Use of Artificial Neural Network for Modeling and Prediction of Reactive Red Dye Removal from Wastewater Using Banana Peels Bio-sorbent

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Bio-sorption of red dye from aqueous solutions onto banana peels was investigated. Effects of initial pH, bio-sorbent dose, initial concentration, contact time, and temperature were studied and they found of 3, 0.4 g/ 100 mL, 50 mg/L, 100 min and 298 K respectively with removal efficiency of 93.44%. Artificial neural network was used for prediction of adsorption efficiency and its outputs showed a better fit than other traditional isotherm models. The negative values of ΔG° and ΔH° indicate that the bio-sorption of red dye was favored and exothermic. The sensitivity analysis signified that the pH was the most influential variable.

Keywords: Dyes; biosorption; isotherms; kinetics; thermodynamic

Dye and dyestuffs are used widely in many industries such as plastic, cosmetic, paper, textile, carpet, and food [1–3] where disposal the effluents of these industries can cause a serious environmental problems because the toxicity and persistent of the dyes. These contaminants can be transported in the ecosystem and affected on the human health through the food chain could affect the human health [4]. Therefore it is necessary to remove these dyes from water before disposed of it. Treatment of wastewater contaminated with dyes can be achieved by physical, biological, and/or chemical processes [2, 5]. The most used technique for treating the wastewater contaminated with dyes is the adsorption by activated carbon [2, 6, 7]. There are five main methods used for the treatment of dye-containing effluents: adsorption, oxidation–ozonation, biological treatment, coagulation–flocculation, and membrane process [3, 8]. Among the various methods described, adsorption is generally preferred for the removal of dyes due to its high efficiency, easy handling, and availability of different sorbents [9, 10]. Activated carbon is the most adsorbent materials used because of their large surface areas, microporous structures, high degree of surface reactivates and a high adsorption capacity [11]. However, activated carbon is expensive and, accordingly, it is necessary to search for cheap, easily available and efficient sorbents. Agricultural waste has attracted great research interest as it offers various advantages such as abundantly available and ability to biodegradation [12]. These sorbents can be disposed of without regeneration because their low cost [13, 14]. Many studies were directed to derive of bio-sorbents from agriculture wastes and using them in the bio-sorption process was investigated by many studies [15, 16]. The bio-sorption process is depended on the functional groups such as alcohols, aldehydes, lignin, cellulose, ketones, carboxylic, phenolic and ether groups available on the bio-sorbents [17]. Hazelnut shells, orange peel, peanut hull, barely husk and sugarcane bagasse tested to use as biomaterials in the removal of dyes from wastewater [18-22]. In this concern, several tons of banana peels are disposed daily and this may be accompanied with environmental nuisance. Accordingly, these wastes can be used as biosorbent for the removal of contaminants from aqueous solutions [23]. The ANNs have drawn great attention in the determination of relationship between operating variables. The ANN is an information processing tool that is capable of establishing a relationship between input and output data. This can be achieved through extracting the controlling features from a database presented to the network and nonlinear relationships are used to understand, solve and thereby achieving ability to predict accurately [24-26]. The objective of the present work is to investigate the adsorption behavior of dry BP as eco-friendly and low-cost bio-sorbent for the removal of RR dyes from aqueous solutions. Langmuir, Freundlich, Langmuir-Freundlich, and Redlich–Peterson models were used for description the experimental sorption data. The data were fitted with different types of kinetic models to understand the mechanism of bio-sorption. Furthermore, the effects of the operational parameters on the sorption capacity were investigated by ANN.

Experimental part

Materials and methods

Sorbent and contaminant

Banana peels (BP) were collected from kitchen waste and the impurities were removed by washing with tap water and, then, with distilled water. Oven at 50°C was used for drying these peels to avoid degradation of the binding sites. The dried peels were ground to a powder and the particles passed through 200 μm mesh were chosen. Table 1 gives the physical properties of used BP.

property	Value
Moisture content (wt %)	13.89
surface area (m^2/g)	12.2
apparent density ($g.cm^{-3}$)	0.39
Porosity (%)	78.1

Table 1
THE PHYSICAL PROPERTIES OF BP

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The commercial-grade reactive red (RR) dye is obtained from Hilla textile factory/Iraq (Origin: Sigma-Aldrich Company, USA). It is the contaminant adopted in this study with formula of $C_{44}H_{24}O_{20}N_{14}Cl_2Na_6S_6$, molecular weight of 1496.98 g/mol, *p*H of 6.2 and wave length of 540 nm. The 1 g of dry powdered dye was dissolved in 1 L of distilled water to prepare of stock solution which was used to obtain the required concentration. The initial *p*H of the aqueous solution can be adjusted using a buffer solution under magnetic stirring. The concentration of dissolved contaminant was measured using UV-Vis spectrophotometer (Model: APEL PD-303 UV, Japan).

