Methotrexate degradation in artificial wastewater using non-thermal pencil plasma jet

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The global rise in cancer rates has led to a significant increase in the consumption of anticancer drugs, which, in turn, has resulted in elevated levels of these pharmaceutical compounds in wastewater. Since the human body does not fully metabolize many of these drugs, they are excreted in urine and feces, contributing to their presence in domestic sewage, hospital effluents, and industrial discharges from pharmaceutical manufacturing facilities. This poses a growing environmental challenge, as many anticancer drugs are resistant to degradation by conventional wastewater treatment processes.

Methotrexate, a widely used drug in the treatment of various cancers, exemplifies this problem. Its complex organic structure makes it particularly resistant to traditional degradation techniques, resulting in its persistent presence in wastewater. As such, there is a pressing need for innovative and effective methods to address the environmental burden posed by methotrexate and other anticancer drugs.

In this study, a novel approach using a non-thermal pencil plasma jet (PPJ) is proposed to degrade methotrexate in aqueous solutions. The plasma jet, which generates reactive species in air at atmospheric pressure, was characterized both electrically and spectroscopically. Electrical characterization provided insights into the power dynamics and stability of the plasma, while optical emission spectroscopy identified the reactive species and radicals produced during the plasma discharge, such as reactive oxygen species (ROS) and reactive nitrogen species (RNS). These species play a critical role in breaking down complex organic molecules, such as methotrexate.

The degradation of methotrexate was closely monitored by evaluating several key parameters. Changes in the physiochemical properties of the solution, such as pH, electrical conductivity, and total dissolved solids (TDS), were measured to assess the extent of degradation. High-performance liquid chromatography coupled with ultraviolet detection (HPLC-UV) was employed to quantify the drug concentration over time, while total organic carbon (TOC) analysis was used to gauge the degree of mineralization, or conversion of organic carbon into inorganic compounds like CO_2.

The results of the study were promising. After just 9 minutes of plasma treatment, methotrexate was completely degraded, following first-order degradation kinetics with a rate constant of 0.38 min^{-1}. The mineralization efficiency was found to be 84.54%, indicating that a significant portion of the organic matter was converted into simpler, less harmful compounds. This was further supported by an increase in electrical conductivity and TDS, which suggested the formation of smaller degradation byproducts, such as 2,4-diaminopteridine-6-carboxylic acid and N-(4-aminobenzoyl)-L-glutamic acid.

In addition to chemical degradation, the toxicity of the plasma-treated solution was evaluated using freshwater chlorella algae. The plasma-treated methotrexate solution exhibited significantly lower toxicity compared to the untreated solution, highlighting the potential of this method to not only degrade harmful pharmaceuticals but also reduce their ecological impact.

Overall, the use of non-thermal plasma jets for the treatment of anticancer drug-polluted wastewater shows great potential. Plasma technology is both economically viable and environmentally friendly, as it does not require high temperatures or harmful chemicals. This method could offer a promising solution to the growing issue of pharmaceutical contamination in wastewater, particularly for drugs like methotrexate that are resistant to conventional degradation methods.

References

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