Research Article

Artificial neural network (ANN) approach for modeling of methyl orange adsorption by *Syzygium cumini* seed coat

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Citation

Faisal Abbas, Fozia Batool, Shahid Iqbal, Jamshed Akbar, Sobia Noreen and Tunzeel Iqbal. Artificial neural network (ANN) approach for modeling of methyl orange adsorption by *Syzygium cumini* seed coat. Pure and Applied Biology. Vol. 10, Issue 3, pp886-896. <http://dx.doi.org/10.19045/bspab.2021.100091>

Received: 01/10/2020

Revised: 18/12/2020

Accepted: 21/12/2020

Online First: 30/12/2020

Abstract

In current study remediation of methyl orange was studied from aqueous media using *Syzygium cumini* seed coat as an active material. Batch adsorption method was utilized for the purpose and parameters optimization, including pH (3, 7 & 12), initial concentration (40, 80 & 120 ppm) and contact time (40, 80 & 120 minutes). After parameters optimization these variables were taken as input layer of Artificial Neural Network (ANN) to calculate predictive model for the removal of dye. For this purpose STATISTICA 10 software was used and architecture used for model generation was 3-8-1, which includes 3 input layers, 8 hidden and 1 output layers. Experimental results shows that *Syzygium cumini* seed coat is an excellent adsorber for methyl orange due to different functional groups (-OH, C=O and C-O) present on its surface as analyzed by FTIR and rough surface shown in SEM image. Predictive modeling was performed by ANN to determine adsorption capacity of the studied adsorbent for dyes. Validation of generated model was done by measuring R-square value (0.96). Results indicates *Syzygium cumini* can be successfully utilized for remediation of methyl orange from aqueous media and predictive modeling by ANN can predict future adsorption on this adsorbent.

Keywords: Adsorption; Artificial Neural Network (ANN); Azo dyes; Predictive modeling; *Syzygium cumini*

Introduction

One of the major problems faced by present world is water pollution. The discharge of industrial waste into water bodies is very harmful as it contains toxic chemicals and dyes that impart unpleasant smell and color to water [1]. Human survival is impossible without water. Out of this 3% is fresh water and just 0.06% is easily accessible to humans while the remaining consists of frozen ice

caps, underground water & marshes [2]. Adsorption had been found a useful approach for elimination of dyes from industrial waste water. For this purpose wide variety of adsorbents is used that possess various characteristics depending on their chemical nature and synthesis techniques [3]. The major source of dye pollution of water bodies is the discharge of untreated textiles and waste water of leather industries that contains

various dyes. Dyes have been used by mankind from many centuries like Indigo dye was used 4000 years ago by Egyptians to envelop mummies [4].

Textile industries uses several types of dyes and the waste water produced during bleaching, washing, dyeing and finishing operations is thrown into water bodies that act as sweet poison for water bodies [5]. Dyes impart severe harms towards ecological system as they possess carcinogenic properties that makes water non suitable for the aquatic life. Actually it was the color of water bodies that pay head on the removal of dyes [6].

Various types of dyes and pigments are used by textile industries to make their product colorful and gorgeous. About 7×10^5 tons of dye material is produced per annum by the use of approximately 100,000 commercially available dyes [7]. These industries use different types of dyes such as azoic dyes, disperse dyes, solvent dyes, direct dyes, reactive dyes, acidic dyes and basic dyes. The azo dyes rank as major industrial effluents and its removal is a necessity of today [8].

There are several methods like chemical, biological and physical methods are used for the removal of dyes from industrial effluents. Even though world environmental organizations compel textile industries to remove coloring substances from waste matter before its disposal. The just removal of color from sewage does not mean that dyes are totally removed from it because the treatment process may just break down the bond of the chromophore of the dye and still the scrap of molecule remains integral so it will shift the absorption of light by the subjected molecule from visible region to Ultra Violet or Infrared region. Adsorption had been used as a physical and chemical process for the last several years and now it is evolved as a major technique for the industrial separation [9]. Food and agricultural industrial waste like rice husk,

bagasse, wheat straw, orange peel, leaves, stems and coconut shells can be easily converted into adsorbents by physical and chemical means [10].

