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**Image-based Measurement and
Modelling of Multiphase Flows**

Image-based Measurement and Modelling of Multiphase Flows

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Preface

This thesis was created during my work at the chair of Separation Science and Technology and the Laboratory of Reaction and Fluid Process Engineering under the supervision of Prof. Dipl.-Ing. Dr. techn. Hans-Jörg Bart. My special thanks go to him for giving me the opportunity to work at the chair and for helping me develop as both a scientist and person. I would also like to thank Prof. Dr. Erik von Harbou where for the opportunity to pursue my work at the Laboratory of Reaction and Fluid Process Engineering. Finally, I would like to thank all of my colleges at both chairs.

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Abstract

The particulate properties of multiphase flows dominate a variety of process engineering applications in all fields such as food processing, pharmaceuticals, or basic chemical production. In present time, industry is still lacking measurement techniques that reliably measure these particulate properties in sufficient temporal and spatial resolution with statistical significance. Therefore, processes are usually developed by experience, safety factors, and rule of thumbs. Depending on the process and type of particles, different techniques can be used, each having its own advantages, disadvantages, and limitations. The most promising approach in recent years are image-based incident light probes because they allow a view into the apparatus and can be used for almost any substance system. Unfortunately, its disadvantages are distance-dependent imaging, low depth of field, and poor contrast due to reflections. These are potential sources of error that can only be partially reduced by complex image processing software. A solution to this is the Optical Multimode Online Probe (OMOP). In this thesis, telecentric shadowgraphic probes that rely on the functionality of the OMOP are utilized to determine particulate properties in a variety of applications. In four case studies the use of the OMOP is explored and the technique is applied to a bubble column, a crystallizer, a dispersion in a stirred vessel, and a two-phase pump-mixer. From these studies, it is shown that shadowgraphic probes can be easily applied and reliably measure the particle size regardless of the type of process. Thereby even small transient changes in the particle size can be recognized, independent of the state of the disperse phase (solid, liquid, gaseous). Together with modern image analysis such as Neural Networks (NN), the technique can be reliably operated at high disperse concentrations. From this, models can be developed and re-correlated to describe particulate properties based on an extensive data base. Hence, shadowgraphic probes with modern image processing are a powerful tool to investigate and control complex multiphase flows.

Kurzfassung

Die partikulären Eigenschaften von Mehrphasenströmungen dominieren einen Großteil von verfahrenstechnischen Anwendungen wie in der Lebensmittelchemie, Pharmazie oder der Erzeugung von Basischemikalien. Obwohl die partikulären Eigenschaften ein Schlüsselparameter sind existieren heutzutage kaum Messtechniken, die diese geforderten Größen mit hinreichender räumlicher und zeitlicher Auflösung statistisch signifikant erfassen können. Daher werden Prozesse heutzutage noch immer mittels Erfahrung, stark vereinfachter Modelle und Daumenregeln ausgelegt. Je nach Prozess gibt es einige wenige Techniken mit verschiedenen Vor- und Nachteilen sowie Einsetzbarkeitsbereichen. Der vielversprechendste Ansatz bisher sind Auflichtsonden, da sie einen Einblick in den Prozess geben und für fast alle Prozessarten einsetzbar sind. Die größten Nachteile von Auflichtsonden sind ihr entfernungsabhängiger Abbildungsmaßstab, geringer Schärfentiefe und durch Reflexionen verursachter schwacher Kontrast. Diese Nachteile sind potentielle Fehlerquellen, welche nur teilweise durch sehr aufwendige Bildverarbeitungssoftware reduziert werden können. Eine Lösung dieser Probleme ist die Optical Multimode Online Probe (OMOP). In dieser Arbeit werden telezentrische Durchlichtsonden auf Basis der initialen OMOP verwendet um, die partikulären Eigenschaften in verschiedenen neuen Anwendungen zu messen. In vier Fallstudien werden eine Blasensäule, ein Kristallisator, eine Dispersion im Rührbehälter und ein zweiphasiger Pump-mixer mittels telezentrischer Durchlichtmesstechnik untersucht. In den Studien konnte gezeigt werden, dass telezentrische Durchlichtsonden unabhängig vom Prozess zuverlässig in verschiedenen Mehrphasenströmungen zur Größenbestimmung der dispersen Phase eingesetzt werden kann. Dabei können selbst kleine Änderungen der Partikelgröße unabhängig vom Aggregatzustand der dispersen Phase (fest, flüssig, gasförmig) erfasst werden. Zusammen mit modernen Bildverarbeitungsmethoden wie Neuronalen Netzen (NN) kann auch bei hohen Phasenanteilen gemessen werden. Mit den so erzielten Daten lassen sich Modelle zu Beschreibung des Sauterdurchmessers entwickeln oder korrelieren. Im Zusammenspiel mit der verwendeten Hardware und moderner Bildverarbeitung lassen sich selbst komplexeste Mehrphasenströmungen untersuchen und steuern.

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