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BIOSORPTION OF MN (II) FROM AQUEOUS SOLUTION BY *SARGASSUM HYSTRIX*ALGAE OBTAINED FROM THE PERSIAN GULF: BIOSORPTION ISOTHERM AND KINETIC

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Abstract

In the present study the biosorption of manganese (Mn (II)) onto *Sargassum hystrix* algae were assessed in a batch system by evaluation of different parameters such as biosorbent dosage (0.5-10 g/l), contact time (3-120 min) and initial manganese concentration level (0.5-100 mg/l). The maximum biosorption rate was obtained at initial Mn (II) concentration level of 10 mg/l and biosorbent dose of 10 g/l at contact time of 120 min with 85.6 percent removal efficiency. The Langmuir and Freundlich isotherms were used to describe the biosorption of Mn (II) from aqueous solution and Freundlich model was better fitted than Langmuir model. According to the results, pseudo first order model (R^2 = 0.99) compared to the pseudo second order and diffusion models was better for description of biosorption process. The results of this study suggested that *Sargassum hystrix* algae can be used as a low cost biosorbent for removal of Mn (II) from aqueous phase.

Keywords: Biosorption, Freundlich model, Manganese, *Sargassum hystrix* algae, Pseudo first order model, Persian Gulf.

Introduction

Organic and inorganic contaminants can be presence in the atmosphere, groundwater, sediment, and food [1-12]. From these contaminants, heavy metals are widely distributed in the environment and is hence of particular concern. Industrial wastewater effluents contain some heavy metals such as cadmium, iron, copper, lead, zinc and manganese. These heavy metals are toxic for human and can make different diseases [13]. Manganese ions are discharged to aquatic environment from different industrial processes such as dry battery cells, glass and ceramics, electrical coils, ink and dyes [14, 15]. Mn (II) exposure is associated with damages to the nervous system function, muscle tightness, reduced learning ability and problems related to liver in children [13]. The U.S. Environmental Protection Agency (EPA) has set the permissible limit of 0.05 mg/l for Mn (II) [16] and World Health Organization (WHO) has set a maximum acceptable concentration level of 0.1 mg/l for Mn (II) [17]. Several methods such as chemical precipitation, oxidation/reduction, ion exchange, evaporate recovery, reverse osmosis, ultra filtration, electro dialysis, solvent extraction have been developed for removal of heavy metals from aqueous solution. However, these conventional methods have disadvantages in addition to their performance in the removal of heavy metals from aqueous solution such as sludge production, high cost of operation and need to large quantity of chemicals[18-21].

Another method that works well in removing heavy metals from aqueous solution is biosorption due to its high performance, low cost, reduced sludge production, biosorbent recovery, possibility of metal recovery and no need for chemicals [22]. Biosorbent are cheap and reproducible materials that are obtained naturally from different sources [23]. Yeast, inactive bacteria, sawdust, agricultural wastes and seafood processing wastes, fungus and algae are examples of biosorbents that have been used for inorganic contaminants removal from aqueous solution [24-36].In recent years use of algae as biosorbents has increased and among different groups of algae, brown algae have been shown high performance in removal of metals[37].

The main objectives of the present study were to evaluate the effects of different parameters such as biosorbent dosage, initial Mn (II) concentration level ,and contact time in removal of Mn (II) from aqueous solution. Also in this study we investigated the biosorptionisotherms as well as kinetics.

Materials and methods

Biosorbent preparation

The brown algae *Sargassum hystrix*was collected along the Persian Gulf in the Bushehr port beaches. After collection, the algae was washed three times by tap water and two times by distillated water to remove impurities, then dried in oven at 105 ˚C for 24h and finally powdered and sieved through a 0.71 mm screen.

