‘NEUE CHEMISCHE PROZESSFENSTER - NOVEL PROCESS WINDOWS’

Kick-Off-Meeting Forschungscluster “Novel Process Windows”

Osnabrück, 21.02.08

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Department of Chemical Engineering and Chemistry

[2] Institut für Mikrotechnik Mainz GmbH
Chemical Micro and Milli Process Technologies

CONTENTS

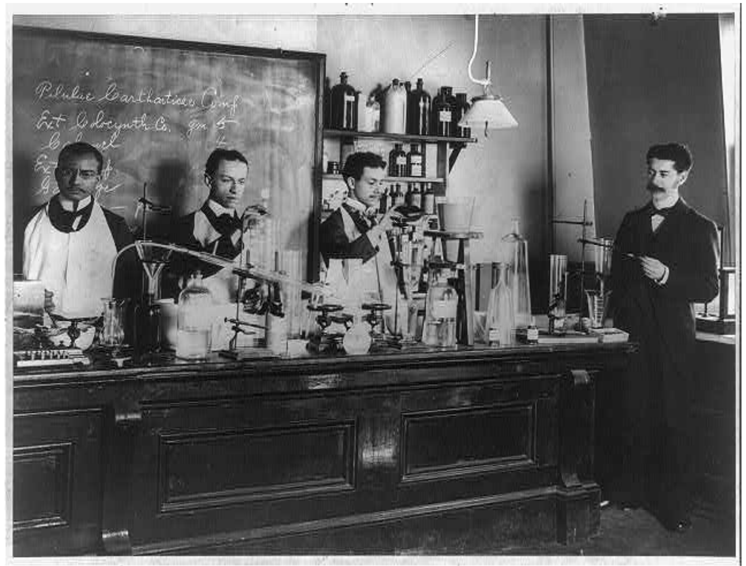
- Starting position
- From concept to research cluster
  - "Novel Process Windows"
- International reception
  – own related activities

- Starting Position

  – Novel Tools! Novel Chemistry?

CHEMISTRY EQUIPMENT OVER CENTURIES

18-19th century



~1900

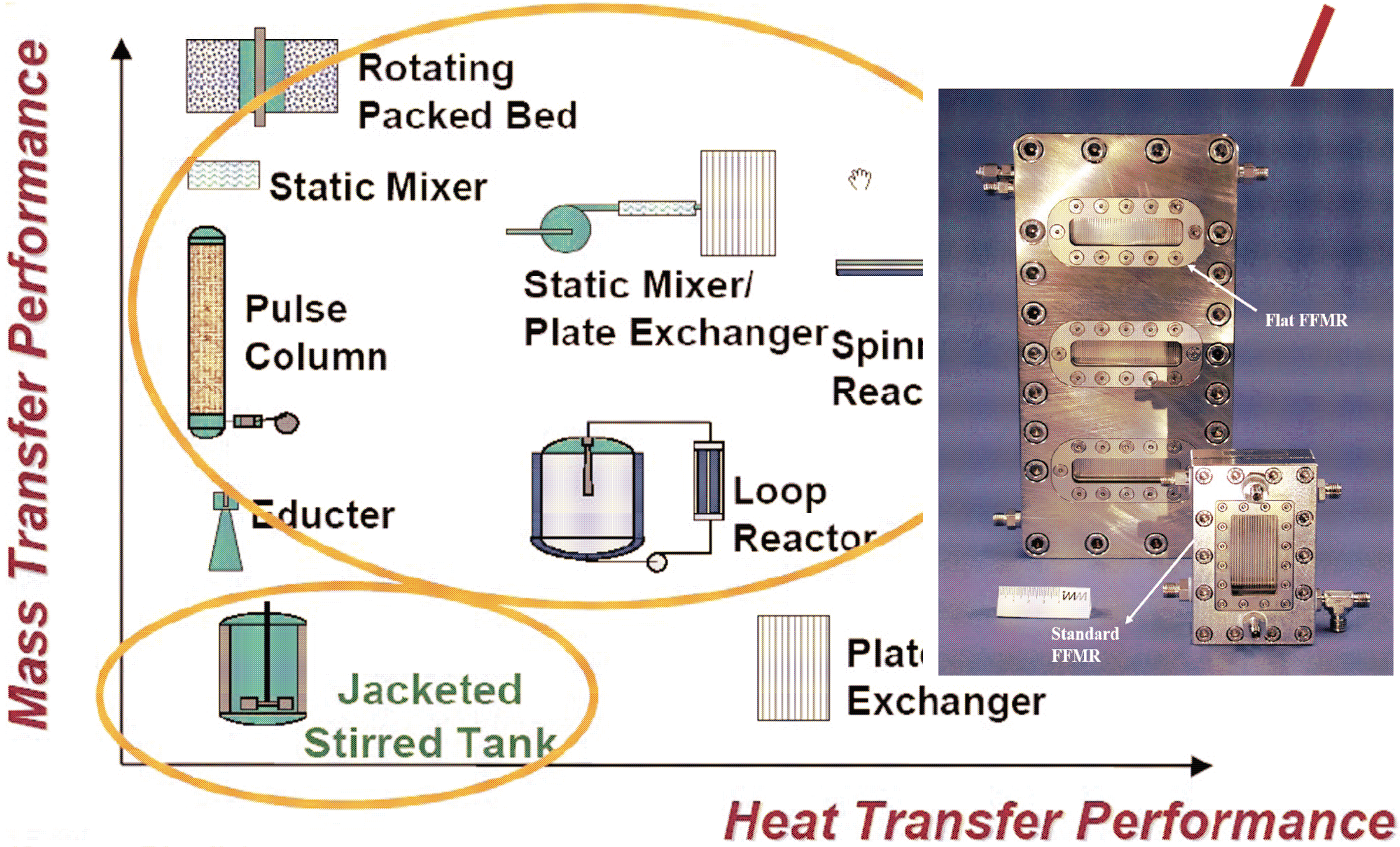
Today

Batch procedure

hessel@imm-mainz.de

CHEMSPEED TECHNOLOGIES

The Continuous Quest *for* Still Better Reactors, *Even Smarter Catalyst Packings, and* More Intensified Processes



(Source: Rhodia)

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Dutch PI Roadmap – Arthur D. Little Full Study

Calculation of energy savings – Results per sector – Fine Chemical A2

Results calculation energy savings estimates for Fine Chemical & Pharma sector

Fine Chem & Pharma		Multi-functional equipment	Micro/milli reactors	Microwave	High gravity fields	Total
Ultimate saving potential	PJ					
- Low		0	5	2	1	8
- High		1	7	3	3	14
penetration 2015		0%	8%	3%	20%	
penetration 2030		70%	88%	71%	100%	
Range 2015	**low**	0,0	0,4	0,1	0,2	**0,7**
	high	0,0	0,6	0,1	0,6	**1,3**
Range 2030	**low**	0,0	4,4	1,4	1,0	**6,8**
	high	0,7	6,2	2,1	3,0	**12,0**
Rate of introduction:						
[n] Introduction new tech.	year	10	12	15	5	
[m] plant/process replacement	year	15	15	15	15	
[y] Year of introduction		2015	2010	2012	2010	

Arthur D Little SenterNovem

Building a Business Case on Process Intensification, July 2006

Presented to Platform for Chain Efficiency (PKE); Full Report

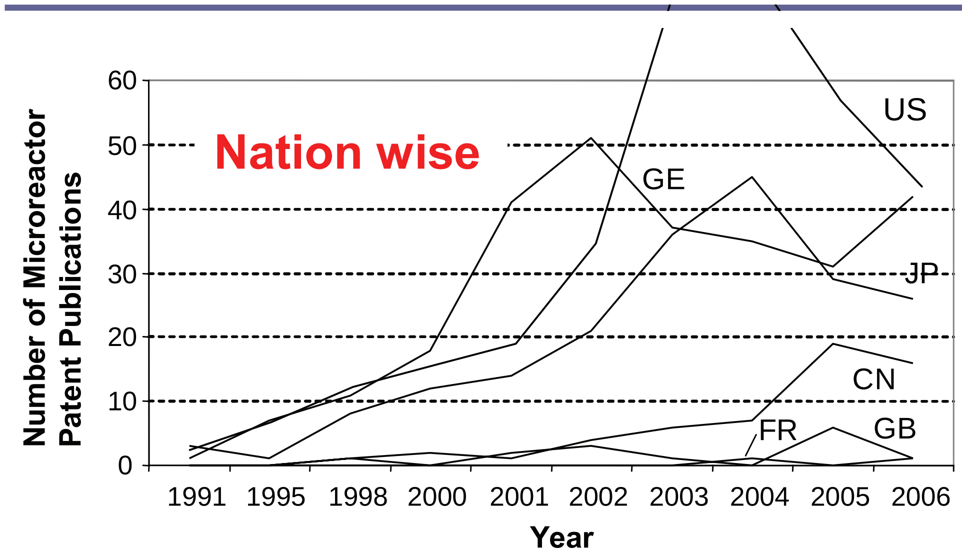
"The question of whether microreactors are going to be used in the future, I think this is already answered 'yes'." — Dominique Roberge

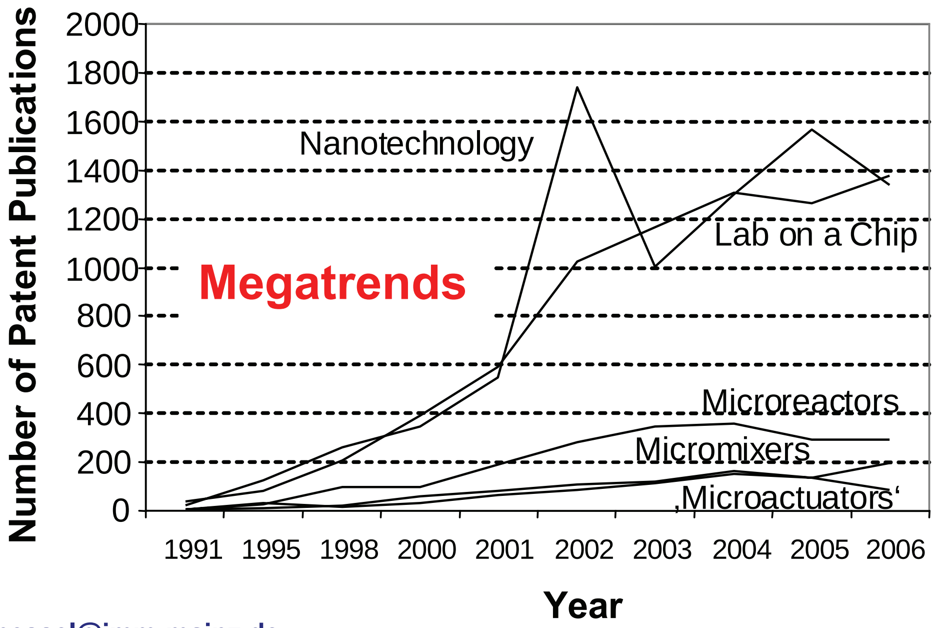
Nature 442, 7101 (2006) 351-352

- **Micro-/millireactors owe highest potential for global energy saving and competitiveness of chemical industry**
- **Focus is on process intensification („milli" and not „micro", where sufficient)**

>> Coming report (2008): European Process Intensification Roadmap, Stichting Energietransitie Ketenefficiency, The Netherlands

IPR AS MEASURE FOR ACTIVITIES





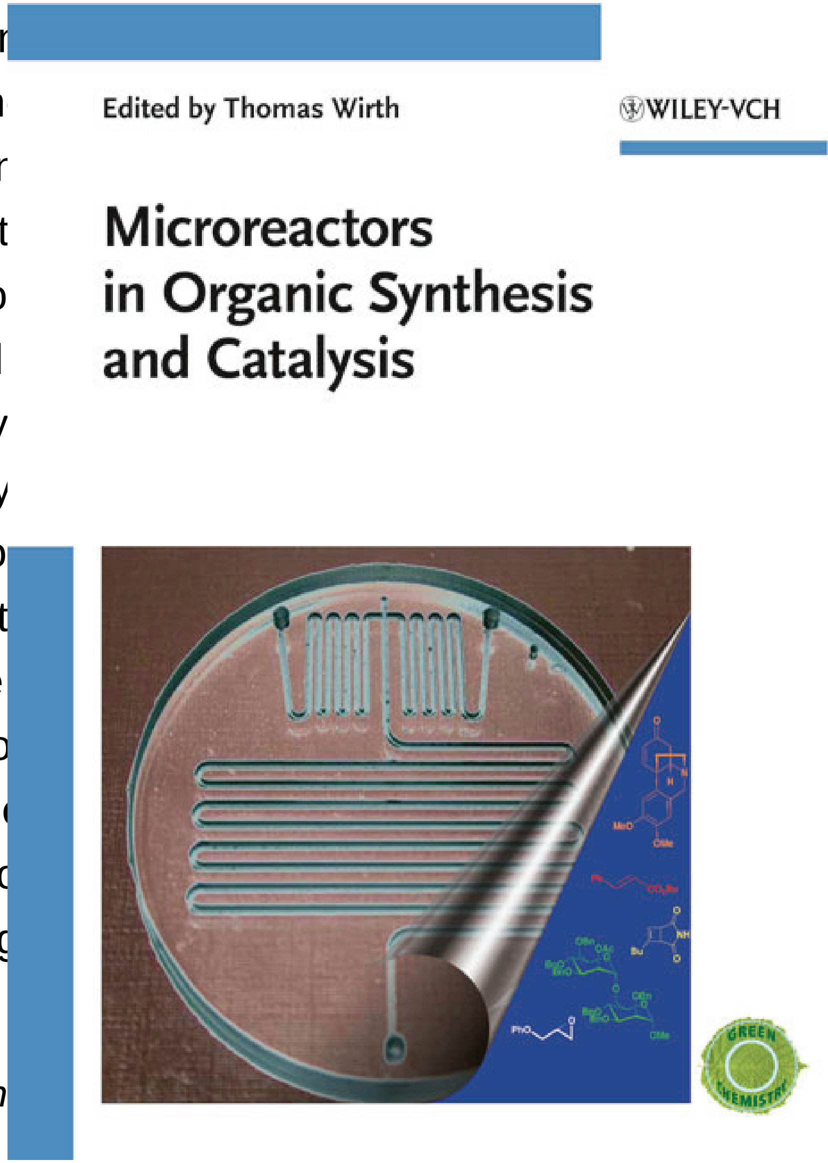
Top-10 Patentees

Ranking	Patent Publications	Patentee
1	144	MERCK PATENT GMBH
2	135	BATTELLE MEMORIAL INSTITUTE
3	129	VELOCYS INC.
4	54	FORSCHUNGSZENTRUM KARLSRUHE GMBH
5	50	UHDE GMBH
6	46	SIEMENS AKTIENGESELLSCHAFT
7	45	CASIO COMPUTER CO., LTD.
8	40	DEGUSSA AG
9	39	BAYER AG
9	39	INSTITUT FUER MIKROTECHNIK MAINZ GMBH
10	37	CLARIANT INTERNATIONAL LTD.

