Green synthesis of zinc oxide nanoparticles loaded on activated carbon prepared from walnut peel extract for the removal of Eosin Y and Erythrosine B dyes from aqueous solution: experimental approaches, kinetics models, and thermodynamic studies

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Abstract
Water contamination due to release of dye containing effluents is one of the environmental problems of serious concern today. The present study investigate the green synthesis of zinc oxide nanoparticles (ZnO-NPs) doped on activated carbon (AC) prepared from walnut peel extract and to estimate its efficiency in the removal of Eosin Y (Eo-Y) and Erythrosine B (Er-B) from its aqueous solution. The synthesized AC-ZnO was identified by field emission scanning electron microscopy (FE-SEM), X-ray diffraction (XRD), and the Brunauer–Emmett–Teller. The influence of various parameters such as pH, dosage of AC-ZnO, contact time, and concentrations of Eo-Y and Er-B was also studied. The pH 3 was observed as the optimum pH while the equilibrium was noticed to reach in 30 min at dosage of 1 g/L and initial concentration 100 mg/L for Eo-Y and Er-B adsorption onto AC-ZnO. The maximum adsorption capacity of Eo-Y and Er-B onto AC-ZnO was found to be 163.9 and 144.92 mg/g (and removal efficiencies of 95.11 and 98.31 %), respectively. The process of Eo-Y and Er-B adsorption on AC-ZnO was observed to be depended on the pseudo-second-order kinetic model which indicates chemisorption processes. Langmuir adsorption isotherm model test described the removal of Eo-Y and Er-B on AC-ZnO. The thermodynamic data indicated that the adsorption was endothermic process. Also, the values, S_BET and V_TOTAL, for the AC-ZnO were equal to 725.65 m²/g and 0.6004 cm³/g, respectively. The results of this study exhibited that AC-ZnO was a very effective method that can be used for the removal of Eo-Y and Er-B from aqueous solutions.

Keywords Green synthesis · Adsorption · Nanoparticles · Dyes · Activated carbon

Introduction
The textile industry uses high volumes of dyes and produces wastewaters containing these dyes at a concentration range of 10–200 mg/L (Khosravi et al. 2015; Mendez-Paz et al. 2005). Studies have shown that most of them are toxic, allergens, and mutants. These compounds provide negative effects on the appearance and quality of water (Khosravi et al. 2016; Ghosh and Bhattacharyya 2002; Zhang et al. 2005). Eosin Y (Eo-Y) causes skin and eye irritation and reduces the

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Adsorption (Abdollahzadeh et al. 2020), advanced oxidation (Tarkwa et al. 2019), ozone (Venkatesh and Venkatesh 2020), wastewaters, including the application of photo decomposition approaches has been implemented for the elimination of textile respiratory capacity of the lungs (Sun et al. 1987). Erythrosine et al. (2006). Therefore, wastewaters that contain the dyes were underlined as one of the most significant threatening factor to the environment and public health (Igwegbe et al. 2019b). Several approaches has been implemented for the elimination of textile wastewaters, including the application of photo decomposition (Tarkwa et al. 2019), ozone (Venkatesh and Venkatesh 2020), adsorption (Abdollahzadeh et al. 2020), advanced oxidation (Seid-Mohammadi et al. 2017), biodegradation (Sonwani et al. 2020), electrocoagulation/flotation (Chigozie and Joseph 2014), coagulation (Obiora-Okafo et al. 2020), and other processes.