Mn (II) biosorption by batch study

$MnSO_4$(Merck, Germany)was used as the source of metal in solutions. Mn (II) solutions were prepared at 0.5, 1, 5, 10, 20, 50,and 100mg/l concentration levels by prepared stock solution (1000mg/l). At each run, 100 ml of Mn (II) solution with specific initial concentration level of Mn (II) was agitatedat 120 rpm. The effects of six contact times (3, 10, 20, 40, 60, and 120 min), seven initial Mn (II) concentration levels (0.5, 1, 5, 10, 20, 50, and 100mg/l) and different doses of biosorbent (0.5-10g/l) were investigated in the batch experiments. Atomic absorption spectrophotometer (Varian 240, Australia) was used to analyze the remaining Mn (II)concentration level in the aqueous solution after each experiment. Following equation was used to calculate the removal efficiency of biosorbent during experiments.

Eq. 1

$$\text{Biosorption yield} = \frac{(C_i - C_e)}{C_i} \times 100 \qquad (1)$$

Where C_i and C_e are the concentration levels of Mn (II) before and after the experiment in any time (mg/l).

The equilibrium biosorption capacity of *Sargassum hystrix* algae at different Mn (II) concentration levels was calculated by using the following Eq. 2:

$$q_e = \frac{(C_i - C_e)V}{m} \qquad (2)$$

q_e is the equilibrium biosorption capacity (mg/g); C_i is the Mn (II) concentration levels at initial time (mg/l); C_e is the concentration levels of Mn (II) in solution at equilibrium time (mg/l); V is the solution volume (L); and m is the biosorbent dose (g).

Results and discussion

Effect of biosorbent dose

The biosorption studies of Mn (II) ions by*Sargassum hystrix* algae were done at room temperature, pH value of6.5, initial concentration level of 10 mg/lMn (II), different dose ranges of biosorbent from 0.5 to 10 g/l and different contact times (3-120 min). The effect of biosorbent dosage in the removal of Mn (II) is shown in Fig 1. As seen, in the first 3 min, biosorption of Mn (II) quickly increased and then after 60 minutes biosorption rate was almost constant. At the first 3 min, biosorption efficiency increased from 2.8% with a biosorbent dose of 0.5 mg/l to 73.64% with a biosorbent dose of 5 mg/l, this showed the high effect of biosorbent dose on biosorption efficiency. This trend is predictable because with increasing biosorbent dosage additional binding sites and surface area are available for the ions [38]. The highest removal rate was obtained at initial concentration level of 10 mg/l Mn (II), biosorbent dose of 10 g/l and contact time of 120 min with 85.6 percent efficiency. Similar results were obtained by other studies. Khalilnezhad et al. examined removal of Mn (II) from aquatic solution by using Penicillium camemberti biomass at various dose in batch and fix bed reactors. They obtained maximum biosorption rate at biomass dosage under 1.5 g/l. By increasing the dosages of nano-biomass and biomass from 1 to 1.5 g/l, the removal efficiency of Mn (II) increased from 98.4% to 99.88% and 39.5% to 97.85% respectively[39].In another study, Akpomie et al. examined adsorption of nickel(II) and manganese(II) ions from solution onto an alkaline-modified montmorillonite and observed that the removal efficiency of Ni (II) and Mn (II) ions from aqueous solution increased with increasing of adsorbent dosage[40].Also Adeogun et al. studied comparative biosorption of Mn(II) and Pb(II) ions by rawand oxalic acid modified maize husk and found that the removal rate increased with increasing biosorbent dosage. The highest percentage of removal obtained at biosorbent dosage of 0.8 g and then biosorption efficiency decreased with increasing biosorbent dosage[41].In another study, Dawodu et al. reported simultaneous adsorption of Ni(II) and Mn(II) ions from aqueous solution onto a Nigerian kaolinite clay. They found by increasing the adsorbent dose from 0.1 to 0.5 g, adsorption efficiency of Ni (II) and Mn (II) increased from 61-76% and 51-65% respectively[42].

