Efficient removal of reactive blue-19 dye by co-electrospun nanofibers

Raheel Ahmed Hakro¹, Mujahid Mehdi², Raja Fahad Qureshi²,³, Rasool Bux Mahar¹, Muzamil Khatri⁴, Farooq Ahmed⁵, Zeeshan Khatri⁶,⁷ and Ick Soo Kim⁸,⁹

¹ US Pakistan Centre for Advance Studies in Water, Mehran Mehran University of Engineering and Technology, Jamshoro, Sindh, Pakistan
² Centre of Excellence in Nanotechnology and Materials, Mehran Mehran University of Engineering and Technology, Jamshoro, Sindh, Pakistan
³ Department of Textile Engineering, Mehran University of Engineering and Technology, Jamshoro, 76060, Pakistan
⁴ Nano Fusion Technology Research Group, Division of Frontier Fibers, Institute for Fiber Engineering (IFES), Interdisciplinary Cluster for Cutting Edge Research (ICCEER), Shinshu University, Tokida 3-15-1, Ueda, Nagano prefecture, 386-8567, Japan
* Authors to whom any correspondence should be addressed.
E-mail: zeeshan.khatri@faculty.muet.edu.pk and kim@shinshu-u.ac.jp

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Abstract
The present work demonstrates the new nanofiber mats prepared through co-electrospinning of two different polymers i.e. corn protein namely Zein and Nylon-6. The composite nanofiber membrane was used as an effective adsorbent material for the removal of toxic reactive dye i.e. Reactive Blue 19 (RB19) from water solution. These co-electrospun nanofibers had good mechanical strength compared to zein nanofibers alone. Experimental results suggested that zein/nylon nanofibers have greater potential for total removal of RB19 at room temperature within 10 min of contact time from aqueous solution. The maximum capacity was found to be 61.2 mg·g⁻¹ of nanofibers. The mechanism of RB19 removal on proposed nanofibers is mainly through hydrogen bond and electrostatic means.

1. Introduction
Cotton is one of the prime consumable product of textile industry and reactive dyes are commonly used for colouring cellulose materials owning to typical characteristics such as wide variety of colour shades, easy formation of covalent bonds with fibres and excellent fastness properties [1]. However, reactive dyes are easily hydrolysed in water and low degradable rate; thus, huge content of these dyes are drained into environment [2, 3]. The precise content of dye effluent is not known, but up-to 50% of reactive dyes may be drained from textile dyeing units and the dye concentration in textile effluent may be found around 10–200 mg·L⁻¹ [4, 5]. The previous reports indicates that the presence of these dyes is potentially toxic and carcinogenic, due to their complex chemical structure [6–8].

Therefore, the removal of such dyestuff is highly desirous. For the removal of dyes, various treatment methods have been employed such as; photo-chemical degradation, advance oxidation, ozonation, and coagulation-flocculation [9]. Among these aforementioned methods, adsorption is the most simple, low cost and highly efficient process for exclusion of various pollutants including synthetic dyestuff [10]. However, the major concern in this method is selection of adsorbent material with superior adsorption capacity and cheapness [11]. Previously, a wide range of low cost adsorbents such as; cashew apple bagasse, pomegranate based activated carbon, rice straw fly ash, peanut hull, and spent tea leaves were utilized for the removal of reactive dyes from aqueous solution [12, 13]. However, the adsorption capacities of these materials were low and required longer pre-treatment steps [10]. In context to this, the exploration of one dimensional nanoscale adsorbent especially nanofibers possess good performance due to their unique properties; such as high surface to low volume ratio, highly porous morphology and better interconnectivity [14]. To produce the nanofibers, one of the simple low-cost methods is electrospinning in which an external electric field is imposed to polymer solution to fabricate a nanofibers with a diameter of submicron to nanoscale [15–18].
In recent years, the electrospinning of natural biopolymer from renewable sources such as Zein has received much attention, due to its economic and environmental green perspectives [19]. A series of previous reports showed that due to its nontoxicity, biodegradability and good biocompatibility. Zein is a promising natural biopolymer for use as a scaffold in drug delivery systems, in wound healing and food packaging [20]. Apart from these applications zein nanofibers membrane is also reported as an adsorbent for reactive dyes removal [21]. However, the poor stability and strength of zein nanofibers in aqueous medium is still a matter of concern to be fixed [22]. When zein nanofiber immersed in aqueous solution, the nanofiber mates get swollen and eventually collapse into films owing to distortion of interconnected pore structure [23]. One of the approach to improve the properties of zein nanofiber is the blending of material that should be strong and water stable [24]. Polymer blending is a very effective technique for enhancing physicochemical properties of polymeric membranes [25]. Some polymer blends have peculiar properties that are completely unlike those of homopolymers. The major challenge involved in the blending of polymers is that most polymers are thermodynamically immiscible and hence separate out unless stabilized using fillers [26]. It is essential that the blends remain stable in order to create functional materials with the desired properties. The advantage of Co-electrospinning is that functional nanofibers can be fabricated from both miscible and immiscible blends [27, 28]. Therefore, in this study Zein and Nylon-6 was fabricated via co-electrospinning technique to enhance the material strength and stability in water. The objective of this study is to explore the feasibility of zein/nylon co-electrospun nanofibers as adsorbent for the removal of commonly used anionic dye i.e. Reactive blue19 (RB19), from aqueous solution by studying the influence of several parameters including contact time, adsorbent dosage, dye concentration, and pH of solution.

