

V. Hessel, A. Renken, J. C. Schouten,
and J. Yoshida (Eds.)

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Micro Process Engineering

A Comprehensive Handbook

Volume 3: System, Process and Plant Engineering



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A Comprehensive Handbook

Volume 3: System, Process and Plant Engineering

Edited by

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and Jun-Ichi Yoshida*



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Preface

Technology Scaled Out – Handbook Full of Facets

A handbook is a type of reference work that is intended to provide ready reference and is an established compendium format originating from the hour of birth of natural sciences, but being still modern today. In its original meaning, this refers to a pocket reference which is intended to be carried at all times - a vade mecum (lat. "go with me"). The emergence of micro reaction or micro process technology is so paramount that all relevant results and research directions cannot put anymore into such smart format. This applies analogously for the micro process plants, which have reached production stage and with increasing throughput and complexity have reached out-scaled formats, albeit being still compact and much smaller than conventional equipment. Accordingly, this handbook of micro process technology provides multiple facets of the new approach, spanning from microfluidics over applications to finally a system technology on respective plants. Actually, this led us giving the handbook a three-volume format, covering fundamental issues of flow within microchannels up to commercial implementation and cost analysis issues.

Volume 1 covers fluid dynamics, modelling, mixing of one-phase and dispersed two-phase systems, heat and mass transfer. One chapter is concerned about purification and separation focusing on extraction, membrane technology, and capillary electrochromatography. This is rounded off by a description on microstructured reactors and their engineering/design for various applications.

Volume 2 provides information on chemical applications, with those in fine chemistry having the largest share. These applications are grouped mechanistically, with the intention that the same or similar reactions ought to have similar process demands and process intensification potentials, thus facilitating comparison of performance. A complete chapter is given to polymerisations and another one to functional materials, reflecting an increasing trend in microfluidic research. Most prominent is particle making, split into pigment/organic, inorganic and polymer particles, and supramolecular assemblies (microencapsulates, vesicles). Emulsions are another class of functional materials frequently investigated using microstructured devices. Finally, fuel processing with its hydrogen making and gas purifying

processes is described which has evolved as major microfluidic application in the past years.

Volume 3 is concerned with the transfer from single-plate device to system and scaled-out multi-plate devices. The system approach includes sensing and analytical functions and thus bridges to optics and microelectronics. Case studies in micro process plants are lively documents of the degree of implementation and mirror imaging the soft human factor in industry, having trust in the new technology or being more reluctant. Economic and eco-efficiency analysis is finally the financial and environmental measure of the concrete impact and provide hints for the decision makers within industry.

We hope this handbook will be a valuable source of information and reference both for the newcomer and practitioner of micro process technology. Each chapter is given by an expert in the field using updated information and providing a compact degree of origin and specific information. As the handbook bridges from small units and devices to large modules and complex systems, it should attract also a readership beyond the microreactor scientific community, being specialists in specific applications, i.e. the user of the novel approach. Finally, with all editors being university professors, we would be pleased if this handbook should be one knowledge piece to establish the new technology in the path of normal education and knowledge within chemical engineering.

December 2008

The Editors (*Volker Hessel, Albert Renken,
Jaap Schouten, and Jun-ichi Yoshida*)

About the Editors



Volker Hessel became part-time professor for the chair of “Micro Process Engineering” at Eindhoven University of Technology, TU/e, in the Chemical Reactor Engineering group of Professor Jaap Schouten in 2005. He has worked at Institut für Mikrotechnik Mainz GmbH since 1994, being appointed Head of the Microreaction Technology Department in 1999. In 2002, Prof. Hessel was appointed Vice Director of R&D and in 2007 as Director of R&D for Chemical Micro and Milli Process Technologies. He is author/co-author of 135 peer-reviewed publications, with 23 extended reviews, 11 book chapters, and 3 books. He received the AIChE award “Excellence in Process Development Research” in 2007 and was the AIChE chair (US) “Microprocess Engineering” (2005–2007). He is also an elected board member of the German industrial platform IPμVT, and chair of the program committees of the SynTOP and IMRET-10 Conferences.



Albert Renken was professor for Chemical Reaction Engineering at the Swiss Federal Institute of Technology in Lausanne until 2006. He is a Swiss delegate in the working party on Chemical Reaction Engineering (Chairman 1996–2003) of the European Federation of Chemical Engineering. He organized the 7th International Conference on Microreaction Technology (IMRET 7) in Lausanne, 2003 and the 19th International Symposium on Chemical Reaction Engineering (ISCRE 19) in Berlin/Potsdam, 2006. In 2007 he was awarded with the DECHEMA-Titanium Medal. He was a member of the research council of the Swiss National Science Foundation from 1992 until 2000 and a member of the Swiss Innovation Promotion Agency from 1999 to 2006. He is author/co-author of more than 450 scientific publications, 19 patents and two textbooks in Chemical Reaction Engineering.



Jaap Schouten is professor of Chemical Reactor Engineering at Eindhoven University of Technology (TU/e). The Secretary of the Working Party on Chemical Reaction Engineering of the European Federation of Chemical Engineering (EFCE), Prof. Schouten is also a member of the Scientific Committees of the International Symposia on Chemical Reaction Engineering (ISCRE) and Microreaction Technology (IMRET), and of the European Process Intensification Conference (EPIC). He was granted the prestigious "Simon Stevin Mastership" award by the Dutch Technology Foundation STW in 2006, and became the recipient of the Chemistry Innovation KTN Award for Innovation in Applied Catalysis and Colloid Science from the British Institution of Chemical Engineers (IChemE) in the same year. In 2007 he was appointed Member of the Royal Holland Society of Sciences. In 2008 he was awarded a prestigious Advanced Grant by the European Research Council (ERC). Professor Schouten has authored/coauthored more than 170 scientific publications.



Jun-ichi Yoshida has been professor in the department of Synthetic Chemistry and Biological Chemistry at the Kyoto University in Japan since 1994. He is the recipient of many awards including the Progress Award of Synthetic Organic Chemistry, Japan (1987), the Chemical Society of Japan Award for Creative Work (2001), Nagoya Silver Medal (2006), and Humboldt Research Award (2007). After receiving his doctorate from the University of Kyoto, he became an associate professor at the Kyoto Institute of Technology. He was also a visiting professor at the University of Wisconsin before moving to Osaka City University in 1985. Professor Yoshida has authored/coauthored numerous scientific publications.

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