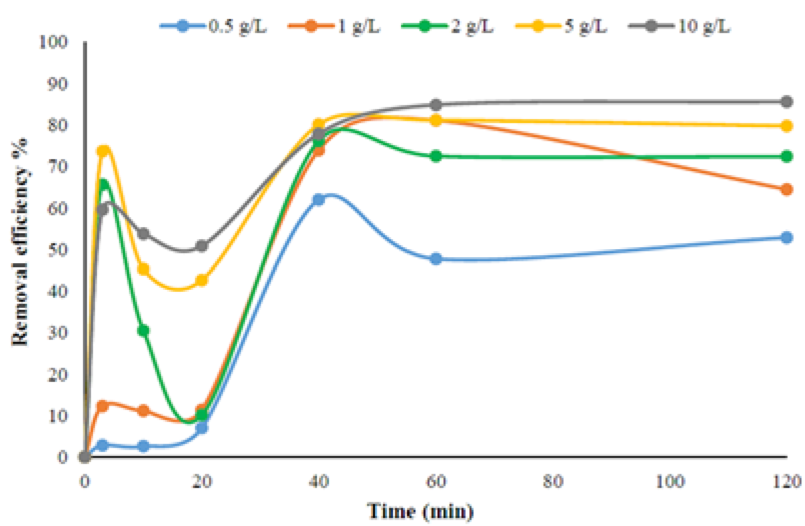

Fig 1. Mn (II) biosorption as a function of biosorbent dose (initial Mn (II) concentration: 10 mg/l, pH: 6.5).

Effect of initial concentration level of Mn (II)

The initial concentration level of metal ions plays a significant role in performance of biosorption process. The effect of initial metal concentration levels on Mn (II) biosorption from aqueous solution is shown in Fig 2. As shown, by increasing Mn (II) concentration level from 0.5 to 100 mg/l at a constant amount of biosorbent (10 g/l) biosorption efficiency decreased. This can be due to certain and limited number of active sites of biosorbent as well as saturation of active binding sites [43, 44]. In agreement with our study, Khalilnezhad et al. reported that biosorption efficiency of Mn (II)by Penicillium camemberti biomass decreasedwith increasing concentration level of metal [39].Also Dawodu et al. found that by increasingMn (II) concentration levels from 100 mg/l to 300 mg/lbiosorption efficiency by using an unmodified Nigerian kaolinite clay (UAK)reduced from 50 to 30% [42].

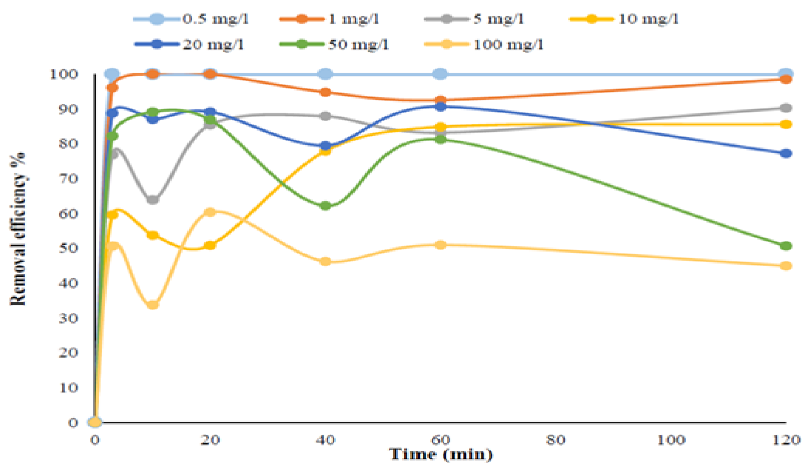

Fig 2. Mn (II) biosorption as a function of initial Mn (II) concentration (biosorbent dose: 10 g/l, pH: 6.5).

Biosorption isotherms

Two different biosorption isotherms, the Langmuir and the Freundlich isotherms, were used to determine the biosorption capacity of *Sargassum hystrix* algae for Mn (II)the removal from aqueous solutions.

Freundlich equation [45] can be represented as Eq. 3:

$$\text{Log}(q_e) = \log(K_f) + 1/n \log C_e \qquad (3)$$

Where q_e (mg/g) is the amount of adsorbed Mn (II)ions per mass of biosorbent biomass, K_f and n are Freundlich equation constants that K_f is the biosorption capacity and 1/n (mg/l) represents the equilibrium concentration level of Mn (II)ions.

