RESEARCH ARTICLE

• Arch Hyg Sci 2015;4(4): 199-207 .
• Journal Homepage: http://jhygiene.muq.ac.ir

The Application of Low-Cost Adsorbent for Reactive Blue 19 Dye Removal from Aqueous Solution: Lemna Minor

Davoud Balarak[a], Yousef Mahdavi[b], Ali Joghataei[c*]

[a]Department of Environmental Health, Health Promotion Research Center, School of Public Health, Zahedan University of Medical Sciences, Zahedan, Iran.
[b]Department of Environmental Health, School of Health, Mazandaran University of Medical Sciences, Sari, Iran.
[c]Student Research Committee, Qom University of Medical Sciences, Qom, Iran.

***Correspondence** should be addressed to Mr. Ali Joghataei, **Email**: joghataei69@yahoo.com

A-R-T-I-C-L-EI-N-F-O

Article Notes:
Received: Aug 15, 2015
Received in revised form: Sep 14, 2015
Accepted: Oct 19, 2015
Available Online: Oct 22, 2015

Keywords:
Lemna minor,
Adsorption,
Kinetic,
Isotherm,
Reactive blue 19 dye

A-B-S-T-R-A-C-T

Background & Aims of the Study: Due to widespread use and adverse effect of dyes, the removal of dyes from effluents is necessary. This study was aimed to remove the reactive blue 19 dye removal from aqueous solution by dried Lemna minor.

Materials and Methods: The effect of various parameters including contact time, solution pH, adsorbent dosage and dye concentration was investigated in this experimental-lab study, Also, the isotherm and kinetic studies was performed for RB19 dye adsorption process.

Results: The results indicated that RB19 dye removal efficiency increases by increasing of contact time and adsorbent dosage. The equilibrium time was 75 min ad the maximum dye removal efficiency was obtained in pH=3. Also, the dye removal efficiency decreases by increasing of pH and initial concentration. It was found that the equilibrium data was best follow by Langmuier isotherm. Also, the pseudo-second-kinetic model was best applicable for RB 19 dye adsorption.

Conclusion: It can be concluded that the dried Lemna minor can be considered as an effective adsorbent to remove the RB19 dye.

Please cite this article as: Balarak D, Mahdavi Y, Joghataeic A. The application of low-cost adsorbent for reactive blue 19 dye removal from aqueous solution: Lemna Minor. Arch Hyg Sci 2015;4(4):199- 207.

Background

Nowadays, the synthetic dyes have an indispensable function in a variety of industries including textile, leather, printing, laundry, tannery, rubber, plastic, painting, etc., (1-2). Despite the widespread use of dyes, they are supposed to be a significant agent to generate the numerous objectionable effects onto water and marine life such as aesthetic problems, diminution of sunlight penetration into water and photosynthetic activity (3-4). Furthermore, human health is another target point of dyes which can be affected by their carcinogenic and mutagenic features. This point suggests that dyes can contribute to development of some illnesses and disorders in kidney, reproductive system, liver, brain and central nervous system(5-6). Reactive dyes are a large group of dyes which are used for various types of fabricates. The reactive blue 19 (RB19) dye is one of most important dyes among this group having an aromatic anthraquinone structure, which makes this dye more resistant (7-8).

Thus, dyes should be considered a significant environmental problem and serious attempts should be carried out to remove them.

The adsorption, membrane separation, electrochemical, flocculation-coagulation, reverse osmosis, ozone oxidation, biological treatments, etc are among the variously -used approaches to remove the dyes (9-11). The economic and environmental problems such as high capital and operating cost, sludge production and complexity of the treatment processes are associated with these methods (12). Nevertheless, it has been found that adsorption is an outstanding and successful method to remove the dyes (13-17). Its simple operation and cost-effectiveness are the important characteristics of adsorption process (17). The commercial adsorbents such as activated carbon has revealed excellent potential in dye removal but their high cost is nominated as an enormous problem which restricts their application. This issue has led to strong motivation in scientists to use various low-cost materials such as adsorbent (18). The literature review has clarified that numerous material such as Canola (19), Chitosan (20), Rice husk (21), Sorel's cement (22), Cotton plant wastes (23), Wood shavings (24), Cupressus sempervirens cones (25), pine tree leaves (23) and etc, have been studied for dye removal. Lemna minor is a common category of duckweeds which grows rapidly. The high water purification capacity of this aquatic plant is identified as a unique property which has become extraordinarily valuable in water treatment (27-28). Furthermore, it can successfully tolerate cold weather (29). Several studies have been conducted to remove the pollutants by this plant, which have indicated the significant ability of Lemna minor in removing these pollutants (29-31). Recently, the dried Lemna minor was also applied for acid red 88 dye removal by Balarak et al. and the dye removal efficiency was obtained to be up to 98% (14).

