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Editorial

Innovations in Wastewater Treatment

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The rapid growth of the world population and climate change are two key factors that immensely affect freshwater availability. Due to resource-intensive consumption habits, a six-fold increase in freshwater use since 1900 has been observed worldwide, with the consequence that water stress and scarcity are now concerns for various parts of the world. Freshwater only represents 2.5–3% of the earth's water; of this 3%, about 70% is ice, and the remaining is groundwater. By 2050, the global population is predicted to reach 9 billion; by 2075, 75% will have inadequate freshwater availability. Reducing water waste and using it more efficiently is mandatory to avoid social and health risks, lower agricultural yields, compromised industrial production, droughts, and fires, and to ensure the security and sustainability of domestic, industrial, and agricultural supply. Poor water quality supply produces 80% of diseases worldwide, directly or indirectly, and pathogenic microorganisms in water determine 19% of global fatalities.

Water can be recovered from various sources, treated, and reused for beneficial purposes and environmental restoration. Urban wastewater, industrial wastewater, cooling water, stormwater, agricultural runoff, and natural resources are water sources eligible for reuse [1]. For example, treating wastewater at urban wastewater treatment plants is a viable option to appease the increasing demand for water resources. This approach aligns with the Circular Economy Action Plan and the new EU Climate Adaptation Strategy. Reusing water will also help achieve Sustainable Development Goal 6, which aims to ensure water and sanitation availability and sustainable management worldwide [1].

The widespread presence of emerging pollutants in the environment has determined their increase and the potential harm they can cause to the environment and human health. Pharmaceuticals, personal care products, and pesticides are included in the list of emerging pollutants. Even if detected in low concentrations ($\mu g \cdot L^{-1}$ or $ng \cdot L^{-1}$), they accumulate in the environment and living organisms. Some of these compounds are not eliminated in conventional wastewater treatment plants and subsequently enter the water cycle. Therefore, innovative methods are needed for their removal.

The applications of nanomaterials, such as carbon nanotubes, graphene-based nanosheets, fullerenes, silver nanoparticles, copper nanoparticles, and iron nanoparticles, are of great interest for wastewater treatment. Silver, copper, and iron nanoparticles show unique physicochemical properties, including their extremely small size, high surface-area-to-volume ratio, which can be functionalized/modified, and excellent magnetic properties. In contrast, carbon-based materials such as carbon nanotubes, graphene-based nanosheets, and fullerenes are characterized by unique performance characteristics and the diversity of their carbon-based structures. In addition, it is relatively easy to functionalize the surface properties of carbon-based materials to target a particular water pollutant [2].

Advances in electrochemical technology have led to the development of electrochemical advanced oxidation processes (EAOPs), among the most promising and innovative alternative water treatment technologies. The basis of EAOPs is the electrochemical generation of highly reactive oxidizing species, such as hydroxyl radicals, capable of mineralizing the target pollutants. These techniques aim to mineralize contaminants in CO_2 and water, or, at least, convert them into harmless, easily degradable products whilst avoiding the

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formation of new toxic species. The EAOPs are particularly interesting because they are environmentally compatible, versatile, and a highly effective means to eliminate many pollutants from wastewater. The materials used as anodes in EAOPs are crucial for achieving efficient water treatment since they generate oxidant species. These electrodes must have a high oxygen evolution overpotential (OEP), such as lead dioxide (PbO_2), tin dioxide (SnO_2), sub-stoichiometric TiO_2, boron-doped diamond (BDD), and some composites such as Sb-SnO_2, Co-PbO_2, TiO_2-nanotubes with PbO_2, Ti/Sb-SnO_2, and La-Y-PbO_2, establishing that the higher the OEP, the higher the oxidation output of the anode [3].

Plasma technologies are prominent among the tools for water purification from harmful and dangerous pollutants. It is known that an electric discharge in gasses and liquids is not only one of the most relatively simple ways to create plasma states of matter, but itself, in turn, has several types: glow, spark, arc, corona, and high-voltage breakdown in a liquid. Implementing every kind of electric discharge leads to the emergence of varying intensity plasma chemical and plasma physical processes, which can play a significant role in solving water purification problems [4].

Acid Mine Drainage (AMD) can be an excellent resource for material recovery due to its high content of valuable metals and minerals. The use of iron particles recovered from AMD as adsorbents for the removal of pollutants from wastewater and manufacturing catalysts for Fenton reactions are of great interest. Photo-Fenton treatment is an advanced oxidation process primarily based on the generation and utilization of short-lived highly reactive radical species, such as hydroxyl radicals. In the presence of solar light, a renewable source of energy, additional hydroxyl radicals can be generated. These radicals can react with organic pollutants and eventually oxidize them into mineral end products such as CO_2 and water. Therefore, using AMD effluent as a source of iron to catalyze the treatment of municipal wastewater in a solar photo-Fenton system represents a potentially breakthrough technology [5].

Constructed wetlands (CW) are non-conventional wastewater treatment systems whose removal mechanisms are based on natural processes. The main CW limitations are the clogging of granular media and large land area requirements. In this regard, anaerobic digesters (AD) have been used as a CW pre-treatment to reduce total suspended solids and the organic matter loading rate, consequently decreasing the required footprint. Combined AD–vertical subsurface flow CW systems can achieve simultaneous organic matter and nitrogen removal through efficient nitrification and denitrification. The elimination of pollutants in CW is mainly influenced by redox potential, temperature, hydraulic retention time, influent concentration, and exposure to sunlight. Hybrid systems that combine different aerobic and anaerobic environments and exposure to light offer the best results, even at high organic loading rates. When the advanced elimination of many emerging pollutants is sought, interest arises in completing hybrid systems based on aerobic and anaerobic stages with advanced photodegradation technologies. Photodegradation (usually as photocatalytic processes) was used as both pre-treatment and post-treatment in combination with CW to treat different kinds of wastewater, such as municipal sewage, pesticide-polluted wastewater, or textile wastewater [6].

The need for freshwater and the simultaneous presence of emerging contaminants in water require the definition, investigation, and development of innovative approaches for water recovery, reducing the depletion of this vital resource. Several techniques are available, but effective application at the proper scale requires further efforts, which cannot be achieved without adequate economic, financial, and social supports.

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