Adsorption refers to adhesion of atoms, ions or molecules to some solid surface. As a result, a thin layer of adsorbate (substance that is adhered) is formed on adsorbent (the solid surface). It may be physical in which adsorption is due to Van der Waals forces between the adsorbent and adsorbate [11]. Adsorption may be chemical that is due to some chemical bond between adsorbent and the adsorbate [12].

Because of its efficiency and effectiveness adsorption is the modern day subject for removal of dyes [13].

The intention of present work is the found a cheaper alternate for the removal of methyl orange from aqueous media using various parameters.

Materials & Methods

In current study we utilized a commonly available agrowaste in Pakistan "*Syzygium cumini*" seed coat commonly called Malabar plum.

Collection & pretreatment of adsorbent

The fresh seed of Malabar plum were collected from different areas of Sargodha city, Pakistan. After drying the seed coat was removed from seed and washed with hot water in order to remove any sort of entrapped pigment or dye [14]. The washed sample was then dried again in an oven at 50°C over night to remove moisture. The dried seed coat was then crushed into fine powder. The conversion into fine powder is done in order to increase surface area of the adsorbent [15]. Adsorbent was then stored in air tight jar for further use.

Characterization of sorbent

In order to find out the efficiency of sorption process and chemical and physical parameters it is crucial to characterize the sorbent. For this purpose Fourier transform infrared spectroscopy (FTIR) and Scanning

Electron Microscopy (SEM) of the sorbent is carried out.

Fourier transform infrared spectroscopy (FTIR)

Fourier transform infrared spectroscopy (FTIR) is a widely used technique to determine the functional groups present in a sample. In this technique a polychromatic light is subjected on a sample and a graph is obtained. From the peaks of graph the functional groups present in a sample can be identified [16]. These functional groups provide information about active functional groups present on the surface of adsorbent for attachment of sorbate. FTIR analysis was performed in Sargodha University on Fourier Transform Infrared Spectrometer (Model Shimadzu AIM-8800).

Scanning electron microscopy (SEM)

Scanning Electron Microscopy (SEM) is another important technique to study surface morphology of adsorbent. It is useful to determine the presence of pores and cavities in the surface of sorbent [17]. We checked surface of our agrowaste by using this technique Scanning Electron Microscope, JEOL model 2300 was utilized for the purpose.

Instruments and chemicals

Adsorption of methyl orange was determined by using UV-Vis spectrophotometer, Model Holdwell UV-8000. All the chemicals used fulfill the analytical grade. Test solutions of methyl orange were prepared by using dilution method from stock solution of 500 mg/l in distilled water.

Adsorption experiment

For the adsorption experiment, the amount of methyl orange adsorbed by adsorbent is

investigated. Batch experimentation was done to evaluate the effect of three parameters like pH, initial concentration of dye and contact time for 100 ml of aqueous dye solution.

The solution is then filtered and the concentration of dye is determined by measuring $\lambda_{\max}$ using UV-Vis spectrophotometer. The adsorbent dose and shaking speed of 1 g and 150 rpm is maintained during the batch experimentation. In order to calculate the amount of adsorbed dye following formula is used:

$$q_e = \frac{(C_0 - C_e)V}{W}$$

q_e , C_0 , C_e , V & W is the amount of dye being adsorbed, initial dye concentration, volume of dye solution, weight of adsorbent [18].

Predictive modeling and optimization

Here we had used two types of predictive models i.e. artificial neural network (ANN) & full factorial design (FDD) for prediction of efficiency of sorbent.

Full factorial design

Full factorial design is useful for those experiments that take various factors into account and it is essential to study the interaction of these factors towards the net response. The main advantage of full factorial design is that it requires only small numbers of experiments for various factors thus saving the time and materials [19]. This design helps us to predict which factor shows more impact and controls the deviation of one factor over another. Here we used 2^3 full factorial design. Three independent factors i.e. contact time; initial dye concentration and pH were varied between low, medium and high levels given in the (Table 1).

Table 1. Factorial design applied on work

Factors	Low	Med	High
(X ₁) pH	3	7	12
X ₂ Initial dye conc.(ppm)	40	80	120
X ₃ Contact time(Mins)	40	80	120

Artificial neural network (ANN)

ANN is a mathematical tool to report for the efficiency of adsorption process. This model is based on human nervous system having several neurons. In this model several neurons are arranged in form of layers. These layers involve input layers, several hidden layers and one output layer. Signal is transferred from input layers to output layer through hidden layers with the help of neurons [20]. The variables used as input in

the adsorption of Methyl orange are initial dye concentration (40, 80 & 120 ppm), contact time (40, 80 & 120 minutes) and PH (3, 7 & 12). Approximately 100 data points are used to nourish the structure of ANN. There are several hidden layers that perform calculations to produce net input that is then applied with activation function to produce the actual output [21]. The structure of ANN is shown in the (Fig. 1).