The influences of *p*H, bio-sorbent dose, contact time, initial contaminant concentration, and temperature on the uptake capacity were investigated. Initially, the solution with dye concentration of 50 mg/L at values of *p*H ranged from 2 to 6 was mixed with 4 g BP at room temperature. Bio-sorbent dose were changed from 0.025 to 0.6 g, while the effects of initial dye concentrations were investigated in the range (25-100 mg/L). Moreover, the contact time was varied between 10 and 120 min for experiments under consideration. In order to study the effect of temperature, experiments were achieved with changing of this parameter to take the values of 25, 30, 35, and 40 °C. The samples were collected after the equilibrium from each flask and centrifugation was used to separate between bio-sorbent and the aqueous solution. Then, the supernatant was filtered by (WHATMAN, No. 42; diameter of 7 cm) and the remaining concentration dye was measured using UV-Vis spectrophotometer.

The bio-sorption isotherms of RR onto BP were performed through changing the dye concentrations from 25 to 100 mg/L and using fixed BP dosage of 0.4 g per 100 mL at agitation speed of 200 rpm with best value of *p*H determined previously. The shaker type (Edmund Buhler, 7400 Tubingen Shaker-SM 25) was used for changing the speed of shaking. The amount of sorbed dye (q_e, mg/g) was calculated from mass balance equation as follows:

$$q_e = \frac{(C_0 - C_e)V}{m} \quad (1)$$

where C_o and C_e are the initial and equilibrium concentration of the adsorbate (mg/L), respectively, V is the volume of used solution (L), and m is the mass of the BP (g).

Artificial neural network (ANN) model

This model can be simulated the influence of operating parameters in the sorption of dyes from contaminated water [27, 28]. The initial concentration, *p*H, temperature, bio-sorbent dosage, and agitation time were used in the input layer, while the dye removal efficiency was the target. The data sets were randomized and divided into training, validation, and test subsets, which included 60, 20 and 20% of the total data, respectively. The structure of back propagation neural network was specified based on mean squared errors (MSE) as follows:

$$MSE = \frac{1}{N}\sum_{i=1}^{i=N}\left(y_{i,pred} - y_{i,exp}\right)^2 \quad (2)$$

where $y_{i,pred}$ and $y_{i,exp}$ are the predicated and measured values, respectively, N is the sample size. Levenberg–Marquardt (LM) algorithm was utilized which is depended on the least-squares estimation of nonlinear parameters. This algorithm is considered the most robust and the fastest. The sensitivity analysis can be analyzed by Garson method [29] where relative importance for each input variable is calculated as follows:

$$I_j = \frac{\sum_{m=1}^{m=Nh}\left(\left(\frac{|W_{jm}^{ih}|}{\sum_{k=1}^{Ni}|W_{km}^{ih}|}\right)\times|W_{mn}^{ho}|\right)}{\sum_{k=1}^{k=Ni}\left\{\sum_{m=1}^{m=Nh}\left(\left(\frac{|W_{km}^{ih}|}{\sum_{k=1}^{Ni}|W_{km}^{ih}|}\right)\times|W_{mn}^{ho}|\right)\right\}} \quad (3)$$

where *Ws* are connection weights, the superscripts *o*, *h* and *i* refer to output, hidden and input layers, respectively, *Nh* and *Ni* are the numbers of hidden and input neurons, respectively, and subscripts *n*, *m* and *k* refer to output, hidden and input neurons, respectively.

Results and discussions

Modeling using ANN

Levenberg–Marquardt backpropagation (LMA) algorithm was developed and programmed using Matlab software for description the removal of contaminant from simulated wastewater by BP. The biggest data was used as training for learning the pattern of neural network through updating the network weights. The quality of this network was evaluated by testing data and validation data was used for checking the performance and generalization of the trained network. In the present study, tangent sigmoid transfer function (tansig) and linear transfer function (purelin) at hidden and output layers were used.

The minimum MSE for training and prediction sets are adopted for finding the best topology of ANN model. Initially, two neurons were tested for optimization of the network and, then, the number of neurons was increased where corresponding MSE for each number can be determined as plotted in figure 1. This figure is proved that the minimum value of MSE achieved with 10 hidden neurons.

The training was stopped after 62 epochs for the LMA because the differences between training error and validation error started to increase. Figure 2 illustrates training, validation, and test mean square errors for the LMA. Finally, results proved that the 5:10:1 is represented the best structure for ANN for predicting the removal of RR dye. Figure 3 presents the best regression for three subsets using algorithm of the Levenberg-Marquardt.