The amounts of Freundlich equation constants can be obtained by drawing log q_e vs log C_e (Fig 3.a). Table 1 shows the values of Freundlich equation parameters of Mn (II)ions onto *Sargassum hystrix*algae.

Langmuir isotherm [46] can be written as:

$$\frac{C_e}{q_e} = \frac{1}{bq_{max}} + \frac{1}{q_{max}} C_e \qquad (4)$$

Where q_e is the mass of Mn (II)per unit mass of biosorbent (mg/g), q_{max} is the monolayer biosorption capacity, b is the Langmuir constant (mg/l).The most important parameter of Langmuir equation is R_L that is calculated by the following equation:

$R_L = \frac{1}{1+bC_0}$ (5)

Since the value of calculated R_L is between zero and one ($0 < R_L < 1$) represents the optimal biosorption[47].The amounts of biosorption Langmuir isotherm parameters are shown in Table 1. As shown in Fig 3.a,b, Freundlich model describe the biosorption process better in compare with Langmuir model.

Table 1: Freundlich and Langmuir equations parameter values of manganese onto *Sargassum hystrix*algae.

Isotherm	Parameter	Value
Freundlich	K_f (mg/g)	0.375
	1/n	2.185
	R^2	0.995
Langmuir	b(mg/l)	0.184
	R_L	0.351
	q_{max}(mg/g)	2.664
	R^2	0.864

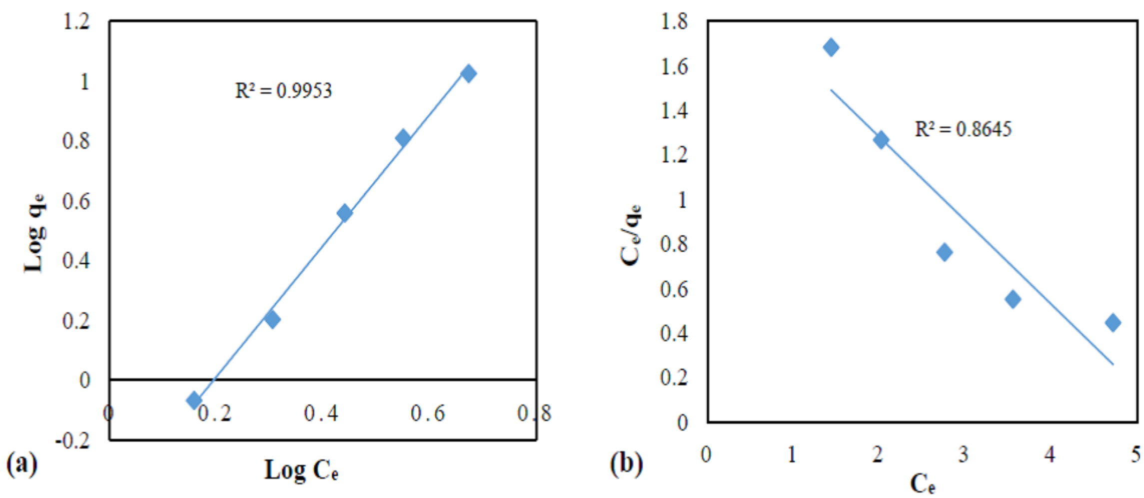

Fig 3. (a) Freundlich and (b) Langmuir isotherms investigation of Mn (II) biosorption by *Sargassum hystrix* algae.

Biosorption kinetics and modeling

Kinetic models of pseudo-first-order, pseudo-second-order and intraparticle diffusion models were used to analyze the mechanism of Mn (II) biosorption from aqueous solution.

