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RESEARCH ARTICLE

Adsorption of Basic Blue 41 using *Juniperus excelsa*: Isotherm, kinetics and thermodynamics studies

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ABSTRACT

In this study *Juniperus excelsa* shavings powder (JESP) was utilized as an adsorbent for the removal of Basic Blue 41 (BB 41) which is one of the common basic dyes, from aqueous solution. The adsorption experiments were carried out in a batch system and effects of initial concentration of dye, interaction time and temperature were investigated. Langmuir, Freundlich and Temkin adsorption isotherms were used to model equilibrium data. According to the results, Freundlich isotherm model becomes more convenient option compared with Langmuir and Temkin models. Freundlich model coefficients are raise as the temperature rises, showing that the adsorption process becomes favorable higher temperature. The kinetic parameters were determined by pseudo first order (PFO), pseudo second order (PSO) and intra-particle diffusion (IPD) models. Results indicated that experimental and calculated qe values are matched to each other. Thus the process fits PSO kinetic model with higher R^2 values than other two models. Kinetic constants become closer to both temperatures and initial concentrations and qe values are increases with increasing concentration of BB 41. Initial dye concentration elevates from 25 to 100 mg L^{-1}, dye adsorption capacity onto JESP from 3.06 to 16.53 mg g^{-1}, respectively. Thermodynamic parameters for instance free energy (ΔG), enthalpy (ΔH) and entropy (ΔS) were assessed. Enthalpy and entropy of this separation process are determined from 3081.91 J mol^{-1} and 12.33 kJ mol^{-1}, respectively. The negative values of $\Delta G°$ showed that this separation process was endothermic and natural. The research results demonstrate that JESP may be a substitute than pricey adsorbents for dye removal.

Keywords: Basic Blue 41, dye adsorption, *Juniperus excelsa*, isotherm models, kinetic and thermodynamic parameters

1. INTRODUCTION

The various pollutants such as dyes, pesticides, herbicides and pharmaceuticals should be remove the water systems because of these materials have a negative effect on human and animal health [1, 2]. Dyes released from various sources, e.g., textile industries, cosmetics, pharmaceuticals, paper and pulp industries are regarded as one of the potent pollutants being added to the natural water resources [3]. Dyes are stable, complex structure and very slow biodegradability materials with toxic to organisms in receiving waters and prejudicial to photosynthetic activities. Especially textile dyes are an important type of pollutants which occur in industrial wastewater and cause serious environmental problems. Among these textile dyes, basic dyes have brilliant and strong color intensity and are very detectable in a low concentration. Basic dyes are quaternary salts whose cations have the positive charge most often on the N, C, O and S atoms and anions are most frequently Cl^-, SO_4^{-2}, HSO_4^- or $(COO^-)_2$ ions [4-6]. In relation with their detrimental effects, it is essential to remove the dyes from wastewater. Several chemical and biological treatment technologies are applied to industrial wastewater such as aerobic and anaerobic microbial degradation, filtration, flocculation, softening, hydrogen peroxide catalysis, coagulation, chemical oxidation, membrane separation, electrochemical treatment, and reverse osmosis [7-10]. Among these methods, the adsorption technique which have relatively economical, flexible and simple

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design, comfort in operation and efficient is proved to be an effective process for the treatment of color wastewater [11, 12]. Performance of adsorption process is related with adsorbent materials and several adsorbents have been used for the dyes removal from wastewater. Low cost and efficient, locally available materials are investigated for the removal of dyes as activated carbon which is commonly used adsorbent is very expensive with high operation costs and regeneration is needed after treatment process [13, 14].

Juniperus genus has too many species which just *J. oxycedrus*, *J. excelsa*, *J. communis* and *J. foetidissima* species are widely grown in Turkey. The chemical composition and the phytochemical characteristics of the principal compounds of *Juniperus* genus are summarized before. *Juniperus* genus has many biological effects which might be antifungal, antiviral, antimicrobial, anticancer, cytotoxic, antifungal and antioxidant [15, 16]. There are few studies and data on chemical compositions of the related *Juniperus* species because of widespread using *Juniperus* species in many areas. But there is no any research on heavy metal and/or dye adsorption capacity of these species in the literature. Therefore, the dye adsorption capacity was examined with *J. excelsa* shavings in this study.

The interference among the adsorbent and the adsorbate molecules is explained with the adsorption isotherms. A plot of adsorption isotherm associates with the quantity of substance adsorbed to the equilibrium concentration of the adsorbate molecules in the solution at an absolute temperature. The adsorbate nature changes the amount adsorbed and adsorbent affect the adsorption isotherm profile shape [17]. Different isotherm models involving in Langmuir, Freundlich and Temkin adsorption isotherms were utilized to investigate the result [18]. In this investigation, all mentioned ones are considered. Considering the Langmuir isotherm, the assumption was made that adsorption of monolayer and all the active sites on the surface of adsorbent are equal in energy. Freundlich isotherm clarifies the multilayer adsorption behavior. Temkin isotherm describes interaction of solute molecules in the aqueous phase with heterogeneous solid surface. The temperature effect on the adsorption process is determined with analyzed thermodynamic parameters like free energy, entropy as well as enthalpy [19]. The kinetic mechanism of the adsorption process is explained with calculated different equations such as PFO, PSO and IPD models [13].

