ORAL/POSTER
Ph.D. Student: Y/N
Journal: NONE

Empowering Remote Communities: Floating Photocatalysts, Innovative Materials, and Sunlight Harvesting for Sustainable Water Remediation

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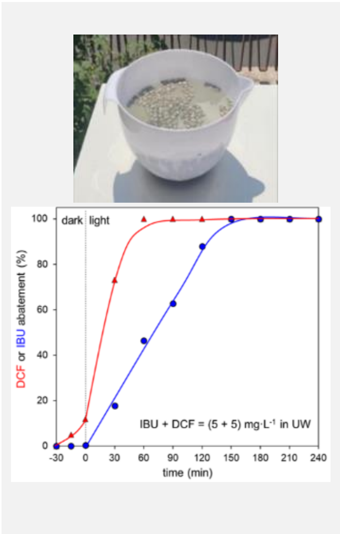

The rapid increase in global population has put a tremendous strain on water resources, a situation that is particularly critical in arid regions. In light of this, many water decontamination technologies have been developed, but their application is often limited in remote areas, such as developing countries. Addressing this challenge, this paper presents the progress of the "Water Decontamination by Sunlight-Driven Floating Photocatalytic Systems (SUNFLOAT)" project. This initiative aims to enhance the quality of life in small, remote communities affected by water scarcity. SUNFLOAT focuses on developing safe, affordable, and highly efficient photocatalytic materials that utilize the sunlight. These materials have been successfully created and mounted on various floating supports, both synthetic and natural. Their effectiveness has been tested in breaking down various pollutants, including pharmaceuticals, pesticides, and dyes. This paper also introduces the SUNFLOAT proof-of-concept (SPoC) device, illustrating its design and potential impact in providing a sustainable solution for water decontamination in remote and resource-limited settings

Introduction

Owing to the exponential population growth, the increase in food demand is placing unprecedented pressure on the land and water resources of our planet [1]. In this context, water scarcity represents a complex problem, and the recent climate crisis has worsened living conditions in many parts of the world. In numerous countries, for many months of the year, people do not have enough affordable and safe water to meet their needs [2], and sometimes, to meet human needs, the environment is damaged. This issue is ever more pronounced in developing countries, where water scarcity is also responsible for numerous pandemic crises during which unsanitary conditions put patients and doctors at risk for disease transmission [3]. Although different technologies have been developed for water depollution (filtration, chemical or biological treatment, etc.), generally, they fail to remove contaminants of emerging concern (CECs) due to their high chemical stability. In the last few years, we have witnessed ubiquitous pollution from antibiotics and other emerging contaminants in hundreds of rivers worldwide, from the Thames to the Tigris. Therefore, developing new strategies capable of mitigating these scenarios becomes urgent. The Sun represents an essential resource in light of the dramatic energy crisis. It is an extremely powerful energy source, and sunlight is by far the most significant energy source on Earth. However, manufacturing photocatalytic materials that can exploit the entire solar spectrum for the photodegradation of pollutants is not easy. Moreover, to date, there is still no simple, economical, and accessible method that allows the application of photocatalysis for water purification in poor scenarios where people have little access to clean water.

Moreover, the most advanced materials reported in the literature are used as dispersed powder [4]. If, on one hand, working on fine powders has several benefits (high dispersion, impressive photoactivity, etc.), on the other hand, particular issues of primary importance need to be addressed. Therefore, photocatalyst immobilization strikes a compromise between the benefits of the photocatalysts and the necessity to ensure their appropriate application by improving stability and facilitating easier handling. Therefore, this topic is of crucial importance for the research communities. Floating photocatalysts give the advantage of maximizing both light utilization and surface aeration since they can float on the air-water interface. Their use also decreases the post-treatment cost. Here, we report the results obtained with the project "Water decontamination by sunlight-driven floating photocatalytic systems (**SUNFLOAT**)." Different safe, cheap, and highly efficient photocatalysts operating under solar irradiation were properly fabricated and immobilized on different synthetic and natural floating supports. These innovative materials were tested for the degradation of diverse classes of organic compounds (drugs, pesticides, and dyes) in different conditions. Finally, the final SUNFLOAT proof-of-concept (SPoC) device is described.

Material and Methods

All the materials and methods are reported in references [4-6].

