Flowing toward sustainability: intensified biocatalytic processes in microreactors

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Highlights

- Biocatalysis supports the transition toward sustainable manufacturing.
- Process intensification is essential for industrial implementation of biocatalysis.
- Continuous flow microreactors intensify biocatalytic processes.
- Biocatalyst immobilization enables high total turnover numbers.

1. Introduction

Biocatalysis has become an important technology for the sustainable production of food ingredients, chemicals, pharmaceuticals, and biofuels. The growing demand for greener and more efficient manufacturing processes requires the development of advanced technological solutions for industrial biocatalysis implementation. Continuous-flow biocatalysis employing immobilized enzymes or whole cells offers significant advantages over conventional batch processing [1]. This work presents selected examples of continuous biocatalytic processes developed in microstructured reactor systems using advanced immobilization techniques and green solvent systems.

2. Methods

Continuous biocatalytic reactions were performed using immobilized enzymes and whole-cell systems in various microreactor configurations. Amine transaminase (ATA) was immobilized *via* a His_6 tag onto Cu-functionalized nanomats integrated into a two-plate microreactor and applied for continuous transamination [2]. A similar reactor design incorporating functionalized filter paper was used for immobilization of tyrosine decarboxylase using diffent crosslinkers.

Various ATAs were screened for furfural amination, and the selected enzyme was immobilized onto magnetite nanoparticles retained in a magnetic-field assisted microreactor [3]. The reaction was investigated in aqueous media and in the presence of deep eutectic co-solvents.

A microfluidics-based approach was developed for the generation and immobilization of nanoscale cross-linked enzyme aggregates (nanoCLEAs) from amine transaminase [4], glucose oxidase, and horseradish peroxidase. The latter two enzymes were co-immobilized and applied in resveratrol oxidation. Whole-cell biocatalysis was investigated in hydrogel-containing microflow reactors, and model-based reactor design was used to optimize reactor performance and operating condions [5].

3. Results and discussion

The investigated continuous biocatalytic microreactor systems demonstrated improved performance compared to conventional batch processes. Reactor miniaturization enabled better process control, improved mass transfer, easier integration with inline analytics, and simplified scalability. Efficient enzyme and cell immobilization, as well as the use of deep eutectic solvents to increase substrate solubility, improved operational stability and catalytic performance in selected biotransformations. Aadditionally, model-based reactor design contributed to process intensification (**Figure 1**).

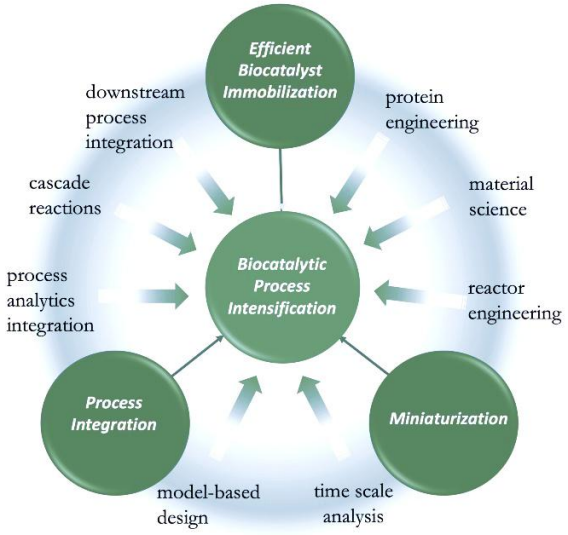

Figure 1. Key factors influencing biocatalytic process intensification and sustainability. Reproduced from [1] with permission from Elsevier.

Nanomaterial-based immobilization of amine transaminases enabled efficient and stable transamination in a two-plate microreactor [2], while functionalized filter paper integrated into a similar reactor configuration also proved suitable for continuous tyrosine decarboxylation. Magnetic-field-assisted reactors containing enzyme-coated magnetite nanoparticles enabled stable furfurylamine production [3], and deep eutectic co-solvents improved substrate solubility without significant loss of enzyme activity.

Microfluidic preparation of nanoCLEAs resulted in uniform and stable biocatalysts with high operational stability during continuous processing [4]. Co-immobilized glucose oxidase and horseradish peroxidase nanoCLEAs were successfully applied in a cascade reaction with *in situ* substrate generation for resveratrol oxidation, enabling valorization of this bio-based compound.

Hydrogel-immobilized yeast cells maintained stable activity in microflow reactors, while model-based reactor design supported increased reactor productivity [5].

4. Conclusions

The presented work demonstrates that microstructured continuous-flow systems provide an effective platform for intensified biocatalytic processing. Various immobilization strategies enabled stable operation of enzymatic and whole-cell reactions, while implementation of green solvents further improved process performance.

References

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Keywords

biocatalysis; continuous processes; biocatalyst immobilization; microreactors