In this research we studied the adsorption capacity of JESP from Balıkesir, Turkey, for cationic dye Basic Blue 41 (BB 41). By considering its toxicity, this dye was selected as adsorbate. For this aim kinetic, isotherm and thermodynamic studies of this dye adsorption on JESP was conducted.

2. MATERIALS & METHOD

2.1. Adsorbent (Juniperus excelsa shavings powder)

Adsorption experiments were carried out with shavings powder from *Juniperus* excelsa which grown on the Balıkesir region in Turkey. The shavings were washed with distilled water to remove dirt and then dried at 65 °C in an oven for 48 h. Then the dried shavings were grinded and passing through a 235 mesh sieve (61.75µm) with high speed disintegrator and named JESP. The chemical composition and the characteristics of the principal compounds of *Juniperus* genus are summarized before [16].

2.2. Adsorbate (Basic Blue 41)

The cationic dye BB 41, was used as the adsorbate in the current research. The IUPAC name of BB 41 is 2-[N-ethyl-4-[(6-methoxy-3-methyl-1,3-benzothiazol-3-ium-2-yl) diazenyl] anilino] ethanol. The formula of BB 41 is $C_{20}H_{26}N_4O_6S_2$ (molecular weight 482.57 g mol^{-1}) which was taken from Sigma-Aldrich Company and used without any purification. A stock solution with a concentration of 1000 mg L^{-1} was prepared by dissolving the required dye amount in distilled water. The required solutions concentration used at the adsorption process was prepared to dilute the stock solution of BB 41 with deionized water to obtain the suitable solution concentrations. 25, 40, 55, 70, 85, 100 ppm solutions of BB 41 were prepared for adsorption experiments using stock dye solution.

2.3. Adsorption experiments

In the batch adsorption experiments which were realized in a temperature-controlled water bath, 2 g of adsorbent was treated with 500 mL of the dye solution. The BB 41 concentration in the solution of dye determined for 180 min while the neutral pH was gradually adjusted by adding H_2SO_4 or NaOH solutions (0.1 M). All experiments were achieved in triplicate at the same conditions which were made for 298, 308 and 318 K temperatures in the water bath and the average values taken to represent the result with all data being calculated.

After adsorption experiments, immediately the suspensions were separated by centrifuge. The concentration of BB 41 in solution at a maximum absorption wavelength of 617 nm was evaluated the UV/VIS spectrophotometer (PG Instruments Ltd, T80 model). A calibration curve was obtained by plotting among absorbance and certain concentrations of the dye solution. Unknown BB 41 concentration was measured using a calibration curve. The dye adsorption capacity on the adsorbent is given Eq. (1):

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

where V symbolizes the solution volume (L), C_0 and C_e represent initial and the equilibrium concentration of dye (mg L^{-1}) and m denotes adsorbent mass (g). Ultimately, obtained data from this study were tested by fitting in isotherm, kinetic and thermodynamic relationships to design the appropriate BB 41 dye remove system using JESP adsorbent.

3. RESULTS & DISCUSSION

3.1. Effect of contact time on dye and initial dye concentrations

One of the critical physical parameters used economically is contact time for the plan and operating wastewater treatment plants. In Fig 1-3, the BB 41 removal from the solutions is rapid at the initial period and from the results that specific adsorption increases with increasing dye concentration at a constant temperature. In the beginning, the surface of the adsorption process is large, so the adsorption to this surface is fast. The equilibrium adsorption time was determined at 120 min for BB 41 removal.

Fig 1-3 demonstrates that the rise at the initial concentration of BB 41 caused the increment in adsorption capacity for three temperatures, respectively. As the initial dye concentration enhances from 25 to 100 mg L^{-1}, the adsorption capacity of dye onto JESP gets up from 2.73 to 15.66 mg g^{-1} for 298 K, 2.92 to 16.45 mg g^{-1} for 308 K and 3.06 to 16.53 mg g^{-1} for 318 K, respectively. These data show that the initial dye concentration plays a critical role in the dye adsorption capacity and that provides a driving force to the interaction between adsorbent and dye. Furthermore, a rise in initial dye concentration induces to elevate in the adsorption amount of dye. Based on the experimental results the maximum dye adsorption rate was obtained with 100 mg L^{-1} initial dye concentration. Previously reported results from various researchers were available for Basic Blue dyes adsorption on different adsorbents and biosorbents such as; activated carbon, inorganic oxide ($MgO\text{-}SiO_2$), natural zeolitic tuff, ground nut shells and Eichhornia charcoals, brick waste, nanoporous silica, alumino silicate, pineapple plant stem, black tea leaves, chitosan [1, 5, 7, 20-24]. Comparison of this research results with relevant results of literature, the dye adsorption capacity of JESP is good and JESP may be an alternative material in accordance with more expensive adsorbent used for dye removal.

