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Article / Book Information

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論 文 要 旨

THESIS SUMMARY

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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

The substantial development of micro-structured devices in recent years allowed micro technology to become an important tool for flow chemistry, enabling production automation and optimization of different processes. Applications of micro-reactors cover wide areas like multiphase flow, photochemistry, and bioengineering. The use of micro-structured devices is opening new windows and possibilities in the field of chemical engineering, however, transport phenomena in conventional microstructures are dominated by diffusion. Among the solutions found in the literature to enhance convective transport we note the use of helical structures. In such structures lateral convective mixing is induced in the flow due to the presence of centrifugal force. A modified coiled structure containing 90-degree bends between coils i.e. Coiled Flow Inverter (CFI) has been shown to further improve transport phenomena by the mechanism of flow inversion.

In the framework of this research our aim is to answer two questions:

1. Is it possible to make CFI design better?
2. To what extent is mass transfer enhanced in multiphase system in coiled and CFI structures?

To answer the first question, a new class of helical micro-reactors i.e. the Arc Flow Inverters (AFIs) is presented. Two modular designs are suggested as AFIs consisting of a quarter-circle or a half-circle channels. Both designs are characterized by a small coil diameter and by the absence of coil pitch. Comparison between the new structures and a conventional CFI were performed by taking into account characteristic geometrical features. It is shown, based on a space design diagram that from manufacturability point of view, that AFIs have a wider feasibility in design compared to CFIs. The new designs were prepared with CAD software, subsequently produced by 3D printing technology to overcome the manufacturing limitations encountered in conventional tubing. For the same reactor length, the new designs provide a substantially reduced footprint compared to conventional CFIs.

Hydrodynamics in AFIs were numerically and experimentally studied in the laminar flow regime. CFD simulations showed that AFIs generated a spatially-periodic flow behavior even at low Reynolds numbers in terms of velocity magnitude and secondary flow magnitude. It was experimentally shown that the pressure loss in 3D printed AFIs and CFI was nearly identical at low Reynolds numbers.

An assessment of micromixing in the AFIs was conducted by using Dushman-Villermaux reaction. The segregation index indicating mixing performance was calculated from the experimental results. Overall, AFIs showed better micromixing performance compared to coiled and straight channels at low Reynolds numbers. Micromixing time was determined from the segregation index by using the incorporation model. The micromixing time varied from 0.04 to 1.5 s in the examined range. Mixing throughout the reactor length was investigated numerically by obtaining the RTD response of a step injection. Results showed that AFIs attained a narrower RTD response compared to CFI structures. The axial dispersion coefficient in AFIs was smaller than that of a CFI.

To answer the second question, multiphase slug flow in helical structures was studied to give more insight into mixing and mass transfer. The study was performed numerically using CFD tools. The modeled system was air-water slug flow and the oxygen diffusion from air into water was evaluated. The developed CFD model "One straight slug model" was implemented by adding a virtual centrifugal body force as a source term to the momentum conservation equation. The implementation of the body force was validated in terms of helicity and secondary flow magnitude in the Reynolds number range lower than 150. The secondary flow magnitude appeared to be a power function of Dean number as reported in the literature. A new correlation for Dean velocity in tubes with circular cross section has been suggested by modifying a semi empirical correlation in the literature. Mass transfer of oxygen across the interface between air and water was studied by determining the volumetric mass transfer coefficient k_La. The new suggested one straight slug model described the temporal and spatial distribution of the species i.e. oxygen in the slug with good accuracy. The numerical results obtained for oxygen distribution in the slug were compared with experimental observation at similar operation condition and they showed good agreement. The enhancement of mass transfer in coiled tubes compared to straight tubes was examined and k_La in coil was found to reach 1.5 times higher than that in straight channel. A new dimensionless quantity i.e. modified Dean number is proposed in this work based on Dean recirculation and Taylor recirculation time scales. The enhancement of k_La reached a maximum at modified Dean number of ca. 1.8. The numerical model showed that k_La in coil and CFI were equivalent in the non-reactive system examined.