Micro Process Engineering for Fine Chemistry and Fuel Processing - from Lab to Pilot/Production and First Issues on Dynamic Operation

Volker Hessel[1,2]

[1] *Institut für Mikrotechnik Mainz GmbH (IMM), Mainz, Germany*
[2] *Eindhoven University of Technology (TU/e), Eindhoven, the Netherlands; v.hessel@tue.nl*

This presentation tries to cover the following two aspects.

- To show up how milli and micro process technologies contribute to green processing and process intensification in chemical industry. Relevant trends in the IMM developments (with some supplements of TU/e research) will be given at the focal points catalyst / fabrication / reactor / plant / processes.
- As outlook and much more briefly, first thoughts on process control for micro processing will be given, showing some issues and examples for process analytics in fine chemistry (taken from Paul Watts, University of Hull) and some IMM results about dynamic operation in fuel processing.

Fine Chemical Applications – Process Intensification by Novel Process Windows

Draw on sustainability for chemical production processes demands the integration of sustainability aspects already during process development, whereas further environmental impacts and production costs become predefined. Micro and milli process technologies [1,2] can provide novel ways for process intensification combined with ecological [3] and economic [4] advantages and first assessments were made here [5], mainly by industry. Microstructured reactors have entered the field of fine chemistry with first pilot and production plants; some examples being reported [6]. To bring these innovative apparatus to their operational limit and thus to process with maximal cost competitiveness and environmental sustainability, the idea of “Novel Process Windows” [7] is discussed referring examples of actual research. A recent case study disclosed the key drivers for ecological and economic optimisation [5] when intensifying the aqueous Kolbe-Schmitt synthesis in a minicapillary reactor [8] by using microwaves as alternative energy source and ionic liquids as alternative solvents.

[1] Hessel, Hardt, Löwe / Hessel, Löwe, Müller, Kolb, Chemical Micro Process Engineering (2 Volumes), Wiley-VCH, Weinheim, 2004/2005. *[2]* Jähnisch, V. Hessel, Löwe, Baerns, Angew. Chem. Int. Ed. 2004, 43 (4), 406. *[3]* Kralisch, Kreisel, Chem. Eng. Sci., 2007, 62 (4), 1094. *[4]* Krtschil, Hessel, Kralisch, Kreisel, Küpper, Schenk, Chimia, 2006, 60 (9), 611. *[5]* Hessel, Kralisch, Krtschil, Energy Environ. Sci. 2008, 1 (4), 467. *[6]* Hessel, Löb, Löwe, Industrial Microreactor Process Development up to Production, in: Microreactors in Organic Chemistry and Catalysis (ed. T. Wirth), Wiley-VCH, Weinheim, 2008, pp. 211-275. *[7]* Hessel, Löb, Löwe, Curr. Org. Chem., 2005, 9 (8), 765. *[8]* Hessel, Löb, Löwe et al., Org. Proc. Res. Dev., 2005, 9 (4), 479.

Hydrogen for Fuel Cells by Fuel Processing – Process System Engineering

For catalysis using microreactors [1], it is essential to have total reaction control at all length scales, ranging from mm to nm, which includes smart engineering of reactor plates and microchannels as well as proper setting of catalyst coatings and metal clusters in mesopores. Most essential here is the reliable finding of activated catalysts and proper introduction of these into the microchannels [2-7]. In continuation, catalytic pilot and production microstructured reactors [8,9] demand for solutions on scale-out (system assembly) [8,9], control over flow distribution and heat management at multi-plate architecture [10,11], integration of reaction and heat exchange / separation, process flow with many coupled reactions and operations (sometimes involving recirculation) [8,9], reduction in expenditure for energy and apparatus required for work-up [12], and increase in the service life of the catalyst including concepts for catalyst change, e.g. by replacement of entire modules. This is accompanied by the development of new microfabrication and joining techniques applicable to large, meter-sized format such as rolling / embossing / etching and brazing / diffusion bonding [13]. System and process design is widely practised at IMM for applications in fuel processing for hydrogen production to feed fuel cells [14]. This has led to industrial implementation already, e.g. the 250 W LPG fuel processor-fuel cell *VEGA* for leisure vehicles and boats (Truma Gerätetechnik) and a 2 kW diesel fuel processor-fuel cell prototype as auxiliary power unit for trucks (Volvo, DAF; assembled by Tenneco) [14]. Applications using fossil fuels being reality, the next step is to explore chances of the technology for biofuels with its more complex processing schemes, different logistics and cost structures.

[1] Kolb, Hessel, Chem. Eng. J., 2004, 98 (1-2), 1. *[2]* Muraza, Rebrov, de Croon, Schouten et al., Chem. Eng. J., 2008, 135S, S99. *[3]* Mies, Rebrov, Jansen, de Croon, Schouten, J. Catal., 2007, 247 (2), 328. *[4]* Rebrov, Kuznetsov, de Croon, Schouten, Catal. Today, 2007, 125, 88. *[5]* Pennemann, Hessel, Kolb, Löwe, Zapf, Chem. Eng. J., 2008, 135 (1), S66. *[6]* Men, Kolb, Zapf, Hessel, Löwe, Catal. Today 2007, 125 (1-2), 81. *[7]* Men, Kolb, Zapf, Hessel, Löwe, Trans IChemE, 2007, 85 (B5), 1. *[8]* Men, Kolb, Zapf, Tiemann, Wichert, Hessel, Löwe, Int. J. Hydrogen Energy, 2008, 33 (4), 1374. *[9]* Kolb, Schürer, Tiemann, Wichert, Zapf, Hessel, Löwe, J. Power Sources, 2007, 171 (1), 198. *[10]* Rebrov, Ismagilov, Ekatpure, de Croon, Schouten AIChE J., 2007, 53 (1), 28. *[11]* Mies, Rebrov, Deutz, Kleijn, de Croon, Schouten, Ind. Eng. Chem. Res., 2007, 46 (12), 3922. *[12]* Delsman, Uju, de Croon, Schouten, Ptasinski, Energy Int. J., 2006, 31 (15), 3300. *[13]* Hessel, Kolb, Brandner, Microfabrication for Energy Generating Devices and Fuel Processors in: Microfabricated Power Generation Devices (eds.: Mitsos, Barton,), in print (2008). *[14]* G. Kolb, Fuel Processing, Wiley-VCH, Weinheim, 2008.