Green Process Synth 1 (2012): 225–227 © 2012 by Walter de Gruyter • Berlin • Boston. DOI 10.1515/gps-2012-0012

Laboratory profile

Profile of the research group "Chemical Micro Process Technology" (CMPT) at the Johannes Gutenberg University Mainz

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The group

The research group of Professor Löwe presently consists of seven PhD students and varying numbers of diploma students working in different fields of research and development. One of their most important working guidelines is to transfer complex chemical reactions, which are commonly performed in standard laboratory-scale equipment, into micro-flow systems. This is not an end in itself but it ensures scale-up possibilities for pilot-scale processing in an industrial environment. For example, the retro-synthesis of natural products, especially carbohydrates and proteins, is sometimes restricted by their batch size and the amount of available substances. Micro-flow systems allow a continuous processing resulting in a remarkable amount of targeted substances. To fulfill these requirements, an interdisciplinary research team of organic chemists, chemical engineers and physicists was established. Strong cooperation between the in-house research groups of different disciplines, connections to the Max Planck institutes located just around the corner, and access to the highly renowned research departments of the Institut fuer Mikrotechnik Mainz GmbH (IMM), allow competent and comprehensive work in different fields. The group also established fruitful bilateral cooperation with global industrial partners, e.g., Roche Diagnostics GmbH, Boehringer Ingelheim Pharma GmbH and Co. KG, and MERCK KGaA. Local industrial partners are also involved, namely, a provider for chemical plant design and construction (Ruland Engineering and Consulting GmbH, Neustadt), a manufacturer for glass micro-structured reactors (Mikroglas chemtech GmbH, Mainz), and a fine chemicals manufacturer (OSC GmbH, Bitterfeld).

The team leader

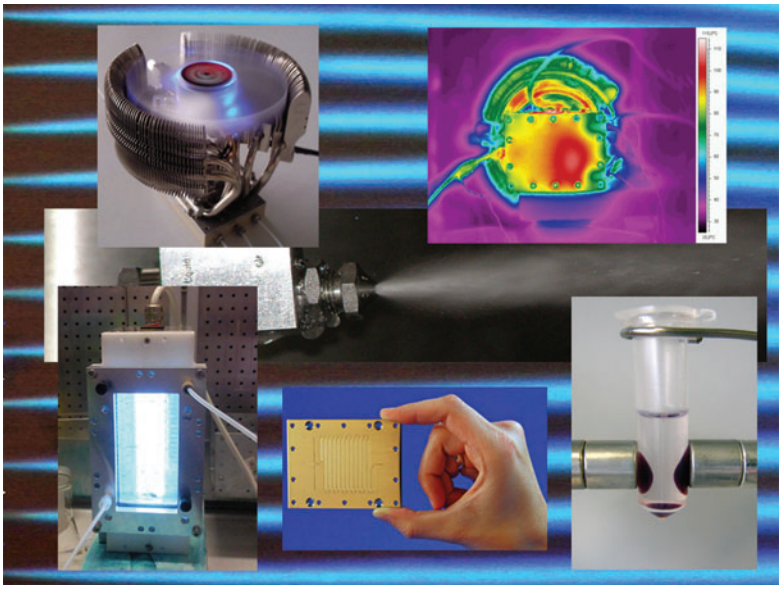
Holger Löwe studied organic chemistry at the University of Leipzig, East Germany from 1973 to 1977 and achieved his diploma with a paper on the thermodynamics of GaP epitaxial growth from the gas phase. From 1977 to 1984, he worked as research group leader in the Basic Research Department

at Filmfabrik Wolfen. He was responsible for the synthesis of new organic dyes for the photographic development process. In 1984, he attained his PhD (Dr. rer. nat.) with work on "Alkylation of phenols at heterogeneous catalysts" (under Professor M. Fedtke, Merseburg). In 1984, Dr. Loewe moved to the Faculty of Electrochemistry at the Technical University in Ilmenau, Germany to work as a research assistant and lecturer.

In 1991, he started a new career at IMM, and later in 1999 became Director of R&D of this institute. He established the Chemistry/Micro-reaction Technology Department and a Bio-microfluidic group at IMM. In 2007, he was appointed as a visiting professor at the Dalian University of Technology; since 2008 he has been a guest professor at the East China University in Shanghai; and since 2011 he has been a professor at the Zhejiang University in Hangzhou (both in China). Dr. Löwe is author or co-author of approximately 150 peer-reviewed papers, 26 contributions to edited books, 46 patents and three books. He is also a reviewer for numerous scientific journals as well as being a member of various organizations.

Current research activities

The group's research activities comprise chemical synthesis, and engineering and processing in combination with aspects of micro-fluidics and simulation. This combination allows for a holistic view on chemical processing, especially for performing chemical reactions close to their kinetic limits, not



necessarily with micro-reactors but preferably with pre-structured fluids at the micro-scale. Therefore, it is not surprising that reactions performed in spray or droplet-based reactors without solid wall contact are one of their main research topics from an engineering point of view. Also, non-conventional heating or cooling devices, e.g., microwave generators or heat pipes in combination with micro-structured flow-through reactors are successfully implemented in laboratory-scale setups.

