A New Temperature Effect Model to Predict Benzoic Acid Isotherm Curves onto Activated Carbon

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ABSTRACT: *The recovery and removal of the most organic acids in liquid solutions is usually treated with fixed-bed adsorption processes. Among many adsorbents, Granular Activated Carbon (GAC) is used to remove organic pollutants such as Benzoic Acid (BA) from wastewaters conventionally. In this research, adsorption isotherm curves of BA onto GAC at varying temperatures 25-60 °C are developed and the amounts of BA concentration in feed fluid and on the adsorbent are obtained. The results show that Radke and Prausnitz (Ra-Pr) model among five applicable isotherm models has best fitting with experimental data. In this paper, for the first time, a new model for temperature effect on isotherm curve of BA is investigated. This model could predict isotherm curves in accordance to the isotherm curve in reference temperature with absolute relative error (ARE) less than 1.2%. Thus Temperature Effect Term (T.E.T) model is able to predict isotherm curves only by using experimental data in one temperature successfully. Furthermore T.E.T and Ra-Pr models jointly, could predict the every isotherm curve only with experimental data in three equilibrium points in one temperature with low error. In this case, the average A.R.E% in comparison with experimental data is less than 1.4%.*

KEY WORDS: *Adsorption process, Isotherm curves, Activated carbon, Benzoic acid, Ra-Pr model temperature effect.*

INTRODUCTION

Most ion exchange systems are comprised of columns containing resin beads that separate the product based on affinity. If an adsorbent could be designed to concentrate selectively and regenerated easily and an adsorbent could remove the water from stream thus, adsorption and ion exchange would be economical for dilute separations [1,2].

Wastewater streams containing low concentrations of acids are inevitably encountered in acid manufacturing plants, industries where acids are used as raw material or as catalyst, fermentation processes, metal plating industries, etc. Wastewater usually contains single or mixture of acids from 0.5 to 4%, depending on the source

of generations [3]. Nowadays, the use of ion-exchange resins is very well established as a unit separation. The applicability of ion exchange resins in industrial processes has steadily grown up, resulting in new techniques and processes that go far beyond the water purification and demineralization that were the first and most important applications of ion-exchange resins [4].

However, investigations using ion exchanges resins in organic media are still rare. The study of adsorption isotherms and the ion-exchange mechanism in this condition is important in order to develop new purification techniques for organic solutions [5]. A large number of water treatment methodologies are available nowadays. Adsorption on Activated Carbon is one of the most frequently applied techniques for the removal of trace pollutants. Though this technique has proved to be broadly applicable, an important disadvantage is the inability of Activated Carbon. To desorb any adsorbed components completely (*Kenedy*, 1973; *Cornel*, 1986) in the early 60s synthetics sorbents became available that can be easily regenerated by acids, bases, or organic solvents. To determine the thermal regeneration of a sorbents, its adsorption should be known as a functional temperature. However, data on adsorption equilibria at elevated temperatures are relatively scarce [6,7]. Benzoic Acid (BA) is widely used as a preservative or reaction intermediate and therefore often presents in domestic as well as industrial wastewaters. Because of its harmful effects, wastewaters containing BA must be treated before discharging to receive water bodies. Popular treatment processes include biological degradation, chemical oxidation and adsorption [8].

Many investigators showed that phenol adsorption was favored by low pH values of solution and high point of zero charge values of activated carbon cloths. The adsorption of 2,4-dinitrophenol was promoted at very low pH values of solution and it was less influenced by activated carbon cloth surface acidity. [9]

Many researchers show that a hybrid approach of Density Functional Theory (DFT) and Hartree-Fock (HF) were used for carboxylic acid. They determined the geometry and the electronic properties of benzoic acid (BA) adsorbed on $MgSO_4$-$H_2O(100)$, which are used as conditioner molecules for the electrostatic separation of minerals. According to their results, these molecules are chemisorbed, with binding energies around 1.9 eV,

forming bonds through the carboxylic "O" atom of the COOH groups in a nonplanar geometry, although the surface is a stoichiometric wide-band-gap insulator and the molecules stay intact. In contrast, planar adsorption geometry turned out to be nonbonding. Bonding takes place by means of surface-molecule resonances due to the overlap of the valence band with molecular orbitals, assisted by a small charge-transfer molecule to the surface of around $0.15e$. These combined interactions cause an intramolecular twist between the COOH group and the benzene ring [10].

