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Editorial

Photocatalytic Processes for Environmental Applications

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Photocatalysis, especially heterogeneous photocatalysis, is one of the most investigated processes for environmental remediation. Indeed, the use of solar light, which is an infinite source of energy, to activate photocatalysts is a sustainable technology [1]. The conversion of solar light into chemical energy via a heterogeneous photocatalyst is a powerful tool to decontaminate the natural environment (water, air, and soil), but also to produce green energy such as hydrogen, which is considered as the most promising alternative to fossil energy [1]. Beside photocatalysis, other photochemical processes can be used for environmental applications, including the photo-Fenton process and photolysis. The Special Issue on "Photocatalytic Processes For Environmental Applications" summarizes all these crucial challenges that the future generation will have to solve. The Special Issue is available online at https://www.mdpi.com/journal/processes/special_issues/photocatalytic_processes (access date: 19 November 2021).

A well-known family of heterogeneous photocatalysts are transition metal chalcogenides. Among them, the most popular one is titanium dioxide (TiO_2), which is still the most investigated owing to its non-toxicity, low cost, and relatively high efficiency under UVA light. While several methods including the design of composite and doping are often found to successfully increase the photocatalytic activity of TiO_2 under visible light, innovative methods could also be used, such as photocatalytic activation through electron beam [2]. In this special issue, Gallegos et al. have demonstrated that microparticulate TiO_2 activated with e-beam exhibited a higher degradation rate constant for Direct Blue 1 removal [2].

It is worth reminding the photocatalytic mechanism during the degradation of organic pollutants in water. After the generation of electron/hole (e^-/h^+) pairs under suitable irradiation ($h\nu > E_g$), highly reactive inorganic radicals, especially reactive oxygen species (ROS), are produced:

$$h^+ + OH^- \rightarrow HO^\bullet \quad (1)$$

$$e^- + O_2 \rightarrow O_2^{\bullet -} \quad (2)$$

These "primary" radicals are responsible of the efficient degradation of water contaminants.

On the other hand, as UVA light represents only 5% of the solar spectrum, intense research is also focused on visible light-driven photocatalysts like, for example, vanadium- and iron-based oxides (V_2O_5, $BiVO_4$, Fe_2O_3, $CoFe_2O_4$, and so on), as well as metal sulfides (CdS, ZnS, CuS, and so on) [1,3,4]. Some of these materials are ternary oxides. Indeed, it helps to tune the energy bandgap, which is an essential feature in heterogeneous photocatalysis [1]. In addition, another important physical factor that should be considered in heterogeneous photocatalysis is the morphology of materials. Morphology can influence the specific surface area as well as the transport properties of charge carriers. In this way, Ullah et al. have published in this Special Issue work related to the preparation of CdS nanorods, which have excellent photocatalytic properties in the degradation of Rhodamine

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B [3]. Moreover, photocatalysts can be composed of chemical elements that are active in Fenton-based reactions (Equations (3)–(5)). It is the case of $CoFe_2O_4$ that has been investigated by To Loan et al. [4]. Indeed, this visible light-driven photocatalyst in combination with Fenton-based processes can almost completely degrade Rhodamine B [4].

$$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + OH^- + HO^\bullet \quad (3)$$

$$Fe^{3+} + H_2O_2 \rightarrow Fe^{2+} + H^+ + HO_2^\bullet \quad (4)$$

$$Fe^{3+} + H_2O + h\nu \rightarrow Fe^{2+} + H^+ + HO^\bullet \quad (5)$$

Concerning these Fenton-based processes, they are usually performed in homogeneous systems using dissolved iron species, thus exhibiting higher kinetic rates compared with heterogeneous systems. By looking at these reactions (Equations (3) and (4)), it appears as a catalytic process owing to the iron cycle ($Fe^{2+} \leftrightarrow Fe^{3+}$). However, in an aqueous solution, Fenton-based reactions face two main drawbacks, including (i) the stability of iron species and (ii) the reduction of Fe^{3+} into Fe^{2+} (which is the limiting step). Therefore, using non-toxic and biodegradable ligands, stable iron complexes can be used under visible light, thus allowing their use at environmental pH and favoring the reduction process via iron photolysis (Equation (5)). That has been investigated in the work of Huang et al., where 2,4-dichlorophenol has been successfully degraded using the Fe(III)–EDDS complex in both synthetic and real water bodies [5].

Another interesting photochemical process is the photolysis of radical precursors. In such a configuration, no material is needed as the action of light of suitable energy can generate ROS like $HO^\bullet$. Usually, hydroxyl radicals can be generated by photolysis of H_2O_2 under UVB light, while strong UVC is required to photolyze water molecules. For the latter, a VUV/UV photoreactor is necessary. In this Special Issue, Luo et al. have investigated the fluid dynamics in a VUV/UV photoreactor by correlating simulations with experiments for the degradation of organic pollutants [6]. Therefore, their work brings interesting knowledge for the development of such a technology for water treatments.

The improvement of photochemical processes can also be reached using physical methods. An example is the application of a voltage to a photocatalyst in the form of a photoelectrode. Such a photoelectrocatalytic process can be employed for various applications including the production of hydrogen by water splitting, the enhanced degradation of water contaminants, and the production of hydrogen peroxide. In this Special Issue, Papagiannis et al. have studied the latter system using a photoanode [7]. Indeed, the production of H_2O_2 by WO_3 photoanode is made sustainable by using organic fuels from biomass derivatives such as glycerol and ethanol. H_2O_2 is a well-known oxidant that is used in both conventional oxidation and advanced oxidation processes. It is a radical precursor used in the production of hydroxyl radicals.

This Special Issue on "Photocatalytic Processes For Environmental Applications" offers an overview (through original full-length and review articles) of the different photochemical processes (photocatalysis, photo-Fenton, and photolysis) triggered by different inorganic compounds that can be used for environmental applications, not for only water treatment, but also for hydrogen production. As guest editors, we thank all the contributors and the editorial team of *Processes* for their work and the successful publication of this Special Issue.

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