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Editorial

Editorial Catalysts: Catalysis for the Removal of Water Pollutants

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Water is an essential resource for society, and it is necessary to guarantee its supply and quality. This is not simple, as only 0.6–0.9% of the water on the planet is easily accessible as ground and/or surface water [1,2]. However, the problem is not only the availability of water but also its pollution, which can affect human health and aqueous ecosystems [3]; thus, it is necessary to ensure that the properties of water are kept adequate, mainly when it is used for human consumption. [4].

Together with air pollution, water pollution is one of the most concerning environmental world issues. According to the World Health Organization (WHO), by 2025, half of the world's population will be living in water-stressed areas [5]. In addition, in less-developed countries, 22% of healthcare facilities have no water service, 21% have no sanitation service and 22% have no waste management service. It was estimated that water sanitation and hygiene could have prevented at least 1.4 million deaths and 74 million disability-adjusted life years in 2019 [6].

Safe and readily available water is essential for public health, whether it is used for drinking, domestic use, food production or recreational purposes. Improved water supply and sanitation and better management of water resources can boost countries' economic growth and contribute greatly to poverty reduction. In 2010, the United Nations General Assembly explicitly recognized the human right to water and sanitation. Everyone has the right to sufficient, continuous, safe, acceptable, physically accessible and affordable water for personal and domestic use. According to this, goal 6 of the 2030 Agenda for Sustainable Development is to "Ensure availability and sustainable management of water and sanitation for all", and goal 14 is to "Conserve and sustainably use the oceans, seas and marine resources for sustainable development" [7]. Clearly, both goals can only be achieved by solving the problems related to water pollution.

In developed countries, more stringent water emission limits have been recently established to decrease the problems related to polluted water. The European Union is revising the Urban Waste Water Treatment Directive to achieve a pollution-free environment by 2050, making the focus on the control of micropollutants such as residues from the use of pesticides, pharmaceuticals and cosmetics. These residues are frequently found in water bodies and have a detrimental effect on nature.

In order to accomplish the new legislation, the use of new technologies is necessary. In this way, it is expected that catalysis plays a vital role by transforming pollutants into non-toxic products without the generation of waste. This differs from other techniques used for water treatment based on separation that generate waste that must be treated or disposed of. This is not an easy issue to resolve as these catalysts must be active at room temperature and atmospheric pressure. They must act in the presence of other natural ions and they should be adapted to continuous flow reactors in existent installations. Finally, the catalysts must be stable, avoiding metal leaching and the use of critical raw materials [8].

Photocatalysis is one of the preferred tools to address the problem of organic micropollutants in water. In this Special Issue, different approaches were proposed. The use of zinc ferrite nanoparticles for the efficient degradation of selected textile dyes is described in contribution 1. The authors show that there is an almost complete degradation of the

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selected dye at pH 10, using 0.1 g of $ZnFe_2O_4$ and 6 mM of H_2O_2 in 30 min, indicating that this may be a promising technology for the elimination of toxic organic dyes from water resources.

Silver oxide can also be used as an active photocatalyst for the degradation of recalcitrant organic pollutants. In contribution 2, a more sustainable method for preparing these catalysts was proposed. The authors use silver oxide microparticles for the degradation of a dye, but the catalyst has been synthesized by a low-cost, green method mediated by green tea leaf extract. The synthesized material shows good photoactivity with an 83% degradation of malachite green at neutral pH for 3 h. They also found that the reaction time can be reduced by adding persulfate ions that have a strong synergistic effect. The results revealed that this can be a promising method for the elimination of toxic organic pollutants from the water environment. Another green approach proposed in contribution 3 is the use of powders from basaltic and granitic rocks that degrade dye in synthetic and industrial effluents. It is shown that despite the smaller surface area of this material, it has a considerable photocatalytic activity. Another example of a waste that can be employed as a catalyst precursor is described in contribution 4, using rice husk as a source of silicon in order to prepare a nano-$HTiO_2$-activated carbon-amorphous silica nanocomposite catalyst that is utilized to photobreak and adsorb chlorpyrifos insecticide. All these proposals are interesting approaches to the circular economy's reuse of waste as catalyst precursors.

The presence of pesticides in water is an important problem, mainly in areas with important agricultural activity [9]. Among others, chloroacetanilide herbicides are widely used in the agricultural sector. Because of their poor biodegradability, high water solubility and long persistence, they have a significant potential of contaminating water, and conventional treatment processes do not ensure the sufficient removal of the pollutant. Heterogeneous photocatalysis can be a powerful tool for the control of these pollutants. In contribution 5, it is shown that TiO_2 catalysts can be used for the degradation of alachlor, acetochlor and metolachlor from water. It is described that the concentration of all herbicides during the photocatalysis process decreases. In the paper, an important issue is addressed as the authors discuss the possible toxicity of the degradation products, revealing the importance of using selective catalysts for these reactions.