The adsorption from aqueous solutions of benzene derivatives (phenol, benzoic acid, and newly synthesized benzoic acid derivatives containing imidazole hetero-cycles on active carbons with various microporous structures) is studied by some investigators.

They analyzed the effect of the nature of adsorbate molecules and the pore sizes of active carbons on the sorption character. They showed that the adsorption from aqueous solutions of the organic derivatives of benzene is determined, on the one hand, by the size of a molecule, and on the other, by its hydration energy [11].

To predict the breakthrough curve with a sophisticated mass transfer model, one needs many parameters that must be determined by independent batch kinetic study or estimated by suitable correlation, without using micro chemical characteristics described above. The breakthrough curve necessary for verification of the mathematical model and identification of the model/parameters were obtained using glass columns [12]. More structure types of models respecting sorbate specification in solution, pH and even electrostatic attraction were recently suggested by *Yang* and *Volesky* [13]. Most separation and purification processes that employ the sorption technology use continuous-flow columns. This operating mode ensures the highest possible concentration difference driving force. Starting at the inlet, the saturated solid sorbent zone gradually extends throughout the column. The sorbate eventually breaking through the column, the record of the breakthrough gives usually a typical S-shaped breakthrough curve whose shape and slope is the result of the equilibrium sorption isotherm relationship [14]. The following assumptions were made for the formulation of model equation.

- The sorption process is isothermal.

- Diffusion coefficient inside the pore is concentration independent.

- Mass transfer in the liquid film is represented by the (*Langmuir, Freundlich, Reddlich-Peterson, Toth, Radke* and *Prausnitz*).

- The sorbent particles are spherical and uniform in density and radius.

- The liquid flow along the bed is ideal plug flow.

- No chemical reactions occur in the column.

- Only mass transfer by convection is significant.

- Radial and axial dispersion are negligible.

- The flow rate is constant and in variant with the column position.

The *Langmuir, Freundlich, Reddlich-peterson, Toth* and *Radke* and *Prausnitz* models are defined as below:

$$Langmuir: \ C^* = \frac{bC_m C}{1 + bC} \tag{1}$$

$$Freundlich: \ C^* = KC^{1/n} \tag{2}$$

$$Reddlich\text{-}Peterson: \ C^* = \frac{aC}{1 + dC^{n_1}} \tag{3}$$

$$Toth: \ C^* = \frac{C_m C}{(1/k_1 + C^{k_2})^{1/k_2}} \tag{4}$$

$$Radke \ and \ Prausnitz: \ \frac{1}{C^*} = \frac{1}{pC} + \frac{1}{qC^{n_2}} \tag{5}$$

EXPERIMENTAL

The sieved GAC with 30 - 35 mesh fraction was washed with 1 N HCl several times to remove oils and impurities and rinsed with deionized water until it showed the same UV absorbance intensity as deionized water. Finally the washed GAC was dried in an oven at 100 to 110 °C. An aqueous solution with various BA concentration at neutral pH and the GAC with known dried weight was put into the forty stirred tanks with equal volume 100 cc, including 40 to 50 cc of aqueous solution, and were agitated periodically during of experiments. In this research work, 40 flasks were used for mixing more than three days, and then were maintained in the oven more than one day to reach equilibrium points in each temperature (25, 30, 35, 40, 45, 50, 55, 60 °C) thus totally, 48 days were spent to

Table 1: The geometry specification of set up.

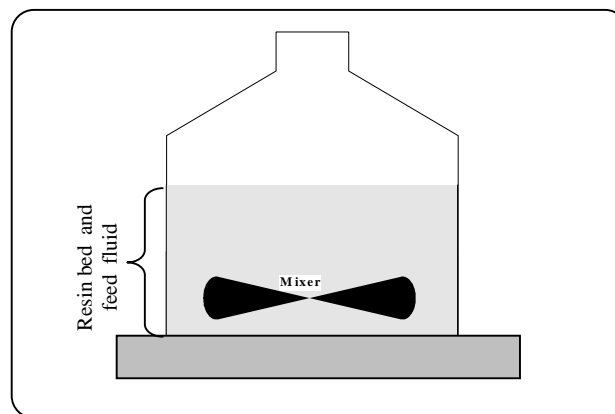| Resin density	462.5 kg/m^3
Weight of resin	6 g
Mesh fraction	30-35

Fig. 1: The schematic of apparatus.

obtain the experimental data in this research work (*Hotech*, model 706). The temperatures in the mixer flasks and oven were fixed during experiment with accuracy of ±1°C. The schematic of an apparatus and the physical properties of GAC resin are presented in Fig. 1 and table 1 respectively.

