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Biosorption of remazol orange RR from aqueous solution: kinetic, equilibrium and thermodynamic studies

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ABSTRACT

Remazol Orange RR (RORR) is one of the most frequently used textile dye which causes environmental pollution. In the present study, parameters affecting the RORR biosorption with dead *Saccharomyces cerevisiae* yeast were investigated. The maximum %RORR removal was found to be 84.9% at 2 g/L biosorbent dosage, 200 mg/L initial dye concentration, pH 3.0, and 25°C. RORR biosorption with *S. cerevisiae* was expalined by pseudo-second-order kinetics model and Langmuir adsorption isotherm with correlation coefficient (R^2) of 0.99 and 0.87, respectively. The enthalpy change (ΔH), entropy change (ΔS) and activation energy (E_a) were determined as 35.9 kJ/mol, 88.1 kJ/mol K and 3.36 kJ/mol, respectively. In addition, Gibbs free energy change was calculated as –10.04, –8.03 and –8.33 kJ/mol for 298, 308 and 318 K, respectively. It is concluded that the biosorption of RORR by *S. cerevisiae* occurs mainly by physical adsorption through a spontaneous process. The high dye removal and biosorbent capacity indicated that *S. cerevisiae* is a promising biosorbent for dye removal.

Keywords: Remazol orange; Biosorption; *Saccharomyces cerevisiae*; Adsorption isotherms; Kinetics; Thermodynamics

1. Introduction

Synthetic dyes are one of the major causes of water pollution. The annual amount of dye production is about 7×10^5 tons, and 10%–15% is released to waterbodies mainly by textile industry [1,2]. Besides, enormous amount of water usage in textile industry results with large quantity of waste water [3,4]. It is reported that dyes exhibit mutagenic, toxic [5] and carcinogenic properties for water creatures [6] and hinder their biological activities [7] as well as disturb the aesthetic appearance [8].

Reactive dyes generally consist of azo-based chromophore and reactive groups by which they can form covalent bond with functional groups of fiber [9]. Due to its harmony with cotton in terms of dyeing properties, reactive dyes are used more widely compared with other types and owing to their high solubility in water reactive dyes can easily pass through conventional water treatment systems. This situation clearly demonstrates the need for alternative methods for the removal of textile dyes from water and decolourization of reactive dyes is a crucial topic for a better environment [10]. Several methods namely electrochemical oxidation, reverse osmosis, coagulation, flocculation, flotation, chemical oxidation, ozonation, precipitation, sedimentation, ultrafiltration and color irradiation or combined usage of abovementioned methods were reported to reduce the dye content of wastewater [11,12] but most of these methods suffer from being expensive [13], requiring complex application protocols [14] and high energy consumption [15]. Among these methods, adsorption is one of the most popular techniques in terms of its advantages such as showing high efficiency [16], involving simple operation conditions [17], and being reasonably priced [18] while selectivity and affinity of the adsorbents to dyes constitutes the major consideration of this technique.

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Biosorption is a type of adsorption technique in which dead or alive biological materials are employed as the adsorbents [19]. Use of dead biomass in biosorption applications provides additional advantages, such as no necessity of aliment, reusability and resistance to wastewater toxicity [20]. Reactive dye biosorption onto several dead or living biosorbents such as *Aspergillus versicolor* [21], banana peel powder [22], barberry powder [23], *Lentinus polychrous* Lev. [24], *Citrus sinensis* [25], *Corynebacterium glutamicum* [26], sunflower seed hull [27], *Metapenaeus monoceros* shells [28], *Pistacia vera* [29], *Trametes subectypus* [30], peanut shell [31], eggshell [32], *Nizamuddinia zanardinii* [33] and *Saccharomyces cerevisiae* [34] have been researched recently. To our knowledge, removal of Remazol Orange RR (RORR) that is a reactive and azo dye, with *S. cerevisiae* has not yet been investigated. In this respect, the present study introduces a novelty to the related literature. It is known that the surface of *S. cerevisiae* contains carboxyl, phosphonate and amine groups [35]. Among these, carboxyl and phosphonate groups do not show affinity to anionic dyes due to electrostatic repulsion while amine groups are expected to interact with anionic dyes due to their tendency to protonate [36]. In this study, biosorption of Remazol Orange RR (RORR) onto *S. cerevisiae* and optimization of the operating parameters such as pH, initial dye concentration and biosorbent dosage were invesitigated. Biosorption mechanisms were explained by applying kinetic and equilibrium isotherms to the obtained data. Thermodynamic parameters of the biosorption process namely free energy ($\Delta G°$), enthalpy ($\Delta H°$), entropy ($\Delta S°$) and activation energy (E_a) were calculated.

2. Materials and methods

2.1. Chemicals

All chemicals used in this study such as yeast extract, peptone, glucose, malt extract, potassium phosphate monobasic (KH_2PO_4), ammonium sulfate ($(NH_4)_2SO_4$), magnesium sulfate heptahydrate ($MgSO_4{\cdot}7H_2O$), calcium chloride ($CaCl_2$), NaOH and H_2SO_4 were of analytical grade and purchased from Sigma-Aldrich (Germany). Remazol Orange RR (RORR) was obtanined from Dyestar (Germany). *S. cerevisiae* as lyophilized stock culture (code number: 251 TP (3–2)) was provided from Refik Saydam Hıfzıhsıhha Presidency (Ankara, Turkey).

2.2. Instruments

Dye concentrations were determined by using UV/VIS Spectroscopy T 80+ (PG Instruments Ltd., UK). Sterilizer and incubator were used for yeast growth. Biosorpsion experiments were performed by using a shaking water bath.

2.3. Preparation of biosorbent and adsorbate

Agar slant, pre-activation and growth media were prepared to obtain *S. cerevisiae* yeast. The yeast was inoculated to agar slant which consists of 5 g yeast extract, 20 g peptone, 20 g glucose, 5 g malt extract and 20 g agar per liter of deionized water. Then, it was placed into the incubator at 30°C for 48 h. The yeast was collected from the agar surface and mixed with the pre-activation medium and incubated at 30°C for 48 h.The activated yeast was transferred to the growth medium which contains 50 g glucose, 12 g KH_2PO_4, 5 g $(NH_4)_2SO_4$, 1 g $MgSO_4{\cdot}7H_2O$, 0.5 g $CaCl_2$ and 5 g yeast extract per liter. Then, it was mixed in a magnetic stirrer at 30°C for 24 h. Finally, the solution was centrifuged, sterilized, filtered and dried. The biosorbent used in this study was sieved (>1.5 mm) for biosorption experiments.

2.4. Biosorption studies

Dye concentrations were quantifed at wavelength of 492 nm where the highest absorbance was detected. The pH values of dye solutions were adjusted by adding 0.1 M HCl or 0.1 M NaOH solution dropwise. After, the biosorbent was added into this solution and placed into shaking water bath at 140 rpm at certain temperature. The percentage of RORR removal and biosorbent capacity were calculated from Eqs. (1) and (2):

$$R(\%) = \frac{C_0 - C_f}{C_0} \times 100 \tag{1}$$

$$q_e = \frac{V\left(C_0 - C_f\right)}{m} \tag{2}$$

where C_0 and C_f represent the initial and final dye concentration, m is the quantity of biosorbent and q_e is the biosorbent capacity at equilibrium.