The pseudo-first order model can be expressed as:

$$\text{Log}\,(q_e - q_t) = \log q_e - \frac{K_{1,ads}}{2.303}\, t, \qquad (6)$$

The Pseudo-second- order model can be expressed as:

$$\frac{t}{q_t} = \frac{1}{q_e^2 K_{2,ads}} + \frac{1}{q_e} t, \qquad (7)$$

The intraparticle diffusion model can be represented as:

$$q_t = k_d\, t^{0.5} + C \qquad (8)$$

where q_e is the mass of Mn (II) adsorbed per unit weight of the biosorbent (mg/g), q_{max} is the monolayer biosorption capacity, b is the Langmuir constant and K_f is the Freundlich capacity factor, 1/n is the equilibrium concentration level of Mn (II) in solution (mg/l) and q_t (mg/g) is the amount of biosorbed Mn (II) onto algae at time t (min), C is the intercept and k_1 (1/min), k_2 (g/mg min) and k_d (mg/g $min^{0.5}$) are the rate constants of pseudo-first order, pseudo second order kinetic and interaparticle diffusion model.

Table 2: Biosorption kinetic parameters of manganese onto *Sargassum hystrix*algae.

Model	Parameter	Value
First-order kinetic	q_e (mg/g)	81.45
	K_1 (1/min)	4.697
	R^2	0.9992
Second-order kinetic	q_e (mg/g)	62.893
	K_2 (g/mg min)	0.00085
	R^2	0.6342
Intraparticle diffusion	K_d	0.0137
	C	0.3737
	R^2	0.2817

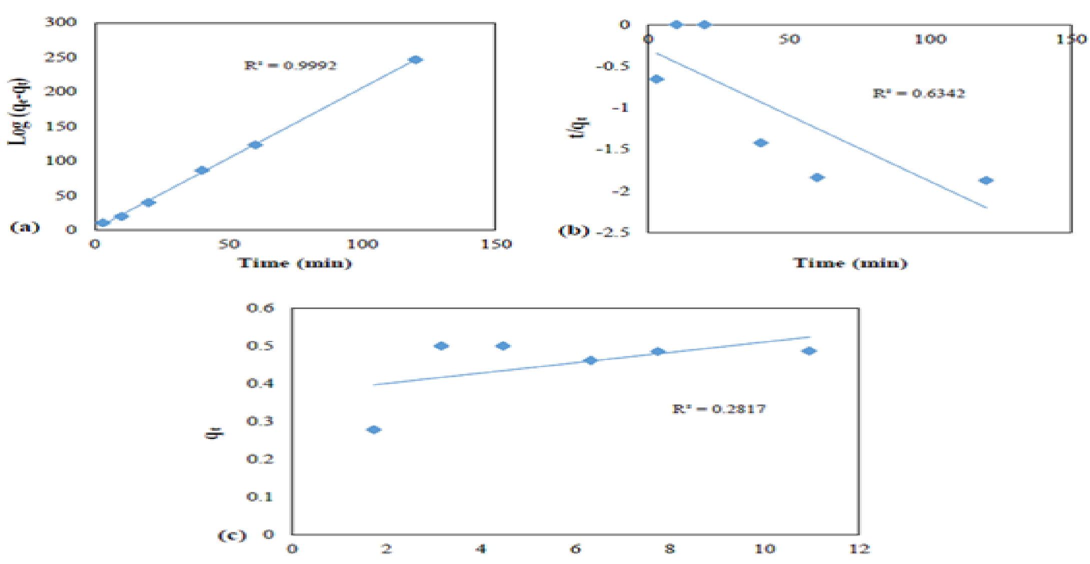

Fig 4. (a) Pseudo-first-order model (b) Pseudo-second-order model of Mn (II) biosorption and (c) intraparticle diffusion kinetic models by *Sargassum hystrix* algae.

Conclusion

The present study examined the efficiency of *Sargassum hystrix*algae in removal of Mn (II) from aqueous solutions. The biosorption studies were done in a batch system at room temperature and the effects of different variables such as initial Mn (II) concentration level, contact time and biosorbent dosage were investigated. The removal of Mn (II) by biosorbent at pH value of 6.5 increased by increasing biosorbent dose, decreasing initial concentration level of Mn (II).The biosorption followed the Freundlich isotherm. Among the biosorption kinetic models pseudo-first order kinetic model was described the biosorption process. At the end it is concluded that *Sargassum hystrix*algae can be used as a low cost and high efficient biosorbent for removal of Mn (II) from aqueous solution.