V. Hessel, C. Knobloch, H. Löwe, „Review on Patents in Microreactor and Micro Process Engineering", *Rec. Pat. Chem. Eng.* **1** (2008) 1-16.

27 INDUSTRIAL PILOT AND PRODUCTION CASES IN FINE AND BULK CHEMSTRY

Hydrogen peroxide syr
Organolithium exchan
Chlorinatior
Dehydrogenat
Polyacrylate formatio
Alkylation reactions based
DAST Fluorination (Bay
Steroid Ozonolysis (Bay
Plasma reactio
Gas-liquid oxidat
PMMA manufacture
Grignard exchange reactio
Halogen-Lithium exchang
Swern-Moffat oxidatic
Yellow nano pig



ion (Japanese company)
ylation (Japanese company)
xidation to 2-methyl-1,4-
ne (Japanese company)
on of ethyl 3-oxobutanoate
sahi Glass)
ormation (Degussa / Uhde)
ate synthesis (Uhde)
natic compounds (Brystol-
yers-Squibb)
lymer intermediates (DSM
hemicals GmbH)
diazo pigments (Clariant)
oduction (Xi’an Company)
production (not disclosed)
enolate production (Merck)

Hessel, V., Löb, P., Löwe, *up to Production"*, in: *"Micro-*
reactors for Organic Synth 'einheim (to be released 2008).

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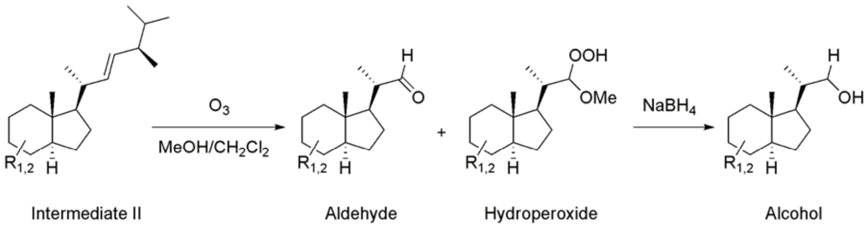
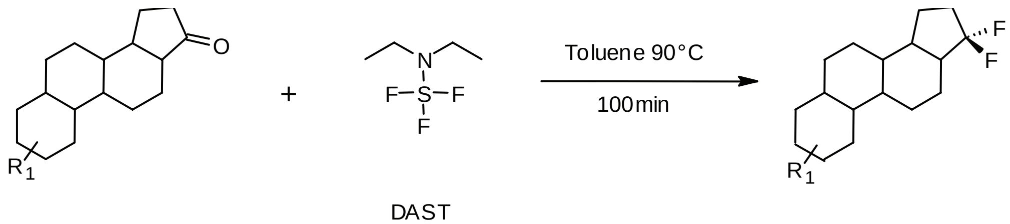
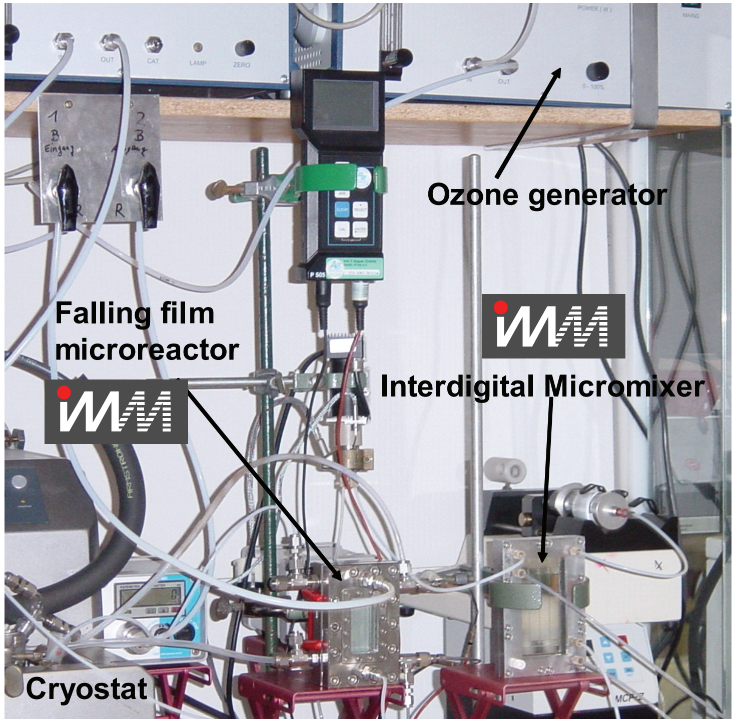
BAYER SCHERING PHARMA: IMM-TOOLS FOR STEROID CHEMISTRY

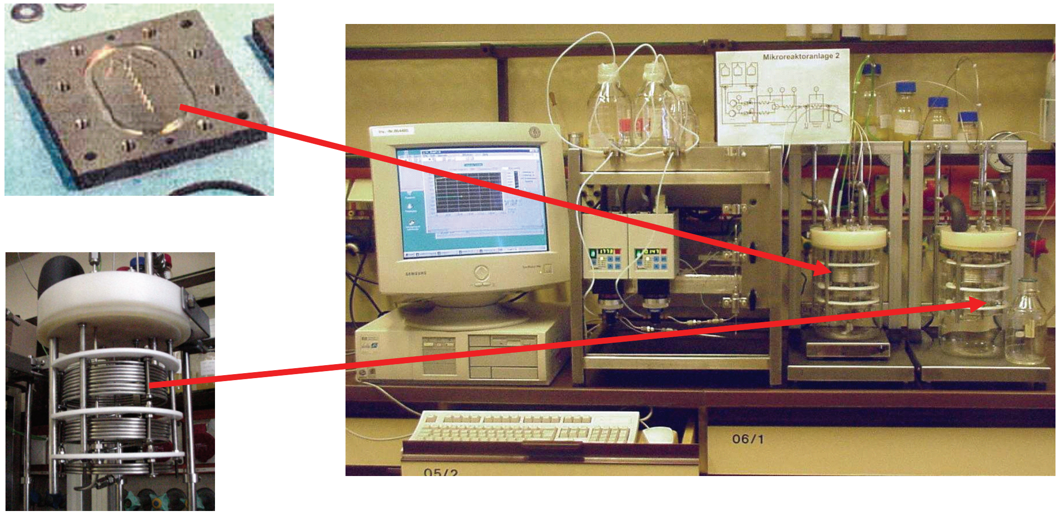
Ozonolysis



Fluorination







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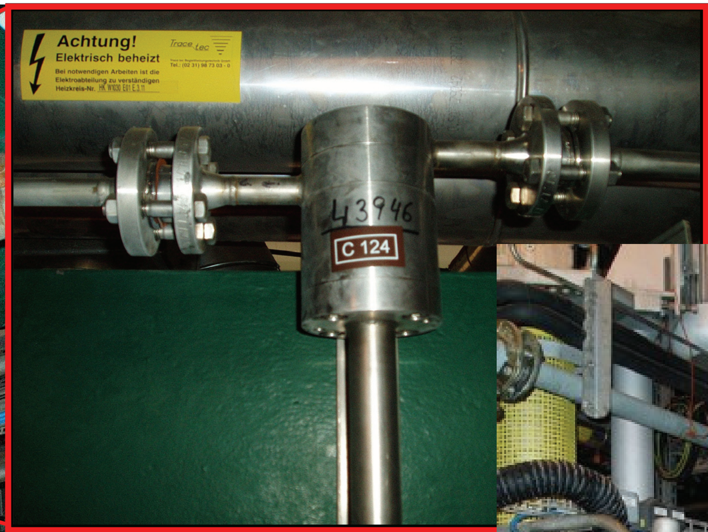
MICROSTRUCTURED REACTOR BASED PRODUCTION-PLANT



micro innova
micro chemical engineering

D. Kirschneck, G. Tekautz, Chem. Eng. Technol. 30, 3 (2007) 305-308.

- **In operation since June 2005**
- **Throughput 3 metric tons per hour; worldwide largest reported productivity by micro process engineering**

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MASS MANUFACTURE:

‚Large Reactors‘ for Bulk Chemistry + Large lot sizes for auotmotive + consumer good industries

Rolling

Brazing

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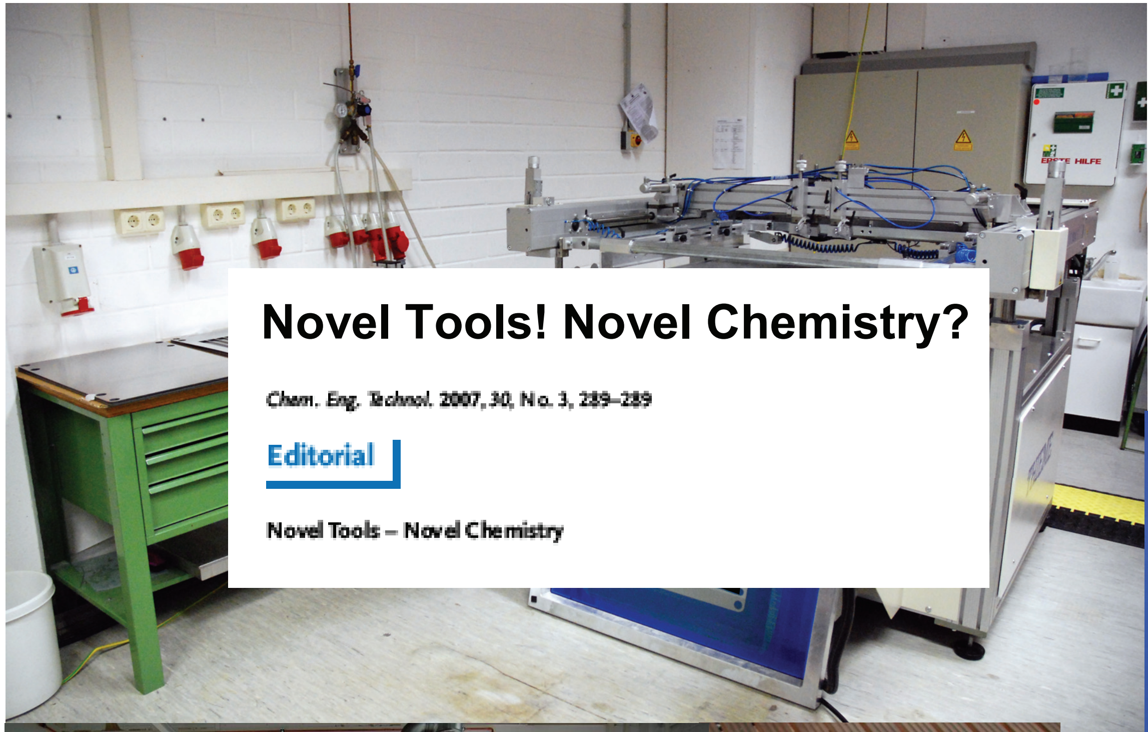
MICROSTRUCTURED PLATES IN METER-FORMAT FOR PILOTS AND PRODUCTION



Novel Tools! Novel Chemistry?

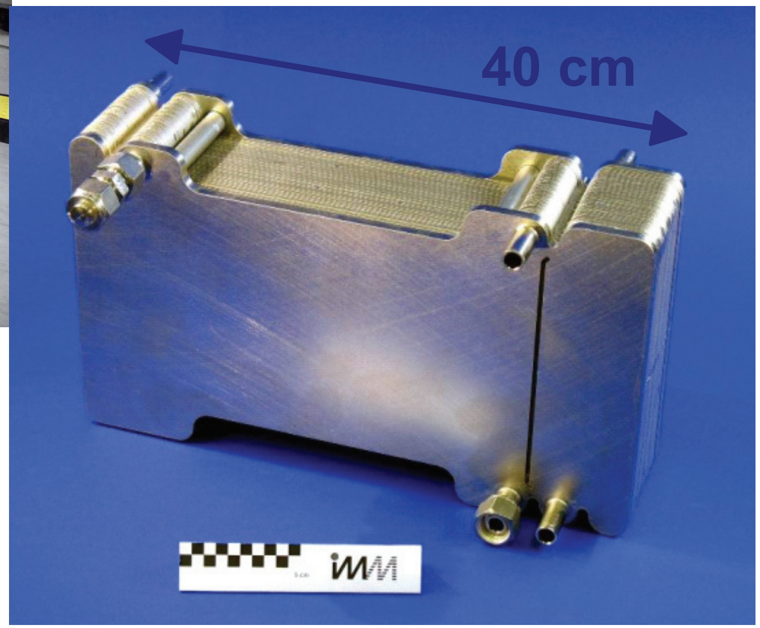
Chem. Eng. Technol. 2007, 30, No. 3, 289–289