Influence of pH

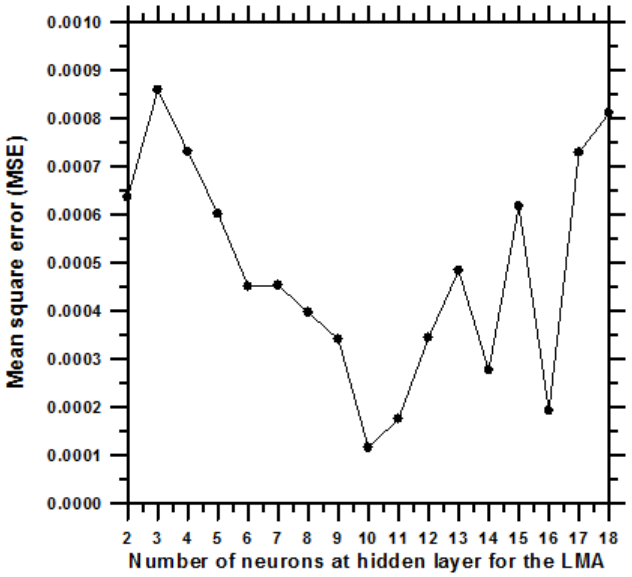

Fig. 1. The values of MSE accompanied with number of neurons for the LMA.

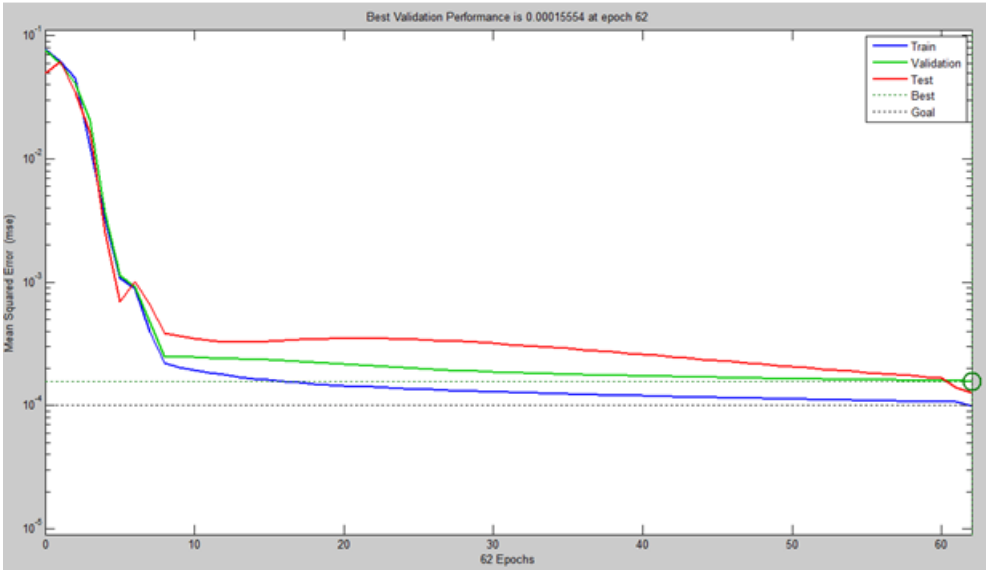

Fig. 2. The values of MSE for training, validation, and test subsets using algorithm of the Levenberg-Marquardt.

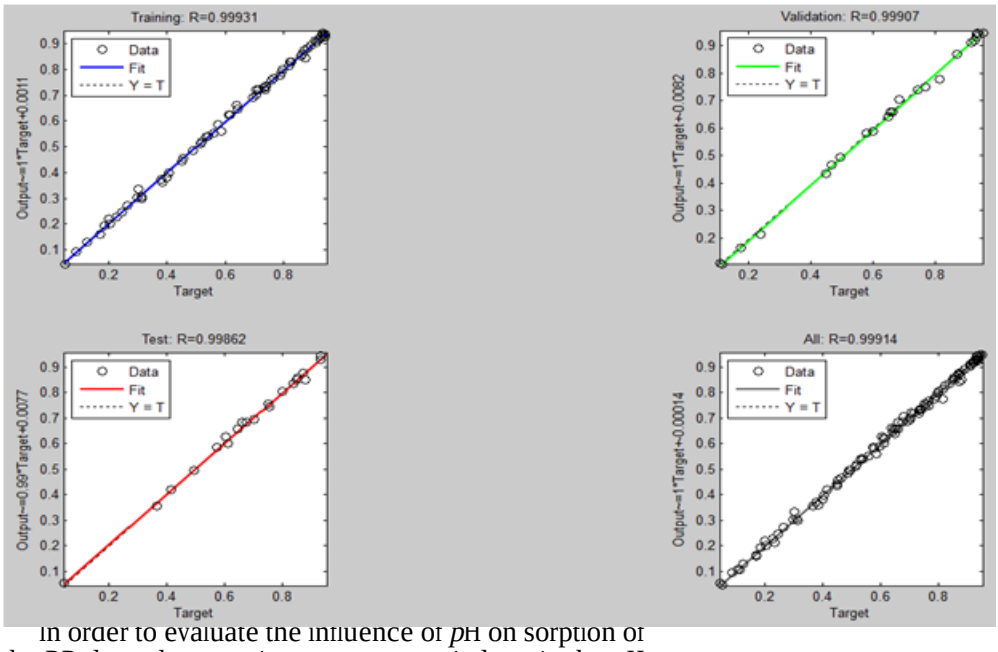

Fig. 3. The best regressions for sorption data using algorithm of the Levenberg-Marquardt