The effect of pH, initial dye concentration and biosorbent dosage on RORR biosorption was investigated in the range of pH 2.0–5.0, 50–400 mg/L of initial dye concentration and 0.5–2 g/L of biosorbent dosage.

2.5. Kinetic and equilibrium models

The biosorption equilibrium experiments were performed in the range of 25°C–40°C and 50–400 mg/L initial dye concentration. The experimental data were evaluated by using Langmuir, Freundlich and Temkin isotherms and their linear forms are given in Eqs. (3)–(5), respectively [37]:

$$\frac{C_e}{q_e} = \frac{1}{bq_s} + \frac{C_e}{q_s} \tag{3}$$

$$\log q_e = \log K_f + \frac{1}{n}\log C_e \tag{4}$$

$$q_e = B\ln A_T + B\ln C_e \tag{5}$$

where C_e is the concentration of adsorbate at equilibrium, b is the Langmuir isotherm constant, q_s is the maximum amount of substance adsorbed per unit mass of adsorbent, K_f is the Freundlich isotherm constant, n is a constant associated with adsorption intensity, B is the constant about the heat sorption and, A_T is the equilibrium binding constant of Temkin isotherm [38–42].

RORR biosorption onto *S. cerevisiae* as a function of time was evaluated by pseudo-first-order and pseudo-second-order kinetic models as well as intraparticle diffusion and liquid film diffusion models which were formulized with Eqs. (6)–(9), respectively [43]:

$$\log\left(q_e - q\right) = \log\left(q_e\right) - \frac{k_1}{2{,}303}t \tag{6}$$

$$\frac{t}{q} = \frac{1}{k_2 q_e^2} + \frac{1}{q_e}t \tag{7}$$

$$q_t = k_i t^{\frac{1}{2}} + c \tag{8}$$

$$\ln\left(1 - \frac{q_t}{q_e}\right) = -R^l t \tag{9}$$

where k_1, k_2, k_i and R^l represent the rate constant of pseudo-first-order, pseudo-second-order, Weber–Morris diffusion constant, and liquid film diffusion constant, respectively [44–46].

2.6. Adsorption thermodynamics

The thermodynamic measurements were conducted at 25°C, 35°C and 45°C to determine $\Delta G°$, $\Delta H°$, $\Delta S°$ and E_a values of the biosorption process. Eqs. (10)–(12) were used for this purpose.

$$\Delta G = \Delta H - T\Delta S \tag{10}$$

$$\ln b = \frac{-\Delta H}{RT} + \frac{\Delta S}{R} \tag{11}$$

$$\ln k_2 = \ln k_0 - \frac{E_a}{RT} \tag{12}$$

where R is the universal gas constant (8.314 J/mol/K), b is Langmuir isotherm constant, k_2 and k_0 are pseudo-second-order kinetic model rate constants (g/mg min), respectively [47].

3. Results and discussion

3.1. Effect of contact time

Equilibrium duration of the biosorption was determined at constant parameters of 25°C, 100 mg/L dye concentration, 2 g/L biosorbent dosage, and 140 rpm shaking rate. Fig. 1 shows the change in RORR concentration as a function of time. It is observed from Fig. 1 that RORR concentration reduced sharply from 90 to 70 mg/L in 50 min, and became almost stable in 150 min. So, the experiment duration was determined as 150 min.

3.2. Effect of pH on biosorption

Favorable removal of reactive dyes at acid pH values has been reported in the literature [28]. Based on this information, the effect of dye solution pH on dye removal and biosorbent capacity were investigated between pH 2.0 and 5.0 while other parameters were kept constant; 50 mg/L initial dye concentration, 1 g/L biosorbent loading, 25°C and 140 rpm shaking rate. Fig. 2 presents RORR removal and biosorbent capacity at different pH values. It was observed that RORR concentration increased from 4.58 to 42.8 mg/L with the increasing pH from 2.0 to 5.0. The highest and

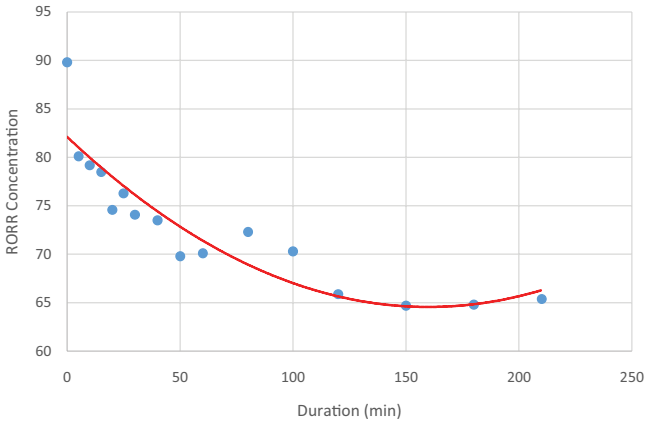

Fig. 1. Effect of contact time on RORR concentration.

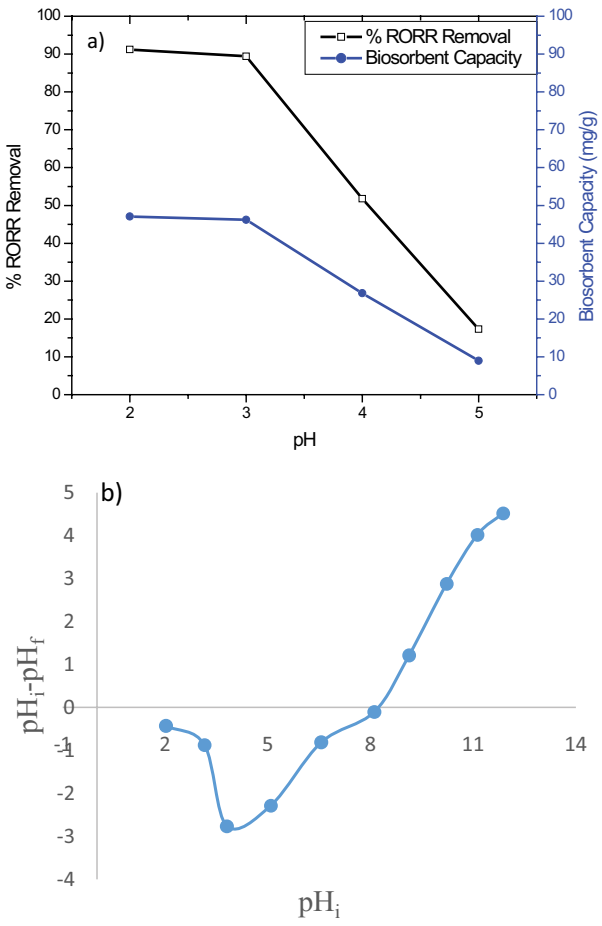

Fig. 2. (a) RORR removal and biosorbent capacity at varying pH and (b) zero charge point of the biosorbent.

lowest RORR removal and biosorbent capacity values were obtained at pH 2.0 as 91.2% and 47.1 mg/g and at pH 5.0 as 17.3% and 8.93 mg/g, respectively. High RORR removal and biosorbent capacity at acidic pH values could be attributed to the electrostatic interaction between dye anions and positively charged cell surface [48–50]. This interpretation was also supported by the plot shown in Fig. 2b. The zero charge point (pH_{pzc}) of the *S. cerevisiae* biosorbent was determined to be 8.13 and it is known that the surface of biosorbent is positively charged at pH values below pH_{pzc} value [51]. It is clear from Fig. 2 that the percentage removal and biosorbent capacity at pH 2.0 are very close to the values obtained at pH 3.0. From this point of view, dye solution of pH 2.0 was considered to be more disadvantageous in terms of ease of application and economical feasibility. Therefore, optimum pH value was determined to be 3.0 for RORR biosorption on *S. cerevisiae*.