Editorial

Novel Tools – Novel Chemistry

Screen printing for brazing

Compact pilot microreactor



Automated catalyst coating line

NOVEL PROCESS WINDOWS

– From concept to research cluster

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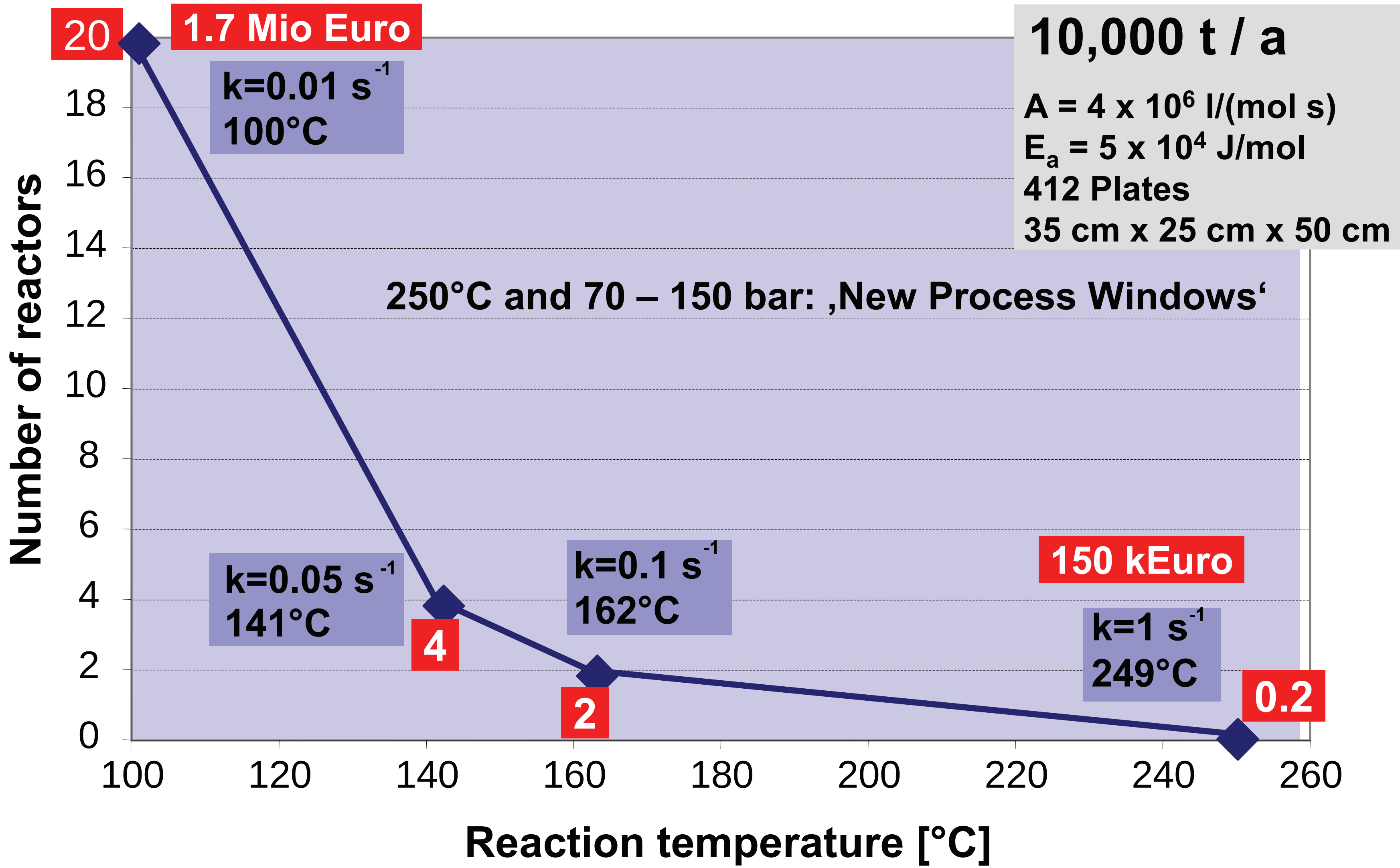
HYPOTHETICAL LIQUID-PHASE REACTION AT THE EDGE TO LARGE-SCALE PRODUCTION



NEED TO CHANGE CHEMICAL PROTOCOLS ('TURN INSIDE OUT')

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{50-130°C; 1 bar; 2-8 h} **Conventional lab batch**

{>200°C; >50 bar; <1 s} **High-p,T microreactor protocol**

'alike gas-phase chemistry'

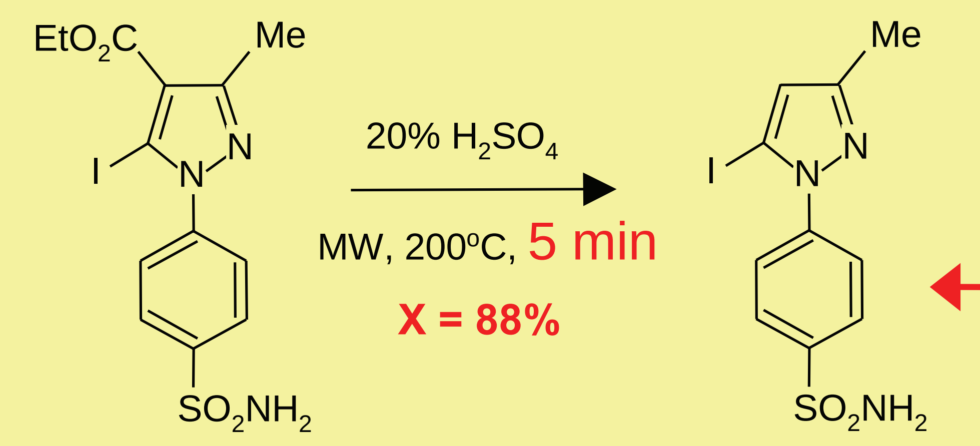
$$k = A \exp(-E_a/RT)$$

$A = 4 \times 10^{10}\ mol^{-1}\ s^{-1}$
$E_a = 100\ kJ\ mol^{-1}$

Temperature [°C]	**27**	**77**	**127**	**177**	**227**
Rate constant k [s^{-1}]	**1.6×10^{-7}**	**4.8×10^{-5}**	**3.5×10^{-3}**	**9.9×10^{-2}**	**1.43**
Time (90% conversion)	**68 days**	**13.4 h**	**11.4 min**	**23.4 s**	**1.61 s**

from: Kappe, C.O., Stadler, A. *Microwaves in Organic and Medicinal Chemistry*, Vol. **25** in: Methods and Principles in Medicinal Chemistry (eds.: Mannhold, R., Kubinyi, H., Folkers, G.) Wiley-VCH (2005) pp. 94-95.

→ **following the routes of microwave assisted continuous synthesis (MAOS)**

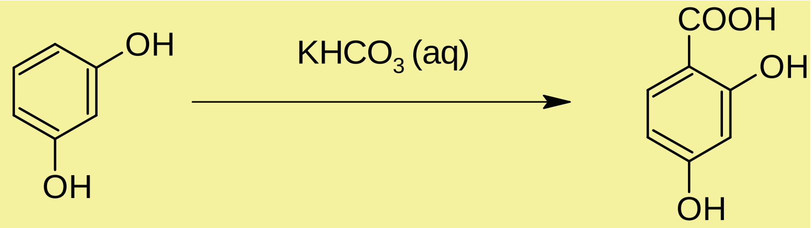


Organ, M.G., Mayer, S., Lepifre, F., M'Zemba, B., Kathri, J. *Mol. Diversity* **7** (2003) 211-227.

Reflux, 100°C, 96 h

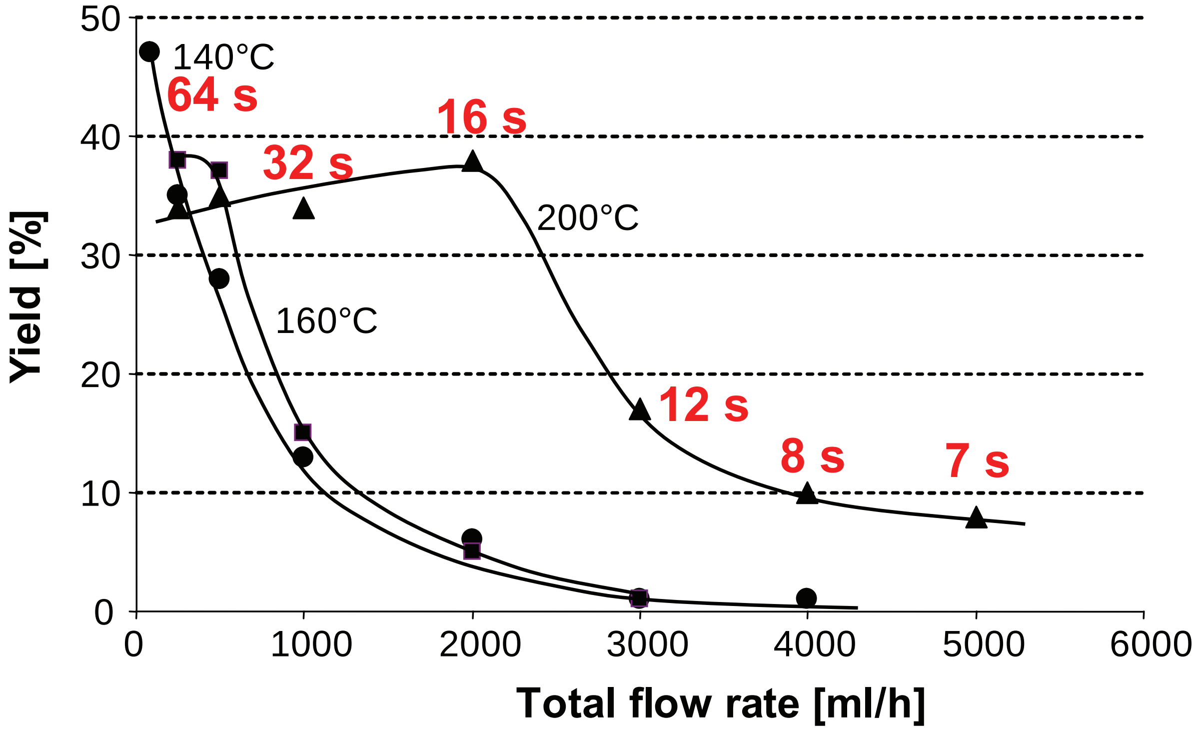
X = 86%

KOLBE-SCHMITT SYNTHESIS: HIGH-p,T PROCESSING



V. Hessel, C. Hofmann, P. Löb, J. Löhndorf, H. Löwe, A. Ziogas
Org. Proc. Res. Dev. **9**, 4 (2005) 479-489

High p,T



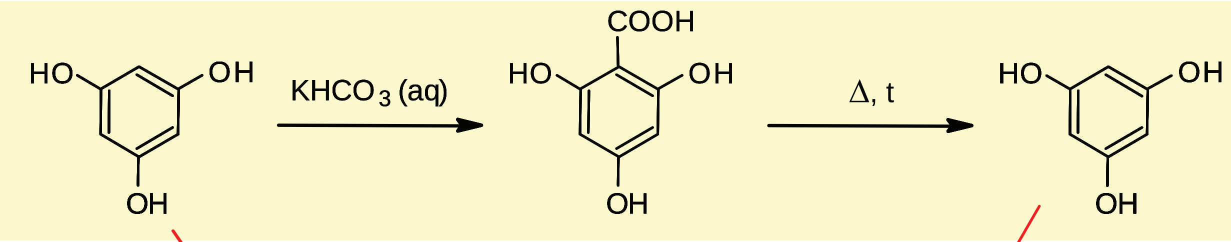
- **Pressure: 40-70 bar**
- **Temperature: 100-220°C**
- **Reaction time: 4 – 390 s**

→ **Reduction of reaction time by ~2000**

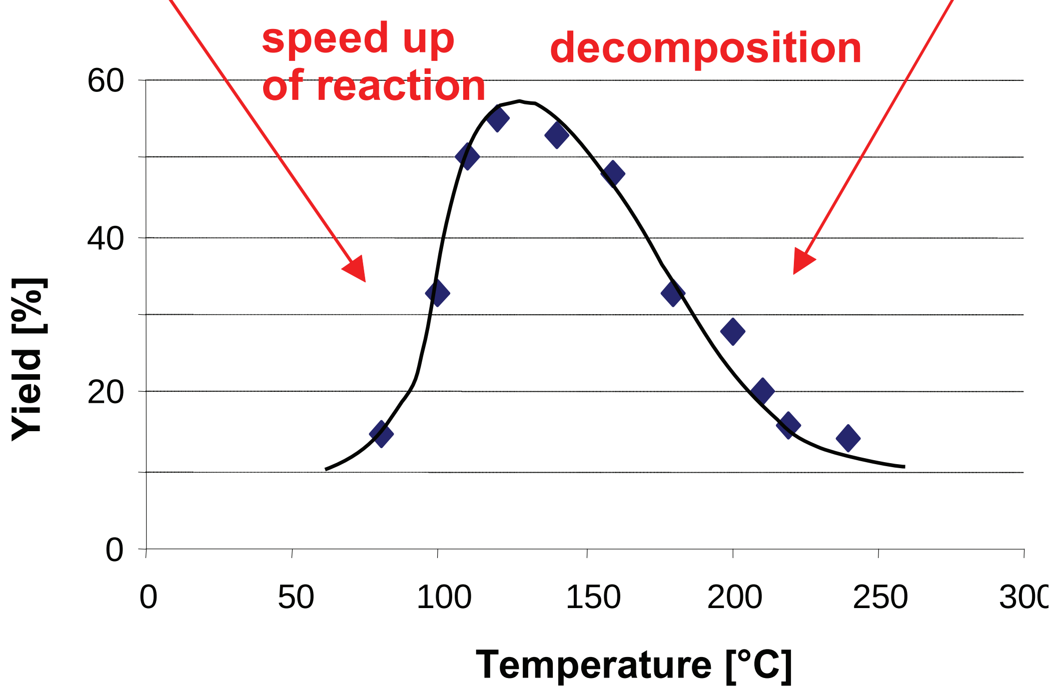
→ **Increase in space-time yield by factor 440**