The adsorption isotherms data were measured in batch, stirred tank with 100 rpm impeller speed at different temperatures. In each experiment, the amount of 6 gr wet resin particles were contacted in the glass flasks with the deionized water solution in different initial acid concentration 5-450 g/m^3. The equilibrium acid concent-ration in the GAC resins was measured for every equilibrium by the UV spectrophotometer with the maximum absorbance wave length at 225 nm. Also, the value of the adsorption heat is measured by calorimeter during the experiments.

EXPERIMENTAL RESULTS AND COMPARISON

In this research paper the adsorption isotherm curves data of BA with GAC at varying temperatures 25, 30, 35, 40, 45, 50, 55 and 60 ºC were drawn as shown in Fig. 2. Because low values of the adsorption heat (<0.45 kj/g) is measured by calorimeter, the adsorption of BA onto GAC is physical adsorption.
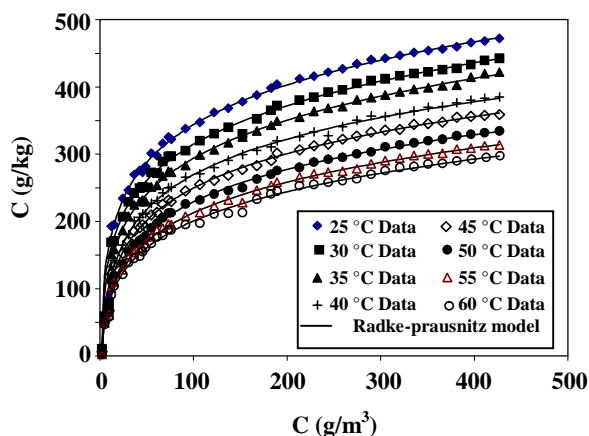
Fig. 2: Comparison of experimental data and Ra-Pr model at different temperatures.

Generally, several applicable models for isotherm curves were investigated by other researchers such as *Langmuir*, *Freundlich*, *Reddlich-Peterson* (Re-Pe), *Toth* and *Radke-Prausnitz* (Ra-Pr). To analyze and compare the experimental results with other investigations, the isotherm curves obtained in this research work, are fitted with isotherm models Eq. (1) to (5), recommended by other researchers.

The constants of models are determined based on ordinary least square (O.L.S) method by "Eviews" software and the results are shown in table 2.

In Eviews software, multifarious examinations are done for analyzing and fitting of data and the models are developed based on the statistical function such as R^2 and *Durbin-Watson* test (D.W.T). R^2 is the most important parameter to determine the model ability in fitting of various models provided on the basis of experimental data. In general, the amount of this parameter is between 0.0 and 1.0, and the level of fitting increases with growing the parameter to 1.0. D.W.T is another parameter considering the difference between real and model amount in every point knowing as residual. In fact, this parameter assesses the relation among residual data. Relation between real and model amounts obviously decreases the validity of prepared equation in modeling. In a good model, the amount of D.W.T must be 1.0 at least, but more than 1.7 will make an appropriate model. According to the amounts of R^2 and D.W.T in table 2, the format of Ra-Pr model have the best fitting with experimental data. In this model, the amount of R^2 and D.W.T are suitable and confirm the definition of modeling basis. Therefore, the isotherm curves at

different temperatures of Ra-Pr models are obtained and the results are shown in Fig. 2. This figure shows that the Ra-Pr model have good fitting with experimental data.

Also, the amounts of A.R.E are measured and the results are shown in table 3. According to table 3, the percentage of A.R.E for two models is lower than 1%.