3.3. Effect of initial dye concentration on biosorption

The experiments were conducted in the range of 50–400 mg/L initial dye concentration while the other parameters were kept constant at 1 g/L biosorbent concentration, pH 3.0, 25°C and 140 rpm in order to observe the effect of initial dye concentration only. From Fig. 3, it can be clearly seen that percentage removal of RORR decreased from 80.3% to 28.1% and biosorption capacity increased from 54.7 to 100.7 mg/g with the increasing initial dye concentration from 50 to 400 mg/L. The highest RORR removal and biosorbent capacity values were found as 80.3% and 100.7 mg/g. The decreasing RORR removal with the increasing initial dye concentration can be explained with the saturation of the sorption sites on *S. cerevisiae* [52,53].

3.4. Effect of biosorbent dosage on biosorption

The experiments were conducted in the range of 0.5–2 g/L biosorbent dosage while the other parameters were kept constant at 200 mg/L initial dye concentration, pH 3.0 and 25°C. The effect of biosorbent dosage on the biosorption capacity and percentage removal is shown in Fig. 4 and an increament was observed in the percentage removal values from 22.5% to 84.9% with the increasing biosorbent dosage. The correlation between these two parameters was attributed to the increased number of the existing adsorption sites [54]. When the biosorbent dosage was increased from 0.5 to 1 g/L, the biosorbent capacity increased, while it was observed that the capacity values for dosages greater than 1 g/L decreased sharply. The decrease in biosorption capacity with the increasing biosorbent concentration over 1–2 g/L could be explained by the fact that increasing amount of adsorbent may increase the number of adsorption sites [13] and becomes more than required for the corresponding dye concentration while these sites remain unsaturated during adsorption [55] and the effective surface area decreases due to the formation of biosorbent aggregates at high biomass concentrations [56,57].

3.5. Kinetic studies

The pseudo-first-order kinetic model, pseudo-second-order kinetic model, intra-particle diffusion model and liquid film diffusion model graphs at constant parameters of 100 mg/L initial dye concentration, pH 3.0, 1 g/L biosorbent concentration and 35°C are shown in Fig. 5. Kinetic and diffusion model parameters are given in Table 1.

In Table 1, it can be seen that the R^2 values for the pseudo-first and second-order kinetic models are 0.85 and 0.99, respectively. According to these values, it was believed that the pseudo-second-order kinetic model was more suitable for the biosorption of RORR with *S. cerevisiae* due to the high correlation coefficient. The main assumption of the pseudo-second-order kinetic model is that the binding rate of dye ions on the biosorbent is proportional to the square of number of free adsorption sites [58]. The R^2 values of employed intra-particle diffusion model and the liquid film diffusion model for determining the diffusion mechanism of the RORR biosorption were found to be 0.91 and 0.85, respectively. From Table 1, it was concluded that the intra-particle

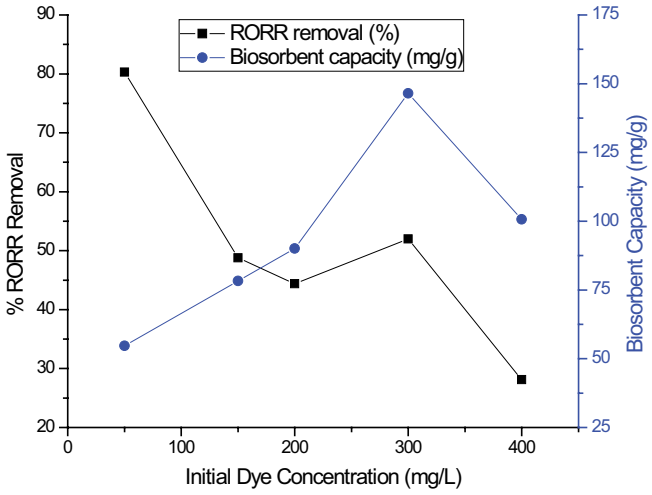

Fig. 3. RORR removal and biosorbent capacity for varying initial dye concentration.

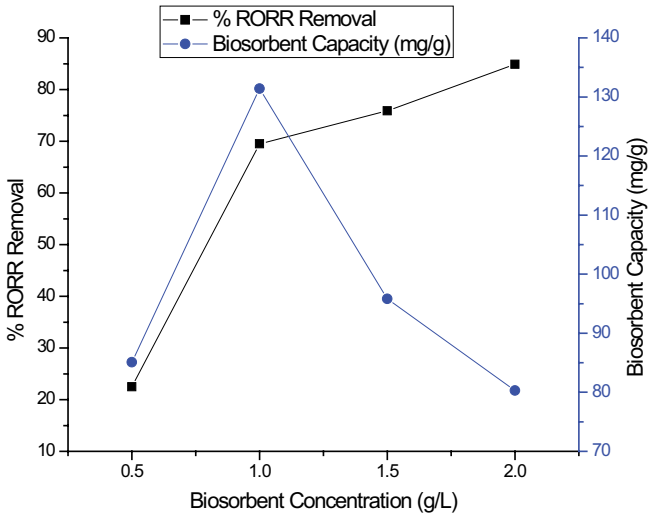

Fig. 4. RORR removal and biosorbent capacity for different biosorbent concentration.