2. Materials and methods

2.1. Materials

Zein from corn (melting point 266–283 °C) was purchased from Wako Pure Chemical Industries, Ltd. Japan. Nylon-6 (Mw ∼ 25,000 g.mol⁻¹), Formic acid (98%) purity was supplied by Sigma Aldrich. C.I reactive blue 19 (C₂₂H₁₆N₂Na₂O₁₁) with a molecular weight 626.54 g.mol⁻¹, and dye content ~50% was supplied by the Sumitomo Chemical Company Ltd., Japan. The chemical structure of the used dye is given in the figure 1.

![Figure 1. Chemical structure of Reactive blue (RB19).](image)

2.2. Preparation of Co-electrospun nanofibers

A solution of 60% (weight. Volume⁻¹) zein was prepared in DMF followed by stirring for 2 h at room temperature. Nylon-6 polymer of 22% (weight. Volume⁻¹) was also prepared separately in formic acid under constant stirring for 24 h at room temperature to obtain a homogeneous solution. Both these solutions were loaded separately onto 5 ml plastic syringes with an inner diameter of 0.6 mm and were positioned oppositely at an angle of 10° from the horizontal plane, and co-electrospinning was performed simultaneously, at 20 kV having tip to collector distance of 15 cm to 20 cm for both zein and nylon-6 solutions, respectively, the grounded rotating metallic drum covered with aluminium foil was used for the deposition of zein/nylon electrospun nanofibers. After completion of co-electrospinning, the samples were dried overnight at room temperature prior to adsorption experiments. The average thickness of zein/nylon nanofibers was found to be 51 ± 2 μm.

a. Adsorption experiments

The adsorption behaviour of anionic dye RB19 from aqueous solution on zein/nylon co-electrospun nanofiber membrane were studied at room temperature using the batch mode, the experiments were performed on an automatic gallenkamp shaker by mixing a fixed adsorbent dose (20 ± 0.2 mg) of nanofiber membrane in 5 ml of 50 mg.l⁻¹ of dye concentration at 200 rpm, the solution was shaken until the equilibrium was achieved.
In order to evaluate the efficacy of dyes removal by the adsorbent, following parameters were analysed; Contact time (1–10 min), pH solution (1–9), adsorbent dosage (5–25 mg), and initial dye concentration (50–300 mg l⁻¹). After the dye adsorption, the nano fiber membrane were separated out manually and the samples were analysed by UV–vis spectrophotometer for the residual dye concentration at wavelength of (λmax-592 nm) for RB19. Adsorption efficiency (AE %) was determined according to the following eq.

\[
\text{Adsorption efficiency (AE)} = \frac{(C_0 - C_t)}{C_t} \times 100\%
\]

(1)

Where \(C_0\) (mg l⁻¹) and \(C_t\) (mg l⁻¹) are the initial and final dye concentrations at time t, respectively. To compare the validity of kinetic and isotherm models, error analysis was also established using following relation.

\[
\text{SSE} = \sum_{i=1}^{N} (q_{cal} - q_{exp})^2
\]

(2)

Where, \(q_{cal}\) and \(q_{exp}\), are the calculated and experimental adsorption capacities of zein/nylon nanofibers, respectively.

