Modification of Textile Wastewater Treatment System by Gamma-Irradiation


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Abstract: To modify a textile wastewater treatment process, the effects of gamma-ray treatment on the biodegradability and toxicity of wastewaters from each unit process of a textile wastewater treatment plant (WWTP) were investigated in this study. Gamma-irradiation did not improve the biodegradability of the raw wastewater (RW) and wastewater after coagulation and flocculation (WCF), but it increased the biodegradability of the final effluent (FE) from 0.008 to 0.17 at a dose of 20 kGy. In addition, gamma-rays significantly improved the biodegradability of weight-loss wastewater (WLW) from 0.72 to 0.91 at a specific dose of 1 kGy. An acute toxicity test, using Daphnia magna, showed that the toxicity change induced by gamma-rays was dependent on the chemical property of the wastewater. Thus, gamma-irradiation decreased the toxicity of RW while increasing the toxicity of WCF. For FE and WLW samples, no toxicity change was observed after radiation treatment. From this study, it appears that radiation treatment of WLW following biological treatment is most desirable.

Keywords: gamma-rays, textile wastewater, radiation treatment, acute toxicity test

Introduction

Wastewater released by the textile industry is almost 22.2 %, amounting to 524277 m³/day, of all of the industrial wastewater produced in Korea [1]. The textile industry is a major source of discharging wastewater, which contains various refractory and toxic chemicals, such as complexing, sizing, wetting, softening, and finishing agents, surfactants, dyes, and many other additives. For the treatment of textile wastewater, chemical coagulation and biological treatment methods are generally used. However, recalcitrant chemicals are not successfully removed by conventional treatment processes. In addition, it has been reported that textile wastewater may remain toxic even after treatment [2,3].

Advanced oxidation processes (AOPs), such as ozonation, the Fenton process, photocatalysis, and radiation treatment, were widely used to purify wastewaters containing refractory chemicals. Compared with other techniques, radiation treatment using gamma-rays is a simple and efficient approach that can remove various organic compounds and disinfect pathogenic microorganisms [4]. Recently, a few studies on applying gamma-rays to the treatment of textile dyes were reported [5]. However, these studies focused mainly on the efficiency of gamma-ray treatment alone.

From an economic point of view, the combination of radiation treatment with conventional techniques, such as biological treatment, is most promising [6]. Therefore, it is necessary to investigate any improvement in biodegradability induced by gamma-rays. In addition, toxicity evaluation is important for gamma-ray-treated wastewater because gamma-irradiation could increase the toxicity of wastewater. For instance, gamma-irradiation efficiently degrades phenol solutions, but the toxicity of the solution was increased after treatment [7]. In this study, therefore, the effects of gamma-rays on the biodegrada-
Table 1. Characteristics of Textile Wastewaters Used in this Study

<table>
<thead>
<tr>
<th></th>
<th>RW(^a)</th>
<th>WCF(^b)</th>
<th>FE(^c)</th>
<th>WLW(^d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>12.75</td>
<td>6.61</td>
<td>7.73</td>
<td>13.38</td>
</tr>
<tr>
<td>Color (ADMI(^e))</td>
<td>1243</td>
<td>1404</td>
<td>352</td>
<td>n.d.(^f)</td>
</tr>
<tr>
<td>TOC (mg/L)</td>
<td>577</td>
<td>411</td>
<td>33</td>
<td>9470</td>
</tr>
<tr>
<td>COD (mg/L)</td>
<td>1827</td>
<td>1214</td>
<td>89</td>
<td>25738</td>
</tr>
<tr>
<td>BOD(_5) (mg/L)</td>
<td>827</td>
<td>694</td>
<td>2</td>
<td>21100</td>
</tr>
<tr>
<td>SS (mg/L)</td>
<td>74</td>
<td>820</td>
<td>46</td>
<td>420</td>
</tr>
</tbody>
</table>

\(^a\) Raw Wastewater  
\(^b\) Wastewater after Coagulation and Flocculation  
\(^c\) Final Effluent  
\(^d\) Weight-Loss Wastewater  
\(^e\) American Dye Manufacturers Institute  
\(^f\) Not determined

Experimental

Textile wastewaters, such as raw wastewater (RW), wastewater after coagulation and flocculation (WCF), final effluent (FE), and weight-loss wastewater (WLW), were obtained from a wastewater treatment plant at the Daegu Dyeing Industrial Complex in Korea (Figure 1). The sampling points of the textile wastewaters used in this study are indicated.

