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Review

Photochemical decomposition of endocrine disrupting compounds – A review

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HIGHLIGHTS

- The photochemical decomposition of six groups of EDCs was reviewed.
- The advantages as well as disadvantages of photochemical methods were presented.
- Despite the modification of catalysts use of visible light it is still inefficient.
- Photosensitized oxidation under visible light is more effective than photocatalysis.
- Singlet oxygen is one of the most promising photochemical oxidants.

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ABSTRACT

Endocrine disrupting compounds (EDCs) are a group of hazardous pollutants, generally present in water environments in very low concentrations and causing adverse effects in living organisms. This paper examines the photochemical decomposition of EDCs, including direct photolysis, advanced oxidation processes (AOPs) and photosensitized oxidation (POx). Particular attention was focused on photocatalytic and photosensitized degradation processes. The most important portions of the report concern the photodegradation of six groups of EDCs: natural hormones and steroids, alkylphenols and bisphenol A, polycyclic aromatic hydrocarbon, preservatives, pesticides and phthalates.

Two new trends in photocatalytic degradation are the immobilization and modification of photocatalysts, which result in eliminating the problem of removing the photocatalyst slurry from purified water and improving the ability to activate photocatalyst in the visible radiation.

Photochemical oxidation, particularly using molecular oxygen, is unquestionably one of the most important photochemical methods because photochemical oxidation does not require additional oxidizers such as ozone or hydrogen peroxide or any additional energy input as are required in cases of ozonation or UV irradiation. The primary reactant formed during photosensitized oxidation is exceptionally reactive species – molecular singlet oxygen.

Although AOPs are effective in removing EDCs from aqueous solutions, the costs of these processes are high; therefore, an interesting option among the photochemical processes appears to be immobilization of the photocatalyst or photosensitizer and using these processes in visible light.

Contents

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Abbreviations

DDT	dichlorodiphenyltrichloroethane
EDCs	endocrine disrupting compounds
PAHs	polycyclic aromatic hydrocarbon
PS	photosensitizer
C	concentration
E_0	photon fluence rate
Φ	quantum yield
DOM	dissolved organic matter
LP	low pressure
MP	medium pressure
HP	high pressure
K	rate constant
Pox	photosensitized oxidation
AOPs	advanced oxidation processes
RB	rose bengal
Rf	riboflavin
HA	humic acids
FA	fulvic acids
SS	simulated sunlight
NS	sunlight
ESHA	Elliott soil humic acid
LHA	Leonardite humic acid
SRHA	Suwanee River humic acid
TOC	total organic carbon
NTs	nanotube arrays
HS	humic substances
SRFA	Suwannee river fulvic acid
NOFA	Nordic lake fulvic acid
NOHA	Nordic lake humic acid
FLHA	Fluka humic acid
CDs	cyclodextrins
α-CD-α	cyclodextrin
β-CD-β	cyclodextrin
CM-β-CD	carboxymethyl-β-CD
HP-β-CD	hydroxypropyl-β-CD
PEG	polyethyleneglycol
TNTs	TiO2 nanotubes
TPP	meso-tetraphenylporphyrin
TPPS4	meso-tetra (4-sulfonatophenyl) porphyrin
CAT	catalyst
K	the dynamic equilibrium constant of EDCs' adsorption onto the carrier/photocatalyst
k_{LH}	Langmuir-Hinshelwood constant – the apparent reaction rate constant
q_m	the maximum compound concentration capable of being adsorbed on the supported catalyst
K_{BET}	the equilibrium constant characterizing the interaction energy of adsorbate on the surface of the adsorbent

Superscripts

*	excited state
1	singlet state
3	triplet state
0	initial conditions

1. Introduction

A specific group of water contaminations present in trace amounts in aqueous environments are highly toxic substances that cause cancers or mutations that interfere with the endocrine glands, thus disrupting essential functions of the organism, including reproduction and development. These pollutants are called xenobiotics, or anthropogenic substances, and do not occur spontaneously in the environment. Nature is unable to cope with the degradation of these compounds biologically because no evolutionary mechanisms can metabolize these compounds. Such substances are often not removed from wastewater treated by conventional methods; these substances are not easily biodegradable and thus accumulate [1–4]. The use of polluted water resources poses a major threat to human health and affects the condition and size of animal and plant populations. Therefore, elimination of hazardous pollution is a subject of research in many scientific centers [5–9].

1.1. Endocrine disrupting compounds (EDCs)

A special group of xenobiotic compounds that have manifested in hormonal activity is called endocrine disrupting compounds (EDCs). These compounds are defined as exogenous substances that alter the function(s) of the endocrine system and consequently cause adverse health effects in organisms, their progeny or (sub) populations [10,11]. A wide range of these substances can be divided into two categories: the compounds naturally occurring in the environment, which are natural hormones, and hormones that are synthesized. The classification is not based on chemical properties and chemical structure, but on biological effects on the endocrine system such as (1) mimicking or antagonizing the action of endogenous hormones, (2) interfering with the synthesis, metabolism, transport and excretion of natural hormones or (3) altering hormone receptor levels. The effects of their actions relate primarily to the wider sphere of reproduction (infertility, sexual underdevelopment, and changes in sexual behavior) [12]; changes in the proper functioning of thyroid, adrenal and pituitary glands [10,11]; and neurological and behavioral disorders (autism and ADHD) [13]. The number of reported cancers and birth defects has increased [3,12]. Although the majority of these reproductive disorders have been observed in animals (mollusks, fish, reptiles, birds, and mammals [14]), according to the precautionary principle, appropriate steps to eliminate these compounds from the environment are required.

The total number of compounds suspected of interacting with the endocrine system is estimated to be approximately 38,000; however, more than 80,000 chemicals require testing to confirm or deny their disrupting action [3]. To identify the list of compounds with endocrine activity, the volume of production,