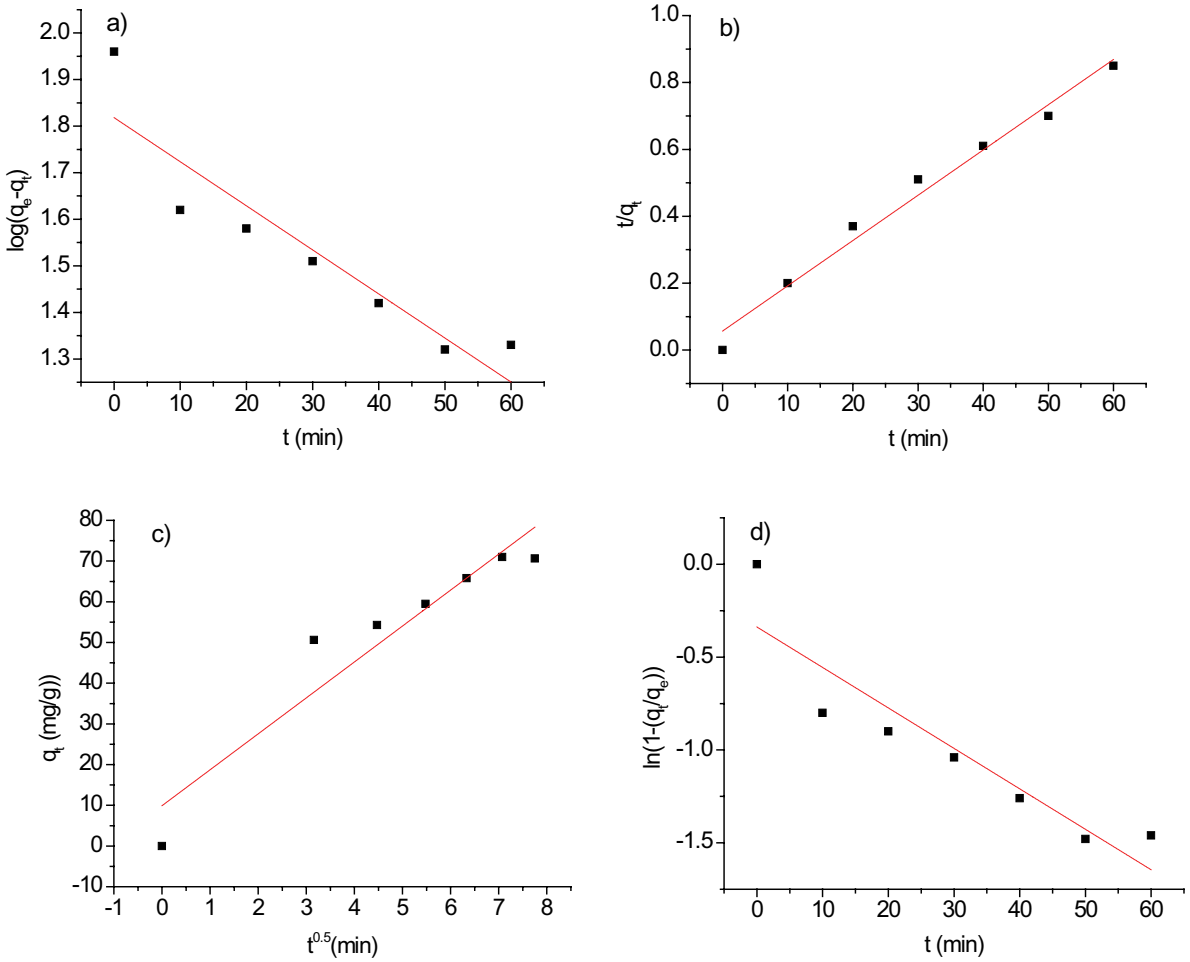

Fig. 5. Kinetic and diffusion models for the biosorption: (a) pseudo-first-order kinetic model, (b) pseudo-second-order kinetic model, (c) Weber–Morris intraparticle diffusion model, and (d) liquid film diffusion model.

Table 1
Kinetic and diffusion models parameters at 35°C

Model	Parameter (unit)	Experimental value	Model value
Pseudo-first-order	q_1 (mg/g)	70.62	52.92
	k_1 (min^{-1})	–	0.0022
	R^2	–	0.85
Pseudo-second-order	q_2 (mg/g)	70.62	68.93
	k_2 (g/mg/min)	–	0.0036
	R^2	–	0.99
Weber–Morris	k_p ($mg/g/min^{1/2}$)	–	8.84
	R^2	–	0.91
Liquid film diffusion	R^1 (min^{-1})	0.022	0.022
	R^2	–	0.85

diffusion model constitutes the major part of this biosorption process. According to the intra-particle diffusion model, adsorbate binding on the adsorbent varies in proportion to the square root of the contact time. The graph of q_t–$t^{1/2}$ is expected to cross through origin when the rate-limiting step of biosorption process is intra-particle diffusion model. But, often this is not the case and the adsorption kinetics is controlled by both liquid film diffusion and intra-particle diffusion models [59]. It can be seen from Fig. 5c that q_t vs. $t^{1/2}$ plot does not cross through origin. Hence, it could be concluded

that the diffusion process cannot be explained only by the intra-particle diffusion model and liquid film diffusion also plays a part in this process.

3.6. Equilibrium studies

The Langmuir, Freundlich and Temkin isotherms obtained for RORR biosorption at constant parameters of 35°C, pH 3.0 and 1 g/L biosorbent concentration are shown in Fig. 6 and the parameters of the model values for these isotherms are given in Table 2. From Table 2, it is seen that the highest compatibility was obtained with the Langmuir model (0.87). R^2 value of the biosorption was found to be 0.99 at 50°C indicating that R^2 values increased with the increasing temperature for the RORR biosorption. Therefore, it was concluded that RORR biosorption onto *S. cerevisiae* is better explained by the Langmuir model. The Langmuir model indicates the constant adsorption energy and no interaction between the adsorbate and adsorbent molecules [60]. In addition, occurrence of single layer adsorption and presence of limited number of bonding sites are proposed by this model [61]. It is stated in the literature that the processes described by the pseudo-second-order kinetic model are compatible with the Langmuir model [61]. Herein, RORR biosorption is consistent with the literature in terms of good fitted data both with pseudo-second-order kinetic model and Langmuir isotherm.

3.7. Thermodynamic studies

Thermodynamic parameters of the RORR biosorption, such as $\Delta G°$, $\Delta S°$, $\Delta H°$ and E_a were determined by Eqs. (13) and (14). The thermodynamic parameters, which are summarized in Table 3, calculated with the aid of Figs. 7 and 8. As can be seen from Table 3, $\Delta H°$ and $\Delta S°$ values for the RORR biosorption were found to be 35.9 kJ/mol and 88.1 J/mol K, respectively, while the $\Delta G°$ values for 298, 308 and 318 K were determined as –10.04, –8.03 and –8.33 kJ/mol, respectively. A negative $\Delta G°$ value indicates that the RORR biosorption was a spontaneous process and the biosorption was suitable thermodynamically [62]. The positive $\Delta H°$ of RORR biosorption (35.9 kJ/mol) indicates that the biosorption was endothermic [63]. In addition, according to the literature, $\Delta H°$ values in the range of 4–40 kJ/mol display the physical adsorption [64]. In this line, it is considered that the RORR biosorption onto *S. cerevisiae* process could be explained by the physical adsorption. The positive $\Delta S°$ value for RORR biosorption shows that there is an affinity between the