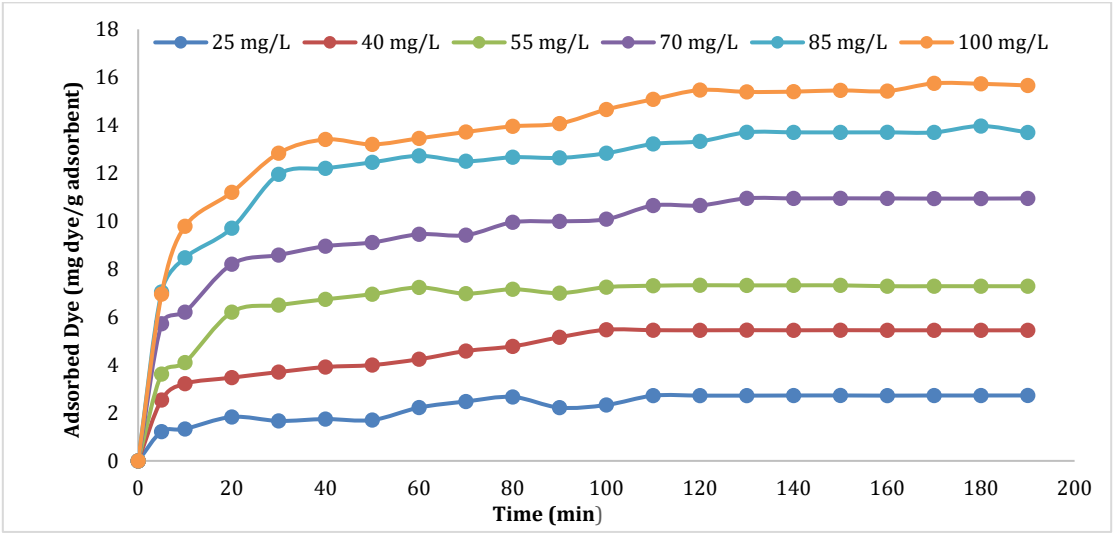

Fig 1. Effect of contact time and initial concentration on dye removal with JESP at 298 K

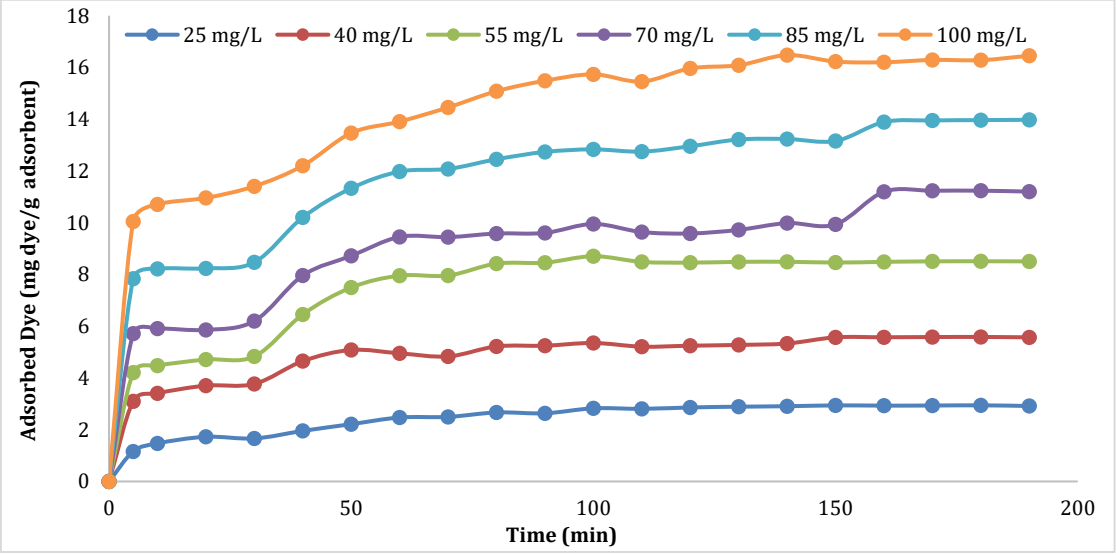

Fig 2. Effect of contact time and initial concentration on dye removal with JESP at 308 K