In this experiment, the potential of dried Lemna minor for RB19 dye removal has been assessed. The effect of contact time, pH, dye concentration and dosage of adsorbent were determined and the isotherm and kinetic of RB19 dye adsorption were studied.

Materials & Methods

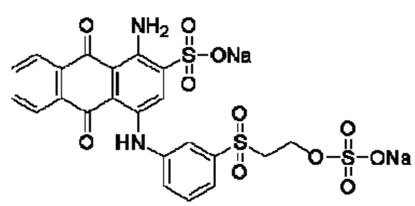
Adsorbent preparation:

Lemna minor was supplied from Agricultural University, Tabriz, Iran. It was sun dried, crushed and then sieved into particle sizes at the range of 1–2 mm. The prepared particles were treated with 0.1 M HCl for 5 h and then washed by distilled water and dried in the shed (32). The resultant adsorbents were stored for further experiments.

The characteristics of the adsorbent were demonstrated as follows: the BET method was utilized to determine the specific surface area of adsorbent by a Gemini2357 surface area analyzer of Micromeritics Instrument Corporation, USA. Scanning electron microscopy (SEM) of the prepared adsorbent was achieved using a Philips XL30 scanning electron microscope to describe the morphological and surface characteristics.

Materials: The Reactive Blue19 (RB19) dye was purchased from Alvan Sabet Corporation, Hamadan, Iran.

Table 1) Chemical structure and properties of RB19 dye

Chemical structure	
Molecular formula	$C_{22}H_{16}N_2Na_2O_{11}S_3$
Molecular weight (g/mol)	626.54
Maximum wavelength(nm)	592

The stock solution (1000 mg/L) of RB19 dye was prepared and diluted to prepare the desired experimental solutions. Table 1 shows the chemical structure and general characteristics of RB19 dye.

Batch adsorption experiments:

The evaluation of the dried Lemna minor ability was performed in batch adsorption system in lab scale experiments. All experiments were carried out in 250 ml Erlenmeyer flasks. The effect of contact time (10-180min), pH (3-11), dosage of adsorbent (0.1-1g/100mL) and initial dye concentration (10-500mg/L) on adsorption efficiency were investigated. The pH of RB19 dye solution was adjusted by 1 M of HCl or NaOH. 100 ml of RB19 dye solution was mixed with certain amount of adsorbent in flasks using a magnetic stirrer at 180 rpm for 75 min and then was centrifuged at 3600 rpm for 10 min. The DR-4800 spectrophotometer was utilized to measure the residues RB19 dye in the obtained samples (32). The adsorption capacity (q_e) was calculated by Eq 1 (33):

$$q_e = (C_0 - C_e)V/m \quad (1)$$

Where q_e is the adsorption capacity (mg/g), C_0 and C_e is the initial and equilibrium concentrations of dye (mg/L), respectively. V is the volume of the RB19 dye solution (L), and m is the mass of the adsorbent (g).

Adsorption isotherms: It has been stated that adsorption isotherm is utilized to obtain the information which can facilitate the design of adsorption system. A number of isotherm models are used for this purpose; however four common models were applied in this study and their equations are presented in table 2.

Table 2) The equation of isotherm models (31)

Model	*Equation*
Langmuir	$C_e/q_e = 1/q_e k_1 + C_e/q_m$
Freundlich	$Log\ q_e = 1/n \log C_e + \log K_F$
Tempkin	$q_e = B_1 \ln(k_t) + B_1 \ln(C_e)$
BET	$C_e/(C_i - C_e)q = 1/A\ q_m + A\text{-}1/A\ q_m$

Adsorption kinetic: the kinetic models are applied to determine the rate of adsorption. The obtained data were analyzed by 3 kinetic models which are shown in Table 3.