→ **Increase in productivity by factor 4**

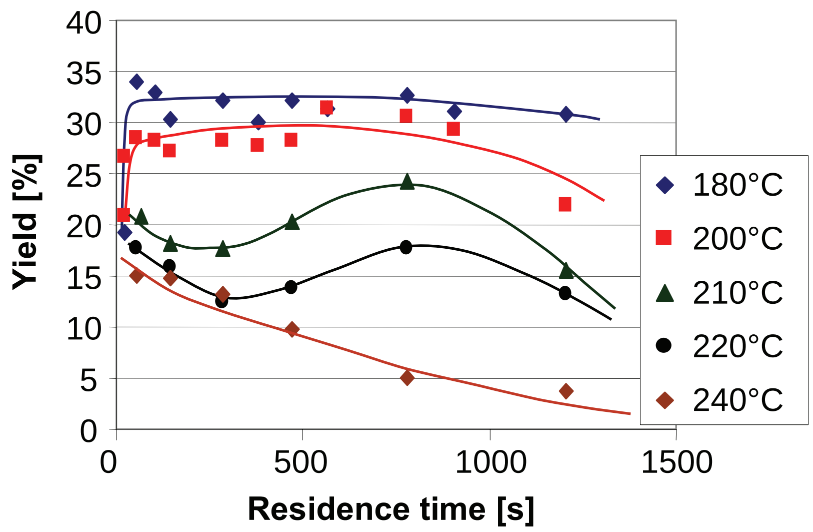
PHLOROGLUCINOL-TYPE KOLBE SCHMITT-SYNTHESIS



High p,T



V. Hessel, C. Hofmann, P. Löb,, H. Löwe, M. Parals *Chem. Eng. Technol. 30, 3* (2007) 355-362.



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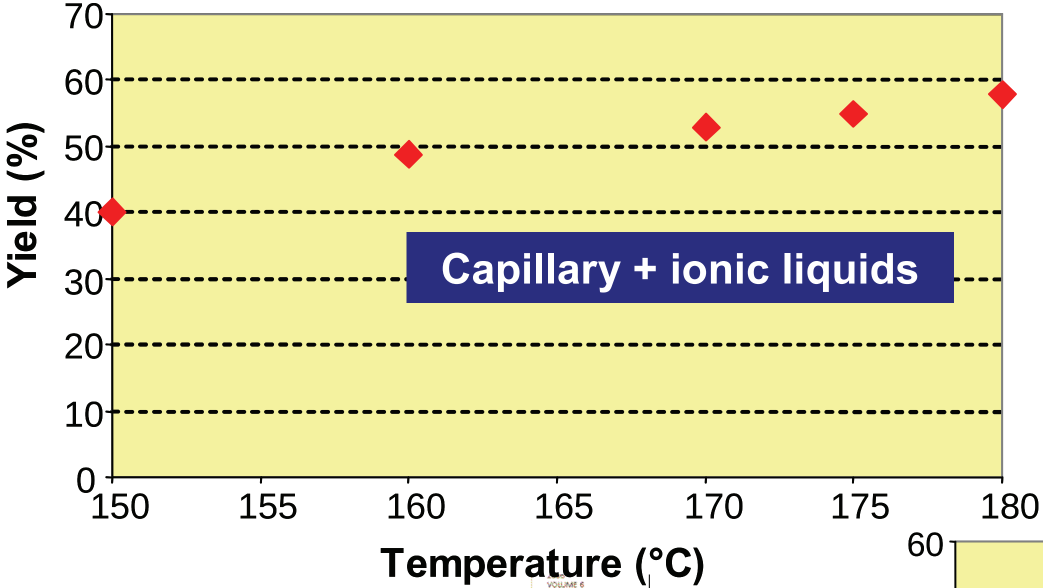
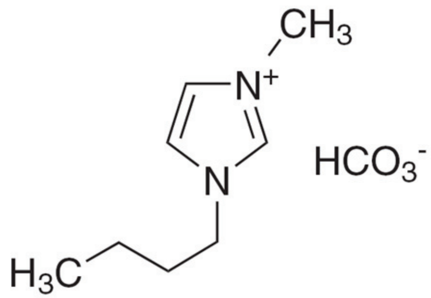
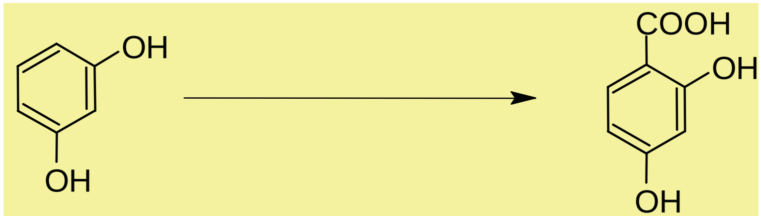
USE OR IONIC LIQUIDS AND MICROWAVE FOR THE KOLBE-SCHMITT SYNTHESIS

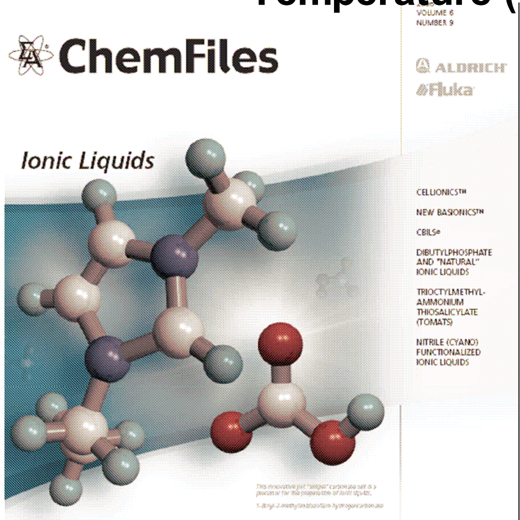
Faysal Benaskar (TUe)
Internship at IMM

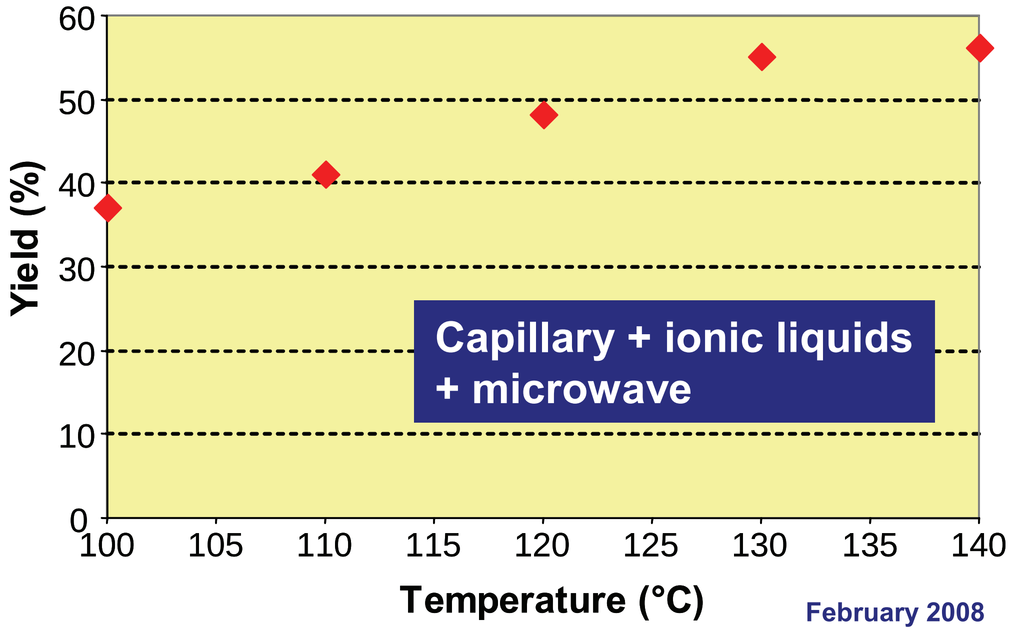




NEW







COSTING ANALYSIS - 2,4-DIHYDROXY BENZOIC ACID SYNTHESIS

Base case: high-p,T	**μ-REAC PLANT – 1 reactor; 4.4 t/a; 10 l/h** 45% selectivity; 200°C / 40 bar (‚high-p,T')	**92.10 € / kg**
Selectivity	**μ-REAC PLANT – 1 reactor; 4.4 t/a; 10 l/h** 70% selectivity; 200°C / 40 bar (‚high-p,T')	**78.43 € / kg**
External numbering-up	**μ-REAC PLANT – 10 reactors; 44 t/a; 100 l/h** 45% selectivity; 200°C / 40 bar (‚high-p,T')	**57.47 € / kg**
Further PI by high-p,T	**μ-REAC PLANT – 1 reactor; 44 t/a; 100 l/h** 45% selectivity; 200°C / 40 bar (‚high-p,T')	**56.95 € / kg**
Without high-p,T	**μ-REAC PLANT – 1 reactor; 0.01 t/a; 0.025 l/h** 45% selectivity; 100°C / 1 bar	**17,352.52 € / kg**
Bench-marking	**BATCH-REACTOR PLANT – 1 l; 0.27 t/a** 45% selectivity; 100°C / 1 bar (‚Reflux')	**985.18 € / kg**
Bench-marking	**BATCH-REACTOR PLANT – 20 l; 4.3 t/a** 45% selectivity; 100°C / 1 bar (‚Reflux')	**107.05 € / kg**

U. Krtschil, V. Hessel, D. Kralisch, G. Kreisel, P. Löb, H. Löwe *Org. Proc. Res. Dev.* (2006) in preparation.
U. Krtschil, V. Hessel, D. Kralisch, G. Kreisel, M. Küpper, R. Schenk *Chimia* **60**, 9 (2006) 611-617.

Ma'moun Al-Rawashdeh (TUe)
Graduation at IMM

SCALE-OUT AND COSTING

291 µm wide; 106 µm deep

~300 Euro

Optimum flow rate (ml/min) per channel	Length to reach 95% (m)	Number of channels needed	Number of plate needed	Material cost [%]	Cutting cost [%]	Etching cost [%]	Total cost [%]
0.0222	0.212	751	1	53	20	30	103
0.0109	0.103	1528	2	52	25	30	107
0.0032	0.030	5155	5	51	40	30	121
0.0001	0.001	130363	104	50	535	30	615

1910 µm wide; 586 µm deep

Optimum flow rate (ml/min) per channel	Length to reach 95% (m)	Number of channels needed	Number of plate needed	Material cost [%]	Cutting cost [%]	Etching cost [%]	Total cost [%]
30.82	57.02	1	1				
9.73	17.63	2	1				
2.27	3.75	7	1				
0.58	0.87	29	1				
0.18	0.30	92	1	55	20	30	105
0.07	0.14	229	2	70	25	30	125

NOVEL PROCESS WINDOWS

first comprehensive report: V. Hessel, P. Löb, H. Löwe, *Curr. Org. Chem.* **9**, 8 (2005) 765-787

- **Direct routes from hazardous elements**
- **Routes at increased concentration or even solvent-free**
- **Routes at elevated temperature and/or pressure**
- **Routes mixing the reactants 'all at once'**
- **Routes using unstable intermediates**
- **Routes in the explosive or thermal runaway regime**
- **Process simplification – e.g. routes omitting the need of catalysts or (complex) separation**

Excellence in Process Development Research Award

AIChE (New Orleans / USA, 2008)

compare: Jähnisch, K.; Hessel, V. et al.; *Angew. Chem. Intern. Ed.* **43**, 4 (2004) 406-446

E. R. Murphy, J. R. Martinelli, N. Zaborenko, S. L. Buchwald, K. F. Jensen, *Angew. Chem.* **119** (2007) 1764

F. B. Lopez, PhD thesis, High Pressure: a Challenge for Lab-on-a-Chip Technology, pp.137ff, University Twente (Reinhoudt group)

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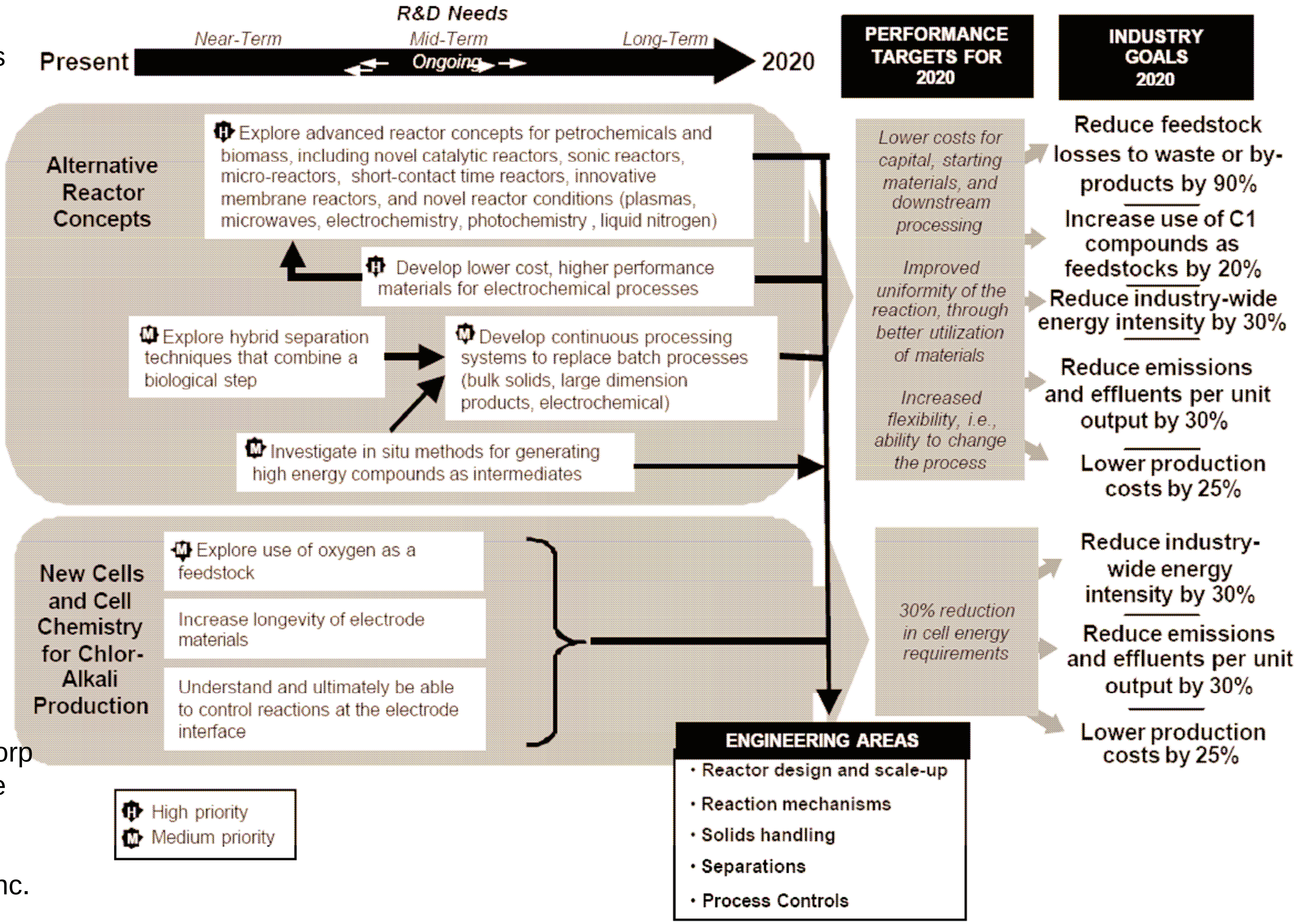
NEW CHEMISTRY ROADMAP, ACS - JOE ZOELLER, EASTMAN KODAK, 2001

A.E. Staley Manufacturing
ARCO Chemical
AGA Gas
Air Products & Chemicals
Akzo-Nobel
Autoclave Engineers
BCI
BF Goodrich
Biofine
BOC Gases
Celanese
Cryo Dynamics
Degussa
DOW Chemical
DOW Corning
DuPont
Eastman Chemical
Electrolux
Eltron Research Inc.
Fedegari Autoclavi
Ford Motor Company
Genentech
GE Plastics
Global Technologies
Great Lakes Chemical Corp
Green Chemistry Institute
Isopro International
Itochu Aviation
Kellogg, Brown & Root, Inc.
…