Adsorption process is a physical method in which natural or synthetic adsorbents are used to bleach the colorful compounds (Baghapour et al. 2013). Nano technology provided a new field in the healthcare. Currently, nano technology is the crucial and effective technology in science and industry (Ahmadi et al. 2020). It helps to change the atom and molecule arrangement to achieve new structure which has never been existed before. Nano technology has found many applications in water treatment including treatment of sewage and industrial wastewaters, and the purification of air (Liu et al. 2019; Shi et al. 2019). Zinc oxide nanoparticles (ZnO-NPs) have been widely used in the removal of contaminants due to their advantages such as high catalytic properties, non-toxicity, and low cost (Ansari et al. 2016). In most chemical methods, a chemical reducing agent has been used as a stabilizer to control particle growth and prevent aggregation. The demand for the synthesis of environmentally friendly nano particles has been increased noticeably in the past two decades. Various plants extracts and their products have been used as an alternative to the synthesis of nanoparticles in biological methods (Fazlzadeh et al. 2017; Ramezani et al. 2013). On the other hand, in order to accelerate the separation and stabilization of nanomaterials on materials such as fillers, polymers, oxides, and activated carbon, it is necessary to use activated carbon which has economic and environmental benefits (Fazlzadeh et al. 2017; Ghaedi et al. 2013). Ghaedi et al. compared the efficiency of palladium, silver, and zinc oxide nanoparticles fixed on active jelly which has been used as an adsorbent to remove dye. In batch adsorption systems, adsorption of adsorbate on adsorbent surface is monolayer adsorption and with increasing pH from 1 to 9, the adsorption of bromophenol red dye decreased from 250 to 142.8 mg/g (Ghaedi et al. 2013). The study of Arabi et al. (Arabi et al. 2019) has showed that Congo red dye adsorption used activated carbon coated with oxidized nanoparticles. The optimal conditions observed for dye removal are contact time of 55 min, dose 9 mg, and temperature 55 °C that ensures efficiencies >99.8%. The study data has also exhibited a quadratic reaction coefficient (Arabi et al. 2019).

The current study focused on the green synthesis of walnut peel extract zinc oxide (ZnO) doped activated carbon (AC) nanoparticles. The purity of the AC-ZnO was identified by scanning electron microscopy (SEM), X-ray diffraction (XRD), and the Brunauer–Emmett–Teller. Further testing was also conducted in order to test efficiency of these nanoparticles in the removal of Eo-Y and Er-B from their aqueous solution. Additionally, the influence of various parameters such as contact time, adsorbent dosage of AC-ZnO, pH, and initial concentrations of Eo-Y and Er-B was also being estimated in order to determine the optimum conditions which will subsequently enhance the efficiency of the AC-ZnO in Eo-Y and Er-B removal. Finally, the kinetics, isotherm, and thermodynamics of the adsorption process were also studied.

**Experimental**

**Materials and methods**

Eo-Y and Er-B dye were used as the pollutant and purchased from Alvan Sabet Corporation, Hamadan, Iran. All reagents were of analytical grade and purchased from Merck (Germany). All solutions were prepared by using de-ionized water. The pH of the solution was adjusted by adding HCl or NaOH 0.1 N solutions. The molecular structure of the Eo-Y and Er-B is shown in Table 1.

**Preparation of the active carbon**

Worn tires were used to prepare activated carbon. Initially, the tires were crushed to a size of 0.5 cm and put in phosphoric acid. Following that, the tires were heated at a temperature of 800 °C for 2 h. The produced AC was washed with distilled water and dried in the oven at 110°C for a period of 2 h (Ali et al. 2020; Fazlzadeh et al. 2017).

**ZnO preparation using green synthesis technique**

Walnut peel extract was prepared by boiling at 80 °C for 60 min followed by filtration. In order to synthesize ZnO-NPs, the ZnCl₂ salt was mechanically blended with the walnut shell in a ratio of 2:3. Following the filtration and drying at 70 °C for 24 h, the blended mixture was calcined for 2 h at 800 °C (Leili et al. 2018; Rashtbari et al. 2020).
Loading ZnO-NPs on AC

Following the preparation of the AC, ZnO-NPs were sanitized. About 0.05 g of ZnO-NPs was added separately into 250 mL of distilled water and the solution was homogenized on a magnetic mixer for 20 min. Following that, the solution was added to the 5 g of the AC and mechanically blended at 500 rpm for 2 h. Finally, the mixture was purified and the stock was repeatedly washed with clean water, and finally dried for 12 h at 95 °C (Rashtbari et al. 2019).