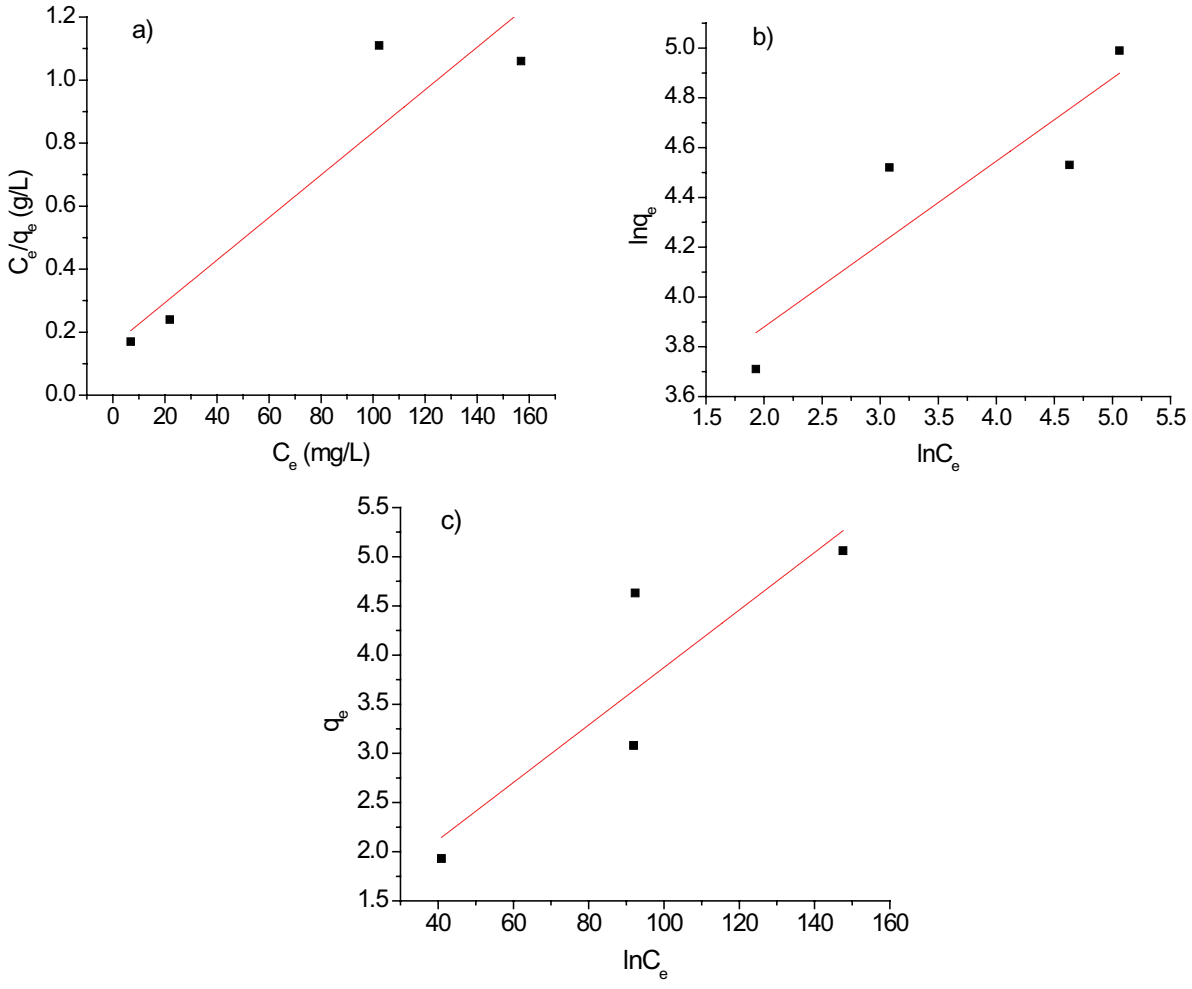

Fig. 6. Adsorption isotherms of RORR biosorption: (a) Langmuir, (b) Freundlich, and (c) Temkin.

Table 2
Model parameters of the Langmuir, Freundlich and Temkin isotherms

Model	Parameter (unit)	Experimental value	Model value
Langmuir	q_m (mg/g)	40.92	34.06
	K_L (L/mg)	–	0.017
	R^2	–	0.87
Freundlich	q_m	40.92	47.31
	K_F (L/mg)	–	92.59
	N	–	2.99
	R^2	–	0.81
Temkin	q_m	40.92	46.49
	A_t	–	–0.20
	B	–	–5.41
	R^2	–	0.78

Table 3
Thermodynamics parameters of the RORR biosorption onto *S. cerevisiae*

Temperature (K)	ΔG (kJ/mol)	ΔH (kJ/mol)	ΔS (J/mol/K)	E_a (kJ/mol)
298	–10.04			
308	–8.03	35.9	88.1	3.36
318	–8.33			

adsorbent and adsorbate, and that the solid/solution interface has increased randomness during the adsorption [65].

The correlation coefficient was found to be 0.998 in Fig. 7 and E_a of RORR biosorption was determined as 3.36 kJ/mol. It was concluded that RORR biosorption onto *S. cerevisiae* was an endothermic process and the biosorption can be explained by the physical adsorption owing to the positive activation energy and low E_a value [66–68].

Table 4 summarizes the biosorbents used for the removal of various textile dyes in the literature. As seen from Table 4,

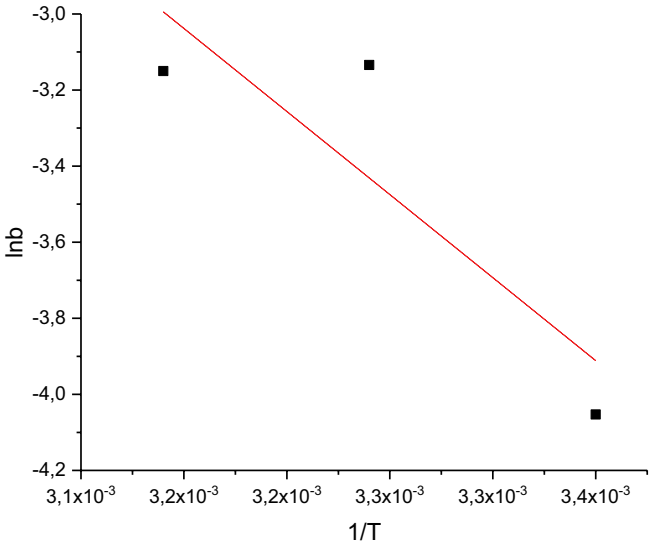

Fig. 7. Activation energy of the RORR biosorption onto *S. cerevisiae*.

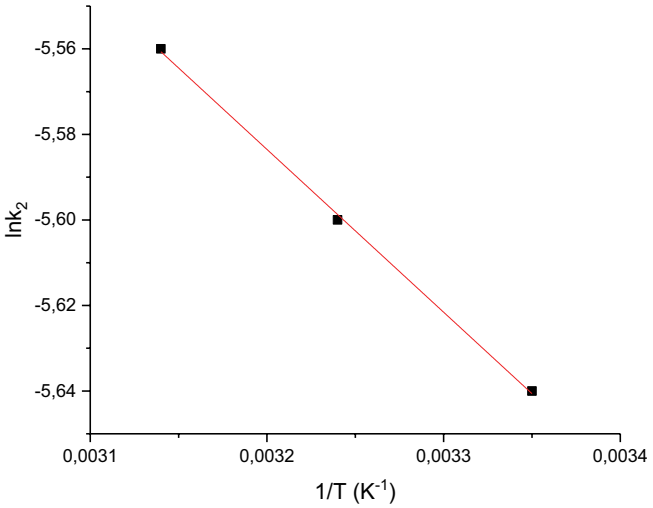

Fig. 8. Van't Hoff plot of RORR biosorption onto *S. cerevisiae*.

Table 4
Comparison of literature about removal of textile dye

Biosorbent	Dye	% Removal	Biosorbent capacity (mg/g)	Reference
S. cerevisiae-MnO_2 Composite	Malachite Green	ca. 90	86.7	[69]
Oyster Shells	Acid Green 25	95.4	33.3	[70]
S. cerevisiae	Basic Blue 41	94.0	23.5	[71]
Nostoc linckia	Reactive Red 198	94.0	93.5	[72]
Orange peels	Reactive Red	89.4	n.a.	[73]
Chitosan–gelatin–graphene composite	Orange II	84.3	72.2	[74]
Nitrogen-doped nanoporous carbon	Methyl Orange	98.5	222.2	[75]
ZIF-8	Acid Orange 7	80.0	80.4	[76]
S. cerevisiae	RORR	84.9	80.3	In this study

S. cerevisiae reported in this study has lower percentage removal value than those of other studies, but the biosorption capacity was higher than or close to these biosorbents. This low percentage removal value could be attributed to the use of less amount of biosorbents compared with other studies. These results show that *S. cerevisiae* is a promising biosorbent for the removal of reactive dyes.