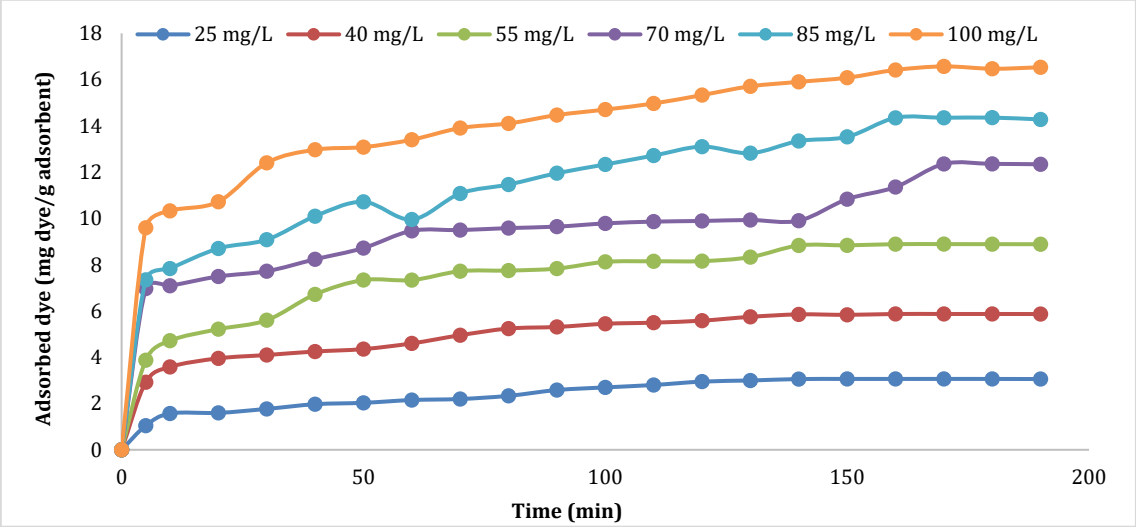

Fig 3. Effect of contact time and initial concentration on dye removal on JESP at 318 K

3.2. Adsorption isotherm studies

Many models used to identify the dyes adsorption on solid surfaces. For the interaction between adsorbate molecules and adsorbent surface investigations, three isotherm models (Freundlich, Langmuir and Temkin) were chosen to endeavor to simplify the interactions between BB 41 and JESP in this study. Three models were applicable for the descriptions of the experimental results obtained at three different temperatures. The parameters of these isotherm models were estimated by using linear regression of isotherms.

Langmuir isotherm has some assumptions for the adsorption occurrence on a homogenous surface with non-interaction adsorbates in the plane of the surface. Langmuir isotherm equation is given Eq. (2):

$$\frac{C_e}{q_e} = \frac{K_L}{q_{max}} + \frac{C_e}{q_{max}} \quad (2)$$

where q_{max} denotes the maximum capacity of adsorption (mg g^{-1}), Ce represents the equilibrium concentration of the solution (mg L^{-1}), K_L is a Langmuir constant associated with the affinity of the binding sites and energy of adsorption (L g^{-1}). q_{max} and K_L values are determined from the slope and intercept of C_e/q_e versus C_e graph. The determination coefficient R^2 of the Langmuir equation demonstrates that the adsorption onto JESP tracks the Langmuir model and this isotherm results of BB 41 adsorption on JESP for 298, 308 and 318 K gives at Fig 4.

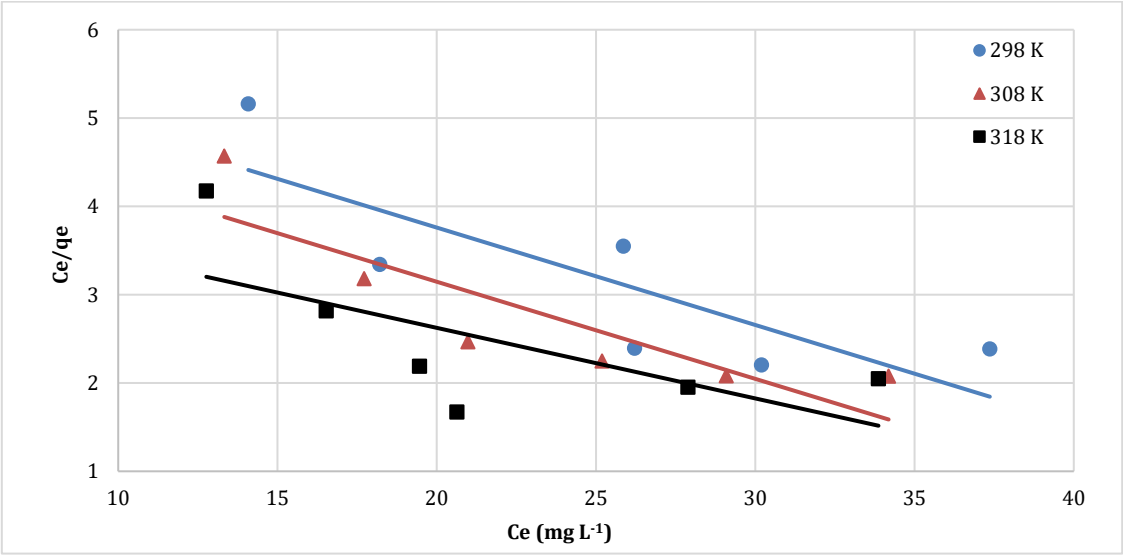

Fig 4. Langmuir isotherms of MB adsorption on JESP for different temperatures

Freundlich isotherm is the empirical one based upon adsorption on a heterogeneous surface and this isotherm equation is given Eq. (3):

$$lnq_e = lnK_F + \frac{1}{n} lnC_e \quad (3)$$

where K_F is a Freundlich constant linked to adsorption capacity (L g^{-1}), $1/n$ is an empirical parameter connected to adsorption intensity. The K_F and n values were determined from the intercept and slope of the plot between lnq_e against lnC_e, respectively. Freundlich isotherm results of BB 41 adsorption on JESP for 298, 308 and 318 K gives at Fig 5.