2.3. Characterizations

The surface morphology of zein/nylon co-electrospun nanofibers membrane before and after adsorption was examined using SEM (S3000N by Hitachi, Japan) with accelerating voltage of 10 kV and maximum magnification of 300,000x after sputtering with Au/Pd. The average diameter of nanofiber was measured using image-J analysis software (image pro R plus, version 5.1, Media cybernetics, Inc.) from SEM images. The chemical structure of zein/nylon nanofibers membrane was characterized by FTIR spectroscopy (IR presige-21 by Schimadzu, Japan) using ATR mode. Ultraviolet-visible (UV–vis) spectrophotometer (Perkin Elmer, USA) was used to measure absorbance of dye solution before and after adsorption experiments. Tensile properties of the zein/nylon nanofibers membrane was determined using titan universal tester (titan 3–910) at jog speed of 1000 mm.min⁻¹. All the tests were performed at room temperature (23 °C–25 °C) followed by ASTM D-638 Standard test method.
3. Results and discussions

3.1. Physical and chemical analysis
The SEM images of neat Zein, Nylon-6 and composite of zein/nylon nanofibers is presented in figures 2(a)–(c). The morphology of zein and nylon-6 nanofibers were bead free and smooth. The average mean diameter of zein, nylon-6 and zein/nylon nanofiber (figures 2(d)–(f)) were found to be 130, 100, 150 nm respectively. The probable reason for slightly average diameter increment in the zein/nylon composite nanofibers is may be due to solvent residual of formic acid which can cause to swell the obtained nanofibers of zein [21].

The chemical analyses of neat zein, pure nylon and blended zein/nylon nanofibers were performed using ATR-FTIR, in order to corroborate functional groups present in the nanofibers. The FTIR spectra of nanofibers in the range of 1000–4000 cm\(^{-1}\) are demonstrated in figure 3. The broad absorption peak at 3300 cm\(^{-1}\) of neat zein nanofibers as shown in spectrum figure 3(a) related to (–NH\(_2\) stretching vibration). Whereas, the characteristic bands indicative of amide vibrational bands at 1655 cm\(^{-1}\), 1584 cm\(^{-1}\), 1478 cm\(^{-1}\) and 1335 cm\(^{-1}\) indicated amide I, amide II, and amide III; correspond to (C=O) stretching, (N–H) bending and axial deformation vibrations of (C–N) stretching respectively [29]. On the other hand spectrum (b) shows the absorption band of nylon-6. The peaks at 3308 cm\(^{-1}\) and 2850 cm\(^{-1}\) are mainly related with NH stretching and –CH symmetric stretching vibrations, respectively. The amide vibrational bands at 1642 cm\(^{-1}\) (amide I, C=O stretch), and 1542 cm\(^{-1}\) (amide II, C–N stretch and CO–N–H bend). Additionally, the peak at 680 cm\(^{-1}\) is
indicative of (O–C–N) bending [30]. The peak of 1616 cm$^{-1}$ (amide I) is observed for the zein/nylon which is attributed to the amino groups of blend nanofibers. The spectrum (c) of blended zein/nylon nanofibers show that amide I, amide II, peaks were slightly shifted to lower wavenumber for zein/nylon nanofibers when compared to pure zein and nylon nanofibers. For instance, the amide I peak was observed at 1616 cm$^{-1}$ for zein/nylon, similarly, the amide II peak was shifted to lower wavenumber as absorption peak of amide II was observed at 1536 cm$^{-1}$, for zein/nylon. The peak shift of amide I and amide II to lower wavenumbers for zein/nylon nanofibers suggested the interaction became more pronounced for nanofibers samples. In fact, the region from 3400–2800 cm$^{-1}$ of zein/nylon nanofibers resembles with nylon-6 FTIR region, while the region from 1700–500 cm$^{-1}$ closely resemble with zein component. This confirms successful blending of two different polymers.