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References

1. S. Dobaradaran, A.H. Mahvi, R. Nabizadeh, A. Mesdaghinia, K. Naddafi, M. Yunesian, N.Rastkari, and S. Nazmara, Hazardous organic compounds in groundwater near Tehran automobile industry, Bull Environ Contam Toxicol., 85 (2010) 530.
2. H. Arfaeinia, I. Nabipour, A. Ostovar, Z. Asadgol, E. Abuee, M. Keshtkar and S. Dobaradaran, Assessment of sediment quality based on acid-volatile sulfide and simultaneously extracted metals in heavily industrialized area of Asaluyeh, Persian Gulf: concentrations, spatial distributions, and sediment bioavailability/toxicity, Environ Sci Pollut Res., 9 (2016) 1.
3. S. Dobaradaran, K. Naddafi, S. Nazmara and H. Ghaedi, Heavy metals (Cd, Cu, Ni and Pb) content in two fish species of Persian Gulf in Bushehr Port, Iran. Afr J Biotechnol., 9 (2010) 6191.
4. D.R. Abadi, S. Dobaradaran, I. Nabipour, X. Lamani, M. Ravanipour, R. Tahmasebi and S. Nazmara, Comparative investigation of heavy metal, trace, and macro element contents in commercially valuable fish species harvested off from the Persian Gulf, Environ Sci Pollut Res., 22 (2015) 6670.
5. A. Rahmani, K. Rahmani, S. Dobaradaran, A.M. Mahvi, R. Mohamadjani and H. Rahmani, Child dental caries in relation to fluoride and some inorganic constituents in drinking water in Arsanjan, Iran, Fluoride., 43 (2010) 179.

6. S. Dobaradaran, A.H. Mahvi, S. Dehdashti, and D.R.V. Abadi, Drinking water fluoride and child dental caries in Dashtestan, Iran, Fluoride., 41 (2008) 220.
7. S. Dobaradaran, A.H. Mahvi, S. Dehdashti, S. Dobaradaran and R. Shoara, Correlation offluoride with some inorganic constituents in groundwater of Dashtestan, Iran, Fluoride., 42 (2009) 50.
8. S. Dobaradaran, D.R.V. Abadi, A.H. Mahvi and A. Javid, Fluoride in skin and muscle of twocommercial species of fish harvested off the Bushehr shores of the Persian Gulf, Fluoride., 44 (2011) 143.
9. S. Dobaradaran, F. Fazelinia, A.H. Mahvi and S.S. Hosseini, Particulate airborne fluoride from an aluminium production plant in Arak, Iran, Fluoride., 42 (2009) 228.
10. A. Mohagheghian, A.H. Mahvi, S. Shekoohiyan, A. Koolivand, S. Nazmara, H. Aslani, M. Binesh Brahmand and S. Dobaradaran, Determination of copper, nickel and chromium contents in cultivated tea in north of Iran, Environmental Engineering and Management Journal., 14 (2015) 2409.
11. M. Keshtkar, S. Dobaradaran, F. Soleimani, V. Noroozi Karbasdehi, M.J. Mohammadi, R. Mirahmadi and F. Faraji Ghasemi, Data on heavy metals and selected anions in the Persian popular herbal distillates, Data in Brief., 8 (2016) 21-25.
12. A.Raeisi, H. Arfaeinia, M. Seifi, M. Keshtkar, S. Dobaradaran, Polycyclic aromatic hydrocarbons (PAHs) in coastal sediments from urban and industrial areas of Asaluyeh Harbor, Iran: distribution, potential source and ecological risk assessment. Water Science and Technology., (2016) wst2016265.
13. Klaudia J, and M. Valko. Advances in metal-induced oxidative stress and human disease, Toxicology, 283 (2011) 65-87.
14. J.E. Mckee, H.W. Wolf, Water Quality Criteria California State Water Quality Control Board, Publication No. 3-A (1963).
15. K. Kannan, Fundamentals of Environmental Pollution, S Chand Co. Limited, New Delhi, 1995.
16. Environmental Protection Agency (EPA): Secondary Drinking Water Standards: Guidance for Nuisance Chemicals, <https://www.epa.gov/dwstandardsregulations/secondary-drinking-water-standards-guidance-nuisance-chemicals> accessed 6/1/16.
17. World Health Organization (WHO), third edition, Guidelines for Drinking Water Quality, volume I, 2004, Geneva, Italy.