Exhibit 4-5. Process Conditions and Equipment



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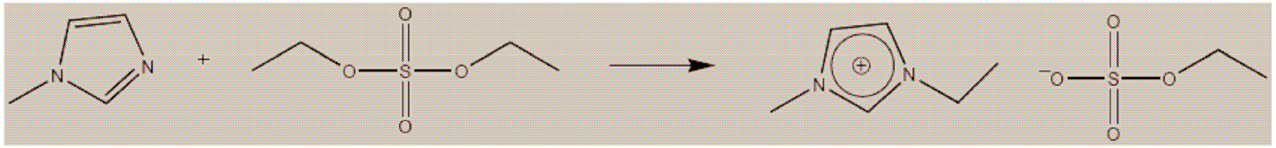
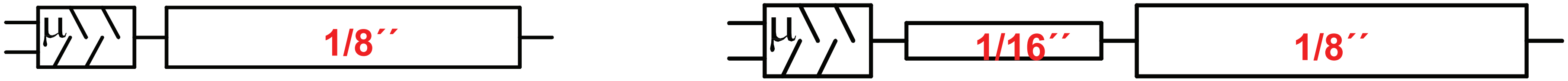
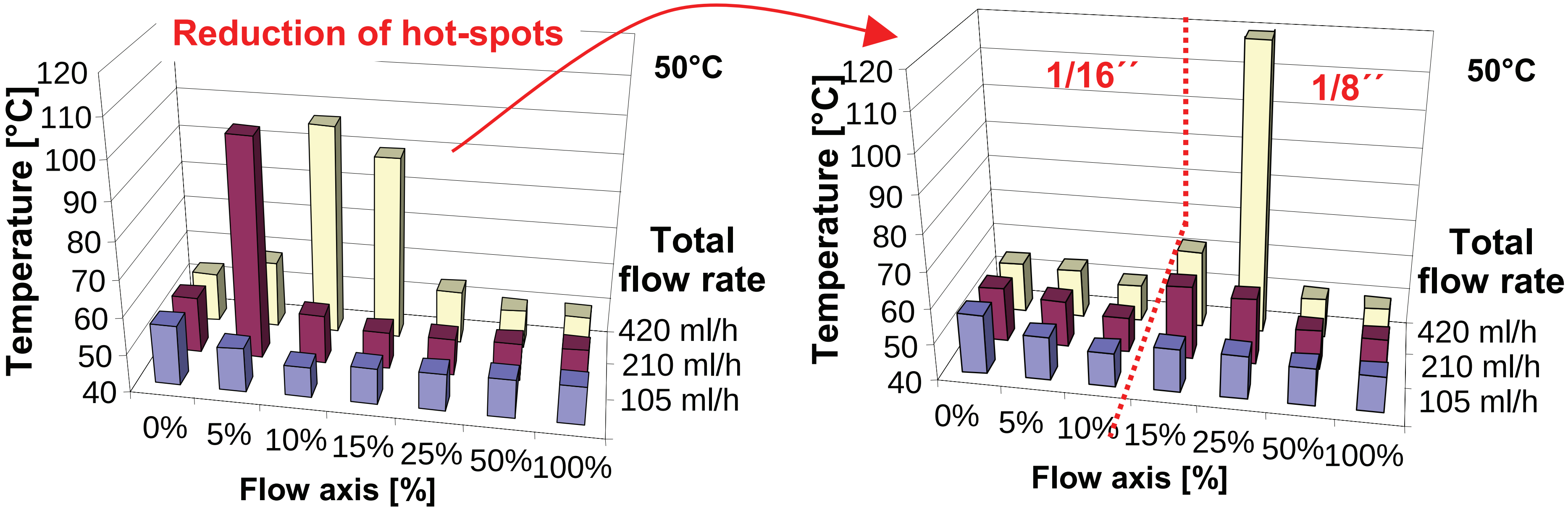
TWO-SCALED TUBE SECTIONS: IMPROVED TEMPERATURE CONTROL







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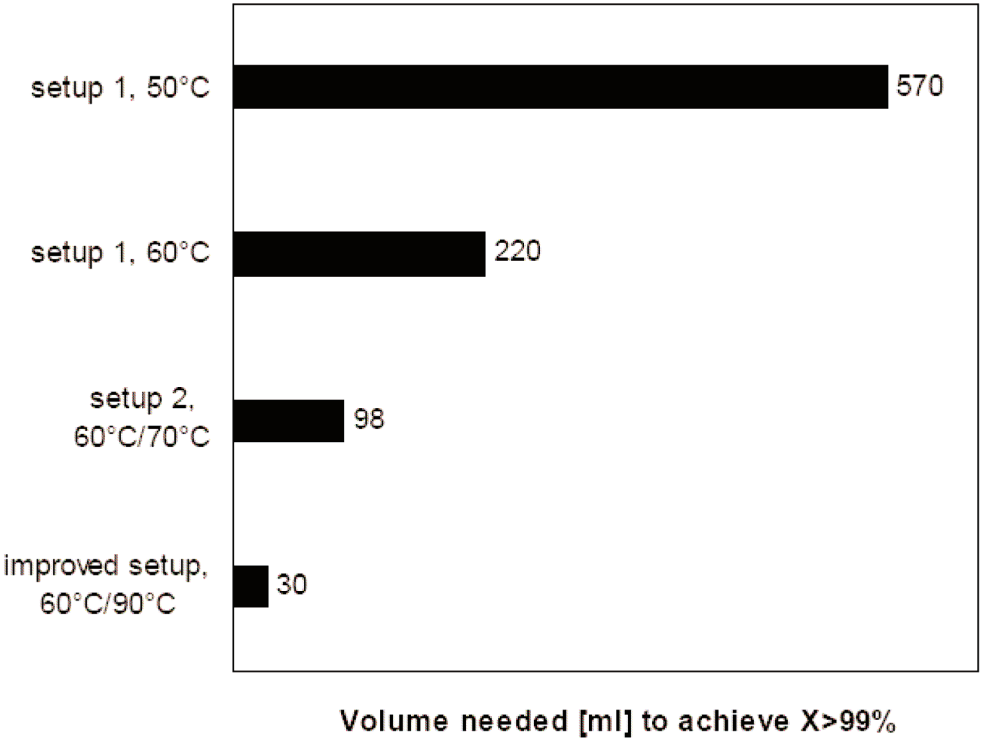
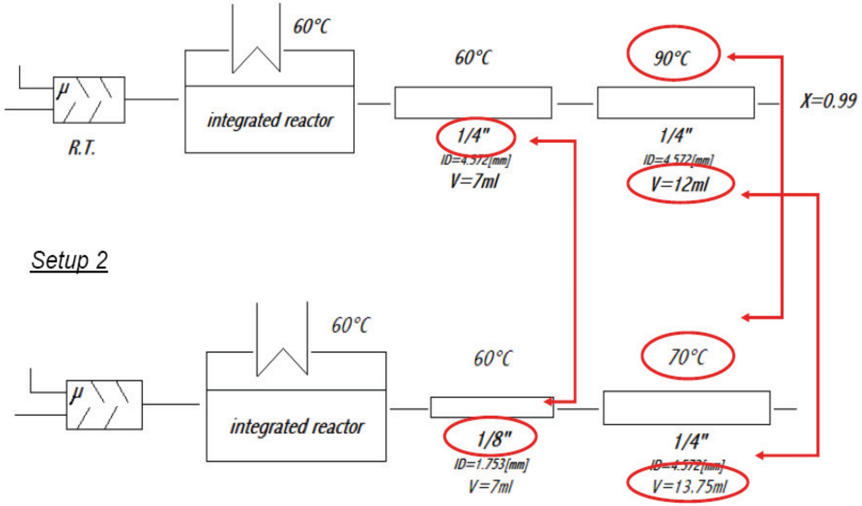
FIGURES OF MERIT

Prof. Albert Renken, Robert Misczuk (Master)



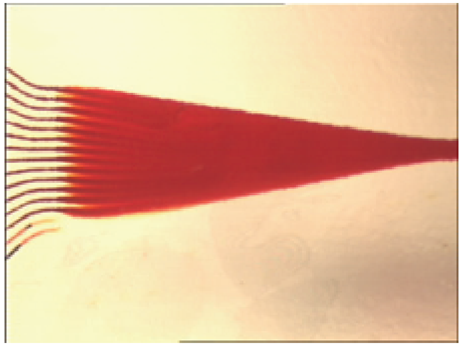
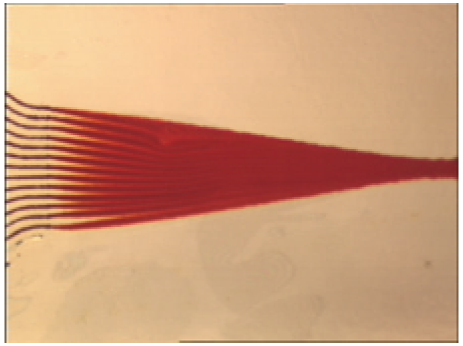
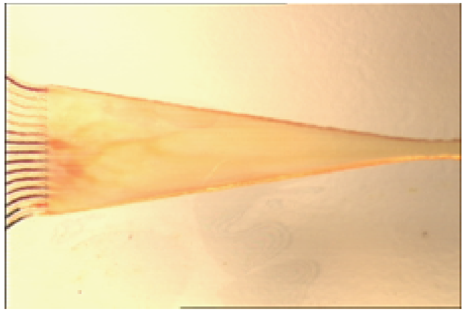
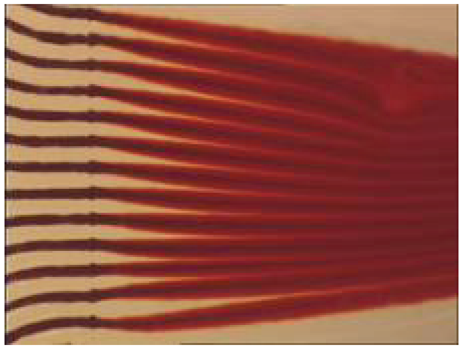
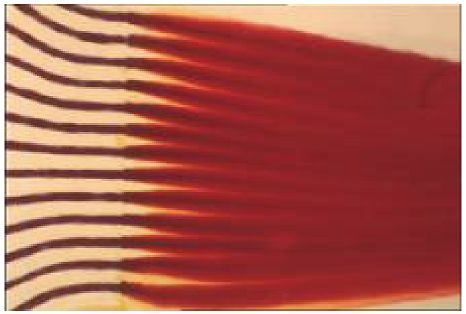
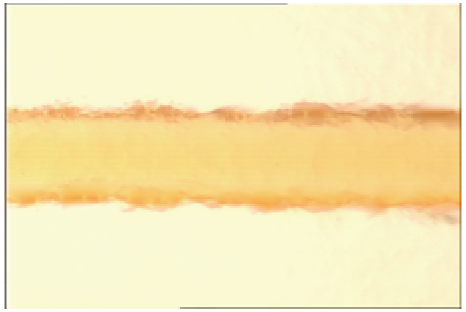


CONTACTING OF THE DIFFERENT EDUCTS WIHT BROMINE (1:1) IN A GLASS MICRO MIXER

meta-nitrotoluene | toluene | thiophene

reaction speed

formation of gaseous hydrogen bromide

18.6 / 42.8

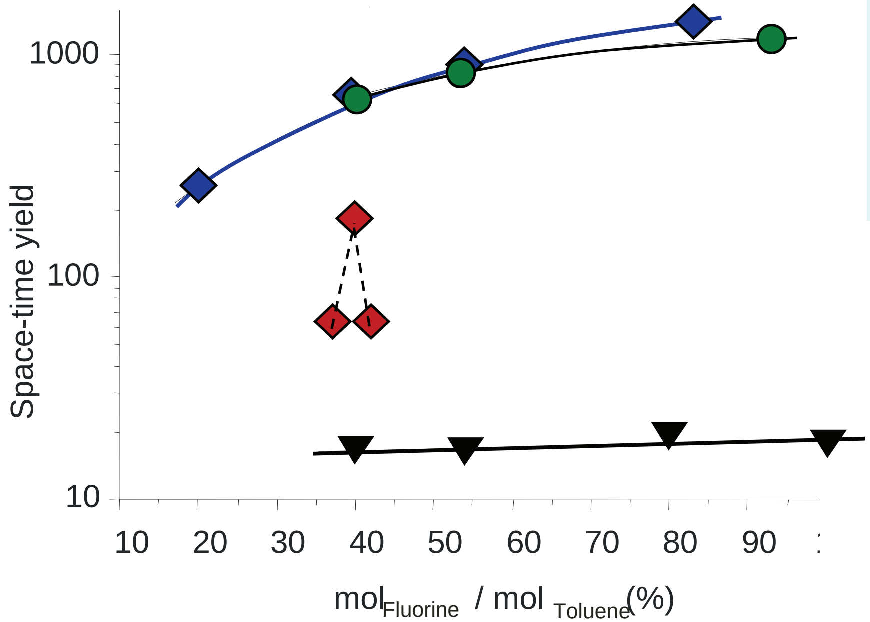
Br_2 [ml/h] / Educt [ml/min]:

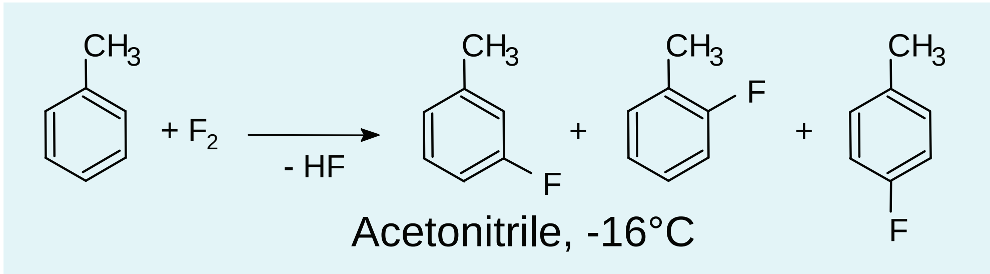
24.5 / 49.8

18.4 / 28.4

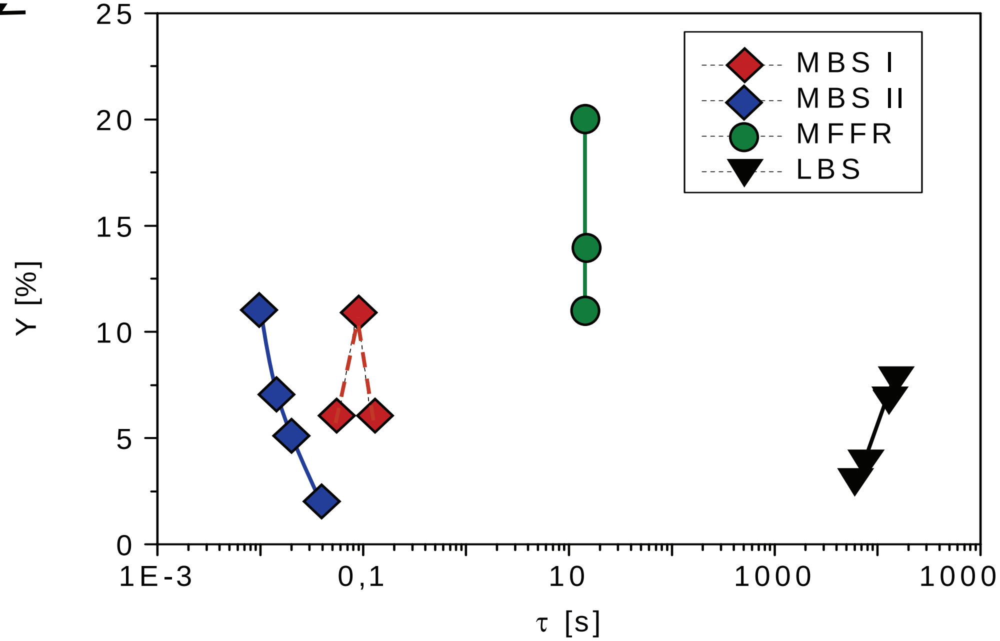
SPACE-TIME YIELD – THE REDUCTION OF RESIDENCE TIME

Reaction volume = Active channel volume





Jähnisch, K., et al..; *J. Fluorine Chem.* **105**, 1 (2000) 117



- **Significant enhancement of space-time yield for the micro-structured reactors compared to the laboratory bubble column**