### 3.2. Adsorption study of nanofibers

#### 3.2.1. Effect of contact time

In order to reach to the best material for RB19 removal, it was realized to compare the adsorption efficiencies of Zein nanofiber, Nylon-6 nanofiber and Zein/Nylon-6 nanofibers. The preliminary results suggested that Zein/Nylon-6 nanofibers were comparatively better for RB19 removal followed by Zein nanofibers and Nylon-6 nanofibers. Therefore, further optimization was made on composite nanofibers. Decolorization of RB19 from aqueous solution was investigated at different time intervals to attain the maximum adsorption by the zein/nylon nanofibers as presented in the figure 4. It is clearly shown that, the rapid and significant removal of RB19
by the nanofibers membrane, was found to be 85% in just 60 s of contact and within 10 min of shortest equilibrium time, the total dye was decolorized, which is relatively higher than other well-known adsorbents. The rapid uptake of dye is due to faster rate of dye mobility towards the abundant vacant sites of the adsorbent. After certain period of time the rate of adsorption was observed to be slightly down this trend may be due to accretion of dye molecules onto available sites [31]. This breakthrough performance of zein/nylon nanofibers is significant for industrial application due to its high efficiency at minimum time.

To calculate the amount of dye adsorbed, different models such as, pseudo-first-order (equation (1)), pseudo-second order kinetic (equation (2)) and intraparticle diffusion models (equation (3)) were used [32].

$$\log (q_e - q_t) = \log q_e - \frac{k_1}{2.503} t$$  \hspace{1cm} (3)

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{q_e}{c}$$  \hspace{1cm} (4)

$$q_t = k_i t^{0.5} + c$$  \hspace{1cm} (5)

Where $q_t$ (mg.g$^{-1}$) is the dye concentration on nanofibers at the time t, $q_e$ (mg.l$^{-1}$) is the solution phase concentration of RB19 at equilibrium, $k_1$ (min$^{-1}$), $k_2$ (g.mg$^{-1}$.min$^{-1}$) and $k_i$ (mg.g$^{-1}$.min$^{0.5}$) are the rate constants associated with pseudo first, pseudo second and intraparticle diffusion models respectively. The calculated kinetics parameters and the correlation coefficients ($R^2$) are given in table 1. Analysis and validation of experimental data to different models suggested that the adsorption of RB19 can be better explained by pseudo second order model rather than pseudo first order as shown in figures 5(a) and (b). The correlation coefficients values ($R^2$) for RB19 obtained from the Pseudo-second-order kinetic model were found to be over 0.99 which is greater than pseudo first order. Also, the experimental values of $q_e$ are very similar to the values calculated by the pseudo-second-order equation ($q_{cal}$). Thus, the adsorption can be better described by the pseudo-second-order kinetic model rather than the pseudo-first-order kinetic model. The best fit of the second-order expression suggests that the chemisorption mechanism is involved in the adsorption [33].

To determine the rate-limiting step involved in the adsorption of dyes by the adsorbent, the intra-particle diffusion model was applied to analyze the kinetic data, according to this model the plot $q_t$ versus $t^{0.5}$ must be linear and should pass through the origin for rate controlling mechanism in intra particle diffusion model. Figure 6(c) clearly shows that adsorption of RB19 on zein/nylon nanofiber consists linear plot between $q_t$ versus $t^{0.5}$ without passing through origin that does not favor intraparticle diffusion mechanism but external diffusion or surface adsorption is the rate controlling step.

3.2.2. The effect of pH on adsorption

The pH of solution is an important parameter to be considered during the adsorption process, as it can influence the degree of ionization of dye, surface charge of the adsorbent, and also dye molecule structure. The adsorption of dye RB19 onto zein/nylon nanofiber membrane was studied at different pH to determine the optimum pH for maximum adsorption as shown in figure 6(a). It was found that the maximum adsorption of RB19 occurred at pH 3. When the pH is low, the adsorbent surface becomes more protonated due to increase in $H^+$ concentration, which increase the electrostatic interaction between the dye anionic (-SO$_3^-$) and adsorbent surface (-NH$_3^+$) resulting more contact between each other that increase the adsorption efficiency [34]. However increasing the pH cause decrease removal efficiency, this is due to more negatively charged ions formed that cause deprotonation of amino groups in zein/nylon nanofibers; as a result adsorbent surface charge turned from highly positive to highly negative, this causing the electrostatic repulsion between adsorbent surface and dye solution.
3.2.3. The effect of adsorbent dosage

