A miniaturized Taylor Couette reactor for continuous flow enzymatic process development

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Highlights

- Design of a miniaturized and rotor seal free Taylor Couette reactor to accommodate reactions at small scales.
- Hydrodynamic modeling via CFD including spatial mean age calculation.
- Geometric optimization to minimize back mixing under low flowrate operation.
- Demonstration of enzymatic transformation of meta-tyrosine to meta-tyramine.

1. Introduction

Taylor Couette reactors (TCR) is a reactor type that utilizes the Taylor Couette flow formed in the annular space between a co-centrically aligned rotor and stator [1]. This type of flow is typically well defined (counter rotating annular vortices along the length of the rotor), and under certain operating conditions (low rotor rotating speed) is characterized by low shear stresses and limited back mixing making this reactor time an attractive option for continuous flow processes utilizing fragile or shear sensitive materials, such as enzymes. However, TCRs are typically large (several ml to liter scale), and expensive, which may discourage their use during the development of enzymatic catalysis processes since the amount of available enzyme is often limited during preliminary investigations. This work presents the development of a small scale (~1 ml) miniaturised TCR (mTCR) that can be easily manufactured via 3D printing and agitated via a magnetic stirrer (available in most laboratories) without the need for a rotor seal. The hydrodynamics of the reactor were investigated experimentally and computationally at low flowrate, as space time of hour is, typical for many enzymatic processes. Finally, the reactor was used in the continuous flow enzymatic transformation of meta-tyrosine to meta-tyramine.

2. Methods

Computational fluid dynamics simulations (models built in COMSOL Multiphysics v6.1) were used to assess the hydrodynamics in various designs of mTCRs. The simulations were run in 2D and in steady state using the frozen rotor approximation, taking advantage of the axial symmetry. CFD simulations were coupled with the computation of the spatial mean age distribution (solved within the COMSOL model), that allowed to characterize the macromxing (e.g. bypassing, backflow) within the reactor [2].

Physical models of a smooth rotor TCR and a ribbed rotor TCR were 3D printed via a commercial stereolithography 3D printer. Macromixing of the TCR was characterized via residence time distribution (RTD) analysis, conducted via optical tracer step input experiments. The experimental results were used to qualitatively verify the simulated reactor hydrodynamics.

The enzymatic reaction was performed in a homogenous single phase, by feeding two streams directly in the reactor from two different inlets: one stream containing the reagent (or substrate) in a HEPES buffer solution (pH = 8.5) and at 0.2 mM concentration and the other containing the enzyme ErTyrDC described in [3] (as cell lysate). The temperature was set at 37ºC by submerging the reactor in a heated and stirred water bath. The results were assessed via HPLC analysis.

3. Results and discussion

The CFD simulations revealed the expected counter rotating annular vortices in both the smooth and the ribbed rotor configurations. In variations of the ribbed rotor mTCR, the size and location of the counter rotating vortices was determined by the size and spacing of the ribs (in all cases vortices appeared in pairs between the ribs). From the spatial mean age distributions, it was found for the smooth rotor reactor that at relatively high flowrates (space time of 1 min) and low rotor speeds (200 rpm) each annular vortex would operate similar to a well mixed stirred tank (homogenous spatial mean age distribution) with the total reactor behaviour resembling that of multiple (>9) continuous stirred tanks in series (limited back mixing). However, at lower flowrates (space time of >30 min) or higher (>500 rpm) rotating speeds, a more homoegenous spatial mean age distribution was obtained throughout the reactor (without significant change of the flow pattern), indicating intensified back mixing. This trend was verified with experimental results of residence time distribution, with the first case (200 rpm, 1 min space time) resulting in an RTD equivalent to >9 CSTRs in series, while the worst tested case (800 rpm, 90 min space time) resulted in RTD equivalent to <2 CSTRs in series.

The ribbed rotor design was found computationally to allow the extension of a limited back mixing operating regime to up to 500 rpm rotor rotating speeds, and space time up to 30 min. The diameter of the ribs compared to the outer diameter of the annular space was found to be a critical parameter for the back mixing behaviour.

The reactor was successfully used for the enzymatic transformation of meta-tyrosine to meta-tyramine with the conversion showing expected variation as a function of residence time distribution when the reactor was operated at different operating conditions (different flowrates and rpm).

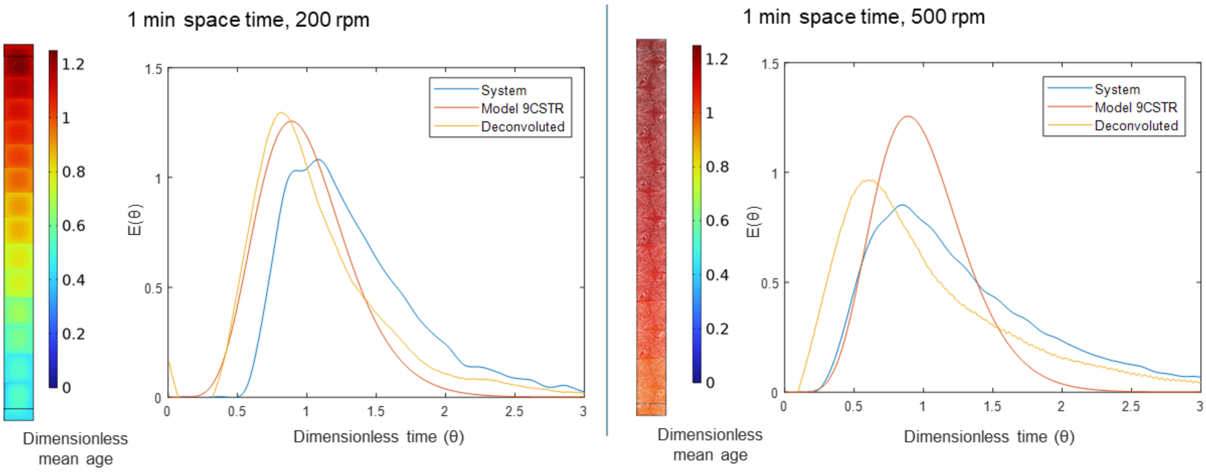

Figure 1. Spatial mean age distribution (computational, left) and residence time distribution (experimental, right) for two conditions resulting in different macromixing behaviour (smooth rotor mTCR)

4. Conclusions

A novel, miniaturised Taylor Couette reactor was designed and optimized via hydrodynamics investigations. A ribbed rotor design with adequately sized ribs was found to extent the operational regime of the reactor. The reactor was used for an enzymatic reaction case study using only a small amount of enzyme.

References

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Keywords

Taylor Couette reactor, enzymatic catalysis, flow chemistry, CFD