Figure 1. Architecture of ANN

Results and Discussion

Characterization of sorbent

For estimation of surface morphology and determination of functional groups present in the sorbent Scanning Electron Microscopy (SEM) and Fourier transform infrared spectroscopy (FTIR) is used.

Scanning electron microscopy (SEM)

For the estimation of surface morphology Scanning Electron Microscope, JEOL model 2300 was utilized for the purpose. In (Fig. 2) it shows the roughness of sorbent surface necessary for the attachment of sorbate with sorbent. From figure it is clear that the tiny pores and cavities available at the surface of sorbent are responsible for multilayer and thick adsorption of sorbate.

Fourier transform infrared spectroscopy (FTIR)

Fourier Transform Infrared Spectrometer (Model Shimadzu AIM-8800) was used for the identification of the functional groups present in *Syzygium cumini* seed coat. The efficiency of adsorption of sorbate by sorbent is defined by the nature of functional groups present in the sorbent [22]. In (Fig. 3) it is represented the major functional groups identified in FTIR spectra of *Syzygium cumini* seed coat. A broad band ranging between $500\text{--}4000\text{ cm}^{-1}$ may be due to stretching and bending vibrations of C=O, O-H and C-H groups. Stretching band of C-H appears between ranges of $3000\text{--}3300\text{ cm}^{-1}$. Peaks appearing between $2500\text{--}3500\text{ cm}^{-1}$ are

due to O-H group while peak appearing at 1750 cm^{-1} is due to C=O group. As C=O, O-H and C-H functional groups are polar in nature so they can form electrostatic interactions with polar groups present in

methyl orange and adsorption occurs. The FTIR of Malabar plum seed coat and structure of methyl orange is shown in (Fig. 3 & 4).

Figure 2. SEM image of raw *Syzygium cumini* at four different resolutions

Figure 3. FTIR Spectra of *Syzygium cumini*

Figure 4. Structure of methyl orange

Predictive modeling by full factorial design

To check the effect of three parameters on the adsorption of methyl orange onto *Syzygium cumini* 2³ full factorial design is adopted. The predicted response is denoted by the equation 1 given below;

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_1X_2 - b_5X_1X_3 - b_6X_2X_3 + b_7X_1X_2X_3$$

Here Y represents predicted response; b_0 represents intercepts while X_1 , X_2 and X_3 represents pH, initial dye concentration and contact time respectively while their products in different combinations represent the interaction of parameters with one another [23]. Predicted response was calculated by using linear model proposed in equation 1. The comparison of predicted response and experimental response along with % variance was presented in the (Table 2).

The closeness of calculated response with experimental response confirmed the validity of model for current study. These results were also examined by ANOVA. Coefficients of all the possible combinations of variables, their standard error, t-stat & p-value were calculated. The p-value is useful to estimate the effect of individual parameter and its interaction with other parameters. Smaller is the p-value more significant is the variable for calculation of response. In this context X_2 & X_3 were found more significant towards the adsorption of sorbate. The

estimated effects and coefficients for R and statistical parameters including coefficients, standard error, t-stat and p-value were shown in (Table 3 & 4) respectively.

Artificial neural network (ANN) for predictive modeling

Artificial Neural Network (ANN) is a mathematical tool to evaluate the efficiency of adsorption process. The variables used as input in the adsorption of Methyl orange are pH (3, 7 & 12), initial dye concentration (40, 80 & 120 ppm) and contact time (40, 80 & 120 minutes). For this presented work a three input layer ANN i.e. X_1 (pH), X_2 (initial dye concentration) and X_3 (Contact time), 3-10 hidden layers and one output layer i.e. % sorption is designed. For *Syzygium cumini* best response is obtained by 3 input layers, 5 hidden layers and one output layer. ANN is a better model providing favorable solution and understanding to explain the actual performance of adsorption process [24]. Design matrix and result of ANN model for adsorption of Methyl orange onto *Syzygium cumini* (Malabar plum) seed coat is given below in (Table 5).