Table 3) the equation of kinetic models (14)

Model	*Equation*
pseudo-first-order	$\log(q_e - q) = \log q_e - k_1 t / 2.3$
pseudo-second-order	$t/q = 1/k_2 q e^2 + 1/q_e t$
Intraparticle diffusion	$qt = k_{dif}\, t\, 0.5 + c$

Results

Characterization of adsorbent:

The SEM images of the dried Lemna minor are presented in Fig 1. It is evident from these images that the surface of dried Lemna minor is the porous with heterogeneous surface. In addition, the specific surface area of the dried Lemna minor was calculated to be 30 m^2/gr.

The effect of contact time:

The effect of contact time on RB19 dye removal by dried Lemna minor was studied by varying the contact time from 10 to 180 min and keeping constant of other parameters. Fig 2 illustrates the effect of this parameter. The dye removal efficiency increases by increasing the contact times. As it can be seen in Fig2, the removal efficiency was 41% in contact time of 10 min but it was increased up to 96.1 in contact time.

The effect of pH:

The effect of pH on RB19 dye removal efficiency is illustrated in Fig 3. This figure shows the range of pH for investigation of this variable effect selected from 3 to 11. In addition, the obtained results indicate that the dye removal efficiency decreases by an increase in pH. The best results were obtained at pH= 3 and in acidic condition. As can be observed, the dye removal efficiency decreased from 96.1% to 54.4% by increasing the pH from 3 to 11.

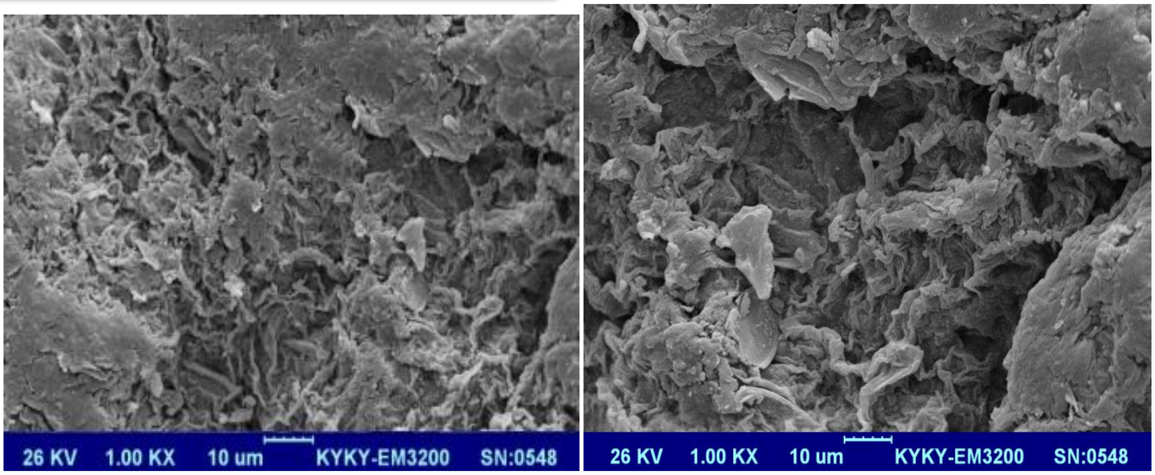


Figure.1) the SEM image of modified Lemna minor before and after use

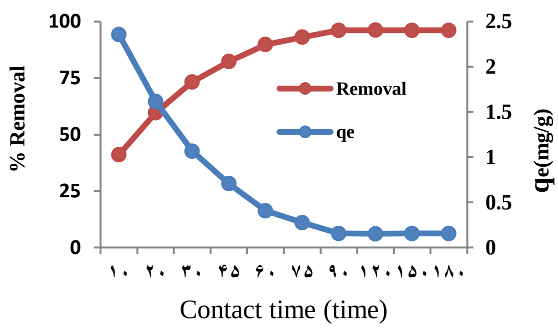


Figure 2) Effect of contact time on RB19 dye removal efficiency (pH=3, adsorbent dosage 5 g/L, RB19 concentration: 20 mg/L)