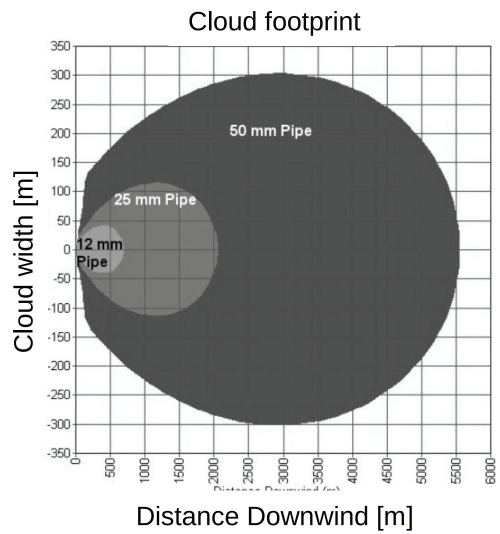
hessel@imm-mainz.de

PLACE	DATE	CHEMICAL	ESTIMATED AMOUNT	CASUALTIES
Oppau/Ludwigshafen	September 21, 1921	ammonium sulfate, ammonium nitrate	4,500 t exploded	ca. 550 + 50 dead, 1,500 injured
Flixborough	June 1, 1974	cyclohexane	400 ton inventory, 40 ton escaped	28 dead, 36 + 53 injured
Beek	November 7, 1975	(mainly) propylene	> 10,000 m^3 inventory, 5.5 ton escaped	14 dead, 104 + 3 injured
Seveso	July 10, 1976	2,4,5 trichlorophenol, dioxin	7 ton inventory, 3 ton escaped	no direct casualties, ca. 37,000 people exposed
San Juan, Mexico City	November 19, 1984	LPG	> 10,000 m^3 inventory	5 + ca. 500 dead, 2 + 7000 injured (mainly outside the plant)
Bhopal	December 3, 1984	methyl isocyanate	41 ton released	3,800 dead, 2,720 permanently disabled
Pasadena	October 23, 1989	ethylene, isobutane hexene, hydrogen	33 ton escaped	23 dead, 130-300 injured
Toulouse	September 21, 2001	ammonium nitrate	200-300 ton	31 dead, 2442 injured

Accidents are due to large inventories !

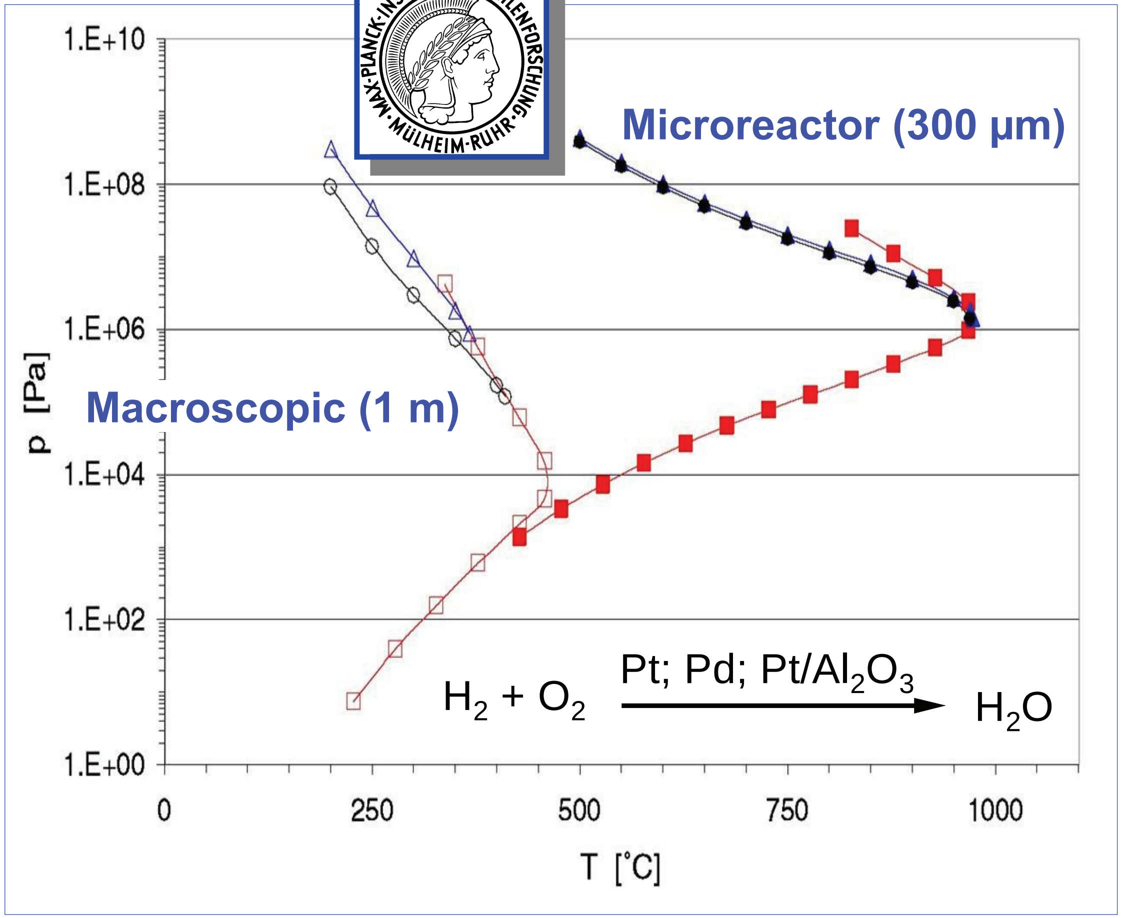
UCC, Bhopal 3 Dec 1984:
cloud of 41 tons MIC
>2 500 killed

An inventory of 10 kg MIC would have been sufficient
(D.Hendershot, CEP 2000)



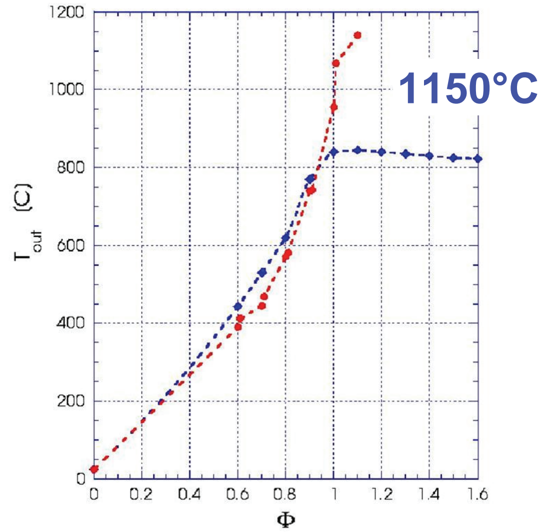
Courtesy A. Stankiewicz (DSM / TU Delft) & J. Jenck (ENKI Tech)

Novel Process Regimes: Kinetic and Thermal Explosion Limits for the H_2 / O_2 Reaction



Veser, G.; Chem. Eng. Sci. **56**, (2001) 1265-1273.

Veser, G., Friedrich, G., Freygang, M., Zengerle, R.; *3rd International Conference on Microreaction Technology, IMRET 3,* pp. 674-686, Springer-Verlag, Berlin, (2000).



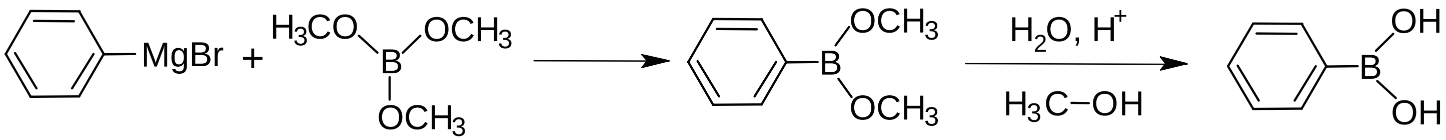
Explosion limits

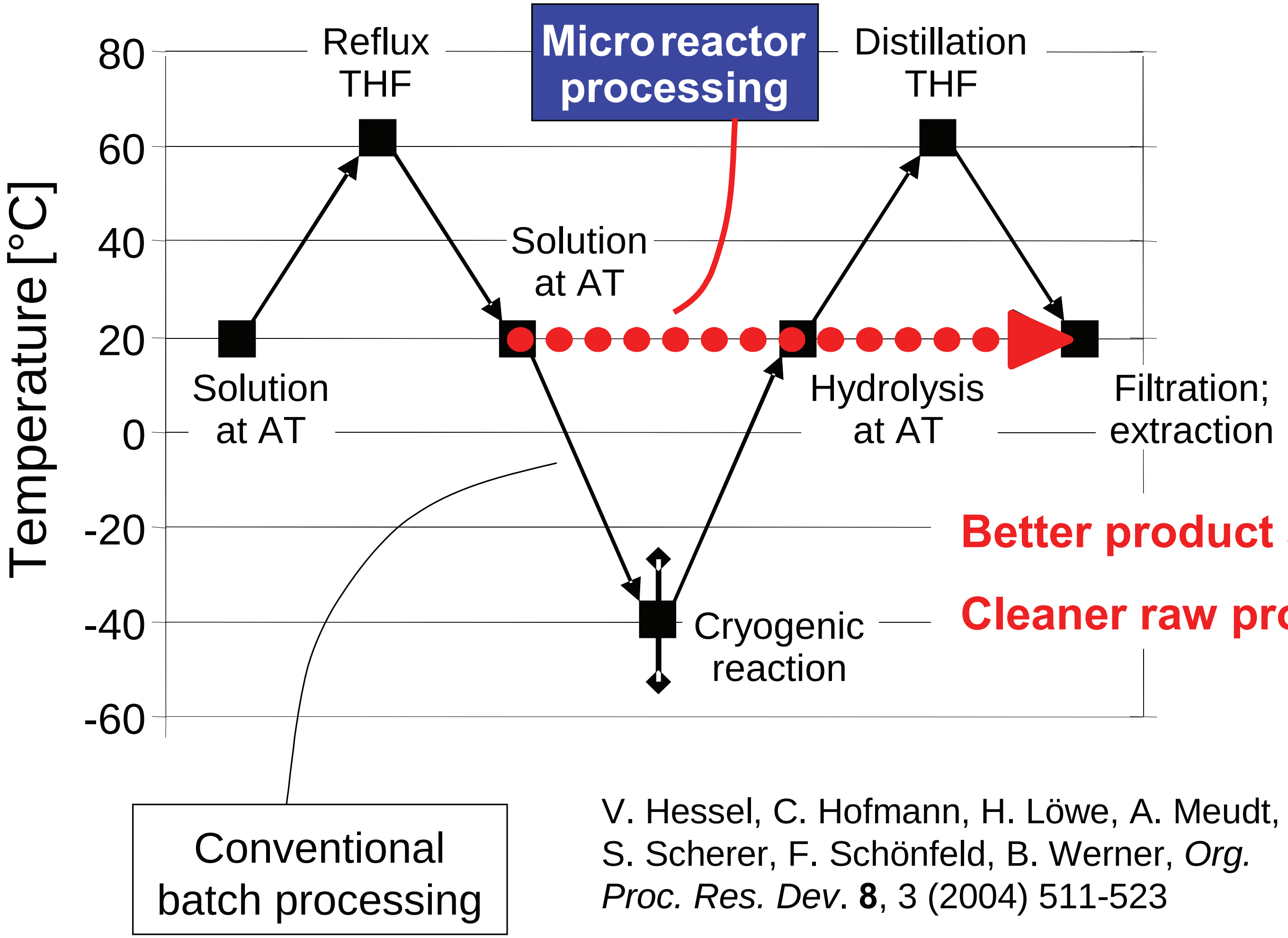
Kinetic limits (squares);
thermal limits (triangles for $T_{wall} = T_{reaction}$)
(circles for $T_{wall} = T_{room}$)

Reactor dimensions

1) Macroscopic (1 m; open symbols)
2) Microreactor (300 µm; filled symbols)

ENERGY SAVINGS FOR THE PHENYL BORONIC ACID PROCESS





Better product selectivity by 25%

Cleaner raw product by 10%

V. Hessel, C. Hofmann, H. Löwe, A. Meudt, S. Scherer, F. Schönfeld, B. Werner, *Org. Proc. Res. Dev.* **8**, 3 (2004) 511-523

Mission

Novel process windows with regard to pressure, temperature, concentration

Sustainable chemical processes by temperature stable, pressurised microreactors

Technical Targets

- **High energy efficiency**
- **Minimisation of waste**
- **Clean and inherently safe product makign**
- **Safe and low-emission syntheses**
- **Process intensification (e.g. increase in space-time yield)**

Relevant Topics

- **High-temperature & high-pressure conti routes, e.g. for functionalisation of alkanes**
- **Syntheses in explosive and thermal runaway regimes**
- **Solvent-less and free syntheses**
- **Multi-step syntheses with immediate conversion of instable intermediates**

TU/e technische universiteit eindhoven IMM

PROJECTS OF THE DBU RESEARCH CLUSTER "NOVEL PROCESS WINDOWS"

New Ways in OLED manufacture	University Jena, POLYMET eV, Jenpolymers Ltd
New process windows for the Kolbe-Schmitt synthesis	IMM, University Jena, Sigma-Aldrich
Preparation of pharmaceutical-grade Chitosan from renewable resources	Heppe Medical Chitosan GmbH, University Bremen
New process windows and manufacturing strategies – batch to conti	University Braunschweig, Pelikan PBS GmbH &CoKG
Ultrasound based catalytic multiphase amination of hydrocarbons at high pressure	Leibnitz-Institut Katalyse, Little Things Factory GmbH, ASD GmbH, JTT
Sustainability evaluation of chemical syntheses during development	University of Applied Sciences Oldenburg

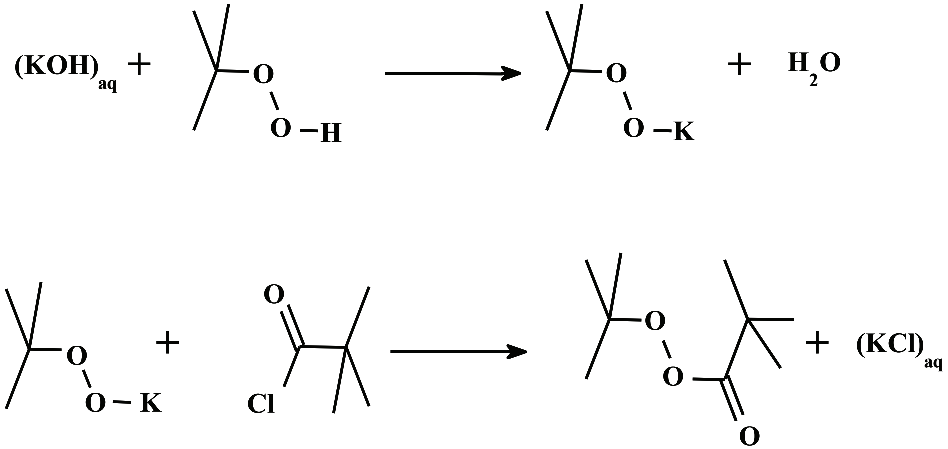
DBU Deutsche Bundesstiftung Umwelt
Wir fördern Innovationen!