4. Conclusion

In this study, the effects of contact time, pH, initial dye concentration and biosorbent dosage on RORR removal and biosorption capacity were investigated. Langmuir equilibrium model was found to be more suitable for RORR biosorption compared with Freundlich and Temkin isotherms. The biosorption obeys the pseudo-second-order kinetic model with R^2 of 0.99. The biosorption heat of this process is calculated as 35.9 kJ/mol and $\Delta G°$ values at 25°C, 35°C and 45°C are found to be –10.04, –8.03 and –8.33 kJ/mol, respectively. $\Delta S°$ and E_a is determined as 88.1 J/mol K and 3.36 kJ/mol. In this direction, the biosorption process take place through physical adsorption, and it is a spontaneous process.

References

[1] M.S. Mahmoud, Decolorization of certain reactive dye from aqueous solution using Baker's Yeast (*Saccharomyces cerevisiae*) strain, HBRC J., 12 (2016) 88–98.

[2] D. Pathania, A. Sharma, Z.-M. Siddiqi, Removal of congo red dye from aqueous system using *Phoenix dactylifera* seeds, J. Mol. Liq., 219 (2016) 359–367.

[3] M. Asif Tahir, H.N. Bhatti, M. Iqbal, Solar Red and Brittle Blue direct dyes adsorption onto *Eucalyptus angophoroides* bark: equilibrium, kinetics and thermodynamic studies, J. Environ. Chem. Eng., 4 (2016) 2431–2439.

[4] H.D. Bouras, A.R. Yeddou, N. Bouras, D. Hellel, M.D. Holtz, N. Sabaou, A. Chergui, B. Nadjemi, Biosorption of Congo red dye by *Aspergillus carbonarius* M333 and *Penicillium glabrum* Pg1: kinetics, equilibrium and thermodynamic studies, J. Taiwan Inst. Chem. Eng., 80 (2017) 915–923.

[5] A. Regti, H.B. El Ayouchia, M.R. Laamari, S.E. Stiriba, H. Anane, M. El Haddad, Experimental and theoretical study using DFT method for the competitive adsorption of two cationic dyes from wastewaters, Appl. Surf. Sci., 390 (2016) 311–319.

[6] M. El Haddad, R. Slimani, R. Mamouni, M.R. Laamari, S. Rafqah, S. Lazar, Evaluation of potential capability of calcined bones on the biosorption removal efficiency of safranin as cationic dye from aqueous solutions, J. Taiwan Inst. Chem. Eng., 44 (2013) 13–18.

[7] M. Naushad, Surfactant assisted nano-composite cation exchanger: development, characterization and applications for the removal of toxic Pb^{2+} from aqueous medium, Chem. Eng. J., 235 (2014) 100–108.

[8] S.T. Akar, A.S. Özcan, T. Akar, A. Özcan, Z. Kaynak, Biosorption of a reactive textile dye from aqueous solutions utilizing an agro-waste, Desalination, 249 (2009) 757–761.

[9] O. Duman, S. Tunç, B.K. Bozoğlan, T.G. Polat, Removal of triphenylmethane and reactive azo dyes from aqueous solution by magnetic carbon nanotube-κ-carrageenan-Fe_3O_4 nanocomposite, J. Alloys Compd., 687 (2016) 370–383.

[10] K.B. Fontana, E.S. Chaves, J.D.S. Sanchez, E.R.L.R. Watanabe, J.M.T.A. Pietrobelli, G.G. Lenzi, Textile dye removal from aqueous solutions by malt bagasse: isotherm, kinetic and thermodynamic studies, Ecotoxicol. Environ. Saf., 124 (2016) 329–336.

[11] M. El Haddad, A. Regti, M.R. Laamari, R. Slimani, R. Mamouni, S. El Antri, S. Lazar, Calcined mussel shells as a new and eco-friendly biosorbent to remove textile dyes from aqueous solutions, J. Taiwan Inst. Chem. Eng., 45 (2014) 533–540.

[12] M. El Haddad, A. Regti, R. Slimani, S. Lazar, Assessment of the biosorption kinetic and thermodynamic for the removal of safranin dye from aqueous solutions using calcined mussel shells, Ind. Eng. Chem. Res., 20 (2014) 717–724.

[13] A. Regti, M.R. Laamari, S.-E. Stiriba, M. El Haddad, Use of response factorial design for process optimization of basic dye adsorption onto activated carbon derived from Persea species, Microchem. J., 130 (2017) 129–136.

[14] S. Banerjee, M.C. Chattopadhyaya, Adsorption characteristics for the removal of a toxic dye, tartrazine from aqueous solutions by a low cost agricultural by-product, Arabian J. Chem., 10 (2017) S1629–S1638.

[15] T.L. Silva, A. Ronix, O. Pezoti, L.S. Souza, P.K.T. Leandro, K.C. Bedin, K.K. Beltrame, A.L. Cazetta, V.C. Almeida, Mesoporous activated carbon from industrial laundry sewage sludge: adsorption studies of reactive dye Remazol Brilliant Blue R, Chem. Eng. J., 303 (2016) 467–476.

[16] S. Karmakar, D. Roy, C. Janiak, S. De, Insights into multicomponent adsorption of reactive dyes on MIL-101-Cr metal organic framework: experimental and modeling approach, Sep. Purif. Technol., 215 (2019) 259–275.

[17] A.A. Alqadami, M. Naushad, Z.A. Alothman and T. Ahamad, Adsorptive performance of MOF nanocomposite for methylene blue and malachite green dyes: kinetics, isotherm and mechanism, J. Environ. Manage., 223 (2018) 29–36.

[18] A.B. Albadarin, M.N. Collins, Mu. Naushad, S. Shirazian, G. Walker, C. Mangwandi, Activated lignin-chitosan extruded blends for efficient adsorption of methylene blue, Chem. Eng. J., 307 (2017) 264–272.

[19] A. Asfaram, M. Ghaedi, G.R. Ghezelbash, E.A. Dil, I. Tyagi, S. Agarwal, V.K. Gupta, Biosorption of malachite green by novel biosorbent *Yarrowia lipolytica isf7*: application of response surface methodology, J. Mol. Liq., 214 (2016) 249–258.

[20] S. Santaeufemia, E. Torres, J. Abalde, Biosorption of ibuprofen from aqueous solution using living and dead biomass of the microalga *Phaeodactylum tricornutum*, J. Appl. Phycol., 30 (2018) 471–482.

[21] J. Huang, D. Liu, J. Lu, H. Wang, X. Wei, J. Liu, Biosorption of reactive black 5 by modified *Aspergillus versicolor* biomass: kinetics, capacity and mechanism studies, Colloids Surf., A, 492 (2016) 242–248.

[22] V.S. Munagapati, V. Yarramuthi, Y. Kim, K.M. Lee, D.-S. Kim, Removal of anionic dyes (Reactive Black 5 and Congo Red) from aqueous solutions using Banana Peel Powder as an adsorbent, Ecotoxicol. Environ. Saf., 148 (2018) 601–607.

