Hydrodynamics, heat transfer, and mixing in a millistructured plate reactor

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Fine chemicals and pharmaceuticals are typically produced in batch processes using stirred tank reactors. In case of fast, highly exothermic reactions, the reaction time is often determined by the poor heat transfer performance, which requires comparatively low temperatures and concentrations to prevent thermal runaway. Additionally, the selectivity of a desired reaction might be affected by slow mixing and an inhomogeneous temperature of the reaction volume. Continuously operated millistructured reactors (0.5 mm < d_h < 2.5 mm) are a promising alternative in those cases. They have higher specific surfaces, elevated heat transfer coefficients and allow for faster mixing compared to conventional stirred tank reactors.

In this work, the results of a comprehensive experimental and theoretical characterization of the ART plate reactor PR37 from Ehrfeld Mikrotechnik GmbH are presented. The process channel of this reactor is meandering and has a rectangular cross-section. The cross-sectional area is periodically changing. These geometric features are designed to intensify transport processes in the channel due to secondary flows such as DEAN vortices.

The results clearly show that the form of the process channel induces secondary flows at considerable low Reynolds numbers, leading to a significant enhancement of heat transfer, mixing performance and residence time distribution compared to a strict laminar flow. However, the pressure drop penalty for the enhancement of this transport processes is very low.

A Nusselt number correlation was developed, describing the heat transfer in the process channel. The parameters of this correlation were adjusted to numerous measurements with various fluids. It was found that the Nusselt number strongly increases with Reynolds numbers larger than Re ~ 11, indicating the onset of secondary flows. The measured friction factors confirm this, indicating a smooth transition from the laminar to the turbulent flow regime at Re > 10. Below this Reynolds number, the friction factor follows the Hagen-Poiseuille equation. The mixing performance, measured by fast competitive parallel reactions, is also significantly increasing in the investigated range (25 < Re < 500), while the residence time distribution is becoming more and more narrow, indicating less axial dispersion. A correlation for the reactor Péclet number (dimensionless number for axial dispersion) was established and adjusted to experiments. Based on these extensive findings, a reactor model for the ART PR37 was developed and implemented in MATLAB. In this poster, the abovementioned experimental results and the reactor model are presented in detail. This model serves as a tool for process design using the reactor under consideration.