18. B. Volesky, Removal and Recovery of Heavy Metals by Biosorption, In: Biosorption of heavy metals, Boston, USA, CRC press., 1990b, pp. 7–43.
19. A.K. Bhattacharyya, T.K. Naiya, S.N. Mandal and S.K. Das, Adsorption, kinetics and equilibrium studies on removal of Cr(VI) from aqueous solutions using different low-cost adsorbents, Chemical Engineering Journal., 137(2008) 529.
20. S. Naeem, U. Zafar, A. Altaf and A. Inayat, Adsoeption Studies of Cr (VI) on Rice Husk Ash (Rha), Journal of Chemical Society of Pakistan., 31 (2009) 379.
21. D.B.A. Fil and C. Özmetin, Adsorption of Cationic Dye from Aqueous Solution by Clay as an Adsorbent: Thermodynamic and Kinetic Studies, Journal of Chemical Society of Pakistan., 34 (2012) 896.
22. S. Tunali, T.Akar, A.S.Ozcan, I.Kiran and A.Ozcan, Equilibrium and kinetics of biosorption of lead(II) from aqueous solutions by Cephalosporium aphidicola, Sep Purif Technol., 47 (2006) 105–112.
23. R. Han, L. Zhang, C. Song, M. Zhang, H.M. Zhu and L, Zhang Characterization of modified wheat straw, kinetic and equilibrium study about copper ion and methylene blue adsorption in batch mode, Carbohydr Polym., 79(2010) 1140–1149.
24. S. Dobaradaran, I. Nabipour, S. Tajbakhsh, M. Khorsand, M. Keshtkar, A. Khaledi, and F. Babaahmadi, Biosorption of cadmium from aqueous solution onto cuttle bone obtained along the Persian Gulf coast as a cheap and effective biosorbent: evaluation of adsorption isotherms and kinetics, International Journal of Pharmacy & Technology., 7 (2015) 9975-9984.
25. M. Keshtkar, S. Dobaradaran, I. Nabipour, S. Tajbakhsh, F. Soleimani, H. Darabi and H. Ghaedi, Removal of Manganese from Aqueous Phase Using Padina sanctae crucis Obtained from Persian Gulf,Journal of Mazandaran University of Medical Sciences., 25 (2016)167-177 (Persian).
26. S. Dobaradaran, I. Nabipour, A.H. Mahvi, M. Keshtkar, F. Elmi, F. Amanollahzade, and M. Khorsand, Fluoride removal from aqueous solutions using shrimp shell waste as a cheap biosorbent, Fluoride., 47 (2014) 253–257.
27. S. Dobaradaran, M. Kakuee, A.R. Pazira, M. Keshtkar, M. Khorsand, Fluoride removal from aqueous solutions using Moringa oleifera seed ash as an environmental friendly and cheap biosorbent, Fresenius Environ Bull., 24 (2015) 1269–1274.

