Chapter 1
Introduction

Brian P. Cahill

1.1 Micro Segmented Flow: A Challenging and Very Promising Strategy of Microfluidics

When scientists and engineers started to realize the idea of the Lab-on-a-Chip, they followed the vision to transfer the power and success of miniaturized systems from solid state electronics into the world of chemistry and molecular biology. The transport and processing of molecules inside highly integrated networks of fluid channels should be controlled in analogy to the transport of electrons through electronic networks and used for powerful analytical procedures, for molecular information management as well as for the synthesis and optimization of new molecules and molecular nanomachines. But during the research on the realization of complex microfluidic systems and experiments guiding homogeneous fluids through microchannels it became more and more clear that this analogy was wrong, that this vision was a delusion.

But, the wrong analogy was only a partial fallacy. The most powerful basic concept behind miniaturization in solid state electronics as well as behind microfluidics is the functional patterning, the hierarchical subdivision of space. It is the same principle which we always observe in living nature and which creates the huge wealth of shapes and structures at the different size scales in the world of organisms. All of the unbelievable plurality of structures and functions in living beings is based on one absolute undispensible concept: fluidic compartmentalization.

The formation of cells is the most fundamental principle of living nature, and liquid compartmentalization is continued in the internal compartmentalization of eucaryotic cells by cell organelles or by the formation of organs and lumens in the development of multicellular organisms. The separation of a small volume from the

B. P. Cahill (✉)
Institute of Chemistry and Biotechnology, Technical University Ilmenau,
Weimarer Str. 32, 98693 Ilmenau, Germany
e-mail: brian-patrick.cahill@tu-ilmenau.de

J. M. Köhler and B. P. Cahill (eds.), *Micro-Segmented Flow*,
Biological and Medical Physics, Biomedical Engineering,
DOI: 10.1007/978-3-642-38780-7_1, © Springer-Verlag Berlin Heidelberg 2014

environment, the subdivision of space into well-defined small units, the partial decoupling of the cell's internal chemistry from the outside conditions and the variation of chemical and biomolecular processes between these compartments have been the essential preconditions for the evolution of life. The generation of droplets and fluid segments in micro fluidic devices was driven by the search of methods for controlled manipulation of small liquid portions, but was not primary motivated by the analogy of liquid compartmentalization in nature. But, the principle of formation, controlled transport and processing of such liquid compartments is an obvious analogy

This book is dedicated to the principle and application potential of micro segmented flow. The recent state of development of this powerful technique is presented in nine chapters by active researchers in this exciting field. In the first section, the principles of generation and manipulation of micro fluid segments are explained. It gives the fundamentals of the fluidic behaviour of micro droplets and microfluidic segments and explains the possibilities for control and reliable manipulation of the liquid compartments. In the second section, the micro continuous-flow synthesis of different types of nanomaterials is shown as a typical example for the use of advantages of the technique in chemistry. These examples show how the specific advantages of transport conditions in segmented fluids can be used in order to improve the conditions for continuous-flow synthesis procedures and for improving the quality of products. In the third part, the particular importance of the technique of micro segmented flow in biotechnical applications is presented demonstrating the progress for miniaturized cell cultivation processes, for cell biology and diagnostics and sequencing as well as for the development of antibiotics and the evaluation of toxic effects in medicine and environment.

There are three main aspects of the use of micro fluid segments in technology:

1. Process homogenization by control of transport processes and realization of highly reproducible local mass and heat transfer conditions ("fluidically determined process homogenization")
2. Subdivision of process volumes in order to generate high numbers of independent process spaces ("fluidically defined separate micro reactors")
3. Interface management by fluidically controlled interaction of liquid compartments ("fluidically designed interface processes").

The first aspect is mainly used in micro reaction technology. It allows the implementation of micro-continuous flow processes with very high homogeneity. These processes are marked by very high rates of mixing and heat transfer as well as by an ultimate narrow distribution of residence times. In addition, the pattern of fluid motion inside micro fluid segments is reproducible. In consequence, it can be expected, that each volume element experiences the same "process history". This quasi-perfect homogenization of all transport and reaction processes in all volume elements means a ultimate step in the quality of chemical engineering in continuous flow processes.

The second aspect concerns the experimental realization of high, but ordered diversity. This aspect is of large interest for combinatorial processes, screenings, variation and investigation of process parameters and for the realization of two- or

higher-dimensional concentration spaces. The automated subdivision, the addressing and separate processing of individual fluid segments is, for example, very promising for combinatorial chemistry, for high-throughput diagnostics, for pharmaceutical screenings and for toxicological investigations.

The third aspect relates to the spatial control of interface management. In contrast to suspensions and emulsions, which consist of statistically distributed volume elements, the micro segmented flow realizes well-defined spatial relations between the single liquid compartments, between different types of liquids and between the liquids and the wall. The ordered processing of fluid segments correlates with an ordered transport and processing of interfaces. This is very important for nearly all types of phase-transfer processes and for operations with micro and nanophases. So, the micro segmented flow is, for example, a very promising tool for the synthesis, modification and manipulation of nanoparticles.

The following chapters will introduce us to the fascinating world of micro droplets and fluid segments, will explain the principles of microfluidic functions, describe designs and realization of fundamental devices and give examples for important applications reaching from inorganic chemistry, over organic materials to biological systems.

http://www.springer.com/978-3-642-38779-1

Micro-Segmented Flow
Applications in Chemistry and Biology
Köhler, J.M.; Cahill, B.P. (Eds.)
2014, XVII, 272 p. 163 illus., 91 illus. in color.,
Hardcover
ISBN: 978-3-642-38779-1