The adsorbent dose is an important parameter in adsorption studies which define the removal efficiency of dye in the given mass of adsorbent. In this study, the removal efficiency of RB19 on the certain mass of nanofiber was investigated at initial dye concentration of 50 mg.l\(^{-1}\) under optimum conditions of pH and time. Figure 6(b) shows that the adsorption of RB19 in the acidic medium increased with the increase in the adsorbent dosage, this is because at higher dosage more binding sites were available and greater surface area that tended to increase dye adsorption. The maximum adsorption efficiency of nanofiber was about 98% at 20 mg nanofiber mass at room temperature.

3.2.4. The performance of different adsorbents

The effect of RB19 on three different adsorbent types such as; Zein, Nylon and composite membrane of Zein/Nylon nanofibers were studied under the optimized parameters (dye concentration 50 mg.l\(^{-1}\), mass of nanofibers 20 mg, pH = 3 and time 10 min) and shown in figure 7(a). The higher adsorption efficiency can be observed on Zein/nylon nanofibers is the result of electrostatic interaction between the dye anionic (–SO\(_3\)) and more active site of the membrane (–NH\(_3^+\)) [21]. Whereas, slightly lower adsorption of pure Zein nanofibers refers to aqueous instability and cause destabilize surface charge. In contrast, lowest adsorption of nylon nanofibers is effect of repulsive forces among the dye molecule and adsorbent surface which further reduced the adsorption efficiency. In addition, the mechanical properties of nanofibers were also compared as shown in figure 7(b). In order to enhance Zein tensile property, nylon was blended with Zein nanofibers to promote the amide linkages and more compact structure. Resulting, slippage of nanofibers reduced, and elasticity improved. The tensile property of was found to 4.6 MPa for zein/nylon nanofibers compared to 0.6 MPa of pure zein nanofibers [27].
3.2.5. The effect of initial dye concentration and Adsorption Isotherms.

The adsorption is greatly influenced by the concentration of the analyte. The adsorption of RB19 on the adsorbent surface of zein/nylon was studied at different initial concentration ranging from 50–300 mg.l\(^{-1}\) at constant temperature and optimum conditions of time, pH and nanofiber mass figure 8. The dye adsorption capacities onto adsorbent increased with the increase of the concentration of dye solutions, the maximum adsorption capacities for RB19 reached 61.2 mg.g\(^{-1}\). It was observed that the removal efficiency of dyes declined slightly with rise in initial dye concentration. This may be due to more vacant number of active sites and large specific area which was subsequently occupied by the dye molecule leading to saturation stage and reduction in further removal of RB19 from aqueous phase [35].

To calculate the adsorption capacity of RB19 on the surface of adsorbent, two well-known adsorption models namely Langmuir and Freundlich [36, 37] isotherm were used respectively to analyze the adsorption isotherms illustrated as:

\[
\frac{c_e}{q_e} = \frac{1}{b \times q_{\text{max}}} + \frac{c_e}{q_{\text{max}}}
\]

\[
\log q_e = \log k_f + \frac{1}{n} \log c_e
\]

Where \(q_{\text{max}}\) is the maximum adsorption capacity (mg.g\(^{-1}\)), \(c_e\) is the equilibrium solution phase concentration, \(b\) is related to adsorption free energy and specifies the adsorbent-dye affinity. \(K_f\) is adsorption capacity and the value 1/n from Freundlich isotherm gives information about the relative distribution of active sites; the relative parameter values calculated from the Langmuir and the Freundlich models were listed in table 2.

For Langmuir model, \(q_{\text{max}}\) which is a measure of monolayer adsorption capacity of the zein/nylon, was calculated 70 mg g\(^{-1}\) for RB19. The values of \(b\) were found to be within the range from 0 to 1, indicating that the zein/nylon adsorbent were suitable for Langmuir adsorption for RB19 as shown in figure 9(a) and Freundlich model, figure 9(b). The value of \(n\) reveals the favorability and degree of heterogeneity. Calculated from Freundlich model, \(n > 1\) suggesting favorable adsorption conditions. Based on R2 value and error analysis, both isotherms favor RB19 adsorptions.

