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Ionizing Radiation Induced Decomposition of Antibiotics in Wastewater

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Background of the study

Wide varieties of toxic organic compounds are entering the aquatic environment. The main sources of these impurities are the waste water treatment plants for domestic sewage. The co-occurrence of sublethal antibiotic concentration and high density of microbial population provides ideal condition for facilitating the selection and propagation of resistant bacteria in sewage treatment plants. To reduce the amount of harmful organic compounds entering into the receiving bodies of waste water a family of new technologies with the name advanced oxidation processes (AOP) is under development. In these technologies highly reactive, oxidizing radical intermediates (mainly OH radicals) are produced by various techniques, e.g. , by ionizing radiation. Radiolysis provides the benefit to produce reactive oxidizing ($^{\bullet}OH$ and H_2O_2) and reduce ($O_2^{\bullet}$, e_{aq}^- and $^{\bullet}H$) species (or from a kinetic point of view highly reactive electrophile and nucleophile species) in situ from water

Methodology

Electron pulse radiolysis experiments were conducted using a Tesla Linac LPR-4 accelerator with kinetic spectrophotometric detection. A ^{60}Co facility with 11.5 kGy/h dose rate was used for γ-irradiation. LC/ESI-MS was used for final product analysis. The samples were also characterized by COD, TOC, TN and pH measurements and by complex toxicological analysis.

Results

The oxidative and reductive decomposition of penicillin derivatives was studied, the change in the antimicrobial activity of the drugs was followed. The reaction mechanism of $^{\bullet}OH$ induced oxidation of penicillins indicates the existence of a short-living and a stabilized long-living $^{\bullet}OH$ adduct to the sulfur. The e_{aq}^- is accommodated on the carbonyl groups of the penicillin skeleton yielding ketyl radicals. Penicillins react with the hydrated electron somewhat similarly to a tripeptide. It appeared that excessive or insufficient absorbed dose is deleterious in relation to elimination of antibacterial activity. At low radical exposure the forming products exhibit enhanced toxicity and antimicrobial potency. The adverse effect at high radical exposure presumably arises from the forming polyhydroxylated phenolic compounds.

The $^{\bullet}$OH induced decomposition of sulfonamide antibiotics in dilute solutions was also studied by a wide variety of analytical techniques. The degradation was shown to start with $^{\bullet}$OH addition to the aromatic ring, the cyclohexadienyl type radical thus formed reacts with dissolved oxygen transforming to peroxy radical. This radical yields hydroxylated molecules by $HO_2^{\bullet}$ elimination, or it undergoes ring opening to aliphatic compounds.

Conclusion

It was shown that e_{aq}^- and $^{\bullet}$OH are able to demolish the penicillin's β-lactam system responsible for their antimicrobial activity. However, careful optimization of the advanced oxidation process, determination of the dose necessary for decreasing the toxicity and improving the biodegradability is necessary. Based on complex investigations for both types of antibiotics the degradation with the formation of inorganic ions is multistep process, the molecules first are step-by-step oxidized and then mineralized.

Country/Organization invited to participate

Hungary

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