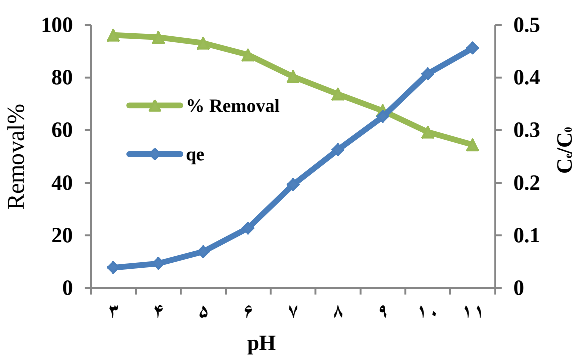


Figure 3) effect of pH on RB19 dye removal efficiency (time=75 min, RB19 dye concentration=20 mg/L, adsorbent dosage =5 g/L)

The effect of initial dye concentration

The examination of effect of this parameter was conducted in constant amount of contact time, pH and adsorbent dosage and various initial dye concentrations in range of 10-200 mg/L. The results of this examination are shown in Fig 4.

As can be observed, the RB19 dye adsorption increased from 1.918 to 25.84 mg/g with the increase of initial concentrations of RB19 dye from 10 to 200 mg/L, whereas the RB19 removal efficacy declined from 95.9 to 64.6 percentage.

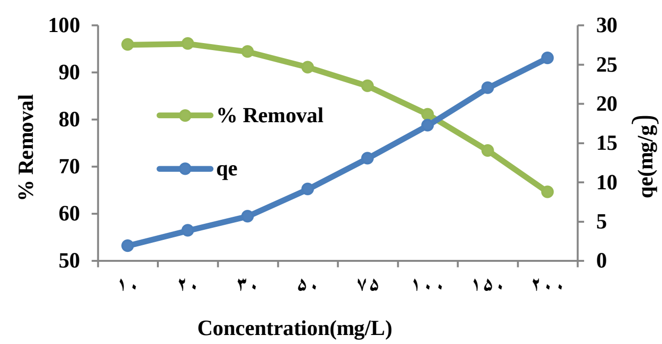


Figure 4) Effect of AR88 concentration on of RB19 dye removal efficiency (time =75 min, dosage: 5 g/L, pH=3)

The effect of adsorbent dosage

The effect of adsorbent dosage on dye removal efficiency was evaluated in different values of adsorbent dosage and constant amount of other parameters with the results shown in Fig 5. As it is obvious from this figure, although the RB19 dye removal efficiency is developed by increasing the adsorbent dosage, the RB19 dye adsorption amount is decreased.

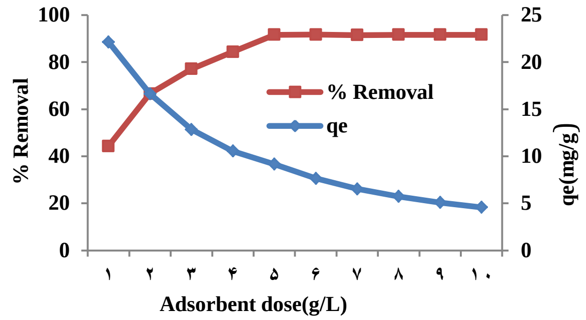


Figure 5) The effect of adsorbent dosage on dye removal efficiency (time= 75 min, dye concentration=10 mg/L, pH=3)

The isotherm and kinetic studies

The results of the isotherm and kinetic studies are presented in Tables 3 and 4. As it was mentioned earlier,4 isotherm models and 3 kinetic models were used.

Table 4) Equilibrium constants for RB 19 dye adsorption

Langmuir Model			Freundlich Model			Tempkin Model			BET Model		
q_m	K_L	R^2	n	K_F	R^2	B_1	A	R^2	A	q_m	R^2
9.45	0.324	0.998	0.432	0.214	0.832	41.7	2.19	0.923	24.4	0.164	0.814

Table 5) Kinetic parameters for the adsorption of reactive blue 19 onto Lemna at various concentrations

Con	q_e	Pseudo-first order			Pseudo-second order			Intra-particle diffusion		
(mg/L)	exp	K_1	q_e	R^2	K_2	q_e	R^2	K_{dif}	C	R^2
10	1.91	0.341	6.19	0.965	0.0021	2.24	0.999	2.18	1.39	0.835
50	9.11	0.574	13.24	0.941	0.0043	7.36	0.998	3.42	3.65	0.842
100	17.25	0.922	18.45	0.972	0.0072	11.14	0.999	5.24	2.66	0.872

Discussion

Adsorbent characterization:

The determination of adsorbent characteristics indicates that the dried leman minor has porous and heterogeneous surface. It is also observed that the surface of adsorbent varied after adsorption of RB19 dye, which may be due to the saturation of the adsorbent surface. In addition, it was found that the size of specific surface area of this adsorbent is 30 m^2/gr, which can verify the high ability of this adsorbent in dye adsorption (14) However, the specific surface area of Canola and Azolla are greater than the studied adsorbent (35).