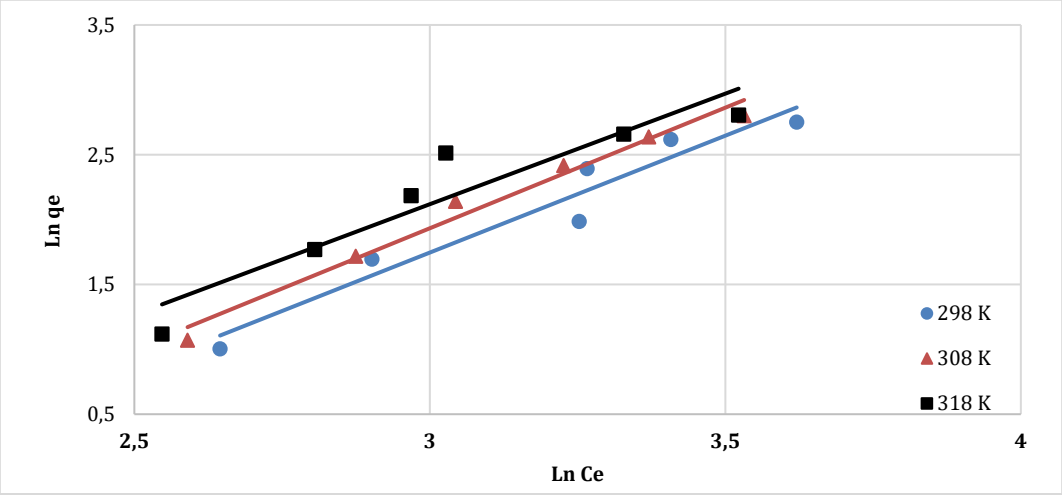

Fig 5. Freundlich isotherms of MB adsorption on JESP for different temperatures

Temkin isotherm represents solute molecule interaction from aqueous phase with heterogeneous solid surface. The isotherm is based upon the notion that heat of adsorption reduces on covering of solid surface. The Temkin equation used for the calculation of isotherm parameters is given Eq. (4):

$$q_e = \frac{RT}{b_T} lnK_T + \frac{RT}{b_T} lnC_e \qquad (4)$$

In the relationships binding energy and heat of adsorption, b_T and K_T are available and they can be determined from the slope and intercept of the *qe* line versus lnC_e respectively. Temkin isotherm results of BB 41 adsorption on JESP for 298, 308 and 318 K gives at Fig 6.

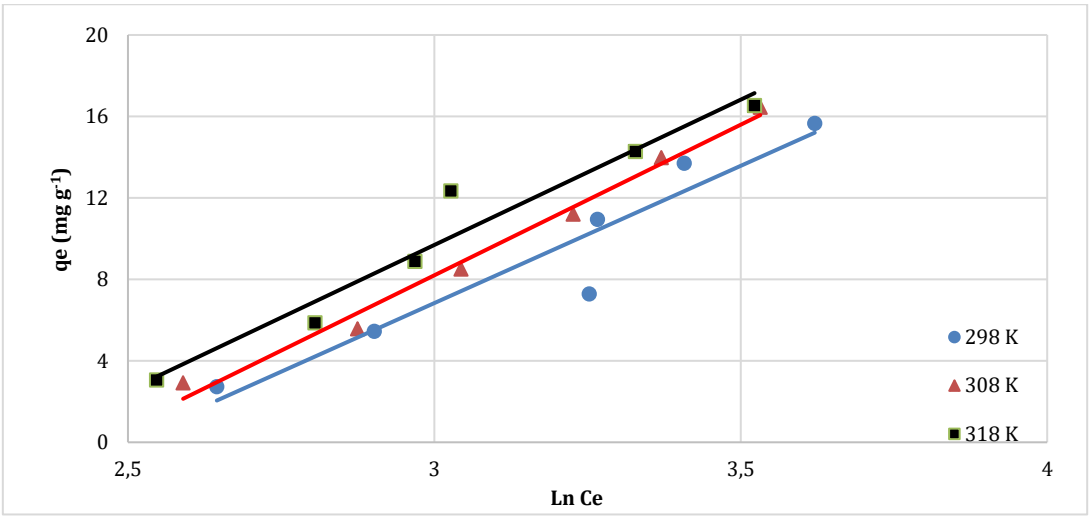

Fig 6. Temkin isotherms of MB adsorption on JESP for different temperatures

The calculated parameters of the Langmuir, Freundlich and Temkin isotherms for adsorption of BB 41 on the JESP were presented in Table 1. Concerning the coefficients determined, Freundlich model is more fitting than the Langmuir and Temkin model. It is noted that KF and n values elevate as the temperature rises, as well as, adsorption is approving at higher temperature. R^2 values of Freundlich model are higher than the other model values for JESP. The maximum adsorption value was improved by increasing the adsorption temperature; this value reached 22.5 mg g^{-1} at 318 K.