Characterization of AC-ZnO

Field emission scanning electron microscopy (FE-SEM) was used to study the morphology of the AC-ZnO nanoparticles by means of a HITACHI S-4160 Instrument (Japan). XRD measurements were performed on a Bruker (Model Inel diffractometer EQuinox 3000, USA) diffractometer with 2θ radiation. The nitrogen adsorption isotherm was measured using Quantachrom ChemBET-3000 USA to observe the B.E.T. surface area of the AC-ZnO.

Evaluation of zero charge point (pHpzc) for the AC-ZnO

To evaluate the pH_{pzc} of the nanocomposite AC-ZnO, the electrolyte, sodium chloride (NaCl) (0.1 mM) was introduced into Erlenmeyer flasks of 100 mL, while H_{2}SO_{4} and NaOH solutions were used as pH control agents. Thereafter, 0.04 g of the AC-ZnO was poured into various Erlenmeyer 250 mL flasks, and the solution pH was balanced at pHs 2–12 and blended at 250 rpm for 48 h. Following this, the pHs of the solutions were re-measured (Rivera-Utrilla et al. 2010).

Batch adsorption studies

The effects of different parameters such as pH, contact time, pollutant concentration, and adsorbent dose were analyzed. At each adsorption test time, the specified volume of the Eo-Y and Er-B solution with a definite concentration was added into the Erlenmeyer flask. The anticipated conditions were set up and a certain dosage of adsorbent was added to the flask followed by thorough mixing with the magnetic stirrer (MODEL: MSH basic) at 250 rpm. The initial and final Eo-Y and Er-B concentrations remaining in solutions were examined by a DR5000 spectrophotometer (Shimadzu Model: HACH®), USA, at a wavelength of maximum absorbance, λ_{max} = 515 and 527 nm, respectively. The removal efficiency, R (%), and the amount of Eo-Y and Er-B adsorbed, q_e (mg/g), of the studied parameters were calculated based on the following formulas (Al-Qodah et al. 2017; Shokoohi et al. 2018):

\[ R = \frac{C_0 - C_f}{C_0} \times 100 \]  
\[ q_e = \frac{(C_0 - C_f)V}{M} \]

Table 1 Characteristics of dyes

| Name                | Molecular structure | Molecular formula | Molecular weight | \( \lambda_{max} \) |
|---------------------|---------------------|-------------------|------------------|---------------------|
| Eosin Y             | ![Eosin Y structure](image) | C_{20}H_{8}Br_{4}O_{5} | 647.89 g/mol     | 515 nm              |
| Erythrosine B       | ![Erythrosine B structure](image) | C_{20}H_{6}I_{4}Na_{2}O_{5} | 879.86 g/mol     | 527 nm              |
where $M$ is the mass of adsorbent (g) and $V$ is the volume of the solution (L). $C_0$ and $C_e$ are the initial and final equilibrium liquid phase concentration of Eo-Y and Er-B dyes (mg/g), respectively.