Gamma-ray treatment of textile wastewaters was performed at room temperature in a high-level \(^{60}\)Co source (AECL IR79, Canada). Samples for gamma-ray treatment were prepared in 1000-mL amber bottles in contact with the atmosphere and irradiated at different dose rates for 2 h.

The color was determined using a DR/4000 spectrophotometer (Hach). The total organic carbon (TOC) was measured using a Shimadzu TOC analyzer (model 5000A). Biodegradability was measured by the ratio of the 5-day biochemical oxygen demand to the chemical oxygen demand (BOD\(_5\)/COD). The BOD\(_5\) values were determined according to the Korea Standard Methods of Water Quality [8]. The COD values were determined using a colorimeter (Thermo Orion AQ2040, USA) and test kits (Humas HS-COD, Korea) in accordance with Standard Methods.

The 48-h acute toxicity tests, before and after gamma-irradiation, were performed using \(Daphnia magna\), which was obtained from cultures at the Korea Research Institute of Chemical Technology. Acute toxicity tests were performed according to the OECD standard procedure [9]. Each toxicity test consisted of five dilutions and one control, with four replicates per treatment. Each test vessel contained 10 mL of the test solution and five animals. All toxicity tests were conducted at 20±2 °C with a 16:8 h light:dark photoperiod. Immobilization data were used to calculate the 24-h EC\(_{50}\) through US EPA Probit analysis. The evaluation of toxicity was performed by transforming the EC\(_{50}\) values into toxicity units (TU=100/EC\(_{50}\)).

Results and Discussion

Gamma-Ray Treatment of Textile Wastewaters

The textile wastewaters used in this study were characterized as shown in Table 1. In particular, WLW exhibited high pH as well as high COD and TOC values, which were caused by the large amounts of ethylene glycol and terephthalic acid that are decomposition products of polyester fabrics. The effects of gamma-rays on the decomposition of textile wastewaters were
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Figure 3. TOC changes of textile wastewaters after gamma-ray treatment. The descriptors \( C_0 \) and \( C \) indicate the concentrations before and after gamma-ray treatment, respectively.

Figure 4. COD changes of textile wastewaters after gamma-ray treatment. The descriptors \( C_0 \) and \( C \) indicate the initial and final concentrations, respectively.

Figure 5. BOD\(_5\) changes of textile wastewaters after gamma-ray treatment. The descriptors \( C_0 \) and \( C \) indicate the initial and final concentrations, respectively.

Figure 6. Biodegradability changes of textile wastewaters after gamma-ray treatment.

evaluated as a function of the absorbed dose by determining the changes in the color, TOC, COD, and BOD\(_5\). As shown in Figure 2, gamma-ray treatment significantly removed the color from RW and FE. The color removal was 40 % at 5 kGy for RW and 34 % at 1 kGy for FE. It is well known that gamma-rays are quite effective at mediating the color removal of wastewater [10-12]. The reduction of color is caused mainly by the decomposition of residual dyes [13]. The efficiency of gamma-irradiation on the TOC removal of textile wastewaters is shown in Figure 3. Gamma-ray treatment hardly decreased the TOC value of wastewaters. Only the TOC value of FE was decreased by 13 % at a dose of 10 kGy. This result suggests that gamma-ray treatment alone cannot completely degrade organic wastes into CO\(_2\).

