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Research Article

Adsorption Kinetics and Thermodynamics Study for the Removal of Anionic Dye Eosin-B From Aqueous Solution by Anion Exchange Membrane: Adsorption Kinetics and Thermodynamics

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Abstract: Batch adsorption of anionic dye Eosin-B (EB) from aqueous solution on anion exchange membrane (EBTAC) has been studied at ambient temperature. The influence of contact time, membrane dosage, ionic strength and temperature on the adsorption of dye from aqueous solution were investigated. Kinetic models such as pseudo-first-order, pseudo-second-order, Elovich model, liquid film diffusion model, modified Freundlich equation and Bangham equation were used to evaluate the experimental data.Endowments such as adsorption capacities, rate constant and related correlation coefficients for every model were measured and discussed.Thermodynamic characteristics illustrated that adsorptionof EB on EBTAC followed pseudo-second-order kinetics.Moreover, change in Gibbs free energy ($\Delta G°$), EB on EBTAC revealed that the adsorption of EB dye on EBTAC is an exothermic process.

Keywords: Adsorption, Eosin-B, Anion exchange membrane, Kinetics,Thermodynamics, Exothermic process

INTRODUCTION

Modern industrial processes and households yield a lot of waste-water every year. Treatment and recycling of wastewater provides a solution for lack of water in the world. The wastewater contains several types of contaminants which are harmful to the environment. Dyes, one of the adverse pollutants, are usually detected in the effluent water from textile, leather, paper, printing, and cosmetic industries. Dye removal from water can be achieved via several techniques, such as physical, chemical and biochemical processes. An effective and attractive process for the treatment of these dyes bearing wastewater involves adsorption technique[1-3]. The adsorbents reported in the literature include naural or synthetic products such as zeolites, activated clay, activated carbons, activated slag, chitosan beads, cellulosic resins, polymeric resin, modified rice husk, modified cross-linked starch, palm kernel fiber, red mud, bottom ash, de-oild soya, ect. [4-20]. Their price and efficiency change from one adsorbent to other.

In recent years, commercial anion exchange resins have been shown to possess excellent adsortion capacity and demonstrate efficient regeneration properpty for the removal and recovery of reactive dyes [4, 21]. As, packed-bed operations in anion exchange resins would suffer from certain disadvantages (e.g slow pore diffusion, low accessible flow rate, high pressure drop and flow channeling). Therefore, in order to eliminate the above limitations, anion exchange membranes, instead of resin particles , have been successfully used to remove the anionic reactive dyes, for example, Cibacron blue 3GA and Cibacron red 3BAagainst water [22]. The macroporous membrane system can not only remove the technical problems of packed-bed operation but also exhibit the property of scale-up by simple stacking several membranes together or by using a large membrane area. Thus, the ion exchange membrane becomes an excellent choice for industrial applications.

In this manuscript, commercial anion exchange membrane EBTAC was employed to remove ani onic dye Eosin-B (EB) from aqueous solution. The effect of contact time, membrane dosage, temperature and ionic strength on the adsorption of EB from aqueous solution was studied in batch mode. Adsorption kinetics was revealed by employing pseudo-first-order model, pseudo-second-order model, Elovich model, liquid film diffusion model, the Bangham equation and the modified Freundlich equation. Thermodynamics has also been studied for adsorption of EB on to anion exchange membrane EPTAC.

EXPERIMENTAL

Adsorbent

The commercial anion exchange membrane EBTAC was provided by Chemjoy Membrane Co. Ltd, Hefei, Anhui, China. The ion exchange capacity (IEC) and water uptake (W_R) of EBTAC membrane are 0.42 mmol/g and 164.31 % respectively. They were used as adsorbents for anionic dye Eosin-B (EB). Prior to experiment, it was conditioned with 1 M HCl and NaOH to withdraw impurities.

Adsorbate

The commercial anionic dye Eosin-B (EB), obtained from Fluka chemicals was used as adsorbate. A stock solution of 1000 mg/L was prepared by dissolving 1.0 g of accurately weighed for each dye into 1 litre of deionized water and required concentrations were obtained by further dilution of stock solution. All the chemicals used in the experiments were of analytical reagent grade. The structures of EB are shown in Fig.1.