Forschungscluster „Novel Process Windows"

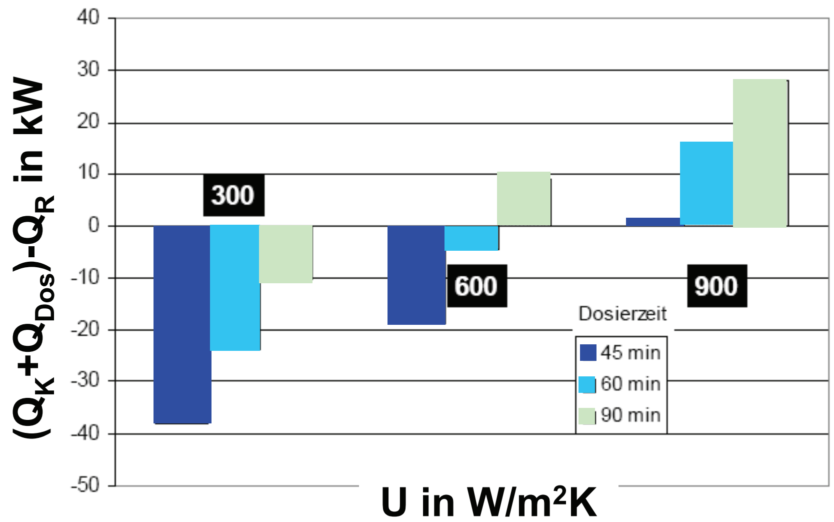
DBU Deutsche Bundesstiftung Umwelt

PhD THESIS ILLG (TU/e; DBU Grant): SYNTHESIS OF *tert.*-BUTYLPEROXYPIVALATE (TBPP)

TU/e technische universiteit eindhoven



Heat balance of TBPP synthesis in 1 m^3 reactor



<u>Turnover organic peroxides 1999</u>

120,000 tons, 900 Mio € market value

Explosion of a benzoyl peroxide plant, Catalyst Systems Inc. (Gnadenhutten, Ohio, 2003)

Kralisch, Hübschmann

Entwicklungsarbeit im Rahmen des Forschungsclusters „*Novel Process Windows*“

Projektbegleitende ökologische Bewertung

Novel Process Windows

→ harsche Reaktionsbedingungen (p, T, c hoch)

- p, T → sehr energieintensiv
- c → Sicherheit, mögliche gesundheitliche Gefährdung

→ Ökologische Bilanz = f(Aufwand/Nutzen)

→ Anforderungen:

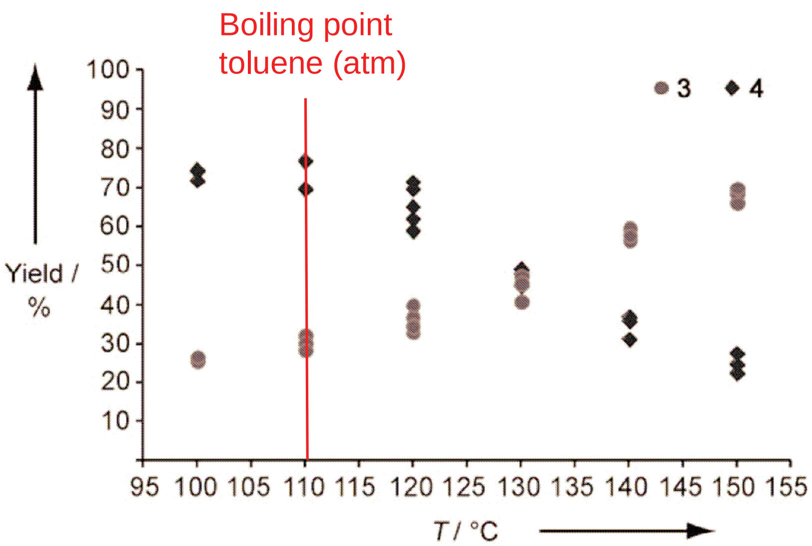
- Signifikant erhöhte Selektivitäten und/ oder Ausbeuten im Vergleich zum Stand der Technik
- Einhaltung von Sicherheitskriterien

International Reception

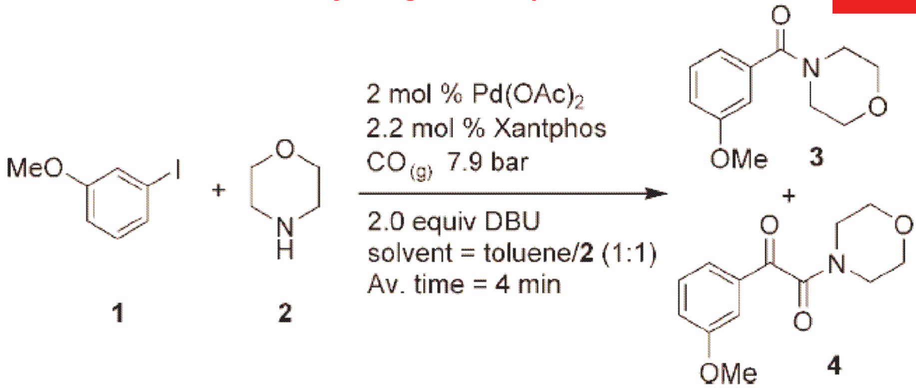
+ own related activities

HIGH-p,T WINDOWS FOR TUNING α-KETOAMIDE / AMIDE SELECTIVITY

Murphy, Martinelli, Zaborenko, Buchwald, Jensen *Angew. Chem. Intl. Ed*. **119**, 10 (2007) 1764-1767

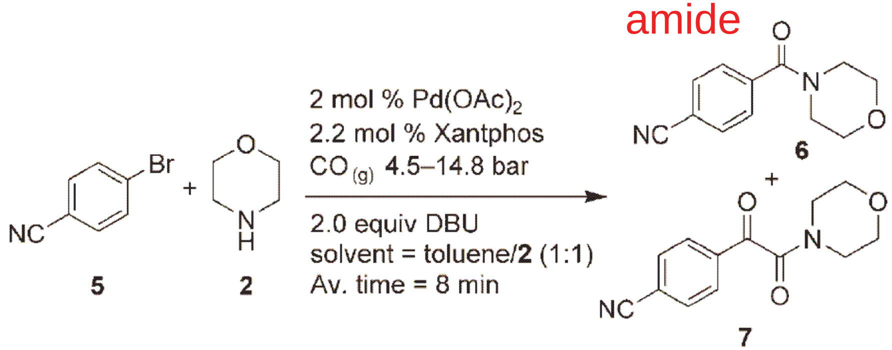


favoured by high temperature ← amide

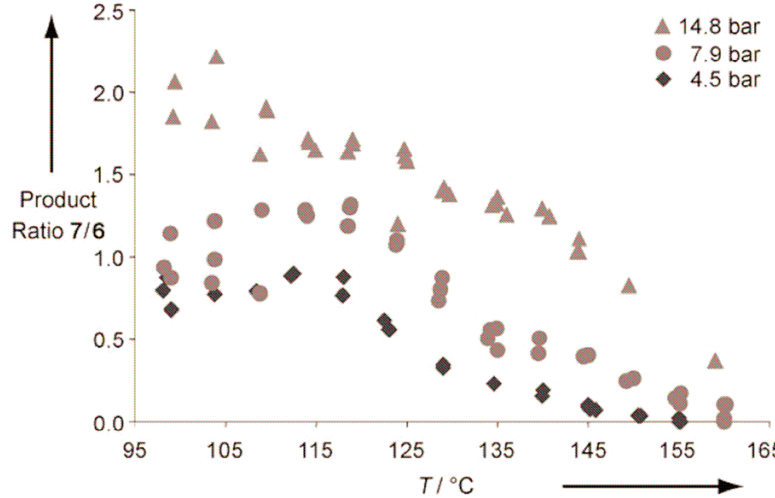


favoured by high pressure (CO) ← α-ketoamide

amide

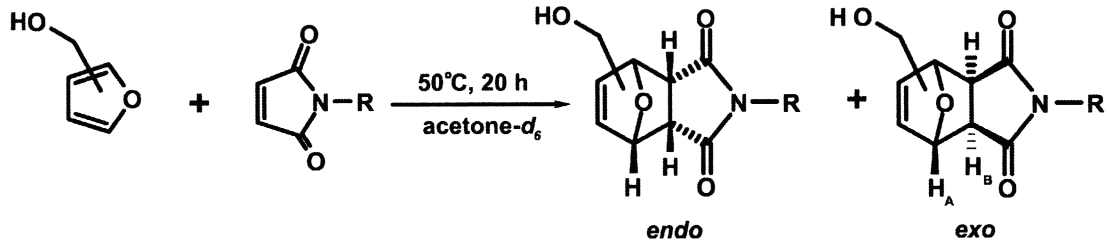


α-ketoamide



PhD THESIS LOPEZ 2006 (REINHOUDT GROUP, UNI TWENTE): HIGH-PRESSURE FOR LAB-ON-A-CHIP

Stereoselectivity of Diels-Alder reactions

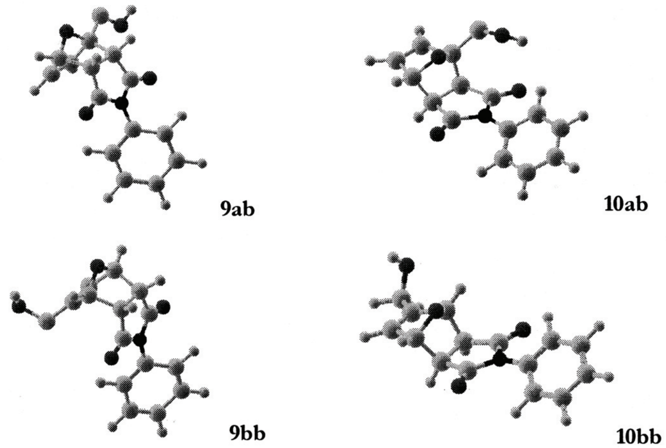


7 8 9 10

a 2-furylmethanol
b 3-furylmethanol

a R = CH_3
b R = Ph
c R = CH_2-Ph

Minimised structures for reaction volumes ΔV

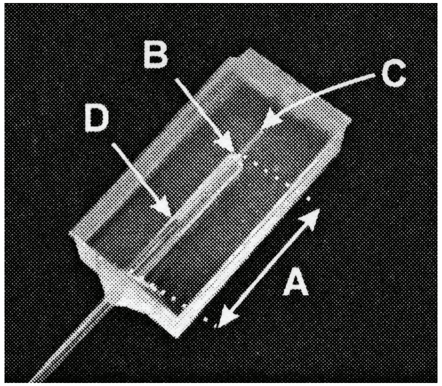


→ **Volume difference of endo and exo transition states**

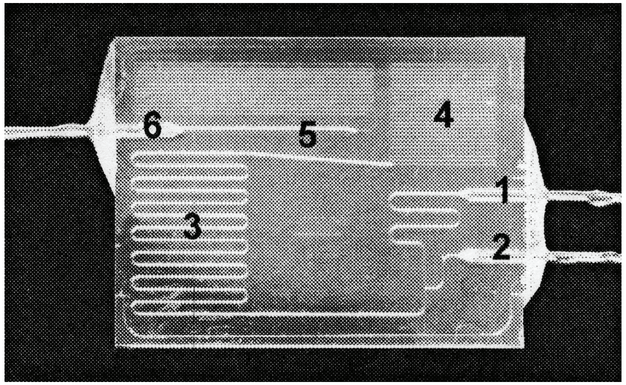
7 + 8	Conversion [%]		endo (9) / exo (10) ratio	
	1 bar	600 bar	1 bar	600 bar
aa	35	66	66:34	59:41
ab	35	55	55:45	52:48
ac	40	62	62:38	57:43
ba	57	57	57:43	57:43
bb	55	54	40:60	39:61
bc	59	58	55:45	54:46

PhD THESIS LOPEZ 2006 (REINHOUDT GROUP, UNI TWENTE): HIGH-PRESSURE FOR LAB-ON-A-CHIP

Capillary microreactor →



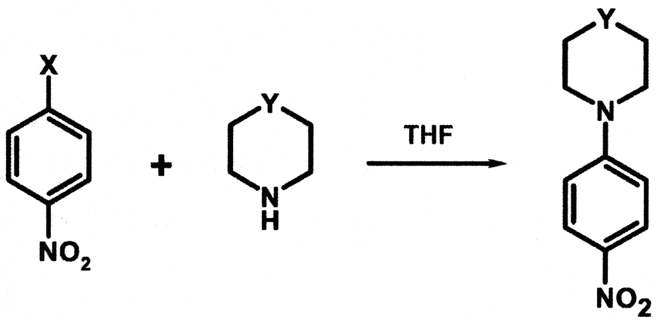
→



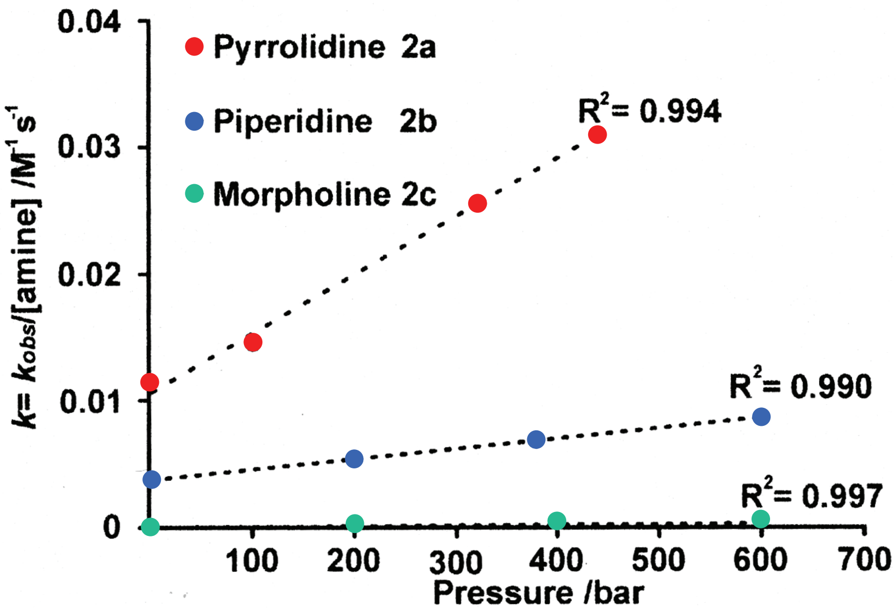
Fiber-based chip interface

Glass high-pressure microreactor

Nucleophilic aromatic substitution



1	2	3
a X = F	a Y = --	
b X = Cl	b Y = CH_2	
c X = Br	c Y = O	



X-CUBE™: NEW COMMERCIAL HIGH-p,T FLOW REACTOR

X-CUBE™

High-temperature, high-pressure bench top flow reactor

200°C and 150 bar

Advantages

- **Completion of many reactions in minutes**
- **Optimization "on the fly"**
- **Low-volume system: conductance of volatile reactions safely and at high pressure**