Figure 4 shows the COD change of textile wastewaters after gamma-ray treatment. The COD changes after gamma-ray treatment depended upon the type of wastewater. In particular, the COD value of FE decreased by 55 % at 20 kGy, whereas for WCF, the value increased by 14 % at a dose of 5 kGy. This increase in the COD value is due to terephthalic acid, which is the main component decomposed from polyester fabrics. According to a previous study, we found that the COD of terephthalic acid increased significantly after gamma-ray treatment [14]. The BOD\(_5\) change of the textile wastewaters after gamma-irradiation is given in Figure 5. Gamma-ray treatment slightly reduced the BOD\(_5\) values of RW and WCF (by 12 and 9 %, respectively). However, the BOD\(_5\) values of FE and WLW increased dramatically (by 917 and 41 %, respectively) at 5 kGy. This increase in the BOD\(_5\) may be caused by conversion of recalcitrant compounds into biodegradable forms upon
gamma-irradiation. A few studies on radiation treatment of wastewaters have found that gamma-rays increased the BOD$_5$ value of wastewaters by degrading toxic or recalcitrant materials [15,16].

The biodegradability changes of the textile wastewaters after gamma-ray treatment are shown in Figure 6. The ratio of BOD$_5$/COD is usually used in evaluating the biodegradability of wastewater. Wastewater can be considered substantially biodegradable if it has a BOD$_5$/COD ratio between 0.4 and 0.8 [17]. The Gamma-rays had little effect on the biodegradability improvement of RW and WCF, but they significantly increased the biodegradability of FE from 0.008 to 0.17 at 20 kGy. However, the value of the biodegradability ratio was far less than 0.4. The biodegradability of WLW, which was initially biodegradable (BOD$_5$/COD = 0.72), also further improved to ca. 1.00 at 5 kGy. The increased biodegradability of WLW could be caused by decomposition of ethylene glycol, which is less biodegradable than terephthalic acid, but is degraded better by gamma-rays [14].

These biodegradability changes are somewhat different from those described previously, where an absorbed dose of 1 kGy was found to be the most effective to increase the biodegradability of WLW by gamma-rays [6]. These contrasting results might be caused by differences in the WLW samples. In this study, on the basis of TOC and COD values, around three times concentrated WLW was used. The noticeable improvement in the biodegradability suggests the benefit of performing combined gamma-ray and biological treatment of WLW. For instance, radiation treatment with electron beams was successfully applied for pretreatment of the Daegu Dyeing Industrial Complex wastewater, including WLW. In this process, preliminary electron-beam treatment was found to improve biological treatment through radiolytic transformation of organic pollutants in WLW [18].

Toxicity of Textile Wastewaters
To investigate the effects of gamma-rays on the toxicity of textile wastewaters, Daphnia acute toxicity tests were performed. In particular, the toxicity of the FE sample was not observed either before or after gamma-ray treatment. As indicated in Figure 7, the toxic unit (TU) value of RW decreased after gamma-irradiation, indicating a reduction of toxicity. In contrast, radiation treatment of WCF significantly increased the TU value from 2.32 to 4.44. These results indicate that the change in toxicity after gamma-irradiation is largely dependent on the chemical properties of the textile wastewater. According to Borrely and coworkers, wastewater toxicity can be increased when hydrogen peroxide is produced as a radiation byproduct in a less-aggressive environment [19]. For the WLW sample, the acute toxicity was examined as a function of the absorbed dose of gamma-rays. As shown in Figure 8, no significant change was observed in the toxicity of WLW after gamma-irradiation. Toxicity identification evaluations (TIE) of RW, WCF, and WLW samples are in progress to evaluate the change in toxicity after gamma-irradiation.

Conclusions
Radiation treatment of textile wastewaters showed that gamma-irradiation could improve the biodegradability of WLW and FE samples; this result suggests a benefit to combine this process with conventional biological treatment methods. Because FE samples treated even at a dose of 20 kGy are not biodegradable, however, gamma-ray treatment of WLW, rather than FE, is preferred. Considering the changes in the biodegradability and toxicity after gamma-ray treatment, pretreatment of WLW at comparatively low doses (less than 1 kGy in this study) is recommended. However, the optimum dose
should be carefully selected because the value is largely dependent on the composition of the WLW.

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References