Micro Reaction Technology with Macro Process Efficiencies – Multi-Ton Production Millireactor substitutes a traditional Batch Process

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Microreaction Technology – First Steps in 1995

First Industrial consortium at IMM Mainz – Prof. Ehrfeld

- Evaluation of potentials of microreactors for technical relevant chemical reaction.
  - Participants e.g. BASF, Daimler Benz, Degussa, DuPont, Hoechst, Hüls, Merck, Rhone Poulenc.
  - Significant increase of yield of Andrussow reaction by using a micro mixer for pre-mixing of reactants.

Prof. Ehrfeld takes over the baton as pioneer for microreaction technology
Microreaction Technology – 1997-2000

First conference on Microreaction Technology 1997 – extract preface – IMRET

› Rising interest of leading companies and research institutes
› Tremendous possibilities of microreactor concepts with huge economic potential
› Initiation of worldwide research and development activities

Microreaction Technology – Integral part of Process Intensification

› Radically innovative principles (paradigm shift) in process and equipment design
› Huge Benefits in process and chain efficiency, capital and operating expenses, quality, waste, process safety and more.
Microreaction Technology – 2001 - present

Raising of interest worldwide:

› Different suppliers of flow equipment raise their businesses
  • Chemtrix, Corning, Vapourtec, Thales Nano etc.
› Different suppliers of peripherie adjust their product portfolio to flow equipment
  • HNP Mikrosysteme, Huber, HiTec Zang etc.
› Chemical and pharmaceutical companies ask for real production units above the lab and pilot scale
Continuous Flow with Microstructures – Benefits

- Rapid mixing
- Rapid heat exchange (no “hot spots”)
- Well defined residence time
- Short response time

Continuous flow + Micro- / Milli-structured channels
Challenges for Establishing the Technology Platform Micro-/Millireactors

→ **Competition against established technologies in process industries**
  - Paradigm change batch-/conti
  - In R&D predominantly use of batch reactors for synthesis of new molecules
  - Infrastructures of production plants /-logistics predominantly aligned to batch processes

→ **Calculation of risk difficult for new technology platforms**
  - Missing or not published references in production scale
  - Missing knowledge about attractive applications as well as design basics
  - Adequate robustness for demands of production plants
  - Risk of investment
Challenges for Establishing the Technology Platform Micro-/Millireactors

→ Critical success factors

› Visible references in production scale
› Demonstration of sufficient robustness for production application
› Strong performance increase
› Know how about attractive applications/market segments

› Readiness for stepping in into innovative technology platform micro-/millireactors in China more pronounced than in Europe and US because of long track record of process industries in Europe and US.

China goes ahead with first visible reference in production scale
## Attractive Market Segments & Applications

<table>
<thead>
<tr>
<th>Segment</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peroxides</td>
<td>• Explosive reactions</td>
</tr>
<tr>
<td></td>
<td>• Highly exothermic reactions</td>
</tr>
<tr>
<td>Alcoxylation / Sulphonation</td>
<td>• Very fast reactions</td>
</tr>
<tr>
<td></td>
<td>• Liquefied gas reactions</td>
</tr>
<tr>
<td>Active Ingredients</td>
<td>• Fast reactions</td>
</tr>
<tr>
<td></td>
<td>• Multi-step synthesis</td>
</tr>
<tr>
<td>Precipitation</td>
<td>• Fast mixing</td>
</tr>
<tr>
<td></td>
<td>• Uniform conditions</td>
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</tbody>
</table>
Examples on lab scale

<table>
<thead>
<tr>
<th>Hydride reduction using RedAl</th>
<th>Grignard Reaction</th>
<th>And many more...</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Batch:</strong></td>
<td><strong>Batch:</strong></td>
<td></td>
</tr>
<tr>
<td>Temp: 0 °C</td>
<td>Temp: 50 °C</td>
<td></td>
</tr>
<tr>
<td>Retention time: 8 hours</td>
<td>Retention time: few min</td>
<td></td>
</tr>
<tr>
<td>Yield: 80...90%</td>
<td>Yield: 80...90%</td>
<td></td>
</tr>
<tr>
<td><strong>Conti:</strong></td>
<td><strong>Conti:</strong></td>
<td></td>
</tr>
<tr>
<td>Temp: 10...20 °C</td>
<td>Temp: 50 °C</td>
<td></td>
</tr>
<tr>
<td>Retention time: 40 seconds</td>
<td>Retention time: 100 sec</td>
<td></td>
</tr>
<tr>
<td>Yield: 95...98%</td>
<td>Yield: 98%</td>
<td></td>
</tr>
<tr>
<td><strong>Output:</strong></td>
<td><strong>Output:</strong></td>
<td></td>
</tr>
<tr>
<td>0,7 kg/hour of isolated product</td>
<td>0,5 kg/hour of isolated product</td>
<td></td>
</tr>
</tbody>
</table>