In order to evaluate the influence of *p*H on sorption of the RR dyes, the experiments were carried out in the *p*H range of 2–6 and measured values are showed in figure 4 where the removal efficiency decreased with increasing *p*H. This behavior could be explained on the basis of pH_{zpc}. The experimental determination of pHzpc for BP revealed that pHzpc equal to 6.2 where electrostatic is lower than pHzpc the dissolved anionic dye is negatively charged in aqueous solution. At low *p*H, the bio-sorbent gathers positive charges by adsorbing H^+ ions and its surface gets positively charged, which is adsorbing more dye due to electrostatic force of attraction. When *p*H is greater than pHzpc, the surface of sorbent has negative charges and this caused a decrease in the capacity of sorption due to electronic repulsion. Many studies signified that predominant mechanism in the sorption of pollutants on the alga is electrostatic attraction [30, 31]. In addition, Aksu and Tezer [32] elucidated that the description of the bio-sorption mechanism as a function of *p*H is very difficult due to the presence a set of parameters affected on the dye bio-sorption such as the number and type of functional groups, water chemistry, etc. Also, the wastewater resulted from dyeing processes can be contained a higher concentration of salt and this concentration (i.e. ionic strength or salinity concentration) can influence on the bio-sorption capacity [7, 8, 18]. It can be seen from figure 4 that the correlation coefficient was greater than 0.99 and this means that ANN model is able to describe the experimental data.

Influence of bio-sorbent dose

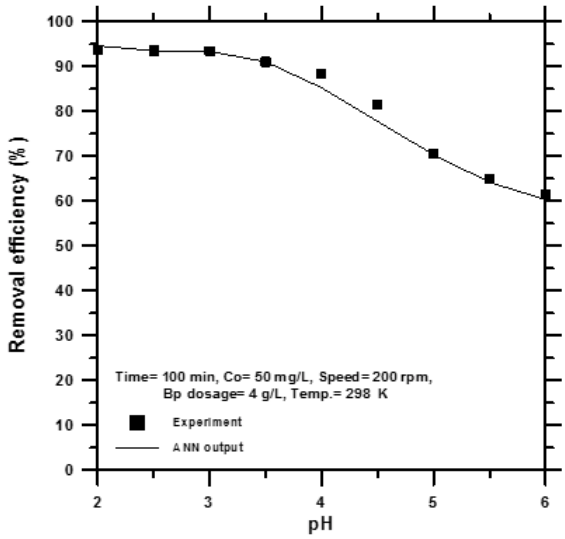

Fig. 4. Effect of pH on removal efficiency of RR dye onto BP

The BP dosage effect on the RR dye removal was investigated through the change of sorbent mass from 0.025 to 0.6 g added to 100 mL with shaking of 200 rpm for 100 min, at 298 K, and *p*H 3. The removal efficiency was increased to 93.44% with increasing amount of bio-sorbent dosage up to 0.4 g/ 100 mL (fig. 5) and this value can be considered the best value for remaining tests. Bio-sorption of RR dyes was increased as the bio-sorbent amount increased. On the other hand, figure 5 shows that the bio-sorption capacity increased with changing the dose from 0.025 to 0.4 g, and then the bio-sorption capacity reached to 11.68 mg/g, it represents a plateau. The results were expected because for a fixed initial metal concentration, increasing bio-sorbent amount provides a greater surface area or sorption site [33, 34]. A good agreement can be recognized between ANN outputs and experimental data as shown in figure 5.

Influence of initial concentration and contact time

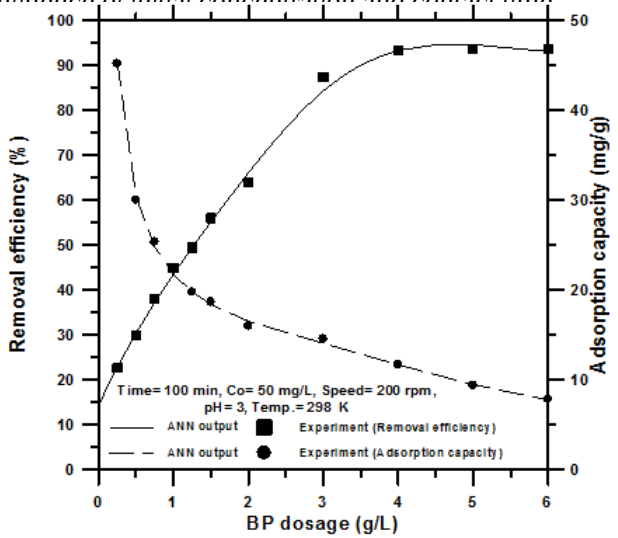

Fig. 5. Effect of bio-sorbent dosage on removal efficiency and experimental capacity of RR dye onto BP