TiO_2 is the main photocatalyst used on the market, but the reactor configuration may influence the final results. This was studied in contribution 6 using a TiO_2 catalyst for the degradation of phenol with different reactor configurations, i.e., a flat-plate reactor and a compound parabolic collector. The results obtained were not conclusive, but they clearly show that the selection of adequate reaction conditions is essential in these types of reactions, and they must be selected individually for the different types of pollutants/water/catalysts.

Together with pesticides, the massive worldwide use of antibiotics leads to water pollution and increases microbial resistance. Photocatalysis is also the preferred way for the destruction of these molecules. Contribution 7 reports the solar light-assisted oxidative degradation of ciprofloxacin (CPF) using H_2O_2, catalyzed by iron(III)-chelated cross-linked chitosan immobilized on a glass plate. The system was found to serve as an efficient catalyst with maximum CPF degradation at pH 3. Another example, shown in contribution 8, is the use of photocatalysis for the degradation of methylthionine chloride (MTC), a compound with several applications both in the clinical and medical industries. The authors studied MTC degradation in a flat plate reactor through solar photolysis and heterogeneous photocatalysis processes with TiO_2 as a catalyst. The results show that acidic pH is the most appropriate for MTC degradation, which ranged between 56% and 69% for photolysis and between 76% and 87% in photocatalysis.

Endocrine-disrupting compounds are also pollutants that must be treated. An innovative "domino" process, based on arene hydrogenation followed by a photocatalytic step, is described in contribution 9 for the remediation of endocrine-disrupting compounds in highly concentrated aqueous effluents. The novelty relies on the use of TiO_2-supported zerovalent Rh nanoparticles as multicatalytic materials. This nanocomposite material, which was easily prepared by a green, wet impregnation methodology, proved to be active in the successive reactions, i.e., the reduction in the aromatic ring and the photodegradation step. This sustainable approach offers promising alternatives in the case of photoresistive compounds.

The combination of catalytic and photocatalytic processes is another alternative, described in contribution 10, to treat persistent pollutants in the water phase. The authors present a kinetic study that compares the mineralization rate of Acid Blue 80 in a model dyework's wastewater. This study was conducted both in the homogeneous phase using the Fenton and photo-Fenton reactions, UV-C and UVC/H_2O_2 processes and in the heterogeneous phase using commercial photocatalysts based on TiO_2. The results show that photocatalysis could be a more adequate way to treat these pollutants.

The treatment of effluents from urban wastewater treatment plants by a combination of photocatalysis and membranes is discussed in contribution 11. A combination of a photocatalytic TiO_2-coated ZrO_2 UF membrane with solar photo-Fenton treatment at circumneutral pH was used. Membrane photocatalytic self-cleaning properties were tested with these effluents under irradiation in a solar simulator. Both permeate and retentate from the membrane process were treated using the solar photo-Fenton treatment, obtaining interesting results.

Together with photocatalysis, traditional catalytic processes are also used for the removal of water pollutants. Zero-valent metal-based persulfate activation systems are described in contribution 12 for the removal of organic pollutants in aqueous environments. Zero-valent copper is employed as the peroxymonosulfate activator for the efficient degradation of Orange G, providing new insights into water treatment technology using this type of catalyst.

Finally, a revision about the application of nanocatalysts in advanced oxidation processes for wastewater purification appears in the Special Issue (contribution 13). This review paper summarizes the recent studies on applying various types of nanocatalysts for wastewater purification. The authors highlight innovative work and identify issues and challenges to overcome for the practical implementation of nanocatalysts in wastewater treatment plants.

In the near future, new research is expected to appear for the control of persistent organic pollutants with catalytic processes but without forgetting other inorganic pollutants such as nitrates, bromates, chlorates and arsenic compounds [10–14], which can also be removed using these methods. However, the research must be carried out under conditions that resemble, as close as possible, real-world conditions. In order to be competitive, these processes must be performed at neutral pH and in the presence of other ionic and non-solved species; that is, the catalyst must be active with water containing different compounds and some turbidity, this being a possible limiting step for photocatalytic reactions. The design of the reactor is also essential as it is likely the case that the process must treat an enormous volume of water in a continuous flow reactor. The catalyst must be very active and stable as the leaching of the catalyst metals may be a significant problem for the environment. Catalysts must also be very selective, avoiding the formation of by-products that can be more toxic than the original pollutants, and they must be performed at room temperature and atmospheric pressure in order to minimize energy consumption. Finally, the use of scarce raw materials for the catalyst preparation must be avoided, and we must endeavor to find more green approaches in the synthesis of the catalysts.

The ideal catalysts for the future will likely not be a simple material but a combination of different elements and supports (multi-metallic catalysts) that will be used in combination with more conventional physical–chemical processes or membranes.

The diversity of contributions in this Special Issue reflects the plethora of research questions for the control of water pollutants. The control of these pollutants is a necessity all over the world, and from the analysis of the different papers, catalysis and photocatalysis will clearly remain critical processes for the cleansing of polluted water originated from different sources.

I wish to express my sincerest thanks to all authors for their valuable contributions, without which this Special Issue would not be possible, and we hope that the review article and the original research papers edited in this Special Issue contribute to the solution of these challenges.

Conflicts of Interest: The authors declare no conflicts of interest.

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