From the above table it is clear that the best response was obtained by 3 input layers, 5 hidden layers and one output layer. Although best response is obtained by highest number of hidden layers but it is not necessary that highest number of hidden layers always give best response.

In (Table 6) it is represented comparison of experimental response; FFD calculated

response & ANN predicted response along with % variance.

Table 2. Comparison of predicted response and experimental response along with % variance

Runs	X ₁ pH	X ₂ Initial conc. (ppm)	X ₃ Time (min)	Experimental Response	Calculated Response	% Variance
1	3	40	40	23.6	21.52862096	2.07137904
2	3	80	40	42.8625	39.77206628	3.09043372
3	3	120	40	52.18333333	58.01551159	-5.83217826
4	7	40	40	2.5	25.70439331	-23.2043933
5	7	80	40	6.75	41.49540359	-34.7454036
6	7	120	40	48.41666667	57.28641387	-8.86974721
7	12	40	40	3.175	30.92410875	-27.7491088
8	12	80	40	15.9375	43.64957524	-27.7120752
9	12	120	40	22.11666667	56.37504173	-34.2583751
10	3	40	80	24.375	22.90226091	1.47273909
11	3	80	80	43.8375	40.5427187	3.2947813
12	3	120	80	52.23333333	58.18317649	-5.94984315
13	7	40	80	5.45	27.30079823	-21.8507982
14	7	80	80	7.35	42.56921716	-35.2192172
15	7	120	80	49.19166667	57.83763609	-8.64596942
16	12	40	80	3.325	32.79896987	-29.4739699
17	12	80	80	16.4125	45.10234023	-28.6898402
18	12	120	80	22.375	57.40571059	-35.0307106
19	3	40	120	24.475	24.27590086	0.19909914
20	3	80	120	43.9375	41.31337112	2.62412888
21	3	120	120	52.4	58.35084139	-5.95084139
22	7	40	120	8.7	28.89720314	-20.1972031
23	7	80	120	7.4625	43.64303072	-36.1805307
24	7	120	120	49.4	58.3888583	-8.9888583
25	12	40	120	3.825	34.673831	-30.848831
26	12	80	120	17.6125	46.55510522	-28.9426052
27	12	120	120	22.48333333	58.43637945	-35.9530461

Table 3. Estimated effects and coefficients for R

Terms	Coefficients	Standard Error	t Stat	P-value
Intercept	0.87933271	21.12591142	0.041623421	0.967233196
X1	0.047548118	0.2509332	0.189485163	0.851722151
X2	-1.58562282	3.241069162	-0.489228321	0.630280077
X3	0.486772512	0.2509332	1.939848982	0.06738939
X1X2	-0.0009194	0.038497362	-0.023882177	0.981195632
X1X3	-0.00038831	0.00298058	-0.13028143	0.89771323
X2X3	-0.01579802	0.038497362	-0.41036618	0.686127912
X1X2X3	1.25619E-05	0.000457271	0.027471462	0.978370197

Table 4. Statistical parameters for 3³ designs

Regression Statistics	
Multiple R	0.900249788
R Square	0.810449681
Adjusted R Square	0.740615353
Standard Error	9.331316186
Observations	27

Table 5. Design Matrix and Results of ANN Model for Adsorption of Methyl Orange onto *Syzygium cumini*