The adsorption capacity of biomass increased with an increase of contact time before equilibrium was reached [11]. Figure 6 shows the effect of contact time on the removal efficiency of RR onto BP at different initial concentration. It can be seen that the adsorption by the inactive instant BP reached equilibrium after 100 min for different initial concentrations of RR dyes. The removal efficiency increased rapidly due to the availability of binding sites present on the inactive BP surface, and with the progressive saturation of the sorbent with increasing contact time the sorption process became less efficient. It can be noticed the trend was similar for all initial concentrations. Therefore, considering the aforementioned observations, 100 min was selected as optimum contact time for RR dyes sorption by the inactive instant BP. Similar behavior for other bio-sorbents with dyes was proved in many studies such as [35, 36].

Isotherm models

Several isotherm models can be used for fitting the measured values and this is very useful in the understanding the physicochemical interactions between sorbate and sorbent. The parameters of models are provided explanations about the surface properties, the sorption mechanism, and the affinity of the sorbent [37]. Freundlich (eq.4), Langmuir (eq.5), Langmuir–Freundlich (eq.6), and Redlich–Peterson (eq.7) models listed below were utilized to represent the sorption data [38].

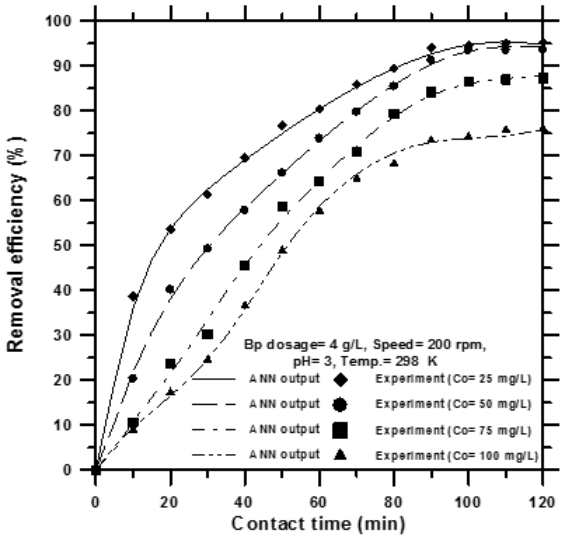

Fig. 6. Effect of contact time on removal efficiency of RR dye onto BP for different initial concentrations

$$q_e = K_f \, C_e^{1/n} \quad (4)$$

where K_f (mg/g)(L/mg)$^{(1/n)}$ and $1/n$ are empirical constants dependent on several environmental factors.

$$q_e = \frac{q_m b C_e}{1 + b C_e} \quad (5)$$

where q_m (mg/g) and b (L/mg) are the constant of Langmuir model.

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

where: q_m (mg/g), b (L/mg)$^{1/n}$ and n empirical constants.

$$q_e = \frac{A_R C_e}{1 + B_R C_e^{m_R}} \quad (7)$$

where: A_R (mg/g. L/mg) and B_R (L/mg)^{mR} are the Redlich-Peterson parameters.

The isotherm models are plotted in figure 7 together with experimental results for bio-sorption process. This figure illustrated that the sorbed quantities were increased with the increase of the equilibrium RR concentration and then the capacity reached a plateau. This may be attributed to many factors such as smallest ionization energy of the considered dye where Allen and Brown (1995) [39] proved

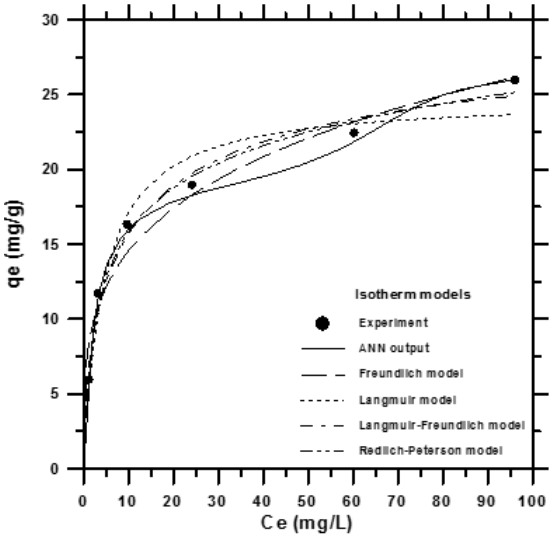

Fig. 7. Isotherm data of batch system for bio-sorption of RR dye onto BP

Table 2
PARAMETERS OF ISOTHERM MODELS FOR RR DYE IONS ONTO BP

Model	Parameters	Value
Freundlich	K_f (mg/g)(L/mg)$^{(1/n)}$	8.0227
	n	3.8610
	R^2	0.9885
Langmuir	q_m (mg/g)	24.7567
	b (L/mg)	0.2253
	R^2	0.9884
Langmuir-Freundlich	q_m (mg/g)	31.2302
	b (L/mg)$^{1/n}$	0.2526
	n	1.6590
	R^2	0.9946
Redlich–Peterson	A_R (L/mg)	13.4830
	B_R (L/mg)^{m_R}	0.7732
	m_R	0.8578
	R^2	0.9967

that more electronegative dye will be more attractive to the bio-sorbent. The sorbed quantities were also determined using ANN model and good matching with experimental results can be recognized.