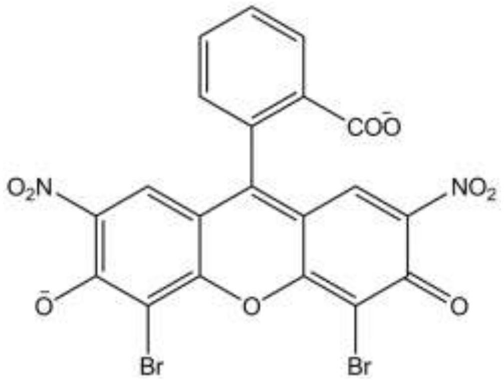

Fig. 1 Chemical strucure of Eosin-B (EB) dye

Adsorption

Batch adsorption of Eosin-B (EB) dye was carried out by immersing anion exchange membrane (EBTAC) into measured volume of aqueous dye solution at room temperature. The bottles were shaked at a constant speed of 120 rpm. EB concentration was determined by UV/Vis spectrophotometer (UV-2550, SHIMADZU) and related calibration curves were obtained. The wavelength used for EB was 514 nm. The EB adsorption on EBTAC at time t, was calculated by equation 1.

$$q_t = \frac{C_o - C_t}{W} \times V \qquad (1)$$

Where C_o and C_t are the concentration of EB at initial state and at time t respectively. Similarly V and W are volume of EB aqueous solution and weight of adsorbent respectively.

RESULT AND DISCUSSION

Effect of Operational Parameters

Herein, the influence of operational parameters such as contact time, membrane dosage, ionic strength and temperature on the removal of EB dye from aqueous solution has been discussed. Their details are given below.

Effect of contact time

The effect of contact time on the percentage removal of EB from aqueous solution by anion exchange membrane EBTAC was investigated keeping membrane dosage (0.1 g), concentration of dye (25 mg/L and 50 mg/L), volume of solution (40 ml) and stirring speed (120 rmp) at room temperature and results are shown in Fig. 2. It is shown in Fig. 2 that the uptake of EB dye was very rapid initially and then continued to increase with contact time at relatively slow rate until it reached a state of equilibrium after 24 hrs. It is attributed to the fact that a lot of vacant active sites are present for adsorption of dye on the membrane surface in the initial stage of reaction. But with the passage of time, the available active sites are hard to be occupied due to repulsive forces between solute molecules on the solid and bulk phase.

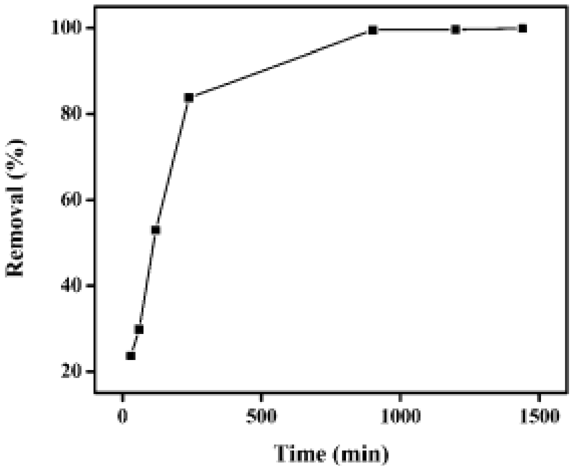

Fig. 2 : Effect of contact time on the removal of EB from aqueous solution by anion exchange membrane EPTAC

Effect of membrane dosage

The influence of membrane dosage on the percentage removal of EB from aqueous solution was studied keeping the other conditions constant and results are represented in Fig. 3. It has been observed that the percentage removal of EB increases with increasing the membrane dosage. The percentage removal of EB is found to be increased from 48.31 % to 99.91 % with increasing membrane dosage from 0.02 g to 0.1 g. This increase in adsorption of EB dye was attributed to the increase in the number of available sorption sites on the surface of the anion exchange membranes. It can be seen from the Fig. 3 that the removal of EB was rapid in the initial stage, and then it becomes almost constant with further increase in the membrane dosage. It can be seen that the removal of EB was maximum at membrane dosage of 0.1 g. Therefore, 0.1 g was selected as the optimum quantity and used in further experiments to get better results. The observed two stage-dependent adsorption behaviour has also been reported in the literature[23].