The effect of contact time:

The contact time has a significant effect in dye adsorption studies. As was mentioned above, the dye removal efficiency is enhanced by increasing the contact time up to 75 min and significant change can't be seen after this time. This result can be supported by results of various studies (32,36). In addition, it can be seen that the dye removal is quickly performed in the initial step of the study which is gradually decreased with time .This is consistent with the results of another study (37). Tan et al have assessed the dye adsorption efficiency by dried Azolla filiculoides. Their results agreed with the results of the present work. Furthermore, they stated that the high availability of binding sites on the surface of adsorbent can be considered the result of greater dye removal efficiency at beginning of adsorption process (38).

The effect of pH:

pH has been introduced as the most effective parameter on dye adsorption process. In the present study, maximum dye removal was obtained in pH=3 and it was observed that the dye removal decreased by increasing pH. This result has been observed in other studies which were conducted on dye removal by adsorption (39-40). Bayramoğlu and et al have assessed the ability of fungus Phanerocheate chrysosporium for reactive dye removal efficacy in adsorption process and have found that the maximum dye removal efficiency was observed at pH=3. The reason for this phenomenon may be because of the –SiO-3 group which is in dye structure and the positive surface of adsorbent in acidic pH. This difference between surface charge of adsorbent and dye molecule lead to the enhancement of the dye removal efficiency (41).

The effect of initial dye concentration:

Another effective parameter on dye removal adsorption is the initial dye concentration which has been studied in this work. As was observed in Fig 4, the RB19 dye removal efficiency can be drastically affected by the initial dye amount. The dye adsorption amount increases by increasing the initial dye concentration but increasing this parameter led to the decrease of dye removal efficiency. These results can be confirmed by other studies (42-43). Increasing the initial dye concentrations leads to develop the driving force in order to overcome the resistance of the mass transfer of dye between the solution and the adsorbent surface, which increases the dye adsorption (35). Grag et al have studied the dye removal efficiency and observed that an increase in initial dye concentration led to an increase in dye adsorption amount and a decrease in dye removal efficiency (44).

The effect of adsorbent dosage

Adsorbent dosage is another effective variable in dye adsorption studies. In this work, it was observed that the increase of adsorbent dosage improved the dye removal efficiency but it led to a reduction in the dye adsorption amount, which is confirmed by other dye adsorption studies (45-46). The increase of dye removal efficiency can be described by the increase of available adsorption site (47). Madrakian et al. have observed the above results in their study on dye removal and stated that their dye removal efficiency increased by increasing the adsorbent dosage due to the increase in contact surface of adsorbent with investigated dyes and the greater availability of the adsorbent (48).

Isotherm studies:

The isotherm studies were conducted with respect to four known models including Langmuier, Freundlich, Tekmin and BET. The constant and parameters of the applied model in this study have been presented in table 4. The comparison of the R^2 values can help to determine the effective isotherm model in RB19 dye removal. As it can be observed, the correlation coefficient (R^2) of Langmuir isotherm was greater than that of the models, which indicates that the obtained data from the isotherm studies are better described by the current model. The monolayer adsorption onto a surface with a finite number of identical and homogeneous sites is assumed by the Langmuier adsorption isotherm. Several dye adsorption studies verify the results of this study (26,49).

Kinetic studies

The kinetics of RB19 dye adsorption on Lemna minor were studied in different initial concentrations. Three common kinetic models e.g. pseudo-first-order and pseudo-second-order kinetic models and intra-particle diffusion were utilized in this study. The variables and the constant related to each model were calculated according to the equation which is presented in table 3 and the obtained values which are shown in table 5. By comparing R^2 values of each model, it can be concluded that the most appropriate model for describing RB19 dye adsorption process mechanism was the pseudo second-order kinetic model, which can be validated by the results of other studies (50-51).