Table 1. Isotherm model parameters of BB 41 adsorption on JESP at different temperatures

Temp	Langmuir			Freundlich			Temkin		
(K)	K_L (L g^{-1})	q_m (mg g^{-1})	R^2	n	K_F (L g^{-1})	R^2	K_T (L g^{-1})	b_T (J mol^{-1})	R^2
298	0.0165	19.0661	0.6707	0.5494	0.0244	0.9409	0.0334	178.23	0.9067
308	0.0177	20.0912	0.7456	0.5645	0.0310	0.9722	0.0800	181.82	0.9492
318	0.0189	22.5156	0.7877	0.5813	0.0481	0.9986	0.1238	183.30	0.9891

3.3. Effect of Temperature and Adsorption Thermodynamics

The temperature effect on the BB 41 adsorption was investigated from the experiments executed with three different temperatures and results indicated that adsorption capacity decreases with rise in temperature. The trend was due to escaping of the adsorbed BB 41 ions on getting higher temperature or energy, indicating physical nature of the adsorption. The thermodynamic investigation is required to determine the importance of adsorption process. Thermodynamic parameters like free energy ($\Delta G°$), enthalpy ($\Delta H°$) and entropy ($\Delta S°$) are significant to detect heat alteration in the adsorption process for dye and JESP. These parameters are calculated by the equations given with Eqs. ((5)-(8)):

$$K_e = \frac{C_{Ads}}{c_e} \quad (5)$$

$$\Delta G° = -RTlnK_e \quad (6)$$

$$\Delta G° = \Delta H° - T\Delta S° \quad (7)$$

$$lnK_e = \frac{\Delta S°}{R} - \frac{\Delta H°}{RT} \quad (8)$$

where, K_e is the equilibrium constant, C_{Ads} represents the dye amount adsorbed mg on the JESP per litter of the solution at equilibrium, the adsorbent of adsorbent per unit litter of solution. Furthermore, *Ce* represents the equilibrium concentration of dye in the solution. *R* is the universal gas constant (8.314 J mol^{-1} K^{-1}) and *T* denotes the temperature. From the graphical representation according to Eq. (8), namely *lnKe* vs. *1/T*, a straight line is obtained in Fig 7. $\Delta H°$ and $\Delta S°$ parameters are analyzed from the slope and intercept of this figure and thermodynamic parameters were illustrated into Table 2.

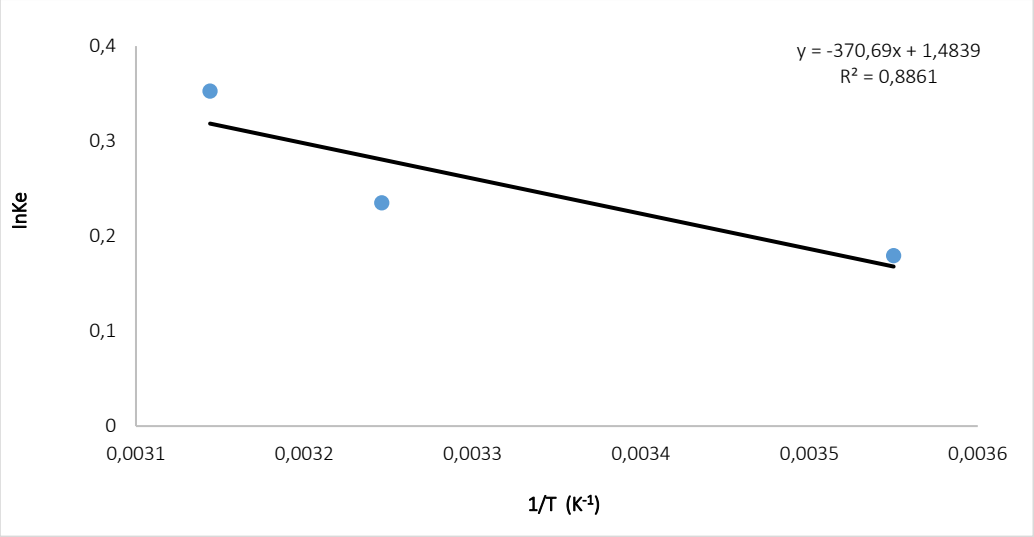

Fig 7. The plot of *ln Ke* vs. *1/T* for BB 41 dye onto JESP

Thermodynamic parameters of BB 41 adsorption onto JESP are calculated with using Eq. 5-8. The absolute values of free energy of BB 41 onto JESP obtained -447.57 J mol^{-1}, -582.20 J mol^{-1} and -902,90 J mol^{-1} for 298, 308 and 318 K temperatures respectively. Enthalpy and entropy values of BB 41 adsorption onto JESP determined 3081.91 kJ mol^{-1}and 12.33 kJ mol^{-1}K^{-1}respectively. The negative ΔG° values indicate that the adsorption is physisorption and ΔG° suggests the feasibility and the spontaneous nature of the adsorption. The absolute values of $\Delta G°$ are decreased as the temperature rises shown that this separation process is constructive at low temperatures. The positive value of $\Delta H°$ shows that the adsorption process is endothermic and the positive value of $\Delta S°$ establishes the enhanced entropy at the solid–solute interface and the affinity of the JESP for BB 41 [25].