To compare the adsorption capacity of current work were compared with the previously used materials for RB19 (table 3). It was observed that the Zein/Nylon-6 nanofibers possessed good adsorption capacity. Moreover, the adsorption time achieved from this new Zein/Nylon-6 composite nanofibers for significant dye removal was minimum (i.e. 5 min) that is the distinctive quality of this adsorbent compared to previously reported materials.

![Figure 9.](image)

Table 2. Isotherm parameters for the adsorption of RB19 on Zein/nylon-6 nanofiber.

| Model     | \(q_{\text{max}}\) (mg.g\(^{-1}\)) | \(b\) (L.g\(^{-1}\)) | \(R^2\) | SSE |
|-----------|-----------------------------------|----------------------|--------|-----|
| Langmuir  | 61.2                              | 0.114                | 0.98   | 0.034 |
| Freundlich| \(\frac{1}{n}\) \(K_f\) \(R^2\) | 12.14                | 0.98   | 0.032 |

![Figure 9.](image)
3.3. The binding mechanism of dye on nanofibers

Figure 10 shows the IR of blended zein/nylon nano fibers. The broad peak at 3298 cm$^{-1}$ corresponds to (\(-\text{NH}_2\) stretching vibration). The stretching at 2950 cm$^{-1}$ and 2845 cm$^{-1}$ are related to (\(-\text{CH}\)) asymmetric and symmetric stretching. The broad/sharp peaks at 1640 cm$^{-1}$, 1535 cm$^{-1}$, 1440 cm$^{-1}$ and 1250 cm$^{-1}$ were indicative of amide I (C=O stretching vibration), amide II (N-H bending) and amide III (axial deformation vibrations of C–N stretching) respectively. While after adsorption with RB19 dye on blended zein/nylon nanofibers, as it can be seen that substantial changes occurred, the new bands at 1050 cm$^{-1}$ and 1210 cm$^{-1}$ were the peaks of –SO$_3$ asymmetric stretchings of dye, that confirm the attachment of dye on nanofibers. The peak due to \(\text{NH}_2\) stretching also reduced in intensity that suggests that \(\text{NH}_2\) group from zein/nylon nanofibers participated in adsorption. Some bands near 1300 cm$^{-1}$ also overlapped with fresh zein/nylon nanofiber sample that may due to interaction of sulphonate groups of dye with C–N groups of zein/nylon. From the FTIR study, it may be assumed that sulphonate group from dye had preferentially attacked –C–N region of zein/nylon nanofibers. This can be possible either through electrostatic means or by hydrogen bonding from NH group that may have altered C–N stretching.

4. Conclusion

Efficient and economically viable nanofibers were fabricated via co-electrospinning of two different polymers for RB19 removal from aqueous solution within 10 min of adsorption. The acidic pH was favorable for maximum adsorption of anionic dye with the removal efficiency of 94%. The dosage 20 mg was sufficient enough to decolorize total dye RB19 at room temperature with adsorption capacity of 61.2 mg g$^{-1}$ of nanofiber which is comparatively higher than other well known adsorbents. The binding mechanism between dye and nanofibers is the result of both physical and chemical interactions. The nanofibers are simple, economic with no secondary toxic sludge and minimum waste generation, due to its high surface area and low volume. Another
advantage of this nanofiber membrane is its potential application for dye filtration as blending of zein/nylon composite nanofiber membrane showed excellent mechanical strength of 4.6 MPa compared to 0.6 MPa of pure zein nanofibers.

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Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

Note

The authors declare no competing financial interests.

ORCID iDs

Mujahid Mehdi  https://orcid.org/0000-0002-4564-303X
Zaheer Khatri  https://orcid.org/0000-0001-8779-3805
Ick Soo Kim  https://orcid.org/0000-0003-2244-4369

