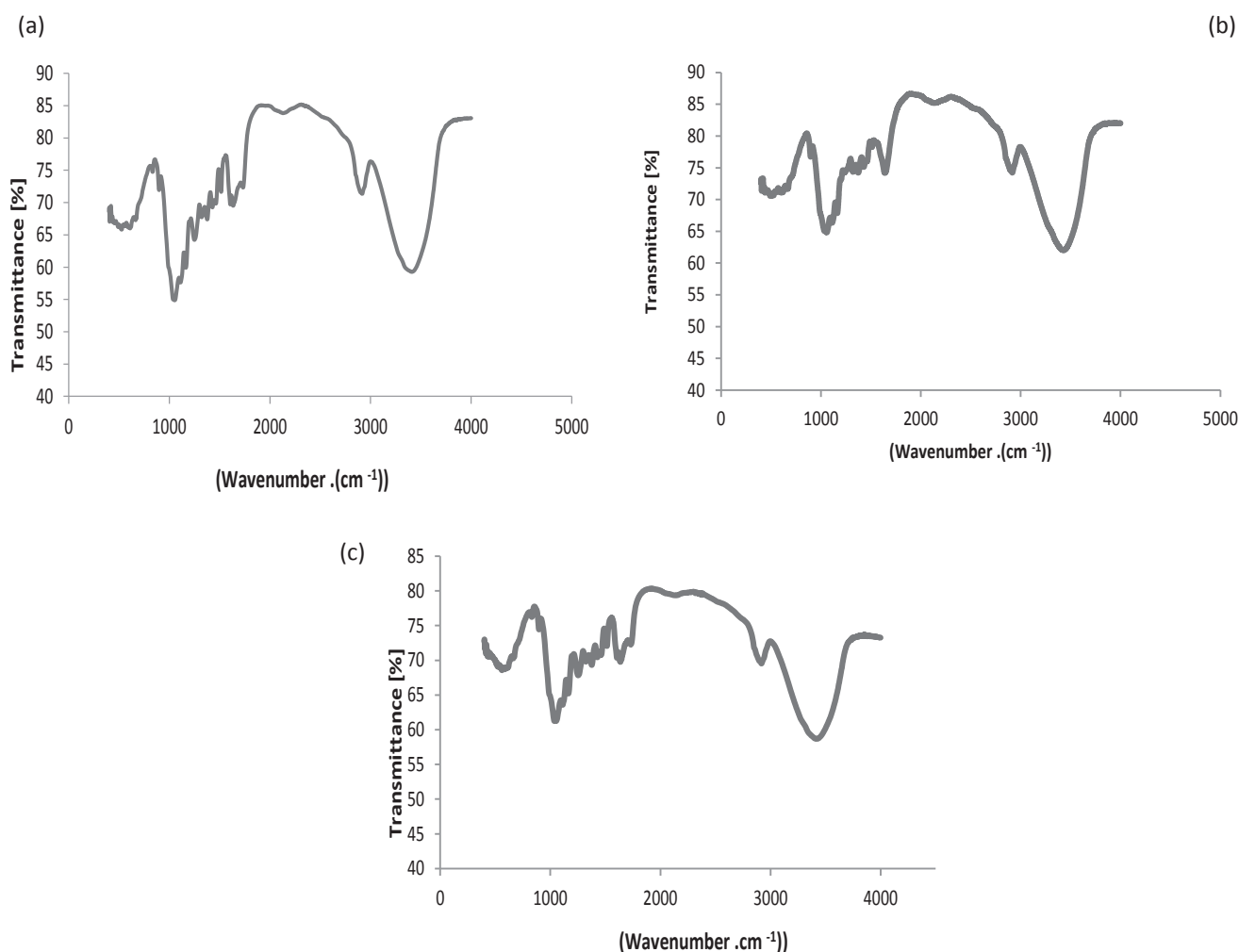


Fig. 7. FTIR analysis of Bagasse (a) untreated biomass (b) NaOH-treated biomass (c) NaOH-treated biomass after biosorption.

appears that styrene biosorption on bagasse is a chemical process.

According to the obtained results, the biosorption of styrene was affected by the pH, in which the maximum biosorption efficiency was determined to be in NaOH-treated bagasse.

Moreover, an equation was presented that could determine the optimum condition for the biosorption process. This equation includes all affecting parameters that had been considered in this study.

The optimum uptake was determined to be 88% at a pH of 12.1, a temperature of 35 °C, a particle size of 88-105 μm , and an adsorbent concentration of 10 g L⁻¹.

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