All parameters of these models were calculated by Statistica software using non-linear regression analysis. The constants of the models are listed in Table 2 and it is clear that these models are represented the experimental data in a good manner ($R^2 > 0.988$). Based on values of R^2, the experimental data fit the selected isotherms in the following order: ANN model > Redlich–Peterson > Langmuir–Freundlich > Freundlich > Langmuir.

Kinetic models

Pseudo-first order and pseudo-second kinetic models have been used to describe the bio-sorption rate in a batch operation. These models are discretion in equations 8 and 9 respectively. The pseudo-first-order kinetic model has been widely used to predict metal biosorption kinetics. The pseudo-first order rate expression suggested originally by Lagergren is based on the solid capacity. While pseudo-second order kinetic model is based on the assumption that the pollutant molecule is sorbed onto two sorption sites of the bio-sorbent surface [40].

$$ln(q_e - q_t) = lnq_e - k_1 t \quad (8)$$

where q_e is the equilibrium sorbed quantity of dye (mg/g); q_t is the sorbed quantity of dye at time t (mg/g); and k_1 is the pseudo ûrst order rate constant (1/min).

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \quad (9)$$

where k_2 is the pseudo second order rate constant, (g/mg min), q_e is the amount of divalent metal sorbed at equilibrium, (mg/g), q_t is the quantity of sorbate on the surface of the sorbent at any time, t, (mg/g).

The experimental results at best operation conditions were fitted with kinetic models to find the predominant mechanisms of bio-sorption process. The constant of pseudo-first-order model for RR dyes (k_1 and q_e) were obtained from the slope of the linear plots of $ln(q_e-q_t)$ against t for several concentrations of RR dyes using equation 8 (fig. 8). The constants of pseudo-second order (k_2 and q_e) were obtained from the slope and intercept of t/q_t against t using equation 9 (fig. 9). The rate constants and the corresponding R^2 are presented in table 3 for both mechanisms; according to these results, the experimental data for three metals followed pseudo-second order. It is clear that R^2 values for pseudo-second-order model are (0.9961, 0.9895, 0.8932, and 0.8554) at initial concentrations of RR dyes (25, 50, 75, and 100) mg/L, respectively. These results suggest that pseudo-second order model successfully describes the kinetics of the bio-sorption of RR dyes onto BP. This means that the biosorption of this dye occurs onto BP surface is most likely to involve chemical interactions leading to binding of the dyes to the bio-sorbent surface by bonding as strong as covalent binding [41]. The adsorption mechanisms were studied according to the concept of Weber and Morris proposed for intra-particle diffusion model, which can be written following equation [41]:

$$q_t = k_{id} t^{1/2} + C \quad (10)$$

where q_t (mg/g) is the amount adsorbed at time t (s), K_{id} (mg/gm. min$^{1/2}$) is the rate constant of intra-particle diffusion, C is the value of intercept which gives an idea about the boundary layer thickness.

According to intra-particle diffusion model, a plot of q_t versus $t^{0.5}$ should be linear if intra-particle diffusion is involved in the bio-sorption process, and if the plot passes through the origin, then intra-particle diffusion is the sole rate-limiting step. Figure10 shows the intra-particle diffusion plot for RR dyes bio-sorption onto BP. It can be seen that this plot is multi-linear, suggesting that the bio-sorption process occurred in three phases [42]. The external surface bio-sorption occurs instantly on the first steeper portion. Whereas, the intra-particle or pore diffusion is rate-limiting in the second stage and the bio-sorption occurs rapidly. When intra-particle diffusion starts to slow down due to extremely low sorbate concentrations left in the solutions , the final equilibrium stage occurs which can be seen in the third portion of the plot. When the straight line plot of intra-particle diffusion (second line) does not pass through the origin, as can be seen in figure 10, intra-particle diffusion was not the only rate-limiting step. Indeed there are three processes that work in a specific time range which control the bio-sorption rate. The parameters of the intra-particle diffusion model K_p and C were calculated from the slope and the intercept of the three linear portions given in Fig. 10, respectively, and the results are listed in table 3. The high value of K_p confirms rapid transfer [41]. In addition, the intercepts (C values) of the first and second trend lines in Fig. 10 give a suggestion about whether surface or intra-particle diffusion has a larger role as the rate-limiting step [43]. From these results, it can be concluded that intra-particle diffusion is the dominating mechanism for the bio-sorption of RR dyes onto BP because all the intercept values of intra-particle diffusion trend lines (second line) are greater than those obtained from surface diffusion trend line (first line). Similar conclusions on the effect of adsorbate concentration on the removal behavior have been reached by [44].

