Monitoring of ORP, pH and DO in heterogeneous Fenton oxidation using nZVI as a catalyst for the treatment of azo-dye textile wastewater

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The nanoscale zero valent iron-Fenton (nZVI-Fenton) process combines the advantages of nZVI reduction and Fenton oxidation, was regarded as a very effective process for the treatment of azo-dye/textile wastewater. In this paper, we present the results of the investigation of the on-line monitoring of oxidation-reduction potential (ORP), pH, and dissolved oxygen (DO) to evaluate the effectiveness of the nZVI-Fenton process for the removal of color and chemical oxygen demand (COD) from azo-dyes textile wastewater. The experimental results indicated that the optimal doses of nZVI and H2O2 for color removal were 60–80 mg/L and 300–400 mg/L, respectively. The nZVI reduction removal around 80–90% of the color; however, less than 15% of the COD was removed. To attain the desired removal of COD, much higher doses of nZVI and H2O2 were required, i.e., 200–225 mg/L and 1000–1125 mg/L, respectively. ORP, pH, and DO had direct and meaningful correlations with the removal efficiencies of both color and COD. Thus, regression models and artificial neural networks (ANN) models were used to predict the color and COD removal efficiencies using the monitoring data acquired for ORP, pH, and DO. The ANN model provided very precise prediction results with R² values in the range of 0.96–0.99. The predictions provided by the regression model had R² values in the range of 0.92–0.95. These results indicated that on-line ORP, DO, and pH monitoring data can be used as input to either model to obtain a reliable evaluation of the effectiveness of the nZVI-Fenton process for the removal of color and COD from azo-dyes textile wastewater.

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1. Introduction

Wastewaters from dyeing and other textile processes contain high levels of color, refractory organics, and solids, and they are difficult to treat with conventional wastewater treatment processes [1–3]. The Fenton process, the most popular of the advanced oxidation processes (AOPs), has been regarded as one of the most efficient processes for the removal of color and refractory COD from wastewaters produced by dyeing, textile manufacturing, and other industrial processes [4–6]. In addition, nZVI can effectively remove color from textile wastewaters that contain azo, reactive, and acid dyes [7–9].

The nZVI-Fenton process is one of the heterogeneous Fenton oxidation processes that uses nZVI as the catalyst. This process combines the advantages of nZVI reduction and Fenton oxidation, and it is regarded as a very effective process for treating wastewater that contains dyes and other waste products from the textile manufacturing industry [10,11]. In addition, the nZVI-Fenton process is regarded as a greener process than the conventional Fenton process [12,13]. When the nZVI-Fenton process is used to treat textile wastewaters, it is usually preceded by an nZVI reduction process mainly for color removal. Subsequently, H2O2 is added to react with the Fe2+ generated by the nZVI reduction reactions to generate hydroxyl radicals. Thus, a subsequent, Fenton-like oxidation is provided to remove the color and COD in textile wastewaters [11,14]. The nZVI-Fenton process also can reduce the typical problems associated with the conventional Fenton process, i.e., the consumption of significant quantities of chemical reagents and the production of significant quantities of chemical sludge, both of which increase operational costs [2,15,16]. However, since the nZVI-Fenton process is much more complex and dynamic than the conventional Fenton process, on-line monitoring and control are very critical for the optimal operation of the process. Unfortunately, the techniques required to

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achieve the required monitoring and control rarely are discussed in the literature.

The monitoring of ORP, pH, and DO provides economical, flexible, and effective parameters for the successful control of various biological and chemical wastewater treatment processes [17–22]. ORP, pH, and DO also have been monitored for process identification and control in the Fenton series of processes [23–30]. The addition of nZVI to a dye solution will significantly decrease the ORP due to the high reductive potential of the nZVI. In addition, the reaction of nZVI with azo-dye materials consumes hydrogen ions [11], thereby increasing the pH in the reactor [8]. Also, nZVI consumes DO [31], so the monitoring of ORP, DO, and pH is important because they have great potential to serve as control parameters for the nZVI-Fenton process.

For more effective simulation of the nZVI-Fenton process, an ANN model also was used in this study because ANN models can be highly effective at representing the correlations between input and output parameters in complex systems [32–34].