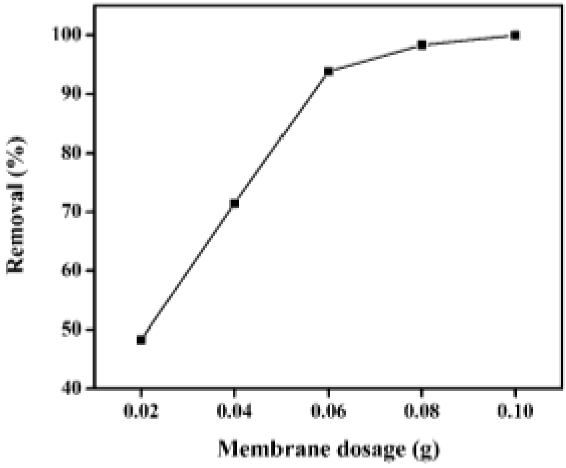

Fig. 3 Effect of membrane dosage on the removal of EB from aqueous solution by anion exchange membrane EPTAC

Effect of ionic strength

The ionic strength of the solution is an important parameter that governs both the electrostatic and non-electrostatic intractions between the dye and the membrane surface. The effect of ionic strengh on the removal of EB from solution was investigated by adding different quantity of sodium chloride to the dye solution and results are given in Fig. 4. It can be seen from Fig. 4 that the romoval of EB dye decreases with increasing salt concentration. The removel of dye is found to be decreased from 94.21% to 53.70 % with increasing salt concentration from 0 M to 1.5 M . This could be due to the competition between EBanions and Cl^- for the active sorption sites [24].

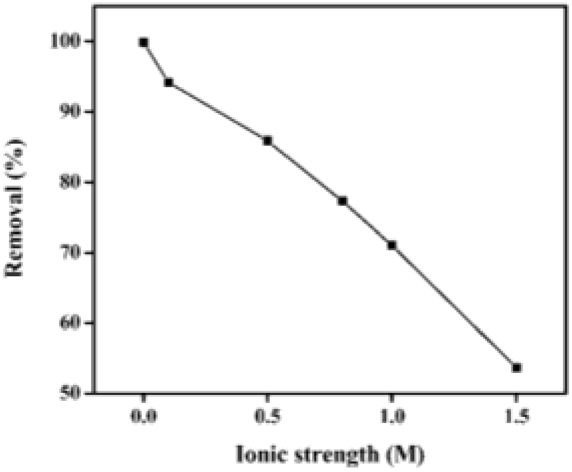

Fig. 4 Effect of ionic strength on the removal of EB from aqueous solution by anion exchange membrane EPTAC

Effect of temperature

The effect of temperature on removal of EB from aqueous solution wasstudied by keeping the contact time, membranes dosage, stirring speed, solution volume and concentration (25 mg/L to 50 mg/L) constant and results are shown in Fig. 5. It has been observed that the removal of EB decreases with increasing temperature. The removal of EB is found to be decreased from 99.91 % to 90.51 with increasing the temperature from 303K to 323 K. These results show that adsorption of EB on anion exchange membrane EBTAC is an exothermic process.

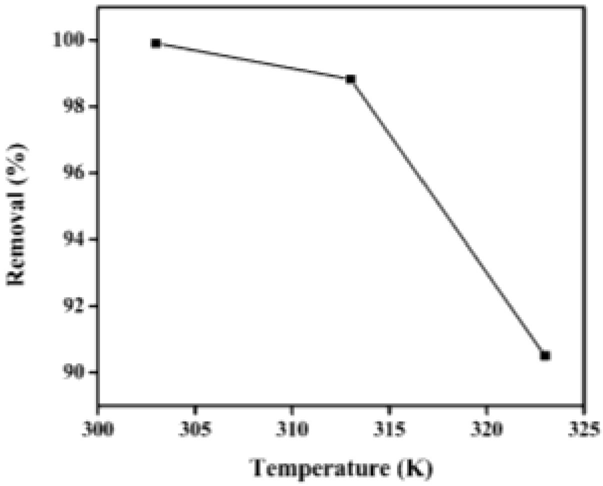

Fig. 5: Effect of temperature on the removal of EB from aqueous solution by anion exchange membrane EPTAC

Adsorption Kinetics

Several adsorption models have been utilized to study the controlling mechanism of adsorption process such as chemical reaction and diffusion control.

Pseudo-first-order model

The linearized form of the Lagergren Pseudo-first-order rate equation is given by[25]

$$loq(q_e - q_t) = \log q_e - \frac{K_1 t}{2.303} \quad (2)$$

Where q_e and q_t are the amount of adsorbate adsorbed at equilibrium and time t repectively, and k_1 (/min) is the rate constant of pseudo-first-order adsorption model. The plot of $\log(q_e - q_t)$ vs time for pseudo-first-order model is given in Fig. 6. The value K_1 is calculated from slope of eq. 2 and given in Table 1. These plots are linear, however the linearity of these curves does not necessarily assure the mechanism due to the inherent disadvantage of correctly estimating the equilibrium adsorption capacity [26]. Furthermore, there is a large difference between experimental adsorption capacity value ($q_{e,exp}$) and calculated adsorption capacity value ($q_{e,cal}$), therefore, pseudo-first-order model does not explain the rate process.