Conclusion

The potential of dried Lemna natural biosorbent for RB19 dye removal from aqueous solution was surveyed in the batch system. The detailed results were so clear that each of studied parameter could influence the dye removal efficiency. The development of RB19 dye removal was observed by increasing contact time and adsorbent dosage. In contrast, the increase of pH and RB19 dye concentration decreased the dye removal efficiency. The equilibrium data were best fitted with the Langmuir isotherm. The kinetic data were best described by the pseudo-second order model. The results indicated that the Lemna minor could be an effective adsorbent for removal of RB19 dye from aqueous solution.

Footnotes

Conflict of Interest:

The authors declared no conflict of interest.

References

1. Yilmaz AE, Boncukcuoğlu R, Kocakerim M, Karakaş İH. Waste utilization: The removal of textile dye (Bomaplex Red CR-L) from aqueous solution on sludge waste from electrocoagulation as adsorbent. Desalination. 2011;277(1–3):156-63.
2. Removal of Azo Dyes from Aqueous Solution Using Fenton and Modified Fenton Processes, Health Scope. 2014;3(2):1-9.
3. Madrakian T, Afkhami A, Ahmadi M, Bagheri H. Removal of some cationic dyes from aqueous solutions using magnetic-modified multi-walled carbon nanotubes. Journal of Hazardous Materials. 2011;196(0):109-14.
4. El Ashtoukhy ESZ. Loofa egyptiaca as a novel adsorbent for removal of direct blue dye from aqueous solution. Journal of Environmental Management. 2009;90(8):2755-61.
5. Amin NK. Removal of direct blue-106 dye from aqueous solution using new activated carbons developed from pomegranate peel: Adsorption equilibrium and kinetics. Journal of Hazardous Materials. 2009;165(1–3):52-62.
6. Kadirvelu K, Kavipriya M, Karthika C, Radhika M, Vennilamani N, Pattabhi S. Utilization of various agricultural wastes for activated carbon preparation and application for the removal of dyes and metal ions from aqueous solutions. Bioresource Technology. 2003;87(1):129-32.
7. Celebi M, Altikatoglu M, Mustafaeva Akdeste Z, Yıldırım H. Determination of decolorization properties of Reactive Blue 19 dye using Horseradish Peroxidase enzyme. Türk Biyokimya Dergisi [Turkish Journal of Biochemistry–Turk J Biochem] 2012;37(2):200–206.
8. Rezaee A GM, Khavanin A, Hashemian SJ, Moussavi Gh, Ghanizadeh Gh, Hajizadeh E,. photochemical oxidation of reactive blue 19 dye (RB19) in textile wastewater by UV/$K_2S_2O_8$ process. Iranian journal of environmental health science engneering 2008;5(2):95-100.
9. Zazouli MA, Yousefi Z, Yazdani-Charati J, Mahdavi Y. Application of Azolla filiculoides Biomass for Acid Black 1 Dye Adsorption from Aqueous Solution. Iranian Journal of Health Science 2014;2(3):24-32.
10. Aksu Z, Tatlı Aİ, Tunç Ö. A comparative adsorption/biosorption study of Acid Blue 161: Effect of temperature on equilibrium and kinetic parameters. Chemical Engineering Journal. 2008;142(1):23-39.
11. Nazari, S., reza Yari, A., Mahmodian, M. H., Reshvanloo, M. T., Matboo, S. A., Majidi, G., & Emamian, M. Application of H2O2 and H2O2/Fe0 in removal of Acid Red 18 dye from aqueous solutions. Archives of Hygiene Sciences,2013;2(3):114-120.
12. Toor M, Jin B. Adsorption characteristics, isotherm, kinetics, and diffusion of modified natural bentonite for removing diazo dye. Chemical Engineering Journal. 2012;187:79-88.
13. Zazouli MA, Balarak D, Mahdavi Y. Effect of Azolla filiculoides on removal of reactive red 198 in aqueous solution. Journal of Advance in Environmental Health Research 2013;1(1):44-50.
14. Balarak D, Pirdadeh F, Mahdavi Y. Biosorption of Acid Red 88 dyes using dried Lemna minor biomass. Journal of Science, Technology & Environment Informatics 2015;01(02):81–90.
15. Nadi, H., Alizadeh, M., Ahmadabadi, M., Yari, A. R., & Hashemi, S. Removal of Reactive Dyes (Green, Orange, and Yellow) from Aqueous Solutions by Peanut Shell Powder as a Natural Adsorbent. Archives of Hygiene Sciences, 2012;1(2):41-47.
16. Mansoorian, H. J., Jafari, A. J., Yari, A. R., Mahvi, A. H., Alizadeh, M., & Sahebian, H. Application of Acaciatortilis Shuck as of Low-cost Adsorbent to Removal of Azo Dyes Reactive Red 198 and Blue 19 from Aqueous Solution. Archives of Hygiene Sciences, 2014;3(1):1-11.
17. Malakootian M, Jafari Mansoorian H, Yari AR. Removal of reactive dyes from aqueous solutions by a non-conventional and low cost agricultural waste: adsorption on ash of Aloe Vera plant, Iranian Journal of Health, Safety & Environment,1(3):117-125.