2. Materials and methods

2.1. The nZVI-Fenton reactor and textile wastewater

A cylindrical, batch, laboratory-scale nZVI-Fenton reactor with an effective volume of 1.50 L (100 cm² cross-sectional area and a height of 15 cm) was set up in this study, as shown in Fig. 1. A 150-rpm mechanical mixer was installed in the reactor to provide sufficient mixing. The on-line monitoring units included a pH probe (Mettler-Toledo, Switzerland), an ORP probe with an Ag/AgCl electrode (Mettler-Toledo, Switzerland), and a DO probe (InPro 6050, Mettler-Toledo M300, Switzerland). These probes were installed in the reactor for on-line monitoring of ORP, pH, and DO. All probes, meters, and dosing pumps (peristaltic micro-tubing pumps) (Masterflex, USA) were connected to a personal computer (PC). LabVIEW 7.1 software (National Instruments, USA) was utilized for on-line data acquisition and dosage control.

In this study, a synthetic textile wastewater was prepared by adding 136.8 mg/L of Reactive Black B dye (I-HWA, Taiwan) and 320 mg/L of polyvinyl alcohol (CH2:CHOH)2 (Panreac, Spain) into distilled water. Reactive Black B dye is one of the most extensively used azo dyes in the textile industry, and polyvinyl alcohol is the main source of COD in textile wastewater. The principal characteristics of this synthetic textile wastewater were its COD range of 750–810 mg/L and its true color range of 7500–8300 ADMI 31 WL units.

2.2. Chemicals and experimental procedure

The nZVI was synthesized in the laboratory using a sodium borohydride reduction method [8]. A 0.45 M solution of iron chloride (FeCl3·6H2O, J.T. Baker, USA) was added dropwise into a 0.25 M solution of sodium borohydride (NaBH4, J.T. Baker, USA) with high-speed stirring at 500 rpm without temperature or pH adjustments. After removing most of the supernatant in the synthesized nZVI solution, the nZVI particles were ready for use. The typical sizes of the particles in this synthesized nZVI were

![Fig. 1. Schematic diagram of the batch nZVI-Fenton reactor and monitoring system in this study.](image-url)
approximately 100–120 nm, as detected by the scanning electron microscope (SEM). The X-ray diffraction (XRD) analysis also showed a peak at 2θ = 44.87°.

Batch nZVI-Fenton experiments were conducted with different initial doses of nZVI and successive doses of H₂O₂. Twenty-eight runs of the nZVI-Fenton experiment were conducted using 13 different nZVI dosages, ranging from 40 to 250 mg/L, with successive concentrations being increased by 10–25 mg/L, the successive doses of H₂O₂ were five times greater than the initial nZVI doses [35].

A volume of 1.5 L of the synthetic textile wastewater was pumped into the reactor. According to studies by Lin et al. [7] and Moon et al. [10], the optimal pH was 3.0 for the removal of azo dyes by nZVI. However, the successive Fenton oxidations were even more critical than nZVI reduction for the removal of COD from the textile wastewater. In addition, the reactions of nZVI with the azo dye materials increased the pH values in the reactor [8,11]. Therefore, an initial pH of 2.0 for the textile wastewater was used in this study because it benefitted the successive Fenton oxidations and did not significantly reduce the efficiency of color removal by nZVI [11].

The prepared nZVI particles were added to the reactor to react with the Reactive Black B dye for color removal, and a contact time of 30 min was allowed for the nZVI reduction, after which H₂O₂ was added to the reactor so the subsequent Fenton-like oxidation could occur. The H₂O₂ reacted with the remaining Fe²⁺ ions that were formed by nZVI to generate hydroxyl radicals. A Fenton-like reaction was conducted for the continuous removal of color and COD from the textile wastewater. A reaction time of 30 min also was provided for this subsequent Fenton oxidation.

During the nZVI reduction period, wastewater samples were withdrawn every 2.5–10 min for 31 WL ADMI true color analysis (ADMI Tristimulus method 2120E), and the COD values also were measured every 10 min according to the closed reflux method (5220D) of the Standard Methods [36]. The true color, COD, and residual H₂O₂ (Iodometric method/4500F) were measured every 10–20 min in the subsequent Fenton oxidation period. The DO, pH, and ORP values in the reactor were simultaneously monitored online throughout the nZVI-reduction and Fenton-oxidation periods. All of the nZVI-Fenton experiments were conducted in an air-conditioned laboratory with a room temperature of 22–25 °C.