On the other hand, the low difference of A.R.E% average between Ra-Pr and Re-Pe models (less than 0.002%), it obtained probably these two models are the same in mathematical structure. Therefore, we compared two models with each other (we initiate with Ra-Pr model and received to Re-Pe model):

$$\frac{1}{C^*} = \frac{1}{pC} + \frac{1}{qC^{n_2}} = \frac{qC^{n_2-1}+p}{pqC^{n_2}} \tag{6}$$

By rearrangement of Eq. (6):

$$C^* = \frac{pqC^{n_2}}{qC^{n_2-1}+p} = \frac{pqC}{q+pC^{1-n_2}} = \frac{pC}{1+\dfrac{p}{q}C^{1-n_2}} \tag{7}$$

From comparing Eq. (7) and Re-Pe model ($C^* = aC/1+dC^{n_1}$), we can define a=p, d=p/q and $n_1=1-n_2$. For example, the value of n_1 and n_2 from table 2 satisfied with $n_1=1-n_2$. Therefore, it would be concluded that the two models are similar and have same structure. On the other hand, the Ra-Pr model was presented in 1972 (Eq. (5)) and rearranged by Reddlich and Peterson in 1978 (Eq. (3)), and so we proposed the Radke and Prausnitz model as appropriate model for isotherm curve of BA onto GAC.

TEMPERATURE EFFECT MODELING

According to Fig. 2, it is observed that the isotherm curves have been varied in special form with respect to temperature. In fact, when the concentration (C) increases, the distances between isotherm curves are increased gradually. Therefore, every curve in comparison with another curve, not only depends on temperature, but also depends on BA concentration in solution.

In this section, a new model for temperature effect term (T.E.T) on isotherm curves are developed. Prediction of the isotherm curves at any temperature based on the data of isotherm curve in one temperature (or reference temperature) can be done with T.E.T.

Table 2: The coefficients of isotherm models at 25 to 60 °C.

Model	Parameters	25 °C	30 °C	35 °C	40 °C	45 °C	50 °C	55 °C	60 °C
Langmuir	B	0.0325	0.0296	0.0271	0.0272	0.0271	0.0255	0.025	0.0248
	C_m	472.14	442.50	422.12	385.00	358.68	334.50	313.54	297.10
	R^2	0.95	0.94	0.95	0.95	0.95	0.95	0.95	0.94
	D.W.T	0.126	0.16	0.104	0.099	0.077	0.053	0.097	0.011
Freundlich	K	115.52	98.87	88.50	75.93	68.43	60.27	55.01	51.59
	n	-0.23	-0.25	-0.26	-0.27	-0.28	-0.28	-0.29	-0.29
	R^2	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
	D.W.T	0.76	1.20	0.94	0.74	0.77	0.45	0.85	0.84
Toth	C_m	472.14	442.50	422.12	385.00	358.68	334.50	313.54	297.10
	k_1	0.0316	0.0292	0.0267	0.0256	0.0249	0.0236	0.0232	0.0231
	k_2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	R^2	1.00	0.95	0.96	0.97	0.97	0.97	0.97	0.96
	D.W.T	0.24	0.22	0.16	0.19	0.18	0.17	0.18	0.21
Radke-Prausnitz	P	55.30	52.50	37.93	23.42	24.53	19.67	21.71	21.41
	q	152.85	129.64	122.64	129.43	108.00	102.05	84.73	78.37
	n_2	0.19	0.20	0.21	0.19	0.20	0.20	0.22	0.22
	R^2	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00
	D.W.T	2.28	1.78	1.81	1.92	1.88	1.55	1.52	1.39

Table 3: A.R.E% between experimental data and models Ra-Pr and Re-Pe at different temperature.