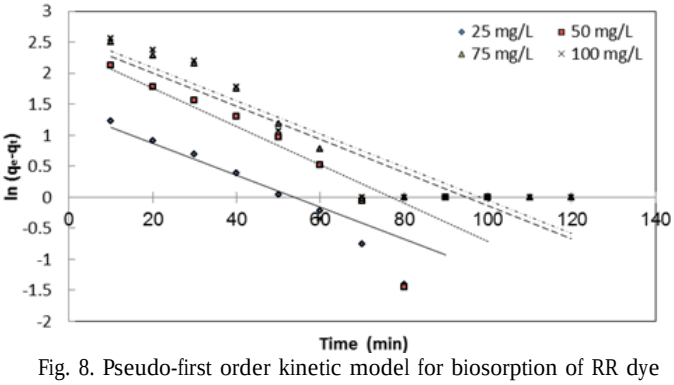

Fig. 8. Pseudo-first order kinetic model for biosorption of RR dye onto BP at (dose = 0.4 g/100 mL; pH = 3; and 200 rpm).

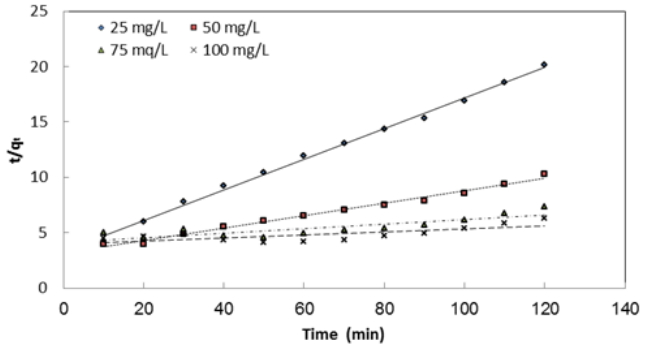

Fig. 9..Pseudo- second order kinetic model for biosorption RR dye onto BP at (pH = 3; biosorbent dose = 0.4 g/100 mL; 200 rpm and time = 0-120 min)

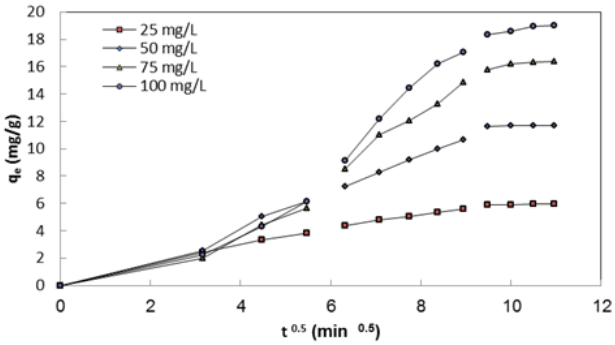

Fig. 10. Intra-particle diffusion plots for RR dye bio-sorption onto BP

Kinetic Model	Parameters	C_o (mg/L)			
		25	50	75	100
Pseudo-first-order	q_{eq} (mg/g)	3.9749	10.8038	13.7151	12.7687
	K_1 (L/min)	0.0265	0.0310	0.0276	0.0268
	R^2	0.7184	0.7502	0.8641	0.7493
Pseudo-second-order	q_{eq} (mg/g)	7.2202	17.7936	48.0769	73.5294
	K_2 (g/mg.min)	0.0057	0.0010	0.0001	0.00004
	R^2	0.9961	0.9894	0.8932	0.8554
Intra-particle diffusion	First Line				
	C	0.0597	-0.2781	-0.3543	-0.3679
	K_p (mg/g.min$^{0.5}$)	0.7130	1.1296	1.0290	1.0789
	R^2	0.9952	0.9656	0.9408	0.9451
	Second Line				
	C	0.0946	-0.0712	-0.3805	-0.6465
	K_p (mg/g.min$^{0.5}$)	0.6380	1.1903	1.6130	1.8965
	R^2	0.9929	0.9989	0.9822	0.9638
	Third Line				
	C	0.0610	0.1257	0.1381	0.1552
	K_p (mg/g.min$^{0.5}$)	0.5710	1.1242	1.5628	1.8096
	R^2	0.9882	0.9871	0.9917	0.9923

Table 3
KINETIC PARAMETERS FOR THE RR DYE BIO-SORPTION ONTO BP AT DIFFERENT INITIAL RR CONCENTRATIONS

Thermodynamic parameters

The thermodynamic parameters of the sorption process such as Gibbs free energy change ΔG°, standard entropy change ΔS° and standard enthalpy change ΔH° are adopted for characterization the influence of temperature on the removal process. The thermodynamic parameters were calculated using the following equation [45]:

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ \quad (11)$$

where T is absolute temperature (K) and R is the universal gas constant (8.314 J/mol. K).