3. Results and discussion
3.1. Color and COD removal by the nZVI-Fenton process

Color and COD are the most critical pollutants in textile wastewater. The typical mechanism for color removal of azo dyes by nZVI is presented in following equations [11,37]:

\[
\text{Fe}^0 \rightarrow \text{Fe}^{2+} + 2e^- \tag{1}
\]

\[
2e^- + 2H^+ \rightarrow H_2 \tag{2}
\]

\[
-N=N- + 2e^- + 2H^+ \rightarrow -\text{NH} + -\text{NH} \tag{3}
\]

The nZVI removes the color of azo dyes by simultaneously destroying the azo linkages and generating Fe²⁺ ions. The Fe²⁺ ions that are generated can react with the H₂O₂ that is subsequently added, providing the Fenton oxidation that removes color and COD in textile wastewater. Fig. 2 shows typical color removal efficiencies for different nZVI and H₂O₂ doses during the nZVI-Fenton process. The color removal efficiencies increased rapidly as the nZVI was added to the reactor, and they became stable after a reaction time of 10 min. The color removal efficiencies were approximately 40% and 67% when the nZVI dose was 40 and 125 mg/L, respectively. Then, color removal efficiencies were improved to around 70% and 80% after Fenton oxidation with successive additions of 200 and 625 mg/L of H₂O₂, respectively.

The color removal can reach around 80% after Fenton oxidation for doses of nZVI in the range of 60–80 mg/L and doses of H₂O₂ in the range of 300–400 mg/L. Color removal did not increase significantly for doses of H₂O₂ greater than 400 mg/L after Fenton oxidation. In this study, the optimal doses of nZVI and H₂O₂ for the removal of color from textile wastewater were 60–80 mg/L and 300–400 mg/L, respectively. After coagulation and sedimentation, the final color removal efficiency typically was greater than 95% when the optimal doses were used.

Fig. 3 presents typical COD removal efficiencies of the nZVI-Fenton process for different dosages of nZVI and H₂O₂. The nZVI reduction did not contribute to significant COD removal, so the subsequent Fenton oxidation was more critical than the nZVI reduction. The nZVI reduction only removed 10–15% of the COD even for the high initial dose of nZVI, i.e., 250 mg/L. It also was noted that the overall COD removal efficiencies were only about 30–35% by the nZVI-Fenton process for the optimal doses for color removal, i.e., initial nZVI doses of 60–80 mg/L and H₂O₂ doses of 300–400 mg/L. However, the COD removal efficiency finally reached about 80% after Fenton oxidation with nZVI doses of 225–250 mg/L and H₂O₂ doses of 1125–1250 mg/L. In this study, the COD removal efficiencies after Fenton oxidation were close to the results obtained using Electro-Fenton for treating RB49 textile
wastewater with similar influent characteristics and Fe\textsuperscript{2+} dosages [30], indicating more effective COD removals than a conventional Fenton process. Typically, the COD removals became stable at a Fenton oxidation period of 20–25 min, and they increased typically as the dosages of nZVI and H\textsubscript{2}O\textsubscript{2} increased.

The Fenton series of processes provide dual functions, i.e., oxidation and coagulation, to remove color and COD from textile wastewaters [26,37]. Fig. 4 shows the COD removals after oxidation and coagulation. COD removal can reach around 85–95% after coagulation and sedimentation, whereas only 63% and 76% of COD were removed by oxidation alone. Therefore, for the final COD removal from textile wastewater in this study, the optimal nZVI doses were 200–225 mg/L and the H\textsubscript{2}O\textsubscript{2} doses were 1000–1125 mg/L, which resulted in the removal of around 76% of the COD after oxidation, and these doses were much greater than those required for optimal color removal. The overall color removals typically were greater than 96% when the optimal doses of nZVI and H\textsubscript{2}O\textsubscript{2} were used for COD removal.

**Fig. 4.** Variations of COD removal efficiencies after oxidation and after coagulation/sedimentation of the nZVI-Fenton process.

**Fig. 5.** Variations of ORP, DO, pH and color and COD removal efficiencies during the nZVI reduction and Fenton oxidation of nZVI-Fenton process (nZVI = 150 mg/L, H\textsubscript{2}O\textsubscript{2} = 750 mg/L).
3.2. Variations of monitoring ORP, pH, and DO in the nZVI-Fenton process

The nZVI-Fenton process involves both reduction and oxidation reactions; therefore, significant variations in ORP values were found in the reactor. In addition, the DO and H₂/OH⁻ joined the reactions in the nZVI reduction or/and Fenton oxidation, and the variations in pH and DO in the reactor also indicated the characteristics of this reduction–oxidation reaction.