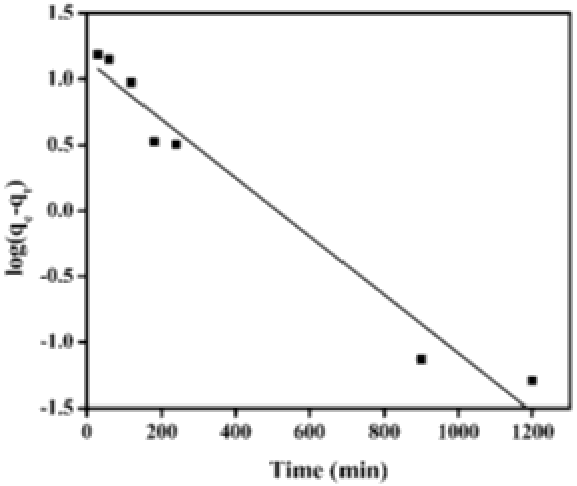

Fig.6: Pseudo-first-order kinetics for adsorption of EB on anion exchange membrane EPTAC

Pseudo-second-order model

The linearized form of pseudo-second kinetic model is expressed as [27]

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \quad (3)$$

where k_2 (g/mg.min) is the rate constant of pseudo-second-order model. The graphical representation of pseudo-second-order model is depicted in Fig. 7. The values of adsorption capacity (q_e) can be determined from slope of Fig. 7 and are given in Table 1. It has been observed that value of experimental ($q_{e,\ exp}$) adsorption capacity is very close to the calculated adsorption capacity ($q_{e,\ cal}$). Moreover, the value of correlation coefficient (R^2>0.995) is close to unity which indicates that experimental data fits well to the pseudo-second-order model.

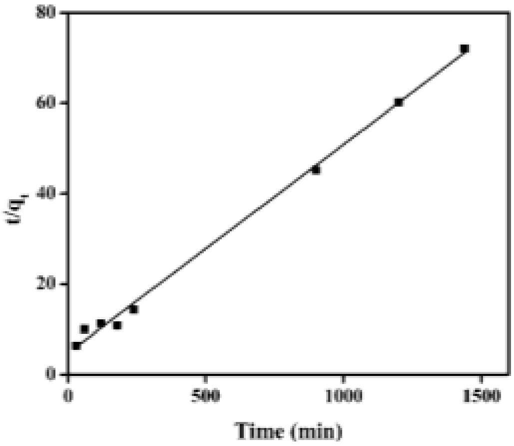

Fig.7: Pseudo-second-order kinetics for adsorption of EB on anion exchange membrane

Elovich model

The most interesting model to describe the activated chemisorption is the Elovich equation[28].

$$q_t = \frac{1}{\beta}\ln(\alpha\beta) + \frac{1}{\beta}\ln t \qquad (5)$$

Where α and β are constants. The parameter α is considered as initial sorption rate (mg/g.min) and β is related to the extent of surface coverage and activation energy for the chemisorption. The plot of q_t vs lnt for Elovich model is given in Fig.8. The values of α and β are determined from intercept and slope of Fig. 8 and are given in Table 1. The values of correlation cofficient (R^2) was 0.873 lower than that of pseudo-second-order model.

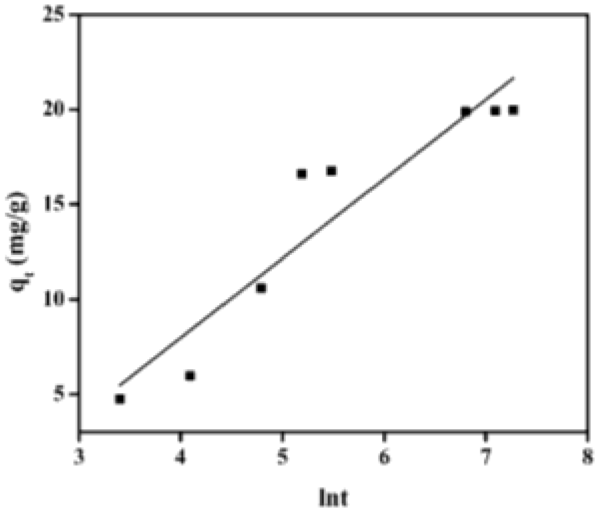

Fig.8 Elovich model for adsorption of EB on anion exchange membrane EPTAC

Table 1: **Pseudo-first-order, pseudo-second-order and Elovich model rate constants (q_e:mg/g; k_1: (/min);k_2:g/mg.min; α: mg/g.min; β: g/mg)**