Table 2. Thermodynamic parameters of BB 41 adsorption on JESP

Temp (K)	K_e	ΔG° (J mol^{-1})	ΔH° (J mol^{-1})	ΔS° (J mol^{-1} K^{-1})	R^2
298	0.1795	-447.57			
308	0.2350	-582.20	3081.91	12.33	0.8861
318	0.3526	-902.90			

3.4. Adsorption kinetics studies

Kinetic models have been applied for checking experimental results of BB 41 adsorption onto JESP. The adsorption kinetics is important to choose the best process conditions for the batch operating. The useful kinetic parameters for the estimation of adsorption rate, provides vital knowledge for designing and modeling adsorption processes [26]. In this study, BB 41 kinetics was calculated using three kinetic models (PFO, PSO and IPD). The most suitable model has been chosen depending on the linear regression coefficient of correlation coefficients R^2 values. These models have been investigated

according to experimental data at varied temperatures and initial BB 41 concentrations.

Lagergren's first order rate equation which is named pseudo first order (PFO) kinetic model is to separate the kinetics equation depending the concentration of solution and solid adsorption capacity. This kinetic model can be the first for the characterization of the liquid-solid adsorption systems depending on solid capacity. This kinetic model is applied for sorption in liquid-solid system. It stated that number of unoccupied adsorptive sites specifies the adsorption rate [18]. The PFO kinetic model is given with Eq. (9):

$$\ln(q_e - q_t) = lnq_e - k_1 t \quad (9)$$

where, the adsorption capacities in time t are q_m and q_t (mg g^{-1}) at equilibrium respectively. k_1 (min^{-1}) is the rate constant of PFO adsorption. To achieve constants of this model, the straight line plots of $ln(q_e\text{-}q_t)$ against t are drawn. The constants detected from the slope and intercept of the line plotted [18].

The pseudo second order (PSO) kinetic model which explained with the chemical bond formation between adsorptive site and solute molecule is the rate-limiting step based on adsorption capacity is given Eq. (10):

$$\frac{t}{q_t} = \frac{1}{k_2 q^2{}_e} + \frac{1}{q_e} t \quad (10)$$

where k_2 represents adsorption rate (g mg^{-1} min^{-1}), q_m denotes adsorbate amount that adsorbed onto adsorbent at equilibrium (mg g^{-1}) and q_t is dye amount adsorbed at any time (mg g^{-1}). The plot of t/q_t vs. t has a linear link. Values of k_2 and equilibrium adsorption capacity q_e were identified from the intercept and slope of the plot of t/q_t versus t according to Eq. 10.

The PSO kinetic model could not identify the diffusion mechanism and the kinetic results were subsequently analyzed with the intraparticle diffusion (IPD) model. Adsorption of the dyes was more gradual when IPD was the rate controlling step. This model assumes that the physical or chemical bond created between solute and solid at solid interspatial sites dominate the overall speed of the adsorption. This was done by testing the possibility of intraparticle diffusion as rate limiting step using IPD model, which can be represented by an Eq. (11):

$$q_t = k_{ipd} t^{0.5} + C \quad (11)$$

where k_{ipd} (mg g^{-1} $min^{-1/2}$) denotes the intra-particle diffusion rate constant and C represents close relation with the boundary thickness. A plot of qt against $t^{0.5}$ at different BB 41 concentrations gave two phases of linear plots.

PFO, PSO and IPD kinetic model parameters of BB 41 adsorption on JESP are given in Table 3. The experimental results indicated that R^2 coefficients are higher than 0.99 with experimental and analyzed qe values close to each other explained that this process fits the PSO kinetic model. Usually the kinetic adsorption data is better represented by a PSO model for most dye adsorption systems [25, 27].

Experimental and calculated qe values of 318 K are higher than 298K and 308K values. According to these tables, it is noted that qe values increases with increasing BB 41 concentration. When kinetic constants are compared, it is seen that constant values are closer to both temperatures and concentrations for PSO model. This result exhibited that BB 41 adsorption kinetics on JESP results from the PSO and suggested that the step of rate-limiting can be the dye chemisorption [18].