Results and Discussion

Concerning the fabrication of highly performing photocatalysts in the visible part of the electromagnetic spectrum (that represents most of the solar irradiation), at first, conducting polymers (CPs)-based photocatalysts (polyaniline@TiO_2 nanoparticles) were properly synthesized and supported on the surface of polyurethane (PU) foam [4]. CPs can act as excellent photosensitizers for traditional semiconductors, such as TiO_2, thanks to their extended π-configuration system, which extends the TiO2 activity to the visible region. The fabricated water-floating polyaniline@TiO_2@PU photocatalysts displayed extraordinary activity towards the photodegradation of rhodamine B (RHB, model dye) from the water matrix. Despite the widespread use of titanium dioxide (TiO_2) nanoparticles in photocatalytic applications due to their properties, there is a growing interest in the scientific community to explore alternative materials. This shift is driven by concerns over the potential carcinogenic nature of TiO_2 and its limited efficiency under solar light irradiation [7]. In this regard, graphitic carbon nitride (g-C_3N_4) has emerged as a metal-free visible photoactive semiconductor for water remediation. Its mid-wide bandgap of 2.7 eV, large surface area, excellent electrical and thermal conductivity, and high chemical stability make it ideal for photocatalytic purposes. At the same time, the possibility of replacing floating synthetic polymers with natural ones to support photocatalytic materials has paved the way for more sustainable devices for wastewater treatment. Based on these premises, biodegradable and biocompatible alginates are particularly interesting. They derive from brown seaweeds and can be used to immobilize photocatalysts under safe and mild conditions. Efficient, reusable floating-C_3N_4/alginate beads were successfully synthesized using two different precursors (urea and melamine) and applied for the photodegradation of different classes of organic pollutants (rhodamine B, diclofenac, and isoproturon) (5) Thanks to its extraordinary high surface area, alginate pearls modified with g-C_3N_4, synthesized by urea as the precursor, showed higher activity than that from melamine in the photodegradation of mixture of pollutants. The use of calcium alginate in fabricating photocatalytic beads presents a challenge: its abundant hydroxyl groups lead to strong adsorption of diclofenac transformation products, which in turn reduces the efficiency of active sites in degrading pollutants like rhodamine B and isoproturon. Despite this, these modified beads demonstrate promising activity and stability over five consecutive uses.

A limitation arises with floating-C_3N_4/alginate beads: the photocatalyst exposure on the bead surface is not maximized. In fact, g-C_3N_4, synthesized via a one-pot polycondensation method, is dispersed in the alginate solution, restricting surface exposure. This issue was addressed by replacing g-C_3N_4 with a TiO_2-free semiconductor, BiOBr, prepared through co-precipitation on the bead surfaces [7]. This method yielded highly active floating photocatalysts, effective even against polyphenols.

However, alginate beads have a drawback: they are too degradable for extended reuse. Over time, their degradation leads to the gradual release of the catalyst into the solution, negatively impacting material performance and causing secondary pollution. For this reason, more stable natural floating supports were explored. Light-expanded clay aggregates (LECA) are cheaply manufactured from natural materials traditionally used in construction industries. LECA is extremely light, chemically inert, and thermally stable up to 1000°C. It is characterized by a low density and high porosity, conferring the ability to float on the water. BiOBr was grown on the surface of LECA beads, obtaining an extraordinary floating photocatalyst tested for CECs degradation under various environmental conditions: laboratory- and real-scale experiments.

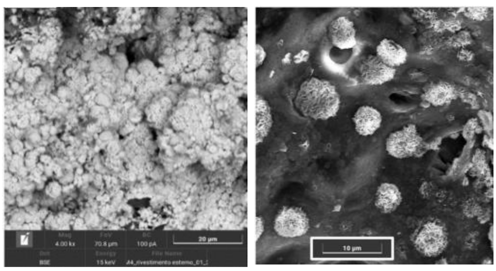

Figure 1. FESEM images of the (left) external and (right) internal part of BiOBr/LECA.

For the realization of the SPoC device, this material was selected in combination with a proper container. In this regard, two different bowls were tested for real-scale tests: one made of transparent glass and the other of white polypropylene to verify the effect of light penetration in the photocatalytic process. Finally, the photocatalytic efficiency of the SPoC under natural sunlight irradiation was verified, and very promising results were obtained [6]. The findings suggest that BiOBr/LECA has the potential to serve as a promising sustainable alternative to traditional materials for potential applications for the degradation of CECs usually present in real surface waters to alleviate water contamination in critical contexts, such as those of vulnerable communities.

Conclusions

The SUNFLOAT project stands out for its real-world application, successfully utilizing actual sunlight, for water remediation. This breakthrough demonstrates the practical viability of floating photocatalysts like BiOBr/LECA and C_3N_4/alginate beads under natural solar conditions. Overcoming a common limitation in photocatalysis research, the project underscores the effectiveness of these innovative materials in harnessing solar energy for sustainable water purification. This real-sunlight functionality marks a significant step forward, offering a tangible, eco-friendly solution for improving water quality in remote communities facing water scarcity.

Acknowledgments

Velux Stiftung Foundation is gratefully acknowledged for their financial support through project 1381, "SUNFLOAT—Water decontamination by sunlight-driven floating photocatalytic systems."

Department of Chemistry, Università degli Studi di Milano, Italy (Piano Sostegno alla Ricerca, PSR, grant 2022).

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