Fig. 5 presents the typical variations that occurred in the monitoring of ORP, pH, and DO during the nZVI reduction and successive Fenton oxidation for the initial doses of nZVI and H₂O₂, i.e., 110 and 550 mg/L, respectively. The ORP dropped sharply from +75 mV to −300 mV as nZVI was added. This occurred because the nZVI had a very strong reductive capacity, with the standard potential of −0.440 V (Fig. 5(a)). The ORP values typically decreased as more nZVI was added during the reduction period. However, after H₂O₂ was added in the successive Fenton oxidation period, the ORP values increased drastically, from around −300 mV up to around +500 mV, because hydroxyl radicals, which are strong oxidants, were generated. Greater increases of ORP values typically occurred for greater doses of H₂O₂ (Fig. 5(b)).

Several possible reactions can increase the pH during the reduction of the azo dyes by nZVI. According to Eqs. (1)–(3), nZVI consumes hydrogen ions in its destruction of the azo linkages of the dyes for color removal. In addition, the reaction of metal reduction consumes hydrogen ions, as shown in Eq. (4); the nZVI will react with DO in the aqueous solution and release hydroxyl ions, as shown in Eq. (5); and the primary production of ferrous iron from nZVI can undergo a further oxidation reaction and form the ferric ion, which also produces hydroxyl ions, as shown in Eq. (6) [31,38,39]. Therefore, pH increased as nZVI was added to the reactor due to the reactions described above.

\[
\text{Fe}^{2+} + \text{RX} + \text{H}^+ \rightarrow \text{Fe}^{2+} + \text{RH} + \text{X}^- \quad (4)
\]

\[
2\text{Fe}^{2+} + \text{O}_2 + 2\text{H}_2\text{O} \rightarrow 2\text{Fe}^{3+} + 4\text{OH}^- \quad (5)
\]

\[
2\text{Fe}^{2+} + 2\text{H}_2\text{O} \rightarrow 2\text{Fe}^{3+} + \text{H}_2 + 2\text{OH}^- \quad (6)
\]

### Table 1

Details of input/output parameters, network architectures and optimization algorithm/results for the regression and BPN models.