Temperature	25 °C	30 °C	35 °C	40 °C	45 °C	50 °C	55 °C	60 °C	Average of A.R.E%
A.R.E% experimental data and Ra-Pr model	0.78	1.03	0.86	0.93	0.93	0.89	1.05	1.29	0.970
A.R.E% of experimental data and Re-Pe model	0.78	1.03	0.86	0.94	0.93	0.89	1.05	1.30	0.972

On the other hand, the best reference temperature for adsorption operation can be room temperature (25 °C) with low operation cost. It is noted that this type of modeling for adsorption curves is done for the first time by authors of this paper. Therefore, according to mentioned discussion, the general correlation is as following:

$$C_{T_2}^* = C_{T_1}^* f(T,C) \tag{8}$$

Where f(T,C) is (T.E.T) and depends on temperature and concentration. Also, $C_{T_2}^*$ is C^* at T_2 and $C_{T_1}^*$ is C^* at T_1 (reference temperature). Therefore, the modeling should be done on f(T,C). According to Fig. 2 and mentioned results, several models are investigated for f(T,C) as following equations:

$$f(T,C) = (\frac{T_1}{T_2})^m (\frac{C}{C_F})^n \tag{9}$$

$$f(T,C) = (\frac{T_1}{T_2})^{m(c/c_F)} \tag{10}$$

$$f(T,C) = \exp(\frac{T_1}{T_2} \cdot \frac{C}{C_F})^m \tag{11}$$

$$f(T,C) = \exp(\frac{T_1}{T_2})^{m(\frac{C}{C_F})} \tag{12}$$

$$f(T,C) = \exp(\frac{C}{C_f})^{m(\frac{T_1}{T_2})} \tag{13}$$

$$f(T,C) = (\frac{C}{C_f})^{m(\frac{T_1}{T_2})} \tag{14}$$

Table 4: The amounts of a and b in according to Eq. (16).

Model Parameters	30 °C	35 °C	40 °C	45 °C	50 °C	55 °C	60 °C	Average
α	4.20	4.10	4.20	4.15	4.27	4.25	4.24	4.20
β	-0.140	-0.140	-0.135	-0.135	-0.135	-0.130	-0.130	-0.135
R^2	0.988	0.985	0.999	0.989	0.990	0.987	0.986	---
D.W.T	2.11	2.02	2.89	2.7 6	2.6 6	2.70	2.03	---

Table 5: A.R.E% between model (Eq. (16)) and experimental data.

Temperature	30 °C	35 °C	40 °C	45 °C	50 °C	55 °C	60 °C	Average of A.R.E%
A.R.E%	0.8	1.3	0.96	0.97	0.95	0.98	2.34	1.185

Table 6: A.R.E% between model (Eq. (17)) and experimental data.

Temperature	30 °C	35 °C	40 °C	45 °C	50 °C	55 °C	60 °C	Average A.R.E%
A.R.E%	1.04	1.48	1.05	1.22	0.94	1.13	2.55	1.344

$$f(T,C) = (\frac{T_1}{T_2})^{\alpha(\frac{c}{c_F})^{\beta}} \qquad (15)$$

Eq. (9) to (15) are analyzed and the amounts of A.R.E, R^2 and other statistical function are prepared for them. Finally, based on the simplicity and error percentage, Eq. (15), is opted as the best appropriate model. By substitution of this model in Eq. (8), the final correlation is obtained as following:

$$C_{T_2}^* = C_{T_1}^* (\frac{T_1}{T_2})^{\alpha(\frac{c}{c_F})^{\beta}} \qquad (16)$$

Then the experimental data are fitted based on Eq. (16) and the amounts of α and β are determined with respect to O.L.S. method by Eviews software. The room temperature (298.15 K) is selected as reference temperature (T_1) based on absolute temperature and the amounts of C^* are used from experimental data as shown in Fig. 2. Generally, the modeling results including the values of α and β and also R^2 and D.W.Tare shown in table 4.

The results in table 4 show the amounts of R^2 and D.W.T are in good range and have good fitting with experimental data. The deviation among values of α and β in each temperature are low and the values laid in a small range. Therefore, we can use averages for $\alpha(=4.2)$ and $\beta(=-0.135)$ and with experimental data at temperature 25 °C (as $C_{T_1}^*$) and Eq. (16), the amounts of $C_{T_2}^*$ is

predicted where T_2 is 30, 35, 40, 45, 50, 55 and 60 °C. The results of prediction with Eq. (16) are shown in Fig. 3. This figure shows that the difference between model prediction results and real experimental data are negligible. Therefore, it is shown that this model can predict isotherm curves successfully. Also, the percentage of A.R.E between model and experimental data in different temperatures (30-60 °C) are presented in table 5 with respect to 25 °C. According to table 5, it is observed that error amounts are very low and the average error is approximately less than 1.2%. Then, we can conclude that this model is a good model for BA adsorption curves. On the other hand, the main advantage of this model is the prediction of isotherm curves only with one temperature isotherm curve data while errors are negligible.