Pseudo-first-order				Pseudo-second-order			Elovich model		
$q_{e(exp)}$	$q_{e\ (cal)}$	$k_1 * 10^{-3}$	R^2	q_e	$k_2 \times 10^{-4}$	R_2	α	β	R^2
19.98	13.80	2.22	0.959	21.73	4.46	0.995	0.51	0.24	0.873

Liquid film diffusion model

The liquid film model is expressed as [29].

$$Ln(1-F)=-K_{fd}t \quad (4)$$

Where K_{fd} is liquid film diffusion rate constant, and $F=q_t/q$. The plot of ln(1-F) vs time for liquid film model is given inFig.9. The values of $K_{fd}$are calculated from slope of Fig. 9 and are given in Table 1. The value of correlation coefficient (R^2) is found to be 0.959 which was lower than pseudo-second-order model. It indicates that liquid film diffusion model is not suitable to explain the experimental data.

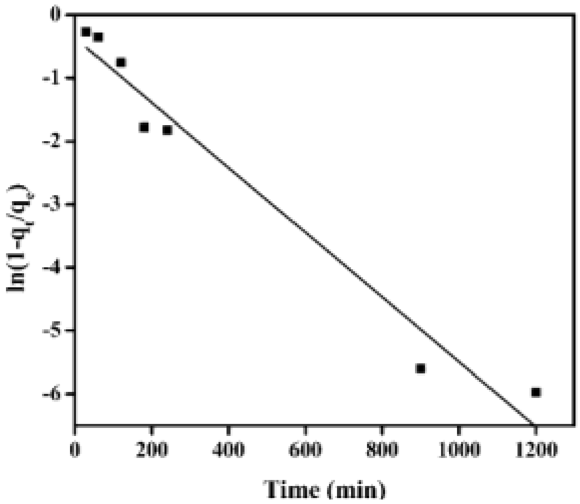

Fig. 9Liquid Film diffusion model for adsorption of EB on anion exchange membrane EPTAC

Modified Freundlich Equation

The modified freundlich eaquation was originally developed by Kuo and Lotse][30]

$$q_t = kC_o t^{1/m} \quad (7)$$

where q_t amount of adsorbed dye (mg/g) at time t, k apparent adsorption rate constant (L/g.min), C_o the initial dye concentration (mg/L), t the contact time (min) and m is the Kuo-Lotse constant. The values of k and m were used to evaluate the effect of dye surface loading and ionic strength on the adsorption process. Linear form of modified Freundlich equation isgiven as;

$$\ln q_t = \ln(kC_o)+\frac{1}{m}\ln t \quad (8)$$

The graphical representation of modified Freundlich model is given in Fig. 10. The parameters m and k were determined from slope and intercept of Fig. 10 and are given in Table 2. The value of m and k increases with increasing the initial concentration of dye. The correlation coefficient values was found to be 0.991 which is lower than pseudo-second-order model. Therefore, it is not suitable to explain experimental data.

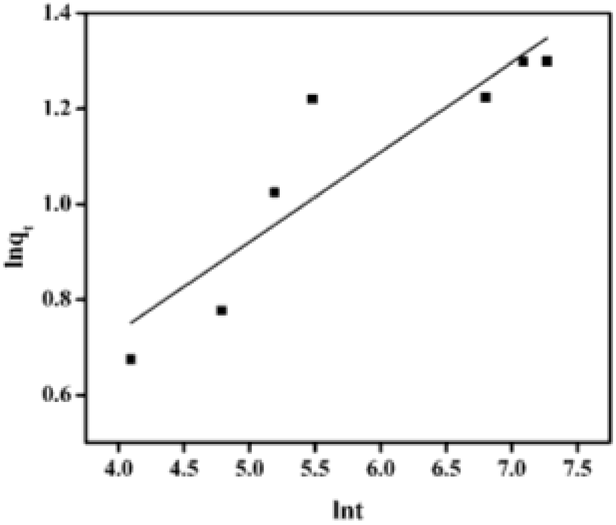

Fig. 10 Modified Freundlich equation plot between logt vs logqt for adsorption of EB on anion exchange membrane EPTAC

Bangham Equation

Bangham equation [31]is given as

$$\log\log\left(\frac{C_o}{C_o - q_t m}\right) = \log\left(\frac{k_o m}{2.303V}\right) + \alpha \log t \quad (6)$$

Where C_o is the initial concentration of dye solution (mg/L), V is volume of solution (mL), q_t isthe amount of dye adsorbed (mg/g) at time t, m isthe weight of adsorbent used (g/L). α (<1) and k_o (mL/(g/L) are constants. The plot of loglog(C_o/C_o-q_tm) Vs logt is given in Fig. 11. The values of α and m were calculated from slope and intercept of Fig. 11 and are given in Table 2. The double logarithmic plot did not give linear curves for EBremoval by anion exchange membrane (EBTAC) indicating that the diffusion of adsorbate into pores of the sorbent is not the only rate controlling step [32, 33]. It may be concluded that both film and pore diffusion were important to different extent in the removal of EB from aqueous solution.