18. Arami M, Limaee NY, Mahmoodi NM. Evaluation of the adsorption kinetics and equilibrium for the potential removal of acid dyes using a biosorbent. Chemical Engineering Journal. 2008;139(1):2-10.
19. Mahmoodi NM, Arami M, Bahrami H, Khorramfar S. Novel biosorbent (Canola hull): Surface characterization and dye removal ability at different cationic dye concentrations. Desalination. 2010;264(1–2):134-42.
20. Crini G, Badot P-M. Application of chitosan, a natural aminopolysaccharide, for dye removal from aqueous solutions by adsorption processes using batch studies: A review of recent literature. Progress in Polymer Science. 2008;33(4):399-447.
21. Safa Y, Bhatti HN. Adsorptive removal of direct textile dyes by low cost agricultural waste: Application of factorial design analysis. Chemical Engineering Journal. 2011;167(1):35-41.
22. Hassan SSM, Awwad NS, Aboterika AHA. Removal of synthetic reactive dyes from textile wastewater by Sorel's cement. Journal of Hazardous Materials. 2009;162(2–3):994-9.
23. Tunç Ö, Tanacı H, Aksu Z. Potential use of cotton plant wastes for the removal of Remazol Black B reactive dye. Journal of Hazardous Materials. 2009;163(1):187-98.
24. Janoš P, Coskun S, Pilařová V, Rejnek J. Removal of basic (Methylene Blue) and acid (Egacid Orange) dyes from waters by sorption on chemically treated wood shavings. Bioresource Technology. 2009;100(3):1450-3.
25. Fernandez ME, Nunell GV, Bonelli PR, Cukierman AL. Effectiveness of Cupressus sempervirens cones as biosorbent for the removal of basic dyes from aqueous solutions in batch and dynamic modes. Bioresource Technology. 2010;101(24):9500-7.
26. Deniz F, Karaman S. Removal of Basic Red 46 dye from aqueous solution by pine tree leaves. Chemical Engineering Journal. 2011;170(1):67-74.
27. Ge X, Zhang N, Phillips GC, Xu J. Growing Lemna minor in agricultural wastewater and converting the duckweed biomass to ethanol. Bioresource Technology. 2012;124(0):485-8.
28. Alvarado S, Guedez M, Lue-Meru MP, Nelson G, Alvaro A, Jesus AC, et al. Arsenic removal from waters by bioremediation with the aquatic plants Water Hyacinth (Eichhornia crassipes) and Lesser Duckweed (Lemna minor). Bioresour Technol. 2008;99(17):8436-40.
29. Li SX, Zheng FY, Yang H, Ni JC. Thorough removal of inorganic and organic mercury from aqueous solutions by adsorption on Lemna minor powder. Journal of hazardous materials. 2011;186(1):423-9.
30. Zazouli M, Belarak D, Karimnezhad F, Khosravi F. Removal of Fluoride from Aqueous Solution by Using of Adsorption onto Modified Lemna Minor: Adsorption Isotherm and Kinetics Study. Journal of Mazandaran University of Medical Science. 2014;23(109):195-204.
31. Uysal Y. Removal of chromium ions from wastewater by duckweed, Lemna minor L. by using a pilot system with continuous flow. Journal of hazardous materials. 2013;263 Pt 2:486-92.
32. Zazoli M, Balarak D, Mahdavi Y, Karimnejad F. Application of Azolla Filiculoides biomass for Acid blue 15 dye (AB15) Removal from aqueous solutions. JBRMS. 2014;1(1):29-37.
33. Evaluating the efficacy of alumina/carbonnanotube hybrid adsorbents in removing Azo Reactive Red 198 and Blue 19 dyes from aqueous solutions 2015. Process Safety and Environmental Protection, 9 6;125–137.
34. Zazouli MA, Mahvi AH, Dobaradaran S, Barafrashtehpour M, Mahdavi Y, Balarak D. Adosrption of fluoride from aqueous solution by modified Azolla Filiculoides Research report Fluoride 2014;47(4);349–358.
35. Zazouli MA, Balarak D, Mahdavi Y. Application of Canola Residuals in Absorption of Reactive Red 198 (RR198) Dye from Aqueous Solutions. Journal of Neyshabur University of Medical Sciences 2014;2(3);56-66 (In perisan).
36. Santhy K, Selvapathy P. Removal of reactive dyes from wastewater by adsorption on coir pith activated carbon. Bioresource Technology. 2006;97(11):1329-36.
37. Sun D, Zhang X, Wu Y, Liu X. Adsorption of anionic dyes from aqueous solution on fly ash. Journal of hazardous materials. 2010;181(1–3):335-42.
38. Tan C-y, Li G, Lu X-Q, Chen Z-l. Biosorption of Basic Orange using dried A. filiculoides. Ecological Engineering. 2010;36(10):1333-40.
39. Yazdanbakhsh M, Tavakkoli H, Hosseini SM. Characterization and evaluation catalytic efficiency of La0.5Ca0.5NiO3 nanopowders in removal of reactive blue 5 from aqueous solution. Desalination. 2011;281(0):388-95.
40. Fettouche S, Tahiri M, Madhouni R, Cherkaoui O. Removal of Reactive Dyes From Aqueous Solution by Adsorption onto Alfa Fibers powder. Journal of Material and Environmental Science 2015;6(1);129-137.
41. Bayramoğlu G, Çelik G, Arica MY. Biosorption of Reactive Blue 4 dye by native and treated fungus Phanerocheate chrysosporium: Batch and continuous flow system studies. Journal of Hazardous Materials. 2006;137(3):1689-97.
42. Tan C-y, Li M, Lin Y-M, Lu X-Q, Chen Z-l. Biosorption of Basic Orange from aqueous solution onto dried A. filiculoides biomass: Equilibrium, kinetic and FTIR studies. Desalination. 2011;266(1–3):56-62.