28. M.A. Zazouli, A.H. Mahvi, S. Dobaradaran, M. Barafrashtehpour, Y. Mahdavi, and D. Balarak, Biosorption of fluoride from aqueous solution by modified Azolla Filiculoides, Fluoride., 47 (2014) 349–358.
29. M. Keshtkar, S. Dobaradaran, I. Nabipour, A.H. Mahvi, F. Faraji Ghasemi, Z. Ahmadi, M. Heydari, Isotherm and kinetic studies on fluoride biosorption from aqueous solution by using cuttlebone obtained from the Persian Gulf, Fluoride 49 (2016) 319-327.
30. S. Dobaradaran, M.A. Zazuli, M. Keshtkar, S. Noshadi, M. Khorsand, F. Faraji Ghasemi, V. Noroozi Karbasdehi, L. Amiri and F. Soleimani, Biosorption of fluoride from aqueous phase onto Padina sanctae crucis algae: evaluation of biosorption kinetics and isotherms, Desalination and Water Treatment., (2016) 1–12.
31. M. Keshtkar, S. Dobaradaran, S. Akbarzadeh, M. Bahreini, D. Ranjbar VakilAbadi, S. Ghaderi Nasab, F. Soleimani, N. Khajeahmadi and M. Mohamadi Baghmolaei, Iron biosorption from aqueous solution by Padina sanctae crucis algae: Isotherm, kinetic and modeling, International Journal of Pharmacy & Technology., 8 (2016) 10459-10471.
32. B.Volesky, H.May and Z.R. Holan, Cadmium biosorption by saccharomyces cerevisiae, Biotechnol Bioeng., 41(1993) 826–829.
33. J.S.Chang, R.Law andC.C.Chang, Biosorption of lead, copper and cadmium by biomass of pseudomonas aeruginosa PU21, Water Res., 31(1997) 1651–1658.
34. A.Shukla, Y.H.Zhang, P.Dubey, J.L.Margrave and S.S.Shukla, The role of sawdust in the removal of unwanted materials from water, J Hazard Mater., 95(2002) 137–152.
35. Sh.Chowdhury, P.D.Saha, Scale-up of a dye adsorption process using chemically modified rice husk: optimization using response surface methodology, Desalin Water Treat., 37(2012) 331–336.
36. V.J.P.Vilar, C.M.S.Botelho and R.A.R.Boaventura, Equilibrium and kinetics modeling of Cd(II) biosorption by algae Gelidium and agar extraction algal waste, Water Res., 40(2006) 291–302.
37. E. Romera, F. Gonzalez, A. Ballester, M.L. Blazquez and J.A.Mu˜noz, Biosorption with algae: a statistical review, Crit. Rev. Biotechnol., 25 (2006) 223–235.
38. S. Karthikeyan, R. Balasubramanian and C.S.P. Iyer, Evaluation of the marine algae Ulva fasciata and Sargassum sp. for the biosorption of Cu(II) from aqueous solutions, Biores. Technol., 98 (2007) 452–455.

39. R. Khalilnezhad, M.E. Olya, M. Khosravi, R. Marandi, Manganese Biosorption from Aqueous Solution by Penicillium camemberti Biomass in the Batch and Fix Bed Reactors: A Kinetic Study, Appl Biochem Biotechnol., (2014) 174(2014) 1919–1934.
40. K.G. Akpomie and F.A. Dawodu, Efficient abstraction of nickel(II) and manganese(II) ions from solution onto an alkaline-modified montmorillonite, Journal of Taibah University for Science., 8 (2014) 343–356.
41. A.I. Adeogun, M.A. Idowu, A.E. Ofudje, S.O. Kareem and S.A. Ahmed, Comparative biosorption of Mn(II) and Pb(II) ions on raw and oxalic acid modified maize husk: kinetic, thermodynamic and isothermal studies, Appl Water Sci.,3 (2013) 167–179.
42. F.A. Dawodu and K.G. Akpomie, Simultaneous adsorption of Ni(II) and Mn(II) ionsfrom aqueous solution unto a Nigerian kaolinite clay, Journal of Materials Research and Technology., 3 (2014) 129–141.
43. W.T.Tsia and H.R. Chen, Removal of malachite green from aqueous solution using low-cost chlorella based biomass, J Hazard Mater., 175 (2010) 844–9.
44. C. Yang, J. Wang, M. Lei, G. Xie,G. Zeng, andS. Luo, Biosorption of zinc(II) from aqueous solution by dried activated sludge, Environmental Sciences., 22 (2010) 675–680.
45. H.M.F. Freundlich, Uber die biosorption in losungen, Z. Phys. Chem. 57 (1096) 385–470.
46. I. Langmuir, The constitution and fundamental properties of solids and liquids, J. Am. Chem. Soc. 38 (1916) 2221–2295.
47. B.H.Hameed and M.I.El-Khaiary, Removal of basic dye from aqueous medium using a novel agricultural waste material: Pumpkin seed hull, J Hazard Mater., 155 (2008) 601-609.

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