<table>
<thead>
<tr>
<th>Model</th>
<th>Input parameter</th>
<th>Output parameter</th>
<th>(R^2)</th>
<th>Regression equation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Regression model</strong></td>
<td></td>
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<tr>
<td>(R_1)</td>
<td>nZVI dose, ΔORP\text{red, red}, ΔpH\text{red, red}, ΔDO\text{red, DO, red, ORP\text{red}}</td>
<td>(R_{\text{color-red}})</td>
<td>0.923</td>
<td>(R_{\text{color-red}} = 58.78 + 0.132026(\text{nZVI dose}) + 14.23213(\Delta DO_{\text{red}}) + 18.13423(\Delta ORP_{\text{red}}) + 0.004723(\Delta pH_{\text{red}}) - 14.6084(\Delta DO_{\text{int}}) - 0.03391(\Delta pH_{\text{int}}))</td>
</tr>
<tr>
<td>(R_2)</td>
<td>nZVI dose, ΔORP\text{red, red}, ΔpH\text{red, red}, ΔDO\text{red, DO, red, ORP\text{red}}</td>
<td>(R_{\text{color-ox}})</td>
<td>0.925</td>
<td>(R_{\text{color-ox}} = 33.33827 - 0.22368(\text{nZVI dose}) - 77.8624(\Delta ORP_{\text{red}}) - 0.00364(\Delta pH_{\text{red}}) + 2.016761(\Delta DO_{\text{red}}) - 0.00248(\Delta ORP_{\text{ox}}) + 43.53078(\Delta pH_{\text{ox}}) + 0.461698(\Delta DO_{\text{ox}}) - 0.035216(\Delta pH_{\text{ox}}) + 9.778475(\Delta ORP_{\text{ox}}) + 73.8624(\Delta pH_{\text{ox}}) - 0.00053(\Delta ORP_{\text{ox}}) - 21.468(\Delta DO_{\text{ox}}) - 2.43411(\Delta DO_{\text{ox}}) + 0.00897(\Delta ORP_{\text{ox}}) + 28.22989(\Delta pH_{\text{ox}}) - 0.8416(\Delta DO_{\text{ox}}))</td>
</tr>
<tr>
<td>(R_3)</td>
<td>nZVI dose, ΔORP\text{red, red}, ΔpH\text{red, red}, ΔDO\text{red, DO, red, ORP\text{red}}</td>
<td>(R_{\text{COD-ox}})</td>
<td>0.951</td>
<td>(R_{\text{COD-ox}} = -25.32215787 + 0.416402513(\text{nZVI dose}) - 0.00053(\Delta ORP_{\text{red}}) - 21.468(\Delta DO_{\text{red}}) - 2.43411(\Delta DO_{\text{red}}) + 0.00897(\Delta ORP_{\text{red}}) + 28.22989(\Delta pH_{\text{ox}}) - 0.8416(\Delta DO_{\text{ox}}))</td>
</tr>
<tr>
<td><strong>BPN model</strong></td>
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</tr>
<tr>
<td>(A_1)</td>
<td>nZVI dose, ΔORP\text{red, red}, ΔpH\text{red, red}, ΔDO\text{red, DO, red, ORP\text{red}}</td>
<td>(R_{\text{color-red}})</td>
<td>0.980</td>
<td>6–9–1</td>
</tr>
<tr>
<td>(A_2)</td>
<td>nZVI dose, ΔORP\text{red, red}, ΔpH\text{red, red}, ΔDO\text{red, DO, red, ORP\text{red}}</td>
<td>(R_{\text{color-ox}})</td>
<td>0.959</td>
<td>7–10–1</td>
</tr>
<tr>
<td>(A_3)</td>
<td>nZVI dose, ΔORP\text{red, red}, ΔpH\text{red, red}, ΔDO\text{red, DO, red, ORP\text{red}}</td>
<td>(R_{\text{COD-ox}})</td>
<td>0.994</td>
<td>7–10–1</td>
</tr>
</tbody>
</table>

where nZVI dose is the initial dosage of nZVI in the reduction period; ΔORP\text{red, red}, ΔpH\text{red, red}, ΔDO\text{red, red, ORP\text{red}} are the differences between initial and final ORP, pH, DO values in the reduction period; ΔORP\text{ox, red}, ΔpH\text{ox, red, DO, ox, red, ORP\text{ox}} are the differences between initial and final ORP, pH, DO values in the oxidation period; \(R_{\text{color-red}}\) and \(R_{\text{color-ox}}\) are color removal efficiencies by the nZVI reduction and Fenton oxidation, respectively; \(R_{\text{COD-ox}}\) is COD removal efficiency after Fenton oxidation.
Complex chemical reactions were involved in both color and COD removal by Fenton oxidation; both hydrogen and hydroxide ions can be consumed or generated during the process [3,40]. However, decreases in pH occurred during the Fenton oxidation period because more hydrogen ions than hydroxide ions were produced, a finding that was consistent with other similar studies [26,41].

Fig. 5 shows the variations pH during the nZVI reduction and Fenton oxidation. The pH values increased from an initial value of 2.0 to the range of 2.1–2.3 as nZVI was added. The pH values became stable after a reduction time of about 15 min. Greater increases in the pH values also were observed as greater doses of nZVI were added to the reactor. However, the pH values decreased back to around 2.0 during the Fenton oxidation period, and it became stable after 25 min of contact time. It also was noted that stable pH values indicated the endpoint for color removal in the nZVI reduction, as well as for COD removal in the Fenton oxidation period, and this information can be useful in controlling the required contact times for the nZVI-Fenton process. In this case, the required contact time for nZVI reduction was around 15 min, and it was around 25 min for Fenton oxidation.

DO in the aqueous solution is a typical oxidant that accepts electrons. In a typical nZVI process, DO is consumed by reacting with the electrons generated from the corrosion of nZVI in the water, as shown in Eq. (5). Fig. 5 shows the variations of DO during the nZVI reduction and Fenton oxidation. The DO decreased rapidly from around 7.0 mg/L to near zero. Afterward, the DO values increased slightly to around 1.0 mg/L for some cases of nZVI doses less than 125 mg/L. Otherwise, the DO dropped to zero and remained there. The concentration of DO was zero for a long time during the Fenton oxidation, but it increased when the pH became stable. This increase of DO was in response to the endpoint of COD removal and the accumulation of H₂O₂ in the reactor, which can assist in controlling the required contact time and proper H₂O₂ dosages or H₂O₂/Fe°C ratios for the Fenton series processes [30]. For the most part, the concentration of DO remained low at the end of Fenton oxidation period, indicating that proper H₂O₂ dosages were used in the study.

