Gerdkian Arc as a Tool for Decomposition of Water-soluble Organic Compounds

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Abstract: Plasma torch with Gerdkian arc was successfully used for decomposition of organic compounds dissolved in water that is forced to swirl around the arc and helps to stabilize it. Therefore treated compounds get to the extreme vicinity of the source of intensive UV radiation. The rapid decrease of the concentrations of treated compounds was measured.

Keywords: Gerdkian arc, decomposition, degradation, water treatment, radiation

1. Introduction
Water pollution is a major problem in the global context and its treatment by processes stimulated by various types of electric discharges has been frequently investigated in recent years. This paper presents the study of capacity of Gerdkian arc for degradation of the organic compounds in water. The plasma torch with high power Gerdkian arc was used for the experiments. In this type of the arc the stabilizing water is in direct contact with plasma of arc column. The main features of Gerdkian arc are very high plasma temperatures and thus high intensity of short-wave ultraviolet radiation. Water flows with high flow rate in a thin layer around the arc column. This configuration results in high level of ultraviolet radiation emitted to water flowing through the torch.

2. Experiments
Hybrid stabilized DC plasma torch WSP®H [1] with the arc power adjustable from 60 to 150 kW was used for experiments. The cathode part of the arc column is created by an arc stabilized by argon flow, argon plasma enters the chamber with Gerdkian arc (the first idea of the arc stabilization by water put out back in twenties by Gerdkian and Lotz [2, 3]), where the arc column is stabilized by a direct contact with water vortex, which surrounds the arc. The schematic of the torch is shown in Fig. 1.

Fig. 1 Schematic of hybrid stabilized plasma torch

Arc power was set up to 100 kW during the experiments and argon flow rate was 22.5 slm. Water with the flow rate of 20 l.min⁻¹ circulates around the arc in the layer depth of 1 mm at the distance of 3 mm from the centreline of high temperature arc column. The centreline...
plasma temperature that was measured by optical emission spectroscopy is 19 000 K [1]. Water is injected tangentially into the arc chamber under constant pressure and flow rate and evaporates at the rate of 15 g.min\(^{-1}\). This value is possible to neglect with regard to the volume of a water tank (40 l) and also to the water mass flow rate (20 kg.min\(^{-1}\)). Water-soluble organic compounds such as dye Orange II, nicotine, oxalic acid and other were placed into the water tank. Water is forced by a pump to flow through the system and swirl around the arc (Fig. 2).

Presented results show decomposition of dye Orange II (1.4 g \(\sim\) \(10^{-4}\) mol.l\(^{-1}\)) and nicotine (0.53 g \(\sim\) 8.2.\(10^{-5}\) mol.l\(^{-1}\)). The changes of concentrations were measured by means of UV/Vis spectroscopy. Intermediates (and partially also final products) produced during degradation [4] were analyzed by total carbon (TC), total organic carbon (TOC), and total inorganic carbon (TIC) measurements.

3. Results and discussion

Absorbance is directly proportional to concentration:

\[ A = \varepsilon l c \]  \hspace{1cm} (1)

where \(A\) is absorbance, \(\varepsilon\) molar absorptivity, \(l\) path length and \(c\) concentration. Absorbance maxima in the spectra of treated water that were measured at different times of experiment showed rapid decrease of the concentrations of dye Orange II (Fig. 3 and 4).

It is possible to see that decomposition proceeds with high effectiveness. All treated dye Orange II passing the torch is decomposed, however, some organic residuals withstood as analyses of total organic carbon revealed. Seemingly slow decomposition rate in Fig. 3 is caused by sampling from the place after the water tank (sampling A) where treated and untreated water is mixed so the resultant concentration can be described by this equation:

\[ \frac{dC}{dt} = -\frac{R}{V} C \]  \hspace{1cm} (2)

where \(R\) is water flow rate (20 l.min\(^{-1}\)), \(C\) concentration, \(t\) time of experiment and \(V\) the volume of the water tank (40 l).
Successful decomposition can be explained by very intensive UV radiation that is emitted by the arc plasma due to its high temperature because centre line temperature is 19000 K at 100 kW [1]. The wavelength ($\lambda_{\text{max}}$) corresponding to the maximum intensity of radiation and other radiation properties might be calculated [5, 6]. $\lambda_{\text{max}}$ for the conditions of the experiments (at power of 100 kW) equals approximately to 150 nm so the emitted UV falls into the far ultraviolet radiation range (FUV) with extremely high energy per photon.

It is necessary to mention that also some reactive species (such as H· and OH· radicals, H$_2$O$_2$ etc.) are formed through the excitation and/or ionization of the water molecules by the energetic electrons [7, 8] and the species react with treated substance. The degradation process will be probably caused by the joint influence of the both effects (UV and reactive species).

Analyses of total carbon (TC), total organic carbon (TOC), and total inorganic carbon (TIC) showed fast decrease of organically bound carbon, however, not as fast as the absorbance spectra revealed (see Table 1.).

Table 1. Total carbon (TC), total organic carbon (TOC), and total inorganic carbon (TIC).

<table>
<thead>
<tr>
<th>Degradation time (min)</th>
<th>TC (mg·L$^{-1}$)</th>
<th>TOC (mg·L$^{-1}$)</th>
<th>TIC (mg·L$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Orange II - sampling A</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>19.37</td>
<td>9.31</td>
<td>10.06</td>
</tr>
<tr>
<td>3</td>
<td>16.08</td>
<td>4.04</td>
<td>12.04</td>
</tr>
<tr>
<td>6</td>
<td>15.88</td>
<td>3.8</td>
<td>12.08</td>
</tr>
<tr>
<td><strong>nicotine - sampling B</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>20.12</td>
<td>8.32</td>
<td>11.8</td>
</tr>
<tr>
<td>12</td>
<td>13.05</td>
<td>2.65</td>
<td>10.4</td>
</tr>
</tbody>
</table>

It is comprehensible when assuming the complex system of chain reactions that lead to the utter decomposition of molecules with high molecular weight (Fig. 5). Organic fragments (intermediates) are formed and analyzed as total organic carbon (TOC). The slight increase of total inorganic carbon is caused by the formation of carbonates which are formed by the oxidation of carbon present at the organic fragments.

Also other compounds such as oxalic acid and chloral hydrate (trichloroacetaldehyde monohydrate) were decomposed by the flow through the torch.

4. Conclusions

It has been shown that Orange II and nicotine dissolved in water were decomposed successfully in hybrid stabilized torch WSP$^\text{H}$ [1], where the treated water flows through the torch and is in a direct contact with the arc so with the very intensive source of far ultraviolet radiation that is probably the main cause of the degradation. However, other not fully understood mechanisms supposedly play a role in degradation process as well. The effectiveness of the process was determined by the measurements of absorbance spectra and analyses of total carbon (TC), total organic carbon (TOC), and total inorganic carbon (TIC).

The direct placing of a treated substance into the part of the plasma torch equipment – into the water circuit that stabilizes the arc column revealed the principal possibility of such an application. However, the torch and the water system have not been optimized for such experiments and...
the presented experiments concern just principal testing for several chemical compounds. That leads to the fact that the ratio energy to mass of decomposed compound is not profitable at all. The optimization of the system would have to include the decrease of the torch power and/or the increase the flow rate through the torch. Also mixing of treated and untreated water is not convenient and should be avoided in the optimized system. Higher concentration of treated compounds would also increase the effectiveness of the process.

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References