References

[1] Gupta V 2009 Application of low-cost adsorbents for dye removal—a review J. Environ. Manage. 90 2313–42
[2] Gök Ö, Ozcakar A S and Ozcakar A 2010 Adsorption behavior of a textile dye of Reactive Blue 19 from aqueous solutions onto modified bentonite Appl. Surf. Sci. 256 5439–43
[3] Nga N K, Chau N T T and Viet P H 2020 Preparation and characterization of a chitosan/MgO composite for the effective removal of reactive blue 19 dye from aqueous solution Journal of Science: Advanced Materials and Devices 5 65–72
[4] Malakootian M, Mansoorian H J, Hosseini A and Khanjani N 2015 Evaluating the efficacy of alumina/carbon nanotube hybrid adsorbents in removing Azo Reactive Red 198 and Blue 19 dyes from aqueous solutions Process Safety and Environmental Protection 96 125–37
[5] Mouraviev G and Mahmoudi M 2009 Removal of azo and anthraquinone reactive dyes from industrial wastewaters using MgO nanoparticles J. Hazard. Mater. 168 806–12
[6] Zhang Y-R et al 2014 A dual function magnetic nanomaterial modified with lysine for removal of organic dyes from water solution Chem. Eng. J. 239 250–6
[7] Cseri L, Topuz F, Abdulhamid M A, Alammari A, Budd P M and Szekely G 2021 Electrosprun adsorptive nanofibrous membranes from ion exchange polymers to snare textile dyes from wastewater Adv. Mater. Technol. 6 2000955
[8] Du L, Quan X, Fan X, Wei G and Chen S 2020 Conductive CNT/nanofiber composite hollow fiber membranes with electrosprun support layer for water purification J. Membr. Sci. 596 117613
[9] Satheesh R et al 2016 Removal of congo red from water using quercetin modified α-Fe2O3 nanoparticles as effective nanoadsorbent Mater. Chem. Phys. 180 53–65
[10] Crini G 2006 Non-conventional low-cost adsorbents for dye removal: a review Bioresour. Technol. 97 1061–85
[11] Alatalo S-M et al 2016 Meso- and microporous soft templated hydrothermal carbons for dye removal from water Green Chem. 18 1137–46
[12] Silva N, Souza M, Silva I Jr, Dos Santos Z and Rocha M 2015 Removal of reactive turquoise blue dye from aqueous solution using a non-conventional natural adsorbent Sep. Sci. Technol. 50 1616–28
[13] Zuorro A, Laura M and Levecchia R 2013 Tea waste: a new adsorbent for the removal of reactive dyes from textile wastewater Advanced Materials Research 803 26–9
[14] Batool S, Imran Z, Hassan S, Rasoool K, Ahmad M and Rafiq M 2016 Enhanced adsorptive removal of toxic dyes using SiO2 nanofibers Solid State Sci. 55 13–20
[15] Xue J, Wu T, Dai Y and Xia Y 2019 Electrosprinning and electrosprun nanofibers: Methods, materials, and applications Chem. Rev. 119 5298–415
[16] Mehdi M et al 2018 Preparation of colored recycled polyethylene terephthalate nanofibers from waste bottles: Physicochemical studies Adv. Polym. Tech. 37 2820–7
[17] Topuz F, Holzta T and Szekely G 2021 Scavenging organic micropolutants from water with nanofibrous hypercrosslinked cycloextrin membranes derived from green resources Chem. Eng. J. 419 128443
[18] Xie X, Zheng Z, Wang X and Lee Kaplan D 2021 Low-density silk nanofibrous aerogels: fabrication and applications in air filtration and Oil/Water purification ACS nano 15 1048–58
[19] Paraman I and Lamsal B P 2011 Recovery and characterization of α-zein from corn fermentation coproducts J. Agric. Food Chem. 59 3071–7
[20] Alkan D et al 2011 Development of flexible antimicrobial packaging materials against Campylobacter jejuni by incorporation of gallic acid into zein-based films J. Agric. Food Chem. 59 11003–10
References:

[21] Qureshi U A, Khatri Z, Ahmed F, Khatri M and Kim I-S 2017 Electrospun zein nanoﬁber as a green and recyclable adsorbent for the removal of reactive black S from the aqueous phase ACS Sustainable Chemistry and Engineering 5 4340–51

[22] Yao C, Li X and Song T 2007 Fabrication of zein/hyaluronic acid ﬁbrous membranes by electrospinning J. Biomater. Sci. Polym. Ed. 18 731–42

[23] McManus M C et al 2006 Mechanical properties of electrospun ﬁbrinogen structures Acta Biomater. 219–28