**Results and discussion**

**Characterization of AC-ZnO**

Fig. 1 a indicates that the AC was loaded with ZnO NPs. The XRD peaks showed the relative broad nature of the AC-ZnO because of the presence of small sized AC particles. The porosity of the AC-ZnO and AC was observed by the total pore volume determination technique. The mesoporosity of the AC-ZnO also determined. Fig. 1 b exhibits the $N_2$ adsorption-desorption isotherms and pore size distribution of AC-ZnO and AC at 1–0 pressure range. The results revealed that the AC-ZnO and AC belong to type IV isotherm and H$_2$ type hysteresis loop. This type of loop is assumed to be frequently caused by agglomerates of spherical particles of uneven size and arrangements (Adelkhani et al. 2011). The B.E.T. specific surface area ($S_{BET}$), micropore specific surface area ($S_{micro}$), mesoporous specific surface area ($S_{meso}$), total pore volume ($V_{Total}$), micropore volume ($V_{micro}$), and mesopore volume ($V_{meso}$) of the AC and AC-ZnO have been compiled in Table 2. The parameters, $S_{BET}$, $S_{micro}$, $V_{Total}$, $V_{micro}$, and $V_{meso}$ presented for AC were improved after the ZnO particles were loaded on the AC to give a better adsorbent. The results obtained showed that the $S_{BET}$ and total pure volume for the AC-ZnO are 725.65 m$^2$/g and 0.6004 cm$^3$/g respectively while for the AC alone were 721.19 m$^2$/g and 0.534 cm$^3$/g. The AC-nZVI showed an average pore diameter ($D_p$) of 3.198 nm, which can play a pivotal role in the
adsorption properties. On the other hand, the mesoporosity feature of materials allows easier penetration of pollutant ions into their pores (Xiao et al. 2015). Figure 1 c explains the surface morphological characteristics of AC-ZnO at 200 kx magnification by field emission scanning electron microscopy (FE-SEM). Furthermore, the image confirms the nanoscale nature of the AC-ZnO. The presence of high porosity and a suitable high surface area (in relation to the irregularity of the AC-ZnO) was visualized. The pores were also asymmetrically distributed.

Effect parameters

Results obtained by studying the pH effect on the adsorption efficiency of Eo-Y and Er-B on nano-composites are presented in Fig. 2a, b. The presented data in Fig. 2a indicated that with increasing of the pH from 3 to 9, the adsorption of Eo-Y and Er-B on nano-composites surface decreased. The rate of Eo-Y and Er-B removal on the nanocomposite at pH 3 was at a maximum rate. At pH<\(\text{pH}_{\text{pzc}}\), the AC-ZnO had a positive charge and in pH > \(\text{pH}_{\text{pzc}}\), it had a negative charge. As a result, for solutions with a pH < 6.76, the nanocomposite had a positive charge at its surface, while the Er-B and Eo-Y dye molecules were negatively charged. As the pH decreases due to the increase of \(\text{H}^+\) ions in the solution and the formation of electrostatic attraction between the \(\text{H}^+\) ion and the dye, the absorption rate increases. On the other hand, nanocomposite had a negative charge due to pH > 6.76, so the anionic dye and the adsorbent repelled (Gupta et al. 2011) as also reported by Carmen Apostol (Carmen Apostol et al. 2016). Fig. 2b is the final pH of the Eo-Y and Er-B solutions after Eo-Y and Er-B adsorption on the nanocomposite, AC-ZnO; linear effect was also observed.

It is clear from the data (Fig. 2c) that the amount of Eo-Y and Er-B from solution decreased as the concentration of nanocomposite particles increased. Regarding this results, 1 g/L absorbent was determined as the optimal concentration. It is clear that increased absorbent particles decreased the adsorption rate because of reducing adsorption surface and less availability to adsorbent sites with increased particles. The percentage of adsorption was nearly fixed after the adsorption sites was occupied reaching equilibrium (Carmen Apostol et al. 2016; Jamshidi et al. 2016). The result of this study is similar to Mouni et al. study of dye removal by kaolin (Mouni et al. 2018).

The results in Fig. 2d highlight that the removal of Er-B and Fig. 2e of Eo-Y decreased as a function of contact time. The absorption rate at first was rapid and with time, the process became slow until to saturation phase that lasted for 15 min. During the Er-B and Er-Y adsorption, the surface of the nanocomposite was saturated by the Er-B and Er-Y molecules so it was impossible to adsorb more adsorbate molecules with increasing concentration; this also led to rapid equilibrium between the nanocomposite and the Er-B and Er-Y. This is because the number of adsorbent particles that treated the fixed volume of liquid was constant even though the Er-B and Er-Y concentrations were increased. In the initial moment of adsorption, more empty sites were available, however, after a while, empty sites would be occupying as the adsorbed dyes molecules and the molecules which were in solution showed repulsion (Mahvi et al. 2020; Saif et al. 2012). Similar result was reported by Regti et al. (2017) and Ong et al. (2007).