One of the most important advantage of T.E.T model, is to predict isotherm curves in any temperature with experimental data in three points for one temperature with low error. In other words, with three equilibrium points in one temperature, isotherm curves for BA adsorption onto GAC can be developed in any temperature.

In addition, T.E.T and Ra-Pr models, could predict isotherm curves in any temperature with assumption p=55.30, q=152.85, n_2=0.19 in 25 °C (reference temperature) for BA adsorption onto GAC without experimental data. Thus, with three equilibrium points, p, q and n_2 of Ra-Pr model can be determined.
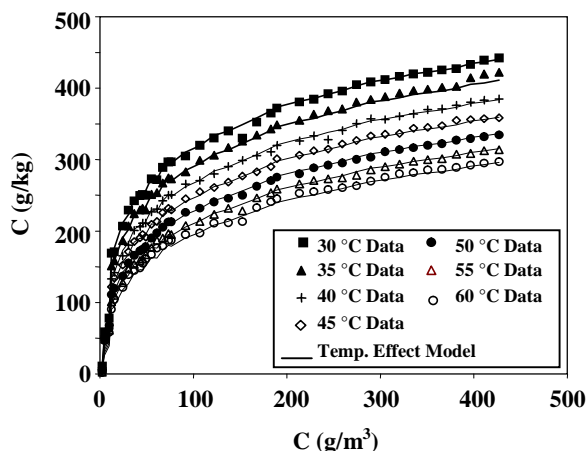
Fig. 3: Prediction of isotherm curves with experimental data by Eq. (16).

Fig. 4: Prediction of Radke-Prausnitz model with Eq. (17).

Therefore, the general form of the model for this state is as bellow:

$$C^*_{T_2\,Ra\text{-}Pr} = C^*_{T_1\,Ra\text{-}Pr}\left(\frac{T_1}{T_2}\right)^{\alpha\left(\frac{c}{c_F}\right)^{\beta}} \qquad (17)$$

Where $C^*_{T_2\,Ra\text{-}Pr}$ is C^* in T_2 and $C^*_{T_1\,Ra\text{-}Pr}$ is C^* in T_1(298.15 K) from Radke-Prausnitz model. Finally, the amounts of $C^*_{T_2\,Ra-Pr}$ are calculated from Ra-Pr model for $C^*_{T_1\,Ra-Pr}$ based on Eq. (17), and the results are shown in Fig. 4.

According to Fig. 4, T.E.T and Ra-Pr models, totally could predict the isotherm curve in any temperature with appropriate tolerance. In addition, the error of these models in comparison with experimental data is calculated and the results are shown in table 6.

As noted before, the results of table 6, is not based on experimental data and are calculated only from Ra-Pr and T.E.T models. However, the results of table 5 are based on experimental data and T.E.T model. The results show that the averages of A.R.E in both tables are allowable. In addition increasing in A.R.E caused by using Ra-Pr instead of experimental data with T.E.T model have a good fitting and is appropriate. In other words, not existing experimental data, to predict isotherm curves in any temperatures, increases the amount of A.R.E less than 0.16% which is negligible.

Another result with comparison of tables 3 and 6, shows good fitting of Ra-Pr. In addition, It shows that
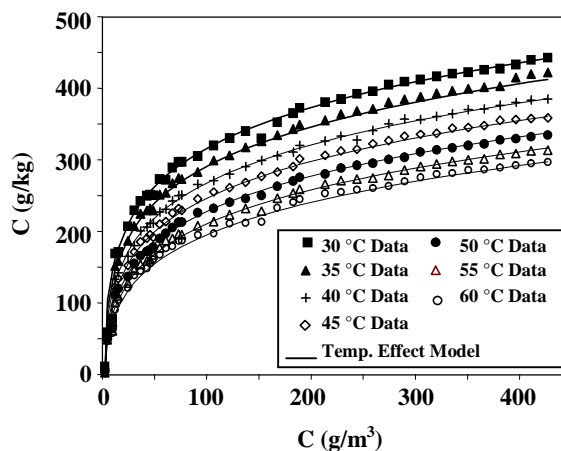
using T.E.T model instead of experimental data increases average A.R.E less than 0.5%. Thus, jointing Ra-Pr and T.E.T models make a negligible deviation.