[24] Huang L, Nagapudi K, Apkarian P and Chaikof R 2001 EL. Engineered collagen–PEO nanoparticles and fabrics J. Biomater. Sci. Polym. Ed. 12 979–93

[25] Holt A et al 2021 Blends of Poly (butylene glutarate) and Poly (lactic acid) with enhanced ductility and composting performance ACS Applied Polymer Materials. 3 1652–63

[26] Ignacz G, Fei F and Szekely G 2018 Ion-stabilized membranes for demanding environments fabricated from polybenzimidazole and its blends with polymers of intrinsic microporosity ACS Appl. Nano Mater. 1 6349–56

[27] Phan D-N, Lee H, Huang B, Mukai Y and Kim I-S 2019 Fabrication of electrospun chitosan/cellulose nanofibers having adsorption property with enhanced mechanical property Cellulose. 26 1781–93

[28] Hussain N et al 2020 A facile approach to synthesize highly conductive electrospun aramid nanoﬁbers via electroless deposition Mater. Chem. Phys. 255 123614

[29] Ali S, Khatri Z, Oh K W, Kim I-S and Kim S H 2014 Zein/cellulose acetate hybrid nanoﬁbers: Electrospinning and characterization Macromol. Res. 22 971–7

[30] Zarrini K, Rahimi A A, Alhosseini F and Fashandi H 2017 Highly efﬁcient dye adsorbent based on polyaniline-coated nylon-6 nanoﬁbers J. Clean. Prod. 142 3645–54

[31] Ma J et al 2012 Enhanced adsorptive removal of methyl orange and methylene blue from aqueous solution by alkali-activated multiwalled carbon nanotubes ACS Appl. Mater. Interfaces 4 5749–60

[32] Mousavi S et al 2018 Efﬁcient dye adsorption by highly porous nanoﬁber aerogels Colloids Surf. A 547 117–25

[33] Wang S, Wei J, Ly S, Guo Z and Jiang F 2013 Removal of organic dyes in environmental water onto magnetic-sulfonic graphene Nanocomposite CLEAN–Soil, Air, Water 41 992–1001

[34] Xu H, Zhang Y, Jiang Q, Reddy N and Yang Y 2013 Biodegradable hollow zein nanoparticles for removal of reactive dyes from wastewater J. Environ. Manage. 125 33–40

[35] Mahar F K et al 2019 Rapid adsorption of lead ions using porous carbon nanofibers Chemosphere. 225 360–7

[36] Mahar F K et al 2017 Dyeability of recycled electrospun polyethylene terephthalate (PET) nanofibers: Kinetics and thermodynamic study J. Mol. Liq. 248 911–9

[37] Abbasi A et al 2020 Adsorptive defluoridation from aqueous solution using a novel blend of eggshell powder and chitosan nanofibers Mater. Res. Express 7 125005

[38] Mousa K M and Taha A H 2016 Adsorption of reactive blue dye onto natural and modiﬁed wheat straw American Journal of Chemical Engineering 4 9–15

[39] Dehvari M, Ghaneian M T, Ebrahimi A, Jamshidi B and Moosab M 2016 Removal of reactive blue 19 dyes from textile wastewater by pomegranate seed powder: isotherm and kinetic studies International Journal of Environmental Health Engineering 5 5

[40] El-Bindary A, Abd El-Kawi M, Hafez A, Rashed I and Aboelnaga E 2016 Removal of reactive blue 19 from aqueous solution using rice straw fly ash J Mater Environ Sci 7 1023–36

[41] Monsef Khoshhesahs Z and Ahmadi M 2016 Removal of reactive blue 19 from aqueous solutions using NiO nanoparticles: equilibrium and kinetic studies Desalin. Water Treat. 57 20037–48

[42] Ayazi Z, Khoshhesahs Z M and Norouziz S 2016 Modeling and optimizing of adsorption removal of Reactive Blue 19 on the magnetite/graphene oxide nanocomposite via response surface methodology Desalin. Water Treat. 52 235301–16

[43] Jiang X, Sun Y, Liu L, Wang S and Tian X 2014 Adsorption of CI Reactive Blue 19 from aqueous solutions by porous particles of the grafted chitosan Chem. Eng. J. 235 151–7