### 3.3. Use of ORP, pH, and DO monitoring data in the evaluation of the removals of color and COD by the nZVI-Fenton process

The chemical dosages of nZVI and H₂O₂ are critical parameters for the control of the nZVI-Fenton process. Fig. 6 presents the correlations of the removal efficiencies of color and COD with the initial nZVI dosages. Both the color removal and COD removal increased as the doses of nZVI increased, and linear correlations were the only acceptable correlations that were identified.

Because variations in the values of ORP, pH, and DO can be correlated theoretically to the removals of color and COD from textile wastewaters by the nZVI-Fenton process, monitoring ORP, pH, and DO can help to evaluate the removals of color and COD in this study. Therefore, for more precise predictions of color and COD removals by the nZVI-Fenton process, changes in the values of pH, ORP, and DO were also included as input parameters to the prediction models. Two types of models, i.e., a multiple regression model and an ANN model, were used in this study. Twenty-eight runs of data sets from the previous nZVI-Fenton experiments for treating textile wastewater that contained azo dyes were used to construct the models. The color removal efficiencies by the nZVI reduction (Rcolor-red) and by the Fenton oxidation (Rcolor-ox), as well as the final COD removal efficiencies after Fenton oxidation (RCOD-ox), were predicted by the regression and ANN models. Details of input and output parameters, the structures of the models, and the predicted results are listed in Table 1.

The multiple regression model provided good prediction results for Rcolor-red and Rcolor-ox with correlation coefficients, R², of 0.92 and 0.93, respectively, as shown in Fig. 7(a) and (b). Moreover, precise prediction of the RCOD-ox with a correlation coefficient, R², of 0.95 also was provided by the regression model, as shown in Fig. 7(c). The equations presented similar trends of color and COD removals based on the variations of the values of ORP, pH, DO and the dose of nZVI (Table 1).

ANN models can effectively represent the correlations between input and output parameters in complex, non-linear systems. A
typical back-propagation neural network (BPN) model consists of three layers, i.e., input, hidden, and output layers, and these three layers were used. This BPN model used the generalized, delta-learning rule as its training algorithm, the gradient-descent method to minimize error, the sigmoid function as the activation function, and root mean square (RMS) to evaluate the performances of the training and test procedures. The ANN models provided very precise prediction results for $R_{\text{color-red}}$, $R_{\text{color-ox}}$, and $R_{\text{COD-ox}}$ with correlation coefficients, $R^2$, of 0.98, 0.96, and 0.99, respectively, as presented in Fig. 8. The BPN model provided more precise prediction results of $R_{\text{color-red}}$, $R_{\text{color-ox}}$, and $R_{\text{COD-ox}}$ than the regression model, indicating that the ANN model has a greater potential to be a control approach for the nZVI-Fenton process.

Both the regression and BPN models provided precise prediction results of the extent to which the nZVI-Fenton process could remove color and COD from textile wastewater that contained azo dyes. A key factor in this achievement was the determination of the values of ORP, pH, and DO by on-line monitoring and their subsequent use in the models. The BPN models provided more precise prediction results than the regression model.

4. Conclusions

This study presents the application of on-line monitoring of ORP, pH, and DO to evaluate the color and COD removal efficiencies from azo-dyes textile wastewater by the nZVI-Fenton process. The experimental results indicated that the nZVI-Fenton process can effectively remove color and COD from the azo-dyes textile wastewater with performance similar to that of the Fenton process. The on-line monitoring of ORP, pH, and DO provided direct and meaningful correlations with the color and COD removals, and they were used as input parameters to the BPN and regression models that were used to predict the color and COD removal efficiency of the nZVI-Fenton process. The BPN models predicted very precise results for both of color and COD removal efficiencies by the nZVI-Fenton process with the $R^2$ values of 0.96–0.99. The BPN model has good capabilities for correlating the relationships between the monitored ORP, pH, DO with color and COD removal efficiencies, presenting high potential for the control of the nZVI-Fenton process.

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