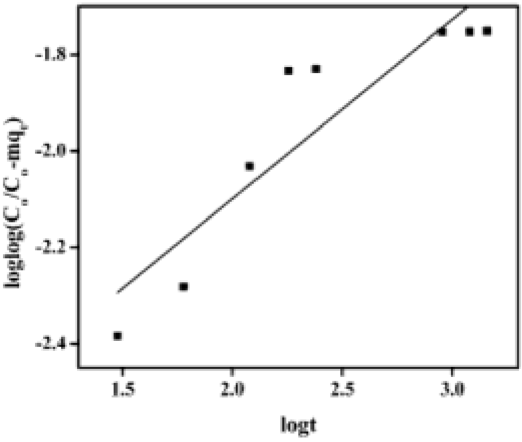

Fig. 11 Bangham equation plot between logt vs log log(C_o/C_o-mqt) for adsorption of EB onanion exchange membrane EPTAC

Table 2: Liquid film diffusion model, modified Freunlich equation and Bangham equation rate constant (k_{fd}: (/min); k : L/g.min; k_o: mL/g/L)

Liquid film diffusion model			Modified Freunlich equation			Bangham equation		
$k_{fd}*10^{-3}C_{fd}$	R^2		m	k	R^2	k_o	α	R_2
5.1	-0.39	0.959	0.76	0.005	0.991	1.33	0.37	0.805

Adsorption Thermodynamics

Thermodynamic parameters show the feasibility and spontaneity of adsorption process. The parameters namely change in Gibb's free energy (ΔG °), enthalpy (ΔH°) and entropy (ΔS °) were determined from given equations

$$\ln Kc = \frac{\Delta S^o}{R} - \frac{\Delta H^o}{RT} \quad (9)$$

$$K_c = \frac{C_a}{C_e} \quad (10)$$

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

where K_c, C_a, C_e, R, T are the the equilibrium constants, amount of dye (mol/L) adsorbed on the adsorbent per litre (L) of the solution at equilibrium, equilibrium concentration (mol/L) of dye in solution, general gas contant (8.31 J/mol.K) and absolute temperature (T) respectively. Similarly ΔG °, ΔH ° and ΔS ° are the change in Gibb's free energy (KJ/mole), enthalpy (KJ/mol) and entropy (J/mol.K) respectively. The plots of lnK_c versus 1/Tfor adsorption of EB on anion exchange membrane is shown in Fig. 12. The adsorption enthalpy (ΔH°) and entropy (ΔS°) were determined from slope and intercept of Fig. 12and are given in Table 3. The values of Gibb's free energy (ΔG°) were positive for adsorption of EB on anion exchange membrane at all temperatures studied.Its values are found to be increased with increasing the temperature as represented in Table 2. It might be owing to interaction between adsorbent and adsorbate, with unbalanced competition imputed to heterogeneity of membrane surface and system got energy from external source at higher temperatures. The nagative value of enthalpy (ΔH°) indicates that the adsorption ofEB on anion exchange membrane is an exothermic process. Similarly, the negative values of entropy (ΔS °) represent decrease in randomness at the dye-membrane interface during the adsorption of EB on anion exchange membrane.

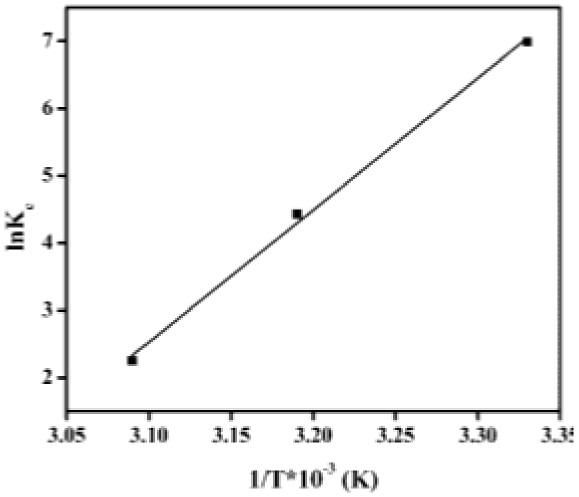

Fig. 12: Plot of 1/T vs lnKc for adsorption of EB on anion exchange membrane EPTAC