Kinetics of adsorption and studies of isotherm

In order to further understand the adsorption process of Eo-Y and Er-B onto AC-ZnO nanostructures, the kinetics of the process was investigated. The experimental kinetic data were fitted into the Lagueree pseudo-first-order and Ho/Mckay pseudo-second-order kinetic models (Ahmadi et al. 2019; Ho and McKay 1999; Lagergren and Svenska 1898).

Pseudo-first-order and pseudo-second-order adsorption kinetic models are frequently used to examine the experimental data obtained. These models can be expressed as below Eqs. (3)–(4) (Alencar et al. 2012; Liu and Liu 2008; Al-Qodah et al. 2017; Zalloum et al. 2008):

\[
q_t = q_e \times (1 - \exp (-K_F \times t))
\]

\[
q_t = \frac{K_S \times q_e^2 \times t}{1 + K_e \times K_S \times t}
\]

where \(t\), \(q_t\), and \(q_e\) are the contact time (min), the sorption capacity at any time \(t\), and equilibrium (mg g\(^{-1}\)), respectively; \(K_F\) and \(K_S\) are the pseudo-first-order rate

| Table 2 Adsorption properties of AC-ZnO |
|-----------------|-----------------|-----------------|-----------------|-------------------|-----------------|-----------------|-----------------|
| Material        | \(S_{\text{BET}}\) (m\(^2\)/g) | \(S_{\text{micro}}\) (m\(^2\)/g) | \(S_{\text{meso}}\) (m\(^2\)/g) | \(V_{\text{Total}}\) (cm\(^3\)/g) | \(V_{\text{micro}}\) (cm\(^3\)/g) | \(V_{\text{meso}}\) (cm\(^3\)/g) | \(D_p\)         |
| AC              | 721.19           | 527.89           | 212.64           | 0.534             | 0.2431           | 0.3252           | 2.785           |
| AC-ZnO          | 725.65           | 513.07           | 212.58           | 0.6004            | 0.1372           | 0.368            | 3.198           |
Fig. 2  Effect of pH (a), AC-ZnO pHpzc (b), AC-ZnO dosage (c), contact time (d, e) on percentage removal of Eo-Y and Er-B
Fig. 3 Kinetic plots for the adsorption of Er-B (a) and Eo-Y (b) onto AC-ZnO at different dye concentration.
constant (min$^{-1}$) and the pseudo-second-order rate constant (mg g$^{-1}$ min$^{-1}$), respectively. The nonlinear models for pseudo-first order, pseudo-second order, and the calculated parameters for kinetic models are presented in Fig. 3 and Table 3.

Overall, all kinetic models showed high $R^2$ values and low RMSE, indicating good fits to the experimental data. Based on Table 3, it is found that the adsorption of Eo-Y and Er-B dye onto AC-ZnO follows the pseudo-second-order model with the highest determination coefficient. This suggests that the rate-limiting stage on the adsorption presses can be chemisorption, which involves valence forces through exchange of electrons between the adsorbent and the dye molecules (Silva et al. 2018). In addition, the $K_2$ values of pseudo-second-order model decreased with increase of the initial concentration of Eo-Y and Er-B dye (Table 3); this can be related to competition between higher levels of ions and the limited adsorption active sites (Silva et al. 2018). Study by Streit et al. (2019) followed the pseudo-second-order kinetic. Study by Afshina et al. (2019) is in similarity with this study.