Table 3. PFO, PSO and IPD kinetic model parameters of BB 41 adsorption on JESP

	Temp (K)		25 mg L^{-1}	40 mg L^{-1}	55 mg L^{-1}	70 mg L^{-1}	85 mg L^{-1}	100 mg L^{-1}
	298	$q_{e\,exp}$(mg g^{-1})	2.727	5.447	7.287	10.941	13.701	15.749
	308	$q_{e\,exp}$(mg g^{-1})	2.935	5.582	8.507	11.235	13.952	16.291
	318	$q_{e\,exp}$(mg g^{-1})	3.063	5.870	8.890	12.355	14.352	16.570
PFO kinetic model	298	k_1(min^{-1})	0.0225	0.0209	0.0216	0.0214	0.0435	0.0442
		$q_{e\,cal}$ (mg g^{-1})	3.339	3.575	3.777	5.007	5.494	7.588
		R^2	0.7750	0.8817	0.8755	0.8243	0.8801	0.8356
	308	k_1(min^{-1})	0.0295	0.0170	0.0202	0.0271	0.0307	0.0333
		$q_{e\,cal}$ (mg g^{-1})	3.202	3.459	6.285	7.019	8.138	10.939
		R^2	0.8360	0.7561	0.9029	0.5821	0.8147	0.8528
	318	k_1(min^{-1})	0.0191	0.0182	0.0244	0.0343	0.0390	0.0435
		$q_{e\,cal}$ (mg g^{-1})	4.934	5.6416	7.333	9.088	11.447	13.415
		R^2	0.7617	0.8532	0.7298	0.8636	0.5349	0.8973
PSO kinetic model	298	k_2(min^{-1})	0.0267	0.0208	0.0173	0.0089	0.0076	0.0059
		$q_{e\,cal}$ (mg g^{-1})	3.038	5.967	7.530	11.600	14.335	16.473
		R^2	0.9913	0.9926	0.9994	0.9977	0.9988	0.9981
	308	k_2(min-1)	0.0171	0.0164	0.0096	0.0089	0.0042	0.0033
		$q_{e\,cal}$ (mg g^{-1})	3.224	6.337	9.208	10.194	15.432	17.423
		R^2	0.9934	0.9972	0.9927	0.9943	0.9993	0.9971
	318	k_2(min^{-1})	0.0158	0.0123	0.0096	0.0086	0.0042	0.0033
		$q_{e\,cal}$ (mg g^{-1})	3.517	6.337	10.194	12.516	15.432	17.423
		R^2	0.9912	0.9947	0.9925	0.9961	0.9969	0.9947
IPD kinetic model	298	k_{id}(mg g^{-1} $min^{-0.5}$)	0.1407	0.2577	0.3414	0.4245	0.4838	0.6059
		C (mg g^{-1})	0.924	2.347	4.564	5.794	7.967	8.283
		R^2	0.8718	0.8184	0.7435	0.8048	0.8088	0.8571
	308	k_{id}(mg g^{-1} $min^{-0.5}$)	0.1574	0.2115	0.4112	0.5019	0.5834	0.6117
		C (mg g^{-1})	1.019	2.646	2.714	4.511	5.833	8.529
		R^2	0.9214	0.8742	0.7995	0.9036	0.9262	0.9369
	318	k_{id}(mg g^{-1} $min^{-0.5}$)	0.1779	0.2596	0.4534	0.5142	0.6187	0.6402
		C (mg g^{-1})	1.029	2.991	3.739	5.500	6.533	8.844
		R^2	0.9645	0.9608	0.8153	0.9125	0.9839	0.9831

4. CONCLUSIONS

The BB 41 adsorption on the JESP was examined at various experimental conditions. By examining the data it was shown that BB 41 adsorption elevates with initial dye concentration, contact time and temperatures for JESP. Dye adsorption capacity onto JESP gets up from 2.73 to 15.66 mg g^{-1}, 2.92 to 16.45 mg $g^{-1}$and 3.06 to 17.53 mg g^{-1} for 298, 308 and 318 K respectively as the initial BB 41 concentration rises from 25 to 100 mg L^{-1}. The equilibrium adsorption time was determined at 120 min for BB 41 removal.

Isotherm studies demonstrate that the Freundlich model shows more suitable profile for BB 41 adsorption on JESP than the Langmuir and Temkin models. It is noted that the parameters of these three isotherms are raise as the temperature increments, and also indicated that adsorption is approving at higher temperature. R^2 values of the Freundlich model are higher than other two model values for BB41 removal with JESP. The JESP monolayer adsorption capacity (q_m) was 19.066, 20.091, 22.516 mg g^{-1} for temperature tested at 298K, 308K and 318K respectively. This result revealed the endothermic adsorption process nature.

Kinetic studies displayed that adsorption of BB 41 process follows the pseudo second order and suggested that the step of rate-limiting could be the dye chemisorption. R^2 coefficients are higher than 0.99 with experimental and evaluated q_e values very close to each other. Kinetic constants are closer to both temperatures and concentrations, and q_e values are increases with increasing concentration of BB 41. During the adsorption of BB 41 on JESP the diffusion

constant (k_{id}) and monolayer concentration (C) increases with the increase in temperature.

Thermodynamic parameters demonstrate that this adsorption occurred is endothermic. The negative $\Delta G°$ values indicate that the adsorption is physisorption and $\Delta G°$ suggests the feasibility and the spontaneous nature of the adsorption. The absolute values of ΔG° are decreased as the temperature rises shown that this separation process is constructive at low temperatures. The positive value of $\Delta H°$ shows that the adsorption process is endothermic and the positive value of $\Delta S°$ establishes the enhanced randomness at the solid–solute interface and the affinity of the JESP for BB 41. All of these results indicated that JESP could be used as an unconventional adsorbent for the cationic dyes removal in wastewater.

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