Table 3 :Thermodynamic parameters for adsorption of EB on anion exchange membrane EPTAC

		ΔG (KJ/mol)		
ΔH (KJ/mol)	ΔS (J/mol)	303 K	313 K	323 K
-163.04	-484.60	14.66	15.15	15.64

CONCLUSION

In this manuscript, the adsorption of anionic dye EB from aqueous solution on anion exchange membrane was investigated using different initial dye concentrations. The influence of contact time, membrane dosage, ionic strength and temperature on the removal of EB from aqueous solution was studied. These results revealed that removal of EB increases with increasing contact time, membrane dosage but decreases with ionic strength and temperature. Adsorption Kinetics showed that experimental data fitted well with the pseudo-second-order model. Moreover, thermodynamic study indicated that the adsorption of EB on anion exchange membrane was exothermic process. The negative value of ΔS^o suggested that the randomness decreases between dye-membrane interface during adsorption. Thus, anion exchange membrane (EBTAC) is an excellent adsorbent for EB dye removal from waste water.

Nomenclature

Code: Full name
EB:Eosin-B
IEC :Ion exchange capacity (mmol/g)
W_R :Water uptake (%)
C_o:Initial Concentration of dye (mg/L)
C_t :Concentration of dye at time t (mg/L)
W :Weight of adsorbent (g)
V :Volume of adsorbate (dm^3)
k_1 :Rate constant of pseudo-first-order model (/min)
k_2 :Rate constant of pseudo-second-order model (g/mg.min)
α :Initialsorptionrate (mg/g.min)
β : Extent of surface coverage and activation energy for the Chemisorption (g/mg).
K_{fd} : Liquid film diffusion rate constant
K :Apparent adsorption rate constant (L/g.min)
m : KuoLotse constant.
ΔG^o : Change in Gibb's energy
ΔS^o :Change in entropy
ΔH^o :Change in enthalpy

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REFERENCES

1. Singh K, Aroras S; Removal of synthetic textile dyes from wastewaters: a critical review on present treatment technologies. Critical reviews in environmental science and technology name, 2011; 41 (9): 807.
2. Crini GS; Non-conventional low-cost adsorbents for dye removal: a review. Bioresource Technology name, 2006; 97 (9): 1061.
3. Gupta VS; Application of low-cost adsorbents for dye removal–A review. Journal of environmental management name, 2009; 90 (8): 2313.
4. Karcher S, Kornmüller A, Jekels M; Screening of commercial sorbents for the removal of reactive dyes. Dyes and Pigments name, 2001; 51 (2): 111.
5. Gupta VK, Srivastava SK, Mohans D; Equilibrium uptake, sorption dynamics, process optimization, and column operations for the removal and recovery of malachite green from wastewater using activated carbon and activated slag. Industrial & Engineering Chemistry Research name, 1997; 36 (6): 2207.
6. Gupta V, Suhas I Ali, Sainis V; Removal of rhodamine B, fast green, and methylene blue from wastewater using red mud, an aluminum industry

waste. Industrial & Engineering Chemistry Research name, 2004; 43 (7): 1740.