Therefore, from the achieved results we concluded that the T.E.T model could predict not only experimental isotherm curves, but also isotherm models. Further more, another important result in this model is that the temperature T_1 can be any temperature (not only room temperature).

Mentioned results, is only about BA adsorption onto GAC. But it can be concluded that about any organic acid adsorption onto any adsorbent, if the form of isotherm curves at different temperatures, became similar to the isotherm curve of BA adsorption onto GAC, T.E.T model and other results mentioned above, can be implemented. It's noted that the form of isotherm curves about the majority of organic acid adsorption onto adsorbent are similar to BA adsorption onto GAC and mentioned results can be used for them. For example α and β can be used for other organic acid as constant coefficients.

Organic acids with similar isotherm curves but with more distance between them or expanded curves, in respect to each other in different temperatures can be analyzed with mentioned results. This situation usually happens when the solution is concentrated with solvent. In this cases, the variation of α and β, must be developed as a function of temperature. In this way, T.E.T model can be used in a wide range of organic acids adsorption onto adsorbent with similar isotherm curves as BA adsorption curves onto GAC.

CONCLUSIONS

- Among five important compatible applicable models about adsorption, the Ra-Pr model has best fitting with experimental data of BA adsorption from wastewater onto Activated Carbon. The percentage of A.R.E for this model is almost 0.97%, so we can conclude that this model can predict experimental data well.

- The Re-Pe and Ra-Pr models have good fitting with experimental data and the results of statistical tests are the same about them. In this investigation, it's obtained that two above models are probably in the same structure and in accordance to the published date, Ra-Pr model is used as a reference equation to modeling isotherm curves.

- By considering several mathematical functions, an appropriate term is opted to prediction temperature effect term of BA adsorption onto GAC knowing as T.E.T model. This term help investigators to predict isotherm curves in a determined temperature and is a function of temperature and acid concentration in solution and feed.

- T.E.T model can predict isotherm curves in any temperature with average A.R.E% less than 1.2% by using isotherm curve in a determined temperature. Thus, this model can predict isotherm curves as well as experimental data and its deviation from reality is negligible.

- With three equilibrium points it's possible to obtain Ra-Pr model coefficients. Then based on T.E.T and Ra-Pr models, the isotherm curves in any temperature could be predicted. In addition, based on the results of experimental data of this research work, with assumption p=55.30, q=15.85, n_2=0.19 in 25 °C (reference temperature) for BA adsorption onto GAC, the isotherm curves could be developed without experimental data and appropriate error. In this case, the average A.R.E% in comparison with experimental data is less than 1.4%. Thus, it is recommended to use T.E.T and Ra-Pr to simulate isotherm curves of BA adsorption on GAC.

- T.E.T model is presented in the first time by the authors of this paper and the big advantage of proposed model is its simplicity and high accuracy. On the other hand, T.E.T model can be used in a wide range of organic acids adsorption onto adsorbent with similar isotherm curves to BA adsorption curves onto GAC.

Nomenclatures

C	Equilibrium acid concentration in the liquid phase, (g/m^3)
C_m	Saturation capacity of the resin, (g/kg)
C^*	Equilibrium acid concentration in the sorbent phase, (g/kg)
b	Langmuir correlation constant
k	Freundlich correlation constant
n	Freundlich model parameter
a	Reddlich-Peterson constant
d	Reddlich-Peterson constant
n_1	Reddlich-Peterson model parameter
k_1	Toth model parameter
k_2	Toth model parameter
p	Radke and Prausnitz model constant
q	Radke and Prausnitz model constant
n_2	Radke and Prausnitz model parameter
ρ	Apparent density, (g/m^3)
C_F	Acid concentration in feed, (g/m^3)
α	T.E.T model constant
β	T.E.T model constant
T	Temperature, (°C,K)
R^2	Least square parameter
D.W.T	Durbin Watson Test
A.R.E%	$\left| \dfrac{\text{Experimental Data - Model Data}}{\text{Experimental Data}} \right| \times 100\%$

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