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Editorial

A Decade of Impressive Advances in Processes

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In the past decade, technologies such as artificial intelligence (AI), augmented reality, 3D printing, and 5G smartphones have become commonplace, driving fundamental innovations in industrial production through the development of smart, highly efficient, and sustainable processes. New tools for process simulation and modelling are now readily available, enabling the integration of chemical, biotechnological, mechanical, and electronic technologies. The outcomes have been remarkable: robotic surgery, electric and autonomous vehicles, wearable devices, and advanced facial and voice recognition are just some of the innovative achievements.

This editorial accompanies and concludes a successful Special Issue dedicated to ten years of *Processes*, covering key research areas ranging from clean energy, environmental remediation, and biomass valorisation to carbon emission mitigation. The growing demand for competitiveness and energy savings has reshaped production, introducing new heating and mixing technologies, as well as innovative downstream and purification methods. The urgent need for energy reduction has prioritised electrified energy sources such as dielectric, induction, and ohmic heating. Significant progress has also been achieved with heat-integrated distillation and membrane technologies [1].

Industrial continuous-flow processes (synthesis, extraction, and manufacturing) have represented one of the greatest challenges of the past decade, with regulatory authorities moving towards simplified authorisations in parallel with technological progress. Continuous handling of hazardous reagents and energetic intermediates reduces risks substantially [2]. For instance, ultrasonic-assisted crystallisation under continuous flow has improved downstream standardisation [3], particularly when combined with process analytical technology (PAT), enabling tight control of supersaturation and crystal properties, while simplifying filtration and facilitating solvent recycling. In both chemical and biotechnological processes, PAT and digital optimisation through inline IR, Raman, MS, and NMR coupled with model predictive control have drastically reduced the risk of process failures.

More sustainable approaches increasingly exploit biocatalysis in aqueous media, supported by the availability of highly efficient specific enzymes and multi-enzyme cascade protocols, often employing supported catalysts in flow reactors. A noteworthy example is enzymatic PET depolymerisation, where engineered polyester hydrolases have progressed from demonstration units to industrial biorecycling plants, enabling closed-loop PET monomer production [4].

Solvent-free mechanochemical methods, such as ball milling and twin-screw extrusion, now allow challenging conversions with a drastic reduction in carbon footprint [5]. Greener solvents are also widely adopted, including cyclopentyl methyl ether, dimethyl carbonate, and propylene carbonate, which are progressively replacing hazardous alternatives (e.g., methyloxolane instead of hexane) [6]. Alongside the established use of supercritical fluids (e.g., SC-CO_2), subcritical water has become increasingly common in extraction and chemical processing over the last decade, enabling rapid hydrolysis, oxidation, and other transformations without organic solvents and high heat transfer rates [7].

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AI has emerged as a powerful tool for chemical process intensification. AI models can analyse vast amounts of process data (pressure, temperature, flow rates, concentrations) to identify optimal operating conditions, leading to substantial improvements in yield, selectivity, and energy efficiency. Moreover, AI and machine learning enable predictive maintenance by detecting early signs of equipment malfunction (pumps, compressors, reactors) through vibration, acoustic, or thermal data, thereby reducing downtime and maintenance costs. By continuously monitoring abnormal conditions and predicting hazardous scenarios (such as explosions or toxic releases) earlier than conventional systems, AI contributes significantly to improving both worker safety and environmental protection [8].

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

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