For the last few years, the synthesis of so-called ionic liquids (ILs) with unusual functionalities has been under investigation. For imidazolium type ILs with unusual anions such as nitrate, acetate or lactate, simple reaction pathways via carboxylation have recently been developed. These materials combine the known advantageous properties of such designer solvents (ILs) with new functionalities. For example, ILs with additional anchor or chelating groups are used as recyclable and homo-coupling suppressing catalysts for Suzuki type C-C coupling reactions. Of major interest are substances with multiple specific functionalities, e.g., noble metal containing paramagnetic liquids, which can act as recyclable liquid heterogeneous catalysts in two-phase flow applications. Owing to the fact that magnetic forces are short ranged, such magnetic liquids are advantageous for manipulating in a micro-structured environment.

Their other activities deal with the continuous syntheses of nanoparticles on a pilot-scale, i.e., the development of applicable equipment and process protocols for scale-up manufacturing from a few grams to tons-scale. The targeted applications range from high-valued pharmaceutical applications to nano-scaled commodities.

In a joint project with other research groups the synthesis of anti-tumor substances are under investigation. An efficient Petasis olefination of sugar lactones under continuous flow microwave conditions has been developed. By applying such a continuous flow procedure, the reaction time can be shortened several hundred times compared with values achievable with batch procedures. This setup is utilizable for a gram-scale synthesis of compounds containing sensitive structures such as enol ethers or exo-glycals.

Unusual protocols or new and simpler pathways are under investigation to speed up chemical reactions. This is in accordance with the needs for establishing "Novel Process Windows" for chemical processing and also for education in standard university laboratories, As it says in the best known textbooks, several chemical reactions should be performed only at very low temperatures, at least by wasting unnecessary amounts of energy to provide the cooling power. However, the order of today is to establish a sustainable and "Green Chemistry". Therefore, diazotization and coupling reactions at elevated temperatures are currently under investigation.

Cooperation with foreign partners

Several foreign universities and institutions are in close contact with the CMPT group. One of them is InnoVenton: Institute for Chemical Technology, a formally registered Research Institute at the Nelson Mandela Metropolitan University (NMMU), Pt. Elizabeth, South Africa, whose principle research areas include applied chemistry and the development of small key production platforms (including micro-structured reactor technologies) for the application of photo-bioreactors, direct liquefaction of microalgae biomass into biofuels and using continuous flow reactors, and the development and evaluation of new plasticizing compounds for the personal care/cosmetics market. A funded exchange program of PhD students and researchers was recently started. Strong cooperation was established between several Chinese universities, notably the Zhejiang University (ZJU), Hangzhou; the East China University (ECUST), Shanghai; the Nanjing University of Technology (NJUT), Nanjing; and the Hong Kong University of Science and Technology (HKUST), Hong Kong. PhD student exchange as well as teaching on-site

are the main themes of this cooperation. In addition, foreign industrial partners are working with the CMPT research group in different research fields. For example, a few notable partners are the C-TRI company (Korea) for Ionic Liquids applications; the NAFINE group (Yuncheng) for inorganic nanoparticles, and the NONFEMET group (Shenzen) for metallic nanoparticles.

The institution

The Institute of Organic Chemistry was established as part of the Faculty of Chemistry, Pharmaceutical Sciences and Geosciences at the Johannes Gutenberg University Mainz (JGU) on April 1, 2005. The faculty currently has 53 professors and 439 further faculty members, working for nine institutes. Almost 3700 students are studying Chemistry, Pharmaceutical Sciences, Biomedical Chemistry, Geography, Geology/Paleontology, and Mineralogy, with various degrees on offer. The main research directions of the Institute of Organic Chemistry are in polymer science as well as in pharmaceutical chemistry and natural product research. Chemical processing in micro-flow is an interdisciplinary approach and can advantageously bridge the gap between fundamental preparative chemistry and chemical engineering.

JGU was founded in 1477, just a few years after the death of its namesake – Johannes Gutenberg, the famous inventor of movable type printing. With more than 36,000 students from approximately 130 nations, JGU is one of the 10 largest universities in Germany. As a comprehensive university, JGU combines almost all academic disciplines under one roof, including the Mainz University Medical Center, the School of Music, and the Mainz Academy of Arts. This is a unique feature in the German academic landscape. Some 4150 academics, including 540 professors, teach and conduct research at JGU's more than 150 departments, institutes, and clinics. JGU is proud to be a research institution of national and international recognition, and is particularly strong in the field of materials science, earth system science, nuclear and particle physics, translational medicine, and media and cultural studies. In September 2011, JGU submitted its definite proposals for one graduate school, three clusters of excellence, and its institutional strategy "The Gutenberg Spirit: Moving Minds – Crossing Boundaries" to the Excellence Initiative by the German Federal and State Governments.