The values of thermodynamic parameters can be calculated from the plot of ΔG° vs. T in equation 11 (fig. 11) and these values are listed in table 4. This table certifies that the nature of bio-sorption process is exothermic and the interaction between RR and BP has chemical nature. The results are in consistent with finding of other studies such as [46]. The negative values of ΔG° prove that the bio-sorption reaction is less favorable at low temperatures.

Sensitivity analysis

The sensitivity analysis was achieved by Garson equation through neural weight matrix for assessment the importance of input variables. The results proved that the initial *p*H was most influential parameter with relative importance equal to 28.4% for the bio-sorption process under consideration (fig. 12), followed by contact time (27%), bio-sorbent dosage (18 %), dye concentration (17.8%) and temperature (8.8%).

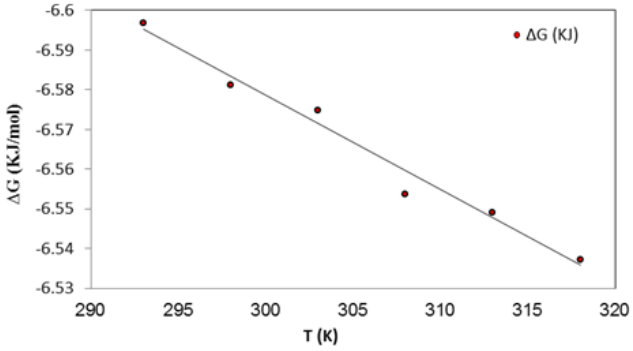

Fig. 11. Free energy change ΔG° versus temperature for bio-sorption of RR dye onto BP

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Table 4
THERMODYNAMICS PARAMETERS OBTAINED OF BIO-SORPTION FOR RR DYES ONTO BP

Temperature (K)	$-\Delta G^\circ$ (kJ.mol^{-1})	$-\Delta H^\circ$ (kJ.mol^{-1})	ΔS° (J.mol^{-1}K^{-1})	R^2
293	6.5968	-7.2911	24	0.9779
298	6.5812			
303	6.5748			
308	6.5537			
313	6.5490			
318	6.5372			
323	6.5968			

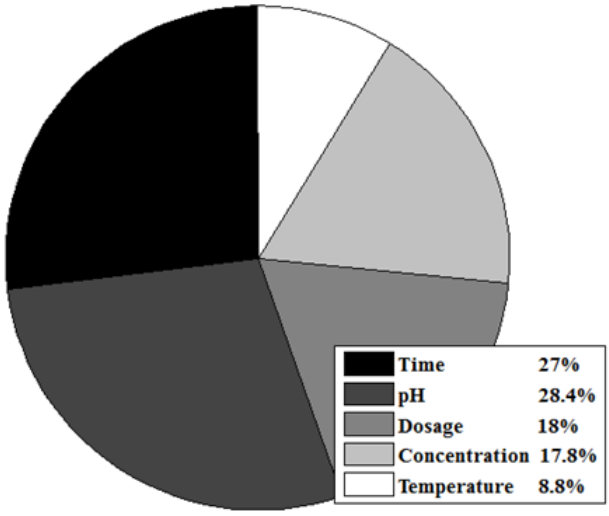

Fig. 12. Sensitivity analysis using artificial neural network

Conclusions

This study confirmed that dry banana peels (BP) are a promising bio-sorbent for reactive red (RR) dyes removal from aqueous solutions. The best conditions for removal process: *p*H= 3, bio-sorbent dosage= 0.4 g/100 mL of solution, initial concentration of dye = 50 mg/L and contact time= 100 min. Maximum removal efficiency and maximum experimental capacity of RR dye are 93.44% and 11.68 mg/g in batch bio-sorption system at best conditions. A three layer ANN with a tangent sigmoid transfer function (tansig) at the hidden layer and a linear transfer function (purelin) at the output layer were proposed to predict the efficiency of RR dye removal. The best number of neuron for LMA was determined and it has value of 10 with MSE of 0.00015554. The proposed ANN model showed a precise and an effective prediction of the experimental data with correlation coefficient greater than 0.999 for five operating variables. The ANN model provides the best fit for the experimental isotherm data of RR dye for batch bio-sorption system. The bio-sorption dynamics process for the dye was better represented by pseudo-second-order kinetic model in comparison with pseudo-first-order and intra-particle diffusion kinetic models. Thermodynamics of RR dye bio-sorption showed the exothermic nature of the process. The initial pH with a relative importance of 28.4% appeared to be the most influential parameter in the bio-sorption process by artificial neural network.

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