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Editorial

Editorial: Air and Water Purification Processes through Photocatalysis—Scale-Up Perspectives, 2nd Edition

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In the face of escalating environmental challenges, innovative solutions for purifying air and water are more critical than ever. Photocatalysis has emerged as a promising technology for addressing these needs. Upon irradiation, photocatalysts generate Reactive Oxygen Species (ROS) capable of breaking down various pollutants, including volatile organic compounds (VOCs), pathogens, and persistent organic pollutants [1,2]. However, transitioning from laboratory success to widespread practical application presents significant challenges that must be meticulously addressed. Moreover, scaling up photocatalytic systems from the lab to industrial applications involves several critical considerations.

First and foremost, the design and optimization of photocatalytic reactors must ensure adequate light penetration and catalyst activation [3]. In laboratory settings, catalysts are often deployed in thin films or nanoparticle suspensions under controlled conditions. However, replicating these conditions on a larger scale requires innovative reactor designs that can maintain the same level of efficiency. One promising approach is the development of immobilized photocatalyst systems [4]. Advances in material science and nanotechnology are pivotal for creating robust and efficient immobilized photocatalysts that can withstand the rigors of industrial applications. Energy efficiency is another critical factor [5]. Laboratory setups often utilize UV light sources, which can be energy-intensive and costly. For large-scale deployment, leveraging natural sunlight or developing low-energy light sources that can effectively activate photocatalysts is crucial. Recent research into visible-light-responsive photocatalysts holds promise, potentially reducing the energy demands and costs associated with the process. Environmental and safety considerations also play a pivotal role [6]. The deployment of photocatalytic systems must ensure that secondary pollution or unintended by-products are minimized. Rigorous testing and monitoring protocols are necessary to ensure that the purification process does not introduce new environmental hazards [7]. Additionally, addressing public perception and educating stakeholders about the benefits and safety of photocatalytic purification systems are crucial for gaining societal acceptance [8].

Among the most explored topics regarding the applicability of photocatalysis on a real scale, the efficacy of photocatalytic processes against recalcitrant pollutants and Contaminants of Emerging Concern (CECs) emerges as a key area, as these contaminants can bypass the common stages of traditional water depuration plants [9].

In particular, within this Special Issue, the rising problem of pharmaceuticals in wastewater has been addressed in Contributions 3 and 4. Indeed, these kinds of compounds often possess aromatic structures or functional groups that decrease biodegradability under aerobic treatment [10], and, in the case of antibiotics, their indiscriminate presence in water can lead to cascade problems, such as favoring the spread of antibiotic multi-resistant bacteria/resistant genes [11]. For this reason, pharmaceutical degradation requires increasingly ad hoc treatments. Ren et al. [12] prepared inorganic–organic hybrid

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supramolecular compounds formed by the self-assembly reaction of divalent nitrogen-containing cationic ligands, namely 1, 2-bis [(4-aminopyridine)-N-methylene] benzene dibromide (**L1**), 1, 3-bis [(4-aminopyridine)-N-methylene] benzene dibromide (**L2**), and 1, 4-bis [(4-aminopyridine)-N-methylene] benzene dibromide (**L3**), with transition metals in the form of Cu_4I_8, Ag_4I_8, $ZnBr_4$, AgI_5, and $CdBr_3Cl$. The rationale behind the modulation of these compositions is that a proper design of organic ligands and the selectivity of specific metals give such supramolecular compounds unique structure–activity relationships. All the prepared materials, belonging to wide-bandgap semiconductors, exhibited photoactivity, degrading ciprofloxacin, with a higher efficiency showed by $[\boldsymbol{L1}]_2{\cdot}[Cu_4I_8]$ and $[\boldsymbol{L3}]_2{\cdot}[AgI_5]$, thanks to their appropriate bandgap. Moreover, the testing conditions, such as the effect of catalyst dosage and pH value on the photocatalytic process, are essential parameters to probe for upscaled decontamination applications. In the work of Ren et al., neutral conditions and a catalyst dosage of 20 mg drove the supramolecular compounds to higher photodegradation levels, with a major role played by the action of hydroxyl radicals (·OH) as an oxygenated active species. Based on this latter result, it is worth underlining that the detection of Reactive Oxygen Species is fundamental to understanding the mechanisms of the degradation pathways, as pointed out by several studies, also in view of scale-up perspectives [7,13,14]. Indeed, the formation of intermediates that are toxic or able to damage the plant components must be carefully evaluated [15].

In Contribution 2, a further step of material implementation was promoted by the production of composites, i.e., trisbipyridylnickel(II) chloride pentahydrate ($[Ni(bipy)_3]Cl_2{\cdot}5H_2O$) impregnated on graphene oxide (GO) [16]. The activity of the Ni-GO nanocomposite was tested by photodegrading a model organic pollutant (Rhodamine B dye) under real sunlight irradiation. The synergy of the Ni(II) complex with the GO surface led to the intensification of the photocatalytic property under direct sunlight exposure with respect to the pristine graphite and GO. Moreover, since materials for water remediation should act against a various spectrum of contaminants [17,18], the same authors evaluated the antibacterial property of the Ni-GO against the bacterium *Klebsiella pneumoniae*. The results demonstrated that both the Ni(II) precursor complex and the Ni-GO nanocomposite possessed optimal antimicrobial efficacy.

Contributions 1 and 5 are again focused on the fine-tuning of photocatalytic materials, thus confirming the important role that this kind of study plays in the research field. If Contribution 1 investigates the efficiency of the nanocomposite formed by Chitosan-loaded Ce-TiO_2, Contribution 5 sees attention paid to one of the parameters to be modulated during the synthesis of photocatalysts. Wang et al. [19] prepared floral Bi_2O_3/TiO_2 composite crystals by varying their calcination temperatures in order to find a correlation with the photocatalytic properties exerted in the degradation of Rhodamine B. The removal efficiencies of the Bi_2O_3/TiO_2 catalyst were 97%, 100%, and 91% when the calcination temperatures were set at 400 °C, 450 °C, and 500 °C, respectively, showing maximum efficiency at 450 °C. From the characterizations, it was demonstrated that suitable thermal treatments promoted the crystallization of the Bi_2O_3/TiO_2 composites, improving their specific surface area and the active sites in which the catalytic reaction occurs and enhancing the separation efficiency of photogenerated electrons and holes.

In conclusion, the scale-up of photocatalytic processes for air and water purification represents a transformative step towards sustainable environmental remediation. While significant challenges remain, continued research and innovation are driving progress. By addressing technical, economic, and environmental considerations, photocatalysis can move from a promising laboratory technique to a cornerstone of large-scale purification systems, offering a cleaner and healthier future for all.

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

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