The Design and Application of Fuzzy Controller in a Novel Plasma Water Treatment System

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Abstract

In water treatment engineering, pH value is one of the most important parameters for optimizing experimental results. Because pH process has serious nonlinearity and delay, it is difficult to obtain effective control for conventional PID controllers without a precise mathematical model. According to the behavior of pH in the process of water treatment, a fuzzy control approach is proposed. The fuzzy controller is simulated with the actual data, and the simulation results demonstrate that the approach is efficient and feasible. In present paper, we construct a novel water treatment system based on microwave plasma technique and TiO$_2$ photocatalytic technique. Experimental results show that the system can enable the value of chemical oxygen demand (COD) and heavy metal ions in water up to the Standards for Drinking Water Quality (GB5749—2006), also it can effectively reduce costs when the fuzzy controller is employed.

Keywords: Fuzzy controller; Drinking water; Plasma; COD.

1 Introduction

Drinking water pollution has become one of the most serious environmental problems. Conventional water treatment methods, such as physical, chemical, and biological techniques, have limitations in water treatment process for their shortcomings of less efficiency, high cost and the possibilities of secondary pollution. In recent years, considerable engineering research and development have focus on advanced oxidation processes (AOPs) which, such as microwave plasma technique and the TiO$_2$ photocatalytic oxidation technique, have become superior techniques for water treatment [1,2]. Therefore, microwave plasma and TiO$_2$ photocatalytic oxidation techniques are adopted in present paper. The principle is described as following. In certain conditions, the microwave can induce gas to discharge with ultraviolet
light emitting. When TiO$_2$ photocatalyst is exposed to ultraviolet light, it can generate much reactive hydroxyl radicals (·OH) on the surface of photocatalyst. Hydroxyl radicals that oxidize a broad range of pollutants quickly and non-selectively can lead to complete mineralization of organic carbon into CO$_2$ [3,4]. In the process of reaction, pH value of the solution which has great impact on the activity of TiO$_2$ photocatalyst varies at all time. It is necessary to keep pH value constant. Because pH process has serious nonlinearity and delay, it is difficult to have an ideal control effect for conventional PID controllers without a precise mathematical model. However, a fuzzy controller which has been proved efficient and feasible by simulation is designed and applied into the water treatment system.

2 pH fuzzy control system

2.1 System structure

The block diagram of pH fuzzy control system is shown in Fig. 1 [5,6]. It uses a two-dimensional single variable fuzzy controller. The error (e) and the rate of change of error (ec) are input variables, u is the output variable. $K_e$ and $K_{ec}$ are quantization factors, $K_u$ is the scale factor. pHs and pHr are the set value and real value of pH respectively. E, EC and U are symbols of subset of e, ec and u. $G_o(s)$ is the mathematical mode of controlled object.

![Fig.1 Block diagram of pH fuzzy control system.](image)

2.2 Fuzzy controller

The fuzzy controller that is proposed on the above is based on Mamdani’s fuzzy technique. Fuzzy subsets of the input variable (ec) and output variable (u) are set as {negative large, negative middle, negative small, zero, positive small, positive middle, positive large} ({NL,NM,NS,ZO,PS,PM,PL} for short ). In order to improve the stability and accuracy of the system, fuzzy subsets of the input variable (e) are set as {negative large, negative middle, negative small, negative zero, positive zero, positive small, positive middle, positive large} ({NL,NM,NS,NO,PO,PS,PM,PL} for short). Basic range of E, EC, U are [-6,6], [-6,6], [-3,3] respectively. In present paper, we choose triangle functions to define membership functions of Fuzzy Logic Control on fuzzy variables. According to the practical experience, we conclude 56 fuzzy control rules as shown in Table 1.

<table>
<thead>
<tr>
<th>e</th>
<th>ec</th>
<th>N</th>
<th>M</th>
<th>NS</th>
<th>ZO</th>
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<td>P</td>
<td>P</td>
<td>ZO</td>
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2.3 Simulation

Simulations of the control system including the conventional PID controller have been carried out in MATLAB environment [7]. The simulation results are shown in Fig. 2 and Fig. 3. Fig. 2 shows response curve of conventional PID control system, Fig. 3 shows response curve of fuzzy control system.

Comparing the two figures, it’s seen that fuzzy control system is superior to conventional PID control system. The overshoot of fuzzy control system is much less than conventional PID control system. So the fuzzy controller that is designed in present paper is effective and feasible.

3 Experimental

In the experiment, COD and heavy metal ions content are the two main indicators. The purpose of the experiment is to make the two indicators achieve drinking water standards. The water samples that are difficult to be treated by traditional water treatment methods in the experiment are from Hangzhou West Lake, Hangzhou Xixi River and copper mine factory separately, their COD values are less than 40 mg/L. They are marked with 1, 2, 3 separately. The reactor used in the experiment is refitted by surfatron cavity [8]. Microwave generator is 2450 MHz full solid state microwave generator developed by our laboratory, power is 100W. The chamber is made of glass coated with TiO₂ photocatalyst (anatase) on the inner wall.
Chamber with the surface wave plasma source system excited by microwave assisted-surfatron combine into the water treatment apparatus. The pH value of the fuzzy control system is set to 5.

4 Results

After 20 minutes, we take out the water samples, and measure their COD by the method of potassium dichromate. The COD values of pre-treating, post-treating and COD remove efficiency of every water body are shown in Table 2. Then we use ESI-TOF mass spectrum to measure the content of heavy metal ions in copper wastewater, the results are shown in Fig. 4 and Fig. 5. Fig. 4 shows ESI-TOF mass spectrum of pre-treating copper wastewater (diluted by 10000 times). Fig. 5 shows ESI-TOF mass spectrum of post-treating copper wastewater.

![Fig.4 ESI-TOF mass spectrum of pre-treating copper wastewater](image)

![Fig.5 ESI-TOF mass spectrum of post-treating copper wastewater](image)

Table 2 COD remove efficiency

<table>
<thead>
<tr>
<th>Samples</th>
<th>COD_{Cr} ( O_2 , [mg/L] )</th>
<th>COD remove efficiency [%]</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Pre-treating</td>
<td>post-treating</td>
</tr>
<tr>
<td>1</td>
<td>15.6</td>
<td>2.42</td>
</tr>
<tr>
<td>2</td>
<td>10.4</td>
<td>1.94</td>
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<tr>
<td>3</td>
<td>30.4</td>
<td>4.86</td>
</tr>
</tbody>
</table>

5 Conclusions

This study preliminary indicates that the dynamic quality and stability of the control system is improved largely when the fuzzy controller is introduced. The application of fuzzy controller in water treatment system makes the reduction of COD and heavy metal ions of the water more effectively. This system satisfies with the Standards for Drinking Water Quality (GB5749—2006) and reduces costs [9].
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References