7. Gupta V, Ali I, Saini V, Van Gerven T, Van der Bruggen B, Vandecasteeles C; Removal of dyes from wastewater using bottom ash. Industrial & Engineering Chemistry Research name, 2005; 44 (10): 3655.
8. Gupta V, Mittal A, Gajbe V, Mittals J; Removal and recovery of the hazardous azo dye acid orange 7 through adsorption over waste materials: bottom ash and de-oiled soya. Industrial & Engineering Chemistry Research name, 2006; 45 (4): 1446.
9. Šimkovic I, Laszlo JA, Thompsons AR; Preparation of a weakly basic ion exchanger by crosslinking starch with epichlorohydrin in the presence of NH 4 OH. Carbohydrate polymers name, 1996; 30 (1): 25.
10. Low K, Lees C; Quaternized rice husk as sorbent for reactive dyes. Bioresource Technology name, 1997; 61 (2): 121.
11. Laszlo JA; Regeneration of azo-dye-saturated cellulosic anion exchange resin by Burkholderia cepacia anaerobic dye reduction. Environmental Science & Technology name, 2000; 34 (1): 167.
12. Wu FC, Tseng RL, Juangs RS; Enhanced abilities of highly swollen chitosan beads for color removal and tyrosinase immobilization. Journal of Hazardous Materials name, 2001; 81 (1): 167.
13. Wu FC, Tseng RL, Juangs RS; Adsorption of dyes and humic acid from water using chitosan- encapsulated activated carbon. Journal of Chemical Technology and Biotechnology name, 2002; 77 (11): 1269.
14. Tseng RL, Wu FC, Juangs RS; Liquid-phase adsorption of dyes and phenols using pinewood-based activated carbons. Carbon name, 2003; 41 (3): 487.
15. Chang MY, Juangs RS; Adsorption of tannic acid, humic acid, and dyes from water using the composite of chitosan and activated clay. Journal of Colloid and Interface Science name, 2004; 278 (1): 18.
16. Ozdemir O, Armagan B, Turan M, Celiks MS; Comparison of the adsorption characteristics of azo-reactive dyes on mezoporous minerals. Dyes and Pigments name, 2004; 62 (1): 49.
17. Wang CC, Juang LC, Hsu TC, Lee CK, Lee JF, Huangs FC; Adsorption of basic dyes onto montmorillonite. Journal of Colloid and Interface Science name, 2004; 273 (1): 80.
18. Lee JW, Choi SP, Thiruvenkatachari R, Shim WG, Moons H; Evaluation of the performance of adsorption and coagulation processes for the maximum removal of reactive dyes. Dyes and Pigments name, 2006; 69 (3): 196.
19. Lorenc-Grabowska E, Gryglewiczs G; Adsorption characteristics of Congo Red on coal-based mesoporous activated carbon. Dyes and Pigments name, 2007; 74 (1): 34.
20. Ofomaja AE, Hos YS; Equilibrium sorption of anionic dye from aqueous solution by palm kernel fibre as sorbent. Dyes and Pigments name, 2007; 74 (1): 60.
21. Karcher S, Kornmüller A, Jekels M; Anion exchange resins for removal of reactive dyes from textile wastewaters. Water Research name, 2002; 36 (19): 4717.
22. Liu CH, Wu JS, Chiu HC, Suen SY, Chus KH; Removal of anionic reactive dyes from water using anion exchange membranes as adsorbers. Water Research name, 2007; 41 (7): 1491.
23. Hameed BH, Din ATM, Ahmads AL; Adsorption of methylene blue onto bamboo-based activated carbon: Kinetics and equilibrium studies. Journal of Hazardous Materials name, 2007; 141 (3): 819.
24. Gong R, Ding Y, Li M, Yang C, Liu H, Suns Y; Utilization of powdered peanut hull as biosorbent for removal of anionic dyes from aqueous solution. Dyes and Pigments name, 2005; 64 (3): 187.
25. Ho YS; Adsorption of heavy metals from waste streams by peat. Ph.D. Thesis, University of Birmingham, Birmingham name, 1995;
26. Kannan N, Sundarams MM; Kinetics and mechanism of removal of methylene blue by adsorption on various carbons—a comparative study. Dyes and Pigments name, 2001; 51 (1): 25.
27. Ho YS; Second-order kinetic model for the sorption of cadmium onto tree fern: A comparison of linear and non-linear methods. Water Research name, 2006; 40 (1): 119.
28. Özacar M, Şengils IA; A kinetic study of metal complex dye sorption onto pine sawdust. Process Biochemistry name, 2005; 40 (2): 565.
29. Chowdhury S, Mishra R, Saha P, Kushwahas P; Adsorption thermodynamics, kinetics and isosteric heat of adsorption of malachite green onto chemically modified rice husk. Desalination name, 2011; 265 (1): 159.
30. Kuo S, Lotses EG; kinetics of phosphate adsorption and desorption by hematite and gibbsite1. Soil Science name, 1973; 116 (6): 400.
31. Aharoni C, Ungarishs M; Kinetics of activated chemisorption. Part 2.-Theoretical models. Journal of the Chemical Society, Faraday Transactions 1: Physical Chemistry in Condensed Phases name, 1977; 73 (0): 456.
32. Elattar A, Elmidaoui A, Pismenskaia N, Gavach C, Pourcellys G; Comparison of transport properties of monovalent anions through anion-exchange membranes. Journal of Membrane Science name, 1998; 143 (1–2): 249.
33. Mall ID, Srivastava VC, Agarwal NK, Mishras IM; Adsorptive removal of malachite green dye from aqueous solution by bagasse fly ash and activated carbon-kinetic study and equilibrium isotherm analyses. Colloids and Surfaces A: Physicochemical and Engineering Aspects name, 2005; 264 (1–3): 17.