[23] M. Kamranifar, M. Khodadadi, V. Samiei, B. Dehdashti, M. Noori Sepehr, L. Rafati, N. Nasseh, Comparison the removal of reactive red 195 dye using powder and ash of barberry stem as a low cost adsorbent from aqueous solutions: isotherm and kinetic study, J. Mol. Liq., 255 (2018) 572–577.

[24] R. Wangpradit and P. Chitprasert, Chitosan-coated *Lentinus polychrous* Lév.: Integrated biosorption and biodegradation systems for decolorization of anionic reactive dyes, Int. Biodeterior. Biodegrad., 93 (2014) 168–176.

[25] M. Asgher, H.N. Bhatti, Mechanistic and kinetic evaluation of biosorption of reactive azo dyes by free, immobilized and chemically treated *Citrus sinensis* waste biomass, Ecol. Eng., 36 (2010) 1660–1665.

[26] J. Mao, S.W. Won, K. Vijayaraghavan, Y.-S. Yun, Surface modification of *Corynebacterium glutamicum* for enhanced Reactive Red 4 biosorption, Bioresour. Technol., 100 (2009) 1463–1466.

[27] G.B. Oguntimein, Biosorption of dye from textile wastewater effluent onto alkali treated dried sunflower seed hull and design of a batch adsorber, J. Environ. Chem. Eng., 3 (2015) 2647–2661.

[28] E. Thiyagarajan, P. Saravanan, S. Shiyamala devi, P. Saranya, N. Nagendra Gandhi, S. Renganathan, Biosorption of reactive red 2 using positively charged *Metapenaeus monoceros* shells, J. Saudi Chem. Soc., 21 (2017) S1–S6.

[29] F. Deniz, R.A. Kepekci, Dye biosorption onto pistachio by-product: a green environmental engineering approach, J. Mol. Liq., 219 (2016) 194–200.

[30] S.A. Medina-Moreno, R. Pérez-Cadena, A. Jiménez-González, A. Téllez-Jurado, C.A. Lucho-Constantino, Modeling wastewater biodecolorization with reactive blue 4 in fixed bed bioreactor by *Trametes subectypus*: biokinetic, biosorption and transport, Bioresour. Technol., 123 (2012) 452–462.
[31] Z.A. Al-Othman, R. Ali, Mu. Naushad, Hexavalent chromium removal from aqueous medium by activated carbon prepared from peanut shell: adsorption kinetics, equilibrium and thermodynamic studies, Chem. Eng. J., 184 (2012) 238–247.
[32] R. Slimani, I. El Ouahabi, F. Abidi, M. El Haddad, A. Regti, M.R. Laamari, S.E. Antri, S. Lazar, Calcined eggshells as a new biosorbent to remove basic dye from aqueous solutions: thermodynamics, kinetics, isotherms and error analysis, J. Taiwan Inst. Chem. Eng., 45 (2014) 1578–1587.
[33] E. Daneshvar, A. Vazirzadeh, A. Niazi, M. Kousha, Mu. Naushad, A. Bhatnagar, Desorption of Methylene blue dye from brown macroalga: effects of operating parameters, isotherm study and kinetic modeling, J. Cleaner Prod., 152 (2017) 443–453.
[34] B. Ramavandi, A.A. Najafpoor, H. Alidadi, Z. Bonyadi, Alizarin red-S removal from aqueous solutions using *Saccharomyces cerevisiae*: kinetic and equilibrium study, Desal. Wat. Treat., 144 (2019) 286–291.
[35] F. Erdem, A. Tosun, M. Ergun, *Saccharomyces cerevisiae* ile Remazol Sari (RR) boyasinin kesikli sistemde biyosorpsiyonu, J. Faculty Eng. Archit. Gazi Univ., 31 (2016) 971–978.
[36] J.Y. Farah, N. Sh. El-gendy, Performance, kinetics and equilibrium in biosorption of anionic dye Acid Red 14 by the waste biomass of *Saccharomyces cerevisiae* as a low-cost biosorbent, Turk. J. Eng. Environ. Sci., 37 (2013) 146–161.
[37] M. El Haddad, R. Mamouni, N. Saffaj, S. Lazar, Evaluation of Performance of Animal Bone Meal as a new low cost adsorbent for the removal of a cationic dye Rhodamine B from aqueous solutions, J. Saudi Chem. Soc., 20 (2016) S53–S59.
[38] T.W. Weber, R.K. Chakravorti, Pore and solid diffusion models for fixed-bed adsorbers, AIChE J., 20 (1974) 228–238.
[39] A. Dada, A. Olalekan, A. Olatunya, O. Dada, Langmuir, Freundlich, Temkin and Dubinin–Radushkevich isotherms studies of equilibrium sorption of Zn^{2+} unto phosphoric acid modified rice husk, IOSR J. Appl. Chem., 3 (2012) 38–45.
[40] E. Voudrias, K. Fytianos, E. Bozani, Sorption–desorption isotherms of dyes from aqueous solutions and wastewaters with different sorbent materials, Global Nest Int. J., 4 (2002) 75–83.
[41] C. Aharoni, M. Ungarish, Kinetics of activated chemisorption. Part 2.—theoretical models, J. Chem. Soc., Faraday Trans. 1 F, 73 (1977) 456–464.
[42] M. Temkin, V. Pyzhev, Kinetics of ammonia synthesis on promoted iron catalysts, Acta Phys. Chim. URSS, 12 (1940) 327.
[43] Y. Achour, M. Khouili, H. Abderrafia, S. Melliani, M.R. Laamari, M. El Haddad, DFT investigations and experimental studies for competitive and adsorptive removal of two cationic dyes onto an eco-friendly material from aqueous media, Int. J. Environ. Res., 12 (2018) 789–802.
[44] Z. Aksu, S. Tezer, Biosorption of reactive dyes on the green alga *Chlorella vulgaris*, Process Biochem., 40 (2005) 1347–1361.
[45] H. Qiu, L. Lv, B.-c. Pan, Q.-j. Zhang, W.-m. Zhang, Q.-x. Zhang, Critical review in adsorption kinetic models, J. Zhejiang Univ. Sci. A, 10 (2009) 716–724.
[46] M.A. Ahmad, N.K. Rahman, Equilibrium, kinetics and thermodynamic of Remazol Brilliant Orange 3R dye adsorption on coffee husk-based activated carbon, Chem. Eng. J., 170 (2011) 154–161.
[47] Y. Wang, Y. Mu, Q.-B. Zhao, H.-Q. Yu, Isotherms, kinetics and thermodynamics of dye biosorption by anaerobic sludge, Sep. Purif. Technol., 50 (2006) 1–7.
[48] Y. Hamzeh, A. Ashori, E. Azadeh, A. Abdulkhani, Removal of Acid Orange 7 and Remazol Black 5 reactive dyes from aqueous solutions using a novel biosorbent, Mater. Sci. Eng., C, 32 (2012) 1394–1400.
[49] H. Korhan, H.N. Halipçi, M. Kertmen, M. Diğrak, *Saccharomyces cerevisiae* biyokütlesi ile remazol navy blue boyar maddesinin biyosorpsiyonu, KSU J. Nat. Sci., 15 (2012) 23–29.
[50] M. El Haddad, R. Slimani, R. Mamouni, S. ElAntri, S. Lazar, Removal of two textile dyes from aqueous solutions onto calcined bones, J. Assoc. Arab Univ. Basic Appl., 14 (2013) 51–59.
[51] A. Aichour, H. Zaghouane-Boudiaf, Highly brilliant green removal from wastewater by mesoporous adsorbents: kinetics, thermodynamics and equilibrium isotherm studies, Microchem. J., 146 (2019) 1255–1262.
[52] K. Kumari, T.E. Abraham, Biosorption of anionic textile dyes by nonviable biomass of fungi and yeast, Bioresour. Technol., 98 (2007) 1704–1710.
[53] J.Y. Farah, N.S. El-Gendy, L.A. Farahat, Biosorption of Astrazone Blue basic dye from an aqueous solution using dried biomass of Baker's yeast, J. Hazard. Mater., 148 (2007) 402–408.
[54] M. Ghaedi, S. Hajati, B. Barazesh, F. Karimi, G. Ghezelbash, *Saccharomyces cerevisiae* for the biosorption of basic dyes from binary component systems and the high order derivative spectrophotometric method for simultaneous analysis of Brilliant green and Methylene blue, Ind. Eng. Chem. Res., 19 (2013) 227–233.
[55] A. Regti, M.R. Laamari, S.-E. Stiriba, M. El Haddad, Removal of Basic Blue 41 dyes using *Persea americana*-activated carbon prepared by phosphoric acid action, J. Ind. Eng. Chem., 8 (2017) 187–195.
[56] T. Akar, S. Arslan, S.T. Akar, Utilization of *Thamnidium elegans* fungal culture in environmental cleanup: a reactive dye biosorption study, Ecol. Eng., 58 (2013) 363–370.
[57] E. Daneshvar, M. Kousha, M. Jokar, N. Koutahzadeh, E. Guibal, Acidic dye biosorption onto marine brown macroalgae: isotherms, kinetic and thermodynamic studies, Chem. Eng. J., 204 (2012) 225–234.
[58] L. Liu, J. Liu, X. Liu, C. Dai, Z. Zhang, W. Song, Y. Chu, Kinetic and equilibrium of U(VI) biosorption onto the resistant bacterium *Bacillus amyloliquefaciens*, J. Environ. Radioact., 203 (2019) 117–124.
[59] S. Madala, S.K. Nadavala, S. Vudagandla, V.M. Boddu, K. Abburi, Equilibrium, kinetics and thermodynamics of Cadmium (II) biosorption on to composite chitosan biosorbent, Arabian J. Chem., 10 (2017) S1883–S1893.
[60] T. Maneerung, J. Liew, Y. Dai, S. Kawi, C. Chong, C.-H. Wang, Activated carbon derived from carbon residue from biomass gasification and its application for dye adsorption: kinetics, isotherms and thermodynamic studies, Bioresour. Technol., 200 (2016) 350–359.
[61] D. Mitrogiannis, G. Markou, A. Çelekli, H. Bozkurt, Biosorption of methylene blue onto *Arthrospira platensis* biomass: kinetic, equilibrium and thermodynamic studies, J. Environ. Chem. Eng., 3 (2015) 670–680.
[62] M. Rahimdokht, E. Pajootan, M. Arami, Central composite methodology for methylene blue removal by *Elaeagnus angustifolia* as a novel biosorbent, J. Environ. Chem. Eng., 4 (2016) 1407–1416.
[63] M. El Haddad, R. Mamouni, N. Saffaj, S. Lazar, Removal of a cationic dye – Basic Red 12 – from aqueous solution by adsorption onto animal bone meal, J. Assoc. Arab Univ. Basic Appl., 12 (2012) 48–54.
[64] D. Suteu, A.C. Blaga, M. Diaconu, T. Malutan, Biosorption of reactive dye from aqueous media using *Saccharomyces cerevisiae* biomass. Equilibrium and kinetic study, Cent. Eur. J. Chem., 11 (2013) 2048–2057.
[65] Z. Belala, M. Jeguirim, M. Belhachemi, F. Addoun, G. Trouvé, Biosorption of basic dye from aqueous solutions by date stones and palm-trees waste: kinetic, equilibrium and thermodynamic studies, Desalination, 271 (2011) 80–87.
[66] A.Y. Dursun, A comparative study on determination of the equilibrium, kinetic and thermodynamic parameters of biosorption of copper(II) and lead(II) ions onto pretreated *Aspergillus niger*, Biochem. Eng. J., 28 (2006) 187–195.
[67] S. Chowdhury, S. Chakraborty, P. Saha, Biosorption of Basic Green 4 from aqueous solution by *Ananas comosus* (pineapple) leaf powder, Colloids Surf., B, 84 (2011) 520–527.
[68] Y. Sağ, T. Kutsal, Determination of the biosorption activation energies of heavy metal ions on *Zoogloea ramigera* and *Rhizopus arrhizus*, Process Biochem., 35 (2000) 801–807.
[69] B.A.P. dos Santos, A.S. Cossolin, H.C.O. dos Reis, K.C. de Castro, E.R. da Silva, G. de Menezes Pereira, P.T. de Sousa Junior, E.L. Dall'Oglio, L.G. de Vasconcelos, E.B. de Morais, Baker's yeast-MnO_2 composites as biosorbent for Malachite