**Lithiation Reaction**

| **Batch:**                   | **Conti:**        |                 |
| Temp: -40 °C                 | Temp: -10 °C      |                 |
| Retention time: 4 h          | Retention time: 45-90 sec |                 |
| Yield: 80%                   | Yield: 96,5%      |                 |
| By-product formation time-depending |                     |                 |
| **Output:**                  |                   |                 |
| 1.0 kg/hour of isolated product |                 |                 |
Production – Analogy to well established equipment

Origin: Plate HEx

Lonza FlowPlate® MicroReactors

ART® Plate Reactors

Origin: Tube Bundle HEx

Miprowa® Reactors

Production – Analogy to well established equipment
Scale-up Strategy – From micro to millimeter dimensions

R&D and Kilo Lab Scale
0.05 – 10 L/h

Pilot Scale
10 – 100 L/h

Production Scale
40 – 10000 L/h

Optimization

Validation

Production

Transfer batch-to-continuous operation
Optimizing your processes and products

Mastering your personalized scale-up

Yielding your product as efficient as possible

EHRFELD Mikrotechnik
Pathway for implementation – Full Customer Support

Research

- Tech meeting
- Proposal for Feasibility test
- Feasibility test
- Feasibility test results

Development

- Process Optimization "Develop a Process Window"
- MRT design
- Pilot Test
- Investment budget

Production

- MRT delivery
- Engineering Design
- Commissioning and startup
- Acceptance test /Training/Service

Efforts

- ~ 100%
- ~ 1%

Time

Crucial success factors

- Control risk at early stage
- Systematical works for process development
- Complete process package
Lighthouse Project – Multi-Ton Production Millireactor

Challenges in Batch Plant:

→ Strong heat release
→ flammable, explosive and toxic
→ Long reaction time
→ low efficiency
→ poor safety
→ uncontrollable capacity expansion
From Batch to Continuous Production
The Chemistry Behind

Reactant + Ethylene Oxide → Product + Q

- Explosive
- Extremely Flammable
- Toxic

Increased Safety Risk

Solution: Reduced Reactor Volume

✓ Increase of Safety
The Chemistry Behind

Reactant + Ethylene Oxide → Product + Q

- Limited Stability of Reactant and Product
- Highly Exothermic
- Side Reactions
- Reaction Time Batch > 100 h

Solution:
- Improved Heat Exchange
- Reduced Reaction Time

✔ Increased Production Efficiency
From Batch to Conti in about 8 Months

\[ V_{\text{tot}} \approx 50 \, \text{m}^3 \]

\[ V_{\text{tot}} \approx 0.04 \, \text{m}^3 \]
Millireactor in Production – Lighthouse Reference Project

→ 6 Modular Miprowa reactor cores in serial
→ 154 channels (18 x 3 x 1200 mm³), each core
→ Dimensions: 7.50 m length, DN 400
→ Total volume: ca. 40 L
→ 5000 – 10.000 t/a throughput
→ Commissioning Sept. 2016

Process Reactor Assembly
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- Former process in ca. 20 batch reactors (Volume ca. 50 m³)
  - 100% capacity increase
  - Significant yield enhancement
  - Higher product quality
  - Upgrade of safety
  - Reduction of energy consumption & space footprint
Summary - Platform Micro-/Millireactors

- Establishing as process technology started and proceeds
- Lighthouse reference in production scale visible – production capacity 30,000 jato
- Attractive market segments/applications and design basics available
- Time efficient integrated scale-up based on established equipment concepts
- Chinese market goes ahead – European market follows