Gamma Irradiation of Polyvinyl Alcohol Wastewater: Optimization by Using Response Surface Methodology

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Introduction
Polyvinyl alcohol (PVA) is a typical refractory organic pollutant with low biodegradability (Chen et al., 2000) and high molecular weight which is difficult to degrade by conventional wastewater plants. In addition, the global annual consumption of PVA had been over 1,000,000 tons (Inoguchi and Chinn, 2010). Large amount of discharged PVA from industrial effluents has become a significant pollution. Ionizing radiation is a special advanced oxidation process. Through water radiolysis, hydroxyl radicals, hydrated electrons and hydrogen atoms, etc. are produced to react with pollutants. So far, little research (Zhang and Yu, 2004; Zhang et al., 2005) was reported on PVA radiolysis. This research focused on the multi-factors effect on PVA degradation by using Box-Benhken design (BBD) and response surface methodology (RSM).

Methods
Gamma radiation was carried out in a $^{60}$Co source at 158 Gy/min. PVA (the average polymerization degree 1700 ± 200) solutions were irradiated in radiation-proof glass tubes ($\phi = 20$ mm). PVA content was analysed according to the procedure described by Finley (Finley, 1961). For test design, data analysis and model building, a Design Expert 8.0.0 software was employed.

Table. 1. Experimental ranges and levels of the independent variables

<table>
<thead>
<tr>
<th>Factor</th>
<th>Unit</th>
<th>Symbol</th>
<th>-1</th>
<th>0</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>mg/L</td>
<td>$X_1$</td>
<td>50</td>
<td>125</td>
<td>200</td>
</tr>
<tr>
<td>concentration</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Absorbed dose</td>
<td>kGy</td>
<td>$X_2$</td>
<td>0.5</td>
<td>2.75</td>
<td>5.0</td>
</tr>
<tr>
<td>Initial pH</td>
<td>-</td>
<td>$X_3$</td>
<td>1.0</td>
<td>7.0</td>
<td>13.0</td>
</tr>
</tbody>
</table>

Results
Model F-value of 5.64 implied the model was significant, and a negative predicted $R^2=0.94$ implied the overall mean was a good predictor. The signal to noise ratio of 7.60 indicated an adequate signal. Thus, the model could be used to navigate the design space. The equation of the design space was shown in Eq. 1. In addition, $X_2$, $X_1X_2$, $X_1^2$, $X_2^2$ were the significant model terms due to their values of "Prob $>F$" less than 0.05. Through numerical optimization of the software, the optimal ranges (PVA removal rate $>90\%$) were obtained at acidic condition and alkaline condition, respectively. A three-dimensional plot and its respective contour plot were shown in Fig. 1.

$$
Y = 11.7767 + 0.51941X_1 + 19.0617X_2 - 2.50324X_3 + 0.08385X_1X_3 - 0.00044X_1X_3 - 0.02963X_2X_3 - 0.00262X_1^2 - 3.80247X_2^2 + 0.19722X_3^2
$$

(1)
Discussion and Conclusions

Due to $X_2$, $X_1X_2$ were the significant model terms, the most important factors which affected PVA removal by gamma radiation were the primary effect of absorbed dose, and the interaction between absorbed dose with PVA initial concentration. As Fig. 1 showed, when PVA initial concentration was at a low level, e.g., 50 mg/L, the PVA removal efficiency increased firstly, then decreased with absorbed dose increasing. Under gamma radiation, soluble monomers and polymers in aqueous solution could be converted into higher molecular weight substances (Getoff, 1996), and hydrogen-abstracted PVAs could recombine (Zhang et al., 2005). Therefore, both PVA polymerization and PVA recombination might exist during PVA radiolysis except PVA decomposition. The same tendency of absorbed dose and initial pH on PVA degradation was observed. Whenever how absorbed dose levels changed, PVA removal efficiency always decreased at first, and then increased with the pH value increasing. At acidic conditions, γ-lactone was the form of a terminal group of PVA. The combination of proton and lone pair electron formed a new bond that destroyed the ester bond in the acidolysis process. At alkaline conditions, the terminal group of PVA was carboxyl salt. PVA degradation mechanism might be dominated by dynamic process (Xia et al., 2000). Therefore, acid and alkali played a catalytic role in PVA degradation.

References


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Disclosures

Authors have nothing to disclose.