43. Kousha M, Daneshvar E, Sohrabi MS, Jokar M, Bhatnagar A. Adsorption of acid orange II dye by raw and chemically modified brown macroalga Stoechospermum marginatum. Chemical Engineering Journal. 2012;192(0):67-76.

44. Garg VK, Gupta R, Bala Yadav A, Kumar R. Dye removal from aqueous solution by adsorption on treated sawdust. Bioresource Technology. 2003;89(2):121-4.

45. Tor A, Cengeloglu Y. Removal of congo red from aqueous solution by adsorption onto acid activated red mud. Journal of hazardous materials. 2006;138(2):409-15.

46. Ponnusami V, Vikram S, Srivastava SN. Guava (Psidium guajava) leaf powder: Novel adsorbent for removal of methylene blue from aqueous solutions. Journal of hazardous materials. 2008;152(1):276-86.

47. Yazdanbakhsh M, Khosravi I, Goharshadi EK, Youssefi A. Fabrication of nanospinel $ZnCr_2O_4$ using sol–gel method and its application on removal of azo dye from aqueous solution. Journal of hazardous materials. 2010;184(1–3):684-9.

48. Madrakian T, Afkhami A, Ahmadi M. Adsorption and kinetic studies of seven different organic dyes onto magnetite nanoparticles loaded tea waste and removal of them from wastewater samples. Spectrochimica acta Part A, Molecular and biomolecular spectroscopy. 2012;99:102-9.

49. Meziti C, Boukerroui A. Removal of a Basic Textile Dye from Aqueous Solution by Adsorption on Regenerated Clay. Procedia Engineering. 2012;33(0):303-12.

50. Vieira AP, Santana SAA, Bezerra CWB, Silva HAS, Chaves JAP, Melo JCP, et al. Removal of textile dyes from aqueous solution by babassu coconut epicarp (Orbignya speciosa). Chemical Engineering Journal. 2011;173(2):334-40.

51. Daneshvar E, Kousha M, Sohrabi MS, Khataee A, Converti A. Biosorption of three acid dyes by the brown macroalga Stoechospermum marginatum: Isotherm, kinetic and thermodynamic studies. Chemical Engineering Journal. 2012;195–196(0):297-306.