The experimental kinetic data were fitted into the Langmuir and Freundlich models (Eletta et al. 2020; Freundlich 1906; Langmuir 1918; Zalloum et al. 2008; Al-Shawabkah et al. 2015). The nonlinear equations of the Langmuir and Freundlich isotherm models are given in Eqs. (5)–(6), respectively.

$$ q_e = \frac{Q_{\text{max}} \times K_L \times C_e}{1 + K_L \times C_e} $$

(5)

$$ q_e = K_F \times C_e^{1/n_l} $$

(6)

Fig. 4 presents the experimental data and fits of the Langmuir and Freundlich models. The according to the $R^2$ and RMSE values, Langmuir model best described the experimental data of Eo-Y and Er-B adsorption onto
adsorbent, considering its highest $R^2$ and the low value of RMSE. With regard to the correlation coefficients of the isotherm models (Table 4), the Eo-Y and Er-B adsorption equilibrium data is more consistent with the Langmuir isotherm compared to the Freundlich isotherm. The result suggests that the adsorption process was favored by the mesoporous structures in the AC-ZnO. The results showed that the capacity of AC-ZnO for Eo-Y and Er-B ($q_m$) was 163.93 and 144.92 mg/g, respectively.

**Thermodynamic study**

The three basic parameters for thermodynamic study are standard enthalpy ($\Delta H^0$), Gibbs free energy ($\Delta G^0$), and standard entropy ($\Delta S^0$). The free energy change can be determined by the following equations (Balarak et al. 2016; Tan and Sen 2020):

$$\Delta G^0 = -RT\ln K$$  \hspace{1cm} (7)

where $\Delta G^0$ is the free energy change of sorption process (kJ/mol), $K$ is the equilibrium constant, $T$ is the temperature in (K), and $R$ is the universal gas constant (8.314 J mol$^{-1}$K$^{-1}$). The free energy change can be expressed in terms of enthalpy change of sorption as a function of temperature as follows (Igwegbe et al. 2019a; Tan and Sen 2020):

### Table 4 Parameters of isotherm models for the adsorption of Eo-Y and Er-B onto AC-ZnO

|            | EO-Y   | Er-B   |
|------------|--------|--------|
| **Freudlich** |        |        |
| $k_F$ (mg g$^{-1}$) | 59.92  | 77.94  |
| $n_F$      | 4.74   | 7.58   |
| $1/n_F$    | 0.21   | 0.13   |
| $R^2$      | 0.9699 | 0.9502 |
| RMSE       | 19.39  | 19.30  |
| **Langmuir** |       |        |
| $q_m$ (mg g$^{-1}$) | 163.93 | 144.92 |
| $k_L$ (L mg$^{-1}$) | 0.143  | 0.33   |
| $R^2$      | 0.971  | 0.9856 |
| RMSE       | 19.63  | 19.06  |
ΔG₀ = ΔH₀ − TΔS₀

\[ \ln K = \frac{\Delta H^0}{RT} + \frac{\Delta S^0}{R} \]  

The ΔH₀ and ΔS₀ values were derived from linear plots of ln K against 1/T, which are the slope and width of the graph linear equations, respectively (Côrtes et al. 2019). The thermodynamic parameters of Eo-Y and Er-B adsorption on AC-ZnO nanocomposites are shown in Table 5. A negative ΔG value indicates that the adsorption occurs thermodynamically by itself. Decreasing ΔG with increasing temperature indicates that adsorption is more applicable at higher temperatures. Similar comments made in literature (Kıvanç and Yönten 2020; Mounie et al. 2018). The positive ΔH₀ of adsorption reaction value showed that the process was endothermic (ΔH > 0). Change in entropy (ΔS₀ = −0.2141 and −0.2687 kJ/mol K of Eo-Y and Er-B respectively) adsorption by AC-ZnO is negative, indicating that the degree of freedom at the stage of the solid solution reduces during adsorption (Acisli et al. 2020; Tan and Sen 2020).