green: an ecofriendly approach for dye removal from aqueous solution, Rev. Ambiente Água, 14 (2019) e2254.
[70] X. Inthapanya, S. Wu, Z. Han, G. Zeng, M. Wu, C. Yang, Adsorptive removal of anionic dye using calcined oyster shells: isotherms, kinetics, and thermodynamics, Environ. Sci. Pollut. Res., 26 (2019) 5944–5954.
[71] N. Sh. El-Gendy, R.A. El-Salamony, S.S.A. Amr, H.N. Nassar, Statistical optimization of Basic Blue 41 dye biosorption by *Saccharomyces cerevisiae* spent waste biomass and photo-catalytic regeneration using acid TiO_2 hydrosol, J. Water Process Eng., 6 (2015) 193–202.
[72] S. Mona, A. Kaushik, C.P. Kaushik, Biosorption of reactive dye by waste biomass of *Nostoc linckia*, Ecol. Eng., 37 (2011) 1589–1594.
[73] F. Temesgen, N. Gabbiye, O. Sahu, Biosorption of reactive red dye (RRD) on activated surface of banana and orange peels: economical alternative for textile effluent, Surf. Interfaces, 12 (2018) 151–159.
[74] M. Wu, W. Chen, Q. Mao, Y. Bai, H. Ma, Facile synthesis of chitosan/gelatin filled with graphene bead adsorbent for orange II removal, Chem. Eng. Res. Des., 144 (2019) 35–46.
[75] A.O. Abo El Naga, S.A. Shaban, F.Y.A. El Kady, Metal organic framework-derived nitrogen-doped nanoporous carbon as an efficient adsorbent for methyl orange removal from aqueous solution, J. Taiwan Inst. Chem. Eng., 93 (2018) 363–373.
[76] A. Ghasemi, M. Shams, M. Qasemi, M. Afsharnia, Data on efficient removal of acid orange 7 by zeolitic imidazolate framework-8, J. Data Brief, 23 (2019) 103783.