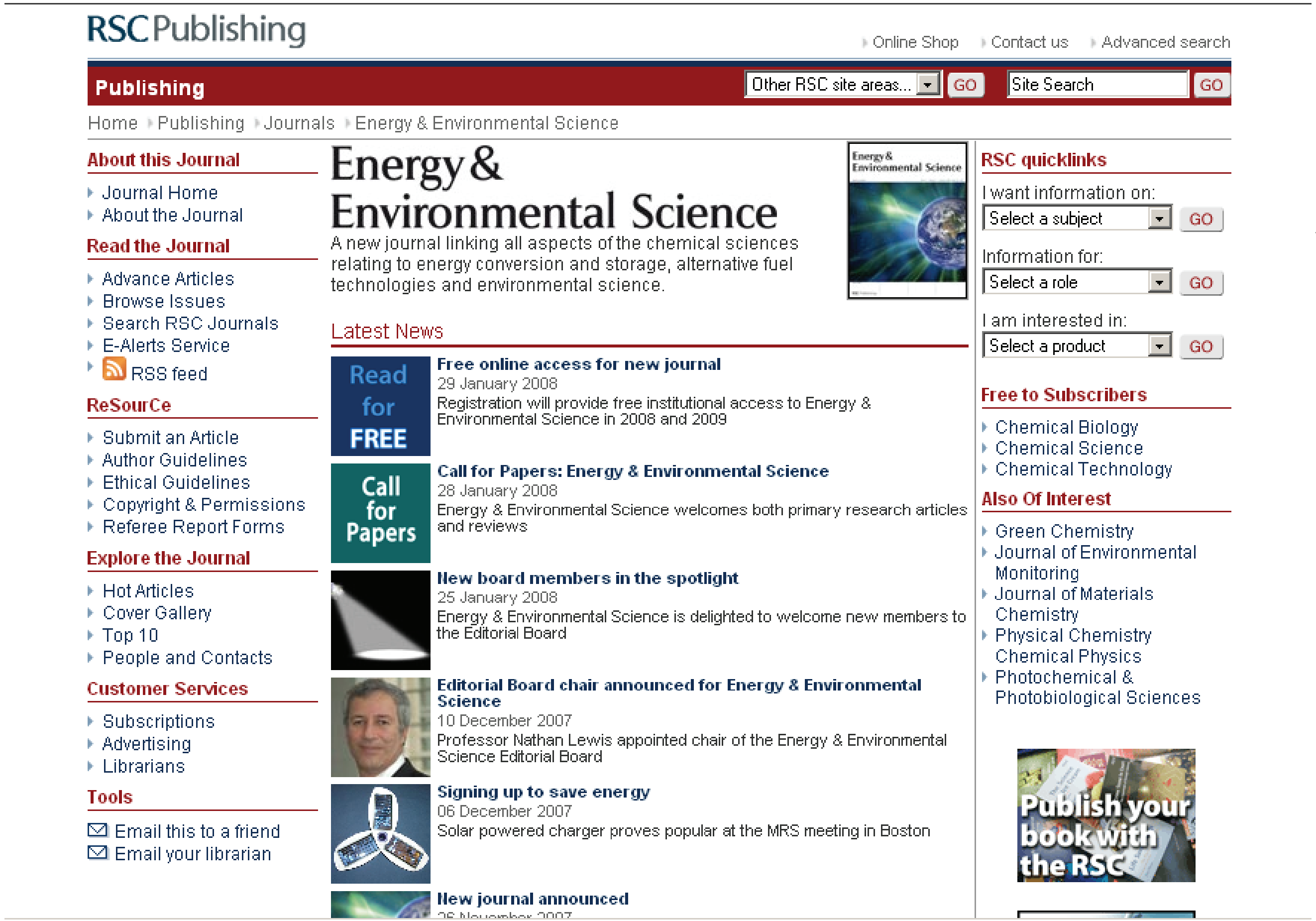
Suzuki, Sonogashira and Heck couplings, Buchwald reaction, Halogenation, Alkylation Dehydration, Esterification, Azide formation

THALESNano

technische universiteit eindhoven

Invited review paper (Hessel, Kralisch) entitled

"Sustainability through Greener Processing - New Process Windows by New Processing Technologies"



Energy and Environmental Science bridges the various disciplines involved with energy.

First issue launched this summer

MENTIONING OF „NOVEL RROCESS WINDOWS“ IN VARIOUS LECTURES AND FEATURE REPORTS

TU/e IMM
technische universiteit eindhoven

/department of chemical engineering and chemistry

TU/e technische universiteit eindhoven

ST Colloquium

Tuesday, 12 February 2008, 4:00 p.m.; Lecture hall STC 0.01

Micro Process Engineering
Novel Process Windows in Organic Chemistry and System Design in Fuel Processing

Prof. dr. Volker Hessel

Institut für Mikrotechnik Mainz (Germany)
Eindhoven University of Technology

Prof. Dr. Volker Hessel, born 1964, studied chemistry at Mainz University. Topic of his PhD thesis in the field of organic chemistry in 1993 was structure-property relationships of specially designed supra-molecular structures, micelles and lyotropic liquid crystals. Since 1994 Prof. Dr. Hessel is an employee of the Institut für Mikrotechnik Mainz GmbH and in 1996 and 1999 he became group and department leader for microreaction technology, respectively. In 2002 he was appointed as Vice Director R&D and in 2007 as Director R&D. His fields of research comprise micro process engineering for mixing, fine chemistry, fuel processing and heterogeneous catalysis. In July 2005, Prof. Dr. Hessel was appointed as part-time professor for the chair of "Micro Process Engineering" at Eindhoven University of Technology, Chemical Reactor Engineering Group, Department of Chemical Engineering and Chemistry. Prof. Dr. Hessel is author or co-author of 129 peer-reviewed publications (with 22 extended reviews), 11 book chapters, and 3 books. Recently, he received the AIChE award "Excellence in Process Development Research". He is AIChE chair "Microprocess Engineering"; elected board member of the German industrial platform IPμVT; member of five editorial boards (e.g. "Catalysis Today", "Chemical Engineering Journal"); Chair of the program committee for the SynTOP and the IMRET-10 conferences.

Abstract

Micro process engineering has improved organic syntheses many times on the laboratory level. Several case studies from industry at the pilot and production level in fine chemistry were reported and show up robust scale-out concepts with competitive plant & process design. Cost analysis is an integral part here. The key to maximise process intensification is to explore novel process windows – e.g. at high temperatures and pressures ('high-p,T'), by solvent-free processing, or exploration of so far 'hidden' explosive regimes. The combination with other promising technologies like microwaves or ionic liquids is another means to improve performance. Another major application is fuel processing for delivering hydrogen to fuel cells. Fuels under investigation are methanol, (bio-)ethanol, diesel, iso-octane, propane, and methane. Catalyst testing is done using small isothermal microreactors with a few microchannels wash-coated with catalyst. Then, numbering-up is made within one step to shoebox-sized microstructured reactors (1-5 kW$_e$), typically comprising several 10,000 microchannels. This includes integration to microstructured heat exchange units. First, the single reactors are tested in a pilot plant; then the complete process flow in a breadboard configuration. Examples of use will be given, e.g. a complete thermally integrated fuel processor to convert LPG into electricity which is now introduced into the market by industry.

CE&T Special Issue „Microreaction Technology“ March 2007

Chem. Eng. Technol. 2007, 30, No. 3, 289–289 289

Editorial

Novel Tools – Novel Chemistry

In 2008, there will be the first joint ACS and AIChE Conference – chemistry meets chemical engineering and vice versa. This is going to be the largest event in both fields ever and almost 10,000 attendees are anticipated. It took a history of 100 years of AIChE and a similar period of time of ACS to put this idea into practice. Both scientific communities are otherwise more separated and still form own groups in companies with separate contributions at different stages in process development. This is slowly changing recently, as the success of joint efforts have been increasingly recognized.

Micro process technology with its new tools – the microreactors – has become some kind of accepted revolution in chemical engineering. Most chemists – and the author of this Editorial and editor of this special issue of Chemical Engineering & Technology is one of them – have not noticed this so far and, and even if so, they still wonder what to do with such ultra-fast mixing and intensified heat transfer ... except to obtain a higher yield, which seems to be outside common research interests; but the novel tools do not seem to result in new molecules, which is in their focus of interest.

There is something to be discovered by the chemists, though. Essentially hardly any of the traditional synthesis pathways can bring a microreactor to its limit. We are used too much to dilute reactants, to prolong reaction times by extended serial procedures, to avoid usage of aggressive reactants. With the new tool, syntheses can be performed within delays below one second, solvent-free, at high pressure and high temperature, performing all steps simultanously, having superior process control – this is really making chemistry possible and revolutionizes chemical protocols up to industrial cost analyses. Most of us are not used to actively tune chemistry in the way depicted – a 'novel chemistry' with proven step-change potential is possible now for everyone in the field. The exact consequences are yet not clear yet, but chemistry will not be unaffected.

Thus, chemists should be open about how to use this novel tool for their benefit. A 'Novel Chemistry' steering forum has been initiated just a few weeks ago by the Deutsche Bundesstiftung Umwelt (DBU). Initiatives of the German Engineering Federation VDI, DBU and the German Chemical Industry Association VCI have just supported university clusters to have access to the novel tool and technology so that this facet is added to the education of the young generation. DECHEMA, Society for Chemical Engineering and Biotechnology, organized and hosted the IMRET9 Conference in Potsdam last year and included a workshop on the economic aspects of micro process technology. The VDI-Wissensforum plans to introduce a new conference "Smart Synthesis and Technologies for Organic Processes" early in summer 2008, also combining the two worlds.

The contributions in this special issue origin from the Topical 1 "Applications of Microreactor Engineering" of the AIChE Spring Meeting, April 23–25, 2006 in Orlan-

Volker Hessel
Eindhoven University of Technology – Chair Micro Process Engineering
AIChE Area Chair Micro Process Engineering (PDD-12e)
Institut für Mikrotechnik Mainz GmbH

Wednesday, April 9, 2008: 2:00 PM-5:00 PM

Room 392 (New Orleans Convention Center)

Topical 5: IMRET-10: 10^{th} International Conference on Microreaction Technology (T5)

#198 - Novel Process Windows – Unusual Ways of Processing (T5015)

This session deals with the benefits of novel process windows like high temperature and high pressure applications or unusual synthesis routes with high heat releases if they are combined with the advantages offered by microreaction technology.

Chair: Volker Hessel

CoChair: Willem Verboom

2:00 PM	198a	Micro-Reaction Technology (MRT) for the Safe Industrial Application of Diazoalkane-Chemistry: New Chances for Process Intensification **Michael Struempel**, Bernd Ondruschka, Annegret Stark
2:25 PM	198b	Synthesis of 5-Hydroxymethylfurfural from Renewable Resources Using Microreaction Technology **Stefan Loebbecke**, Tobias Tuercke, Srinivas Yada, Slobodan Panic, Detlef Schmiedl, Birgit Kamm, Thomas Frank
2:50 PM	198c	Continuous Microreactor Processing, Reactive Ionic Liquids and Microwave Heating – Approaches towards Intensified Kolbe-Schmitt Synthesis **Ulrich Krtschil**, Faysal Benaskar, Volker Hessel, Patrick Löb
3:15 PM	198d	Effect of Surface-to-Volume Ratio in Microplasma Reactors **Anil Agiral**, K. Seshan, Leon Lefferts, J.G.E. (Han) Gardeniers
3:40 PM	198e	Advantages of on-Site Microreactors from Safety Viewpoint **Eero Kolehmainen**, Fatemeh Ebrahimi, Terhi Virkki-Hatakka, Benguang Rong, Ilkka Turunen
4:05 PM	198f	Reaction Engineering Investigations of the Uncatalysed Cyclohexane Oxidation in A Microstructured Reactor Thomas Lange, Johannes Fischer, **Elias Klemm**
4:30 PM	198g	Novel Routes to Fluidized Bed Process Intensification Using a Centrifugal Field **Juray De Wilde**

See more of Topical 5: IMRET-10: 10^{th} International Conference on Microreaction Technology

SynTOP CONFERENCE POTSDAM, JUNE 2008: BRIDGING CHEMISTRY AND CHEMICAL ENGINEERING

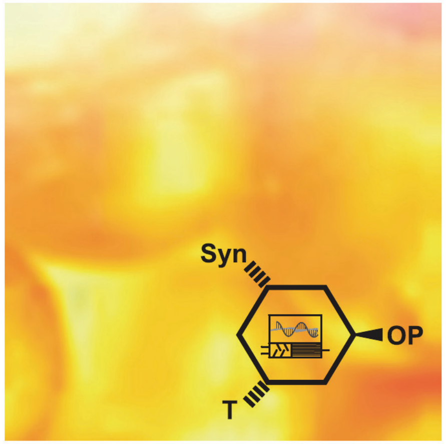
VDI Wissensforum

Conference Announcement and
Call for Papers
1st SynTOP

June 11-13, 2008
Potsdam, Germany

Smart Synthesis and Technologies for Organic Processes

Bridging Chemistry and Engineering



www.SYNTOP2008.com

358852

Main Topics of the Conference

1 **Micro and Milli Continuous Process Technologies**
Microfabricated reactors and other devices (plate-type)
Capillary and tube reactors
Foams, monoliths and other structured media

2 **Alternative Energy Sources**
Microwaves
Ultrasound
Photochemistry
Electrochemistry

3 **Alternative Reaction Media**
Ionic liquids
Supercritical liquids

4 **Intensified Plants and Processes**
Intensified equipment
Modular concepts
Case studies
Process development
Piloting
Scale-out

5 **Advanced Organic Synthesis & Process Chemistry & Automation**
Multi-step synthesis in micro reactors
Challenging reactions in micro reactors
Case studies