### Comparision of AC-ZnO nanocomposite for Eo-Y and Er-B removal with other adsorbents

The deposition of Eo-Y and Er-B on the composite AC-ZnO was compared with other adsorbents (Table 6). In general, the results reported by the researchers shown in Table 6 demonstrated that the various adsorbents could be integrated through the adsorption mechanism to extract Eo-Y and Er-B with higher performance.

### Adsorbent reclamation

The adsorbent recovery process has been considered in order to get their economic value and solve operational problems. As seen in Fig. 5, the performance was 93.44 %, which decreased to 81.74 % (five recovery cycles), suggesting that the restored adsorbent has a high potential to be used regularly. Nanocomposite has a high potential for wastewater treatment in the pharmaceutical industry, because it can be reused after five consecutive periods by recovering the adsorbent and by its ability to maintain the removal efficiency. It is also cost-effective and therefore very necessary for industrial applications.

### Table 5

| Pollutant  | Temperature (K) | Thermodynamic parameters (KJ/mol) |
|------------|-----------------|-----------------------------------|
| Eo-Y       | 288             | ΔG₀ = 2.408                       |
|            | 298             | ΔG₀ = −1.649                      |
|            | 318             | ΔG₀ = −4.399                      |
| Er-B       | 288             | ΔG₀ = −0.1337                     |
|            | 298             | ΔG₀ = −4.3647                     |
|            | 318             | ΔG₀ = −8.503                      |

### Table 6

| Adsorbent                  | Pollutant | pH | q_max (mg/g) | Reference                  |
|----------------------------|-----------|----|--------------|---------------------------|
| Chitosan hydrobeads        | Eo-Y      | 4  | 76           | Chatterjee et al. (2005)  |
| Jute fiber carbon          | Eo-Y      | 3  | 31.49        | Porkodi and Kumar (2007)  |
| Diethylentriamine-montmorillonite | Eo-Y  | 4  | 11.9         | Elhami et al. (2013)      |
| Teak leaf litter powder    | Eo-Y      | -  | 31.64        | Oyelude et al. (2017)     |
| Pumpkin seed hulls         | Er-B      | 5.6| 16.4         | Carmen Apostol et al. (2016) |
| Prosopis spicigera L. wood carbon | Er-B  | 3  | 22.88        | Manickam (2016)           |
| Commercial AC              | Er-B      | 7  | 89.3         | Al-Degs et al. (2012)     |
| Ziziphusnummularia kernel  | Er-B      | 7  | 101          | Mohbibi et al. (2014)     |
| AC-ZnO                     | Eo-Y      | 3  | 163.93       | This work                 |
|                           | Er-B      | 3  | 144.92       |                           |
to prevent secondary pollution in the treatment of wastewater (Chieng et al. 2015; Mansour et al. 2018).

**Conclusions**

The investigational results obtained from application of AC-ZnO nanoparticles as adsorbent showed that the maximum adsorption capacity of Eo-Y and Er-B onto AC-ZnO was 163.9 and 144.92 mg/g (and removal efficiencies of 95.11 and 98.31 %), respectively. This suggests the high potential of adsorbing Eo-Y and Er-B by the prepared AC-ZnO composite particles which followed the pseudo-second-order kinetics and Langmuir isotherm models.

**Author contribution** Yousef Poureshgh, Yousef Rashtbari, and Mehdi Fazlzadeh participated in the conceptualization and design of the research and supervised the work. Shirin Afshin and Asghar Hamzezadeh are responsible for experimental analysis and interpretation of data. Abdolmajid Gholizadeh contributed to literature search and quality assessment. All authors have read and approved the final paper as submitted

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**Data Availability** The data used and analyzed during the current study are available from the corresponding author upon reasonable request.

**Declarations**

**Ethical approval** The protocol was approved by the Institutional Review Board of Ardabil University of Medical Sciences (Approval ID: IR.ARUMS.REC.1398.015).

**Consent to participate** Not applicable.

**Consent for publication** All the authors agreed to publish the data in this journal.

**Conflict of interest** The authors declare no competing interests.

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