Sample	%sorption= Cad/Ci*10 0	%sorption= Cad/Ci*100 - Output	%sorption= Cad/Ci*100 - Output	%sorption= Cad/Ci*100 - Output	%sorption= Cad/Ci*100 - Output	%sorption= Cad/Ci*100 - Output
	Target	1. MLP 3-8-1	2. MLP 3-7-1	3. MLP 3-6-1	4. MLP 3-5-1	5. MLP 3-4-1
Test	23.60	22.16	22.94	23.81	23.93	22.23
Train	42.86	43.95	42.29	41.50	42.89	43.93
Test	52.18	51.57	52.88	50.81	50.80	52.11
Train	2.50	3.22	2.95	2.17	5.30	2.34
Train	6.75	7.25	6.84	8.26	6.70	7.25
Train	48.41	48.85	48.43	49.25	48.45	48.71
Test	3.17	3.80	2.84	3.01	4.69	3.26
Train	15.93	15.21	15.42	15.38	16.42	15.07
Train	22.11	21.89	22.07	21.15	22.45	21.18
Train	24.37	23.63	24.08	24.56	24.20	24.38
Train	43.83	43.60	43.27	43.21	43.31	43.63
Train	52.23	51.52	52.76	52.34	51.84	52.12
Train	5.45	5.41	5.18	4.59	5.55	5.25
Train	7.35	7.30	7.90	8.69	6.90	8.12
Train	49.19	48.56	48.81	48.92	48.98	48.19
Train	3.32	3.86	3.65	3.84	4.73	4.31
Test	16.41	16.76	16.01	15.98	16.62	16.81
Train	22.37	22.34	22.17	22.23	22.64	22.58
Train	24.47	25.14	24.73	24.83	24.48	25.33
Train	43.93	43.28	43.75	44.42	43.75	42.74
Train	52.40	51.47	52.29	53.77	53.04	52.10
Train	8.70	7.37	7.60	6.90	5.82	6.87
Test	7.46	7.65	8.76	8.82	7.11	8.19
Train	49.40	48.24	48.67	47.95	49.64	47.29
Train	3.82	3.81	5.05	5.05	4.76	4.44
Train	17.61	18.17	17.19	16.75	16.75	17.43
Train	22.48	22.95	22.62	22.89	22.76	23.08

Table 6. Comparison of Predicted Response & % Variance of RSM & ANN Models for *Syzygium cumini*

X ₁	X ₂	X ₃	Exp. Resp	FFD predicted. Resp	%Variance	ANN predicted. Resp	%Variance
3	40	40	23.6	21.52	2.07	23.93	0.51
3	80	40	42.86	39.77	3.09	42.89	0.08
3	120	40	52.18	58.01	-5.83	50.80	0.85
7	40	40	2.50	25.70	-23.20	5.30	-0.70
7	80	40	6.75	41.49	-34.74	6.70	-0.14
7	120	40	48.41	57.28	-8.86	48.45	-0.45
12	40	40	3.17	30.92	-27.74	4.69	0.82
12	80	40	15.93	43.64	-27.71	16.42	0.11
12	120	40	22.11	56.37	-34.25	22.45	-0.08
3	40	80	24.37	22.90	1.47	24.20	0.50
3	80	80	43.83	40.54	3.29	43.31	0.29
3	120	80	52.23	58.18	-5.94	51.84	0.12
7	40	80	5.45	27.30	-21.85	5.55	0.44
7	80	80	7.35	42.56	-35.21	6.90	0.29
7	120	80	49.19	57.83	-8.64	48.98	0.46
12	40	80	3.32	32.79	-29.47	4.73	0.46
12	80	80	16.41	45.10	-28.68	16.62	0.61
12	120	80	22.37	57.40	-35.03	22.64	0.01
3	40	120	24.47	24.27	0.19	24.48	-0.50
3	80	120	43.93	41.31	2.62	43.75	-0.64
3	120	120	52.40	58.35	-5.95	53.04	-0.71
7	40	120	8.70	28.89	-20.19	5.82	1.16
7	80	120	7.46	43.64	-36.18	7.11	-0.43
7	120	120	49.40	58.38	-8.98	49.64	0.37
12	40	120	3.82	34.67	-30.84	4.76	-0.60
12	80	120	17.61	46.55	-28.94	16.75	0.82
12	120	120	22.48	58.43	-35.95	22.76	-0.90

The value of FFD predicted response and ANN predicted response is slightly different. But % variances calculated for both FFD and ANN model show that the value of % variance is low for ANN. Smaller the value of % variance means that experimental and calculated responses are close to each other.

As % variance for ANN is small so it is better fit model then SEM for modeling of % sorption of methyl orange onto Malabar plum. It is also evident from the (Fig. 5 & 6) that the experiment response is more closer to ANN calculated response than FFD calculated response.

Figure 5. Experimental response vs FFD calculated response

Figure 6. Experimental response vs ANN calculated response

Conclusion

Removal of *Methyl orange* by means of *Syzygium cumini* was successfully performed. Efficiency of the adsorbent was checked experimentally as well as predicted by ANN, and closeness of experimental and predicted results shows success of generated ANN model for current work. Surface morphology and functional groups analysis also support the results. This study is a

fruitful addition in pool of adsorption study and predictive modeling.

Authors' contributions

Conceived and designed the experiments: F Batool, Performed the experiments: F Abbas & T Iqbal, Analyzed the data: S Iqbal & J Akbar, Contributed materials/ analysis/ tools: S Noreen, Wrote the paper: F Batool & Faisal Iqbal.

References

- Banat MI (1996). Microbial decolorization of textile-dyecontaining effluents: A review. *Bioresour Technol* 58: 217-227.
- Santos SC & Boaventura RA (2008) Adsorption modelling of textile dyes by sepiolite. *Appl Clay Sci* 42: 137-145.
- Rijsberman FR (2006) Water scarcity: fact or fiction. *Agric Water Manag* 80: 5-22.
- Gordon PF & Gregory P (2012) Organic chemistry in color. *Springer Science & Business Media* 19: 42-47.
- Hao OJ, Kim H, & Chiang PC (2000) Decolorization of wastewater. *Crit Rev Environ Sci Technol* 30: 449-505.
- Ogugbue CJ & Sawidis T (2011) Bioremediation and detoxification of synthetic wastewater containing triarylmethane dyes by *Aeromonashydrophila* isolated from industrial effluent. *Biotechnol Res Int* 12: 357-365.
- Vandevivere PC & Bianchi R (1998) Treatment and reuse of wastewater from the textile wet-processing industry: Review of emerging technologies. *J Chem Technol Biotechnol* 72: 289-302.
- Hunger K (2007) Industrial dyes: chemistry, properties, applications: John Wiley & Sons. *Adsorption Sci & Technol* 12: 151-170.
- Perry RH & Green DW (1999) Perry's chemical engineers' handbook: McGraw-Hill Professional. *J of Res (Sci)* 14: 135-134.
- Li R, Gong M, Yang C, Sun Y and Chen J (2005) Removal of cationic dyes from aqueous solution by adsorption on peanut hull. *J Hazard Mater* 121: 247-250.
- Linsen BG (1970) Physical and chemical aspects of adsorbents and catalysts. *J Porous Mater* 15: 119-130.
- Adamson AW & Gast AP (1967) Physical chemistry of surfaces. *J Appl Polym Sci* 18: 42-60.
- Mantell CL (1951). Adsorption, second ed."McGraw-Hill Book Company, Inc., New York.
- Morton JF (1987) Fruits of warm climates. *Appl Surf Sci* 23: 856-862.
- Bajpai MA & Pande (2005) Phenolic contents and antioxidant activity of some food and medicinal plants. *Int J Food Sci Nutr* 56: 287-291.
- Griffiths PR & De JA (2007) Haseeth, Fourier transform infrared spectrometry, John Wiley & Sons World Academy of Science. *J Eng Technol* 5: 1473-1478.
- Goldstein JI & Newbury DE (2017) Scanning electron microscopy and X-ray microanalysis. 3rd Edition. Springer.
- ShojaeimehrTF & Rahimpour (2014) A modeling study by response surface methodology (RSM) and artificial neural network (ANN) on Cu²⁺ adsorption optimization using light expanded clay aggregate (LECA). *Ind Eng Chem* 20: 870-880.
- Annadurai G & Juang RS (2002) Factorial design analysis for adsorption of dye on activated carbon beads incorporated with calcium alginate. *Adv Environ Res* 6: 191-198.
- Cavas L & Karabay Z (2011) Thomas and artificial neural network models for the fixed-bed adsorption of methylene blue by a beach waste *Posidonia oceanica* (L.) dead leaves. *Chem Eng J* 17: 557-562.
- Daneshvar N & Khataee A (2006). The use of artificial neural networks (ANN) for modeling of decolorization of textile dye solution containing CI Basic Yellow 28 by electrocoagulation process. *J Hazard Mater* 137: 1788-1795.
- Byler DM & Susi H (1986) Examination of the secondary structure of proteins by deconvolved FTIR spectra, *Biopolymers: Original Res on Biomol* 25: 469-487.
- Kavak D (2009) Removal of boron from aqueous solutions by batch adsorption on calcined alunite using experimental design, *J Hazard Mater* 16: 308-314.
- Dutta S & Parsons SA (2010) Development of an artificial neural network model for adsorption and photocatalysis of reactive dye on TiO₂ surface. *Expert Syst Appl* 3: 8634-8638.