

Principles and Applications of Droplet Formation in Porous-Wall Channels

Grundlagen und Anwendungen der Tropfenbildung in Kanälen
mit poröser Wand

Von der Fakultät für Maschinenwesen der Rheinisch-Westfälischen Technischen
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vorgelegt von

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Berichte aus der Verfahrenstechnik

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To my parents.

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Abstract

Droplets play a fundamental role in a large variety of fields such as pharmaceuticals, food technology or chemical processing. These can be used as templates for production of polymeric spheres or capsules, as part of unit operation like liquid-liquid extraction or for cell encapsulation and drug delivery. Particularly when droplets act as templates, the control of size, shape and size distribution is paramount to ensure product quality. A new technology for droplet generation taking advantage of porous-wall channels addresses these requirements.

The method as presented in this thesis consists of a porous-wall channel, either as a hollow-fiber membrane or as an embedded channel in a porous flat-sheet membrane. Within these channels, two immiscible phases are brought in contact as coflowing streams and the liquid filament of the inner phase breaks up in the form of droplets either in a dripping or a jetting regime depending on the dominating forces. This is demonstrated both experimentally and with the help of CFD simulations that are able to depict the droplet formation mechanics occurring within the channels.

In addition to the study of the principle behind droplet break-up, a design for the generation of droplets at low micron ranges is presented. Furthermore, the potential of this technology is investigated for different applications of commercially available hollow-fiber membranes in the generation of aqueous two-phases systems (ATPS) droplets, droplet solidification, formation of elongated particles, and liquid-liquid extraction, being the latter the one showing most promising results.

Zusammenfassung

Tröpfchen spielen eine wesentliche Rolle in vielen Bereichen wie in der Pharmazeutik, in der Lebensmitteltechnik oder in der chemischen Prozesstechnik. Die Tröpfchen können als Vorlage für die Herstellung von Polymerkugeln oder -kapseln, als Bestandteil von Grundoperationen wie in der Flüssig-Flüssig Extraktion oder für Zellverkapselung und Wirkstofffreisetzung verwendet werden. Insbesondere für das erste Beispiel ist die Kontrolle der Größe, Form und Größenverteilung von Bedeutung für die Produktqualität. Eine neue Technologie zur Tröpfchenbildung verwendet Kanäle mit poröser Wand um diese Anforderungen zu bewältigen.

Die hier präsentierte Methode basiert auf Kanälen mit poröser Wand, entweder als Hohlfasermembranen oder als eingebettete Kanäle in einer porösen Flachmembran. Innerhalb dieser Kanäle entsteht eine koaxiale Strömung durch den Kontakt von zwei ineinander nicht mischbaren Phasen. Die innere Phase zerfällt in Tröpfchen, entweder durch *Dripping* oder *Jetting* in Abhängigkeit davon welche Kräfte dominieren. Dieses Verhalten wird experimentell und mit Hilfe von numerischen Strömungssimulationen dargestellt, die die Mechanismen der Tröpfchenbildung beschreiben.

Zusätzlich zu diesen Untersuchungen wird ebenfalls ein neues Design zur Herstellung von Tröpfchen im unteren Mikrometer-Bereich vorgestellt. Ferner werden die potentiellen Anwendungen von kommerziell erhältlichen Hohlfasermembranen zur Bildung von Tröpfchen in wässrigen Zweiphasensystemen, zur Herstellung von sphärischen und verlängerten Partikeln und für die Flüssig-Flüssig Extraktion untersucht. Dabei zeigt die letzte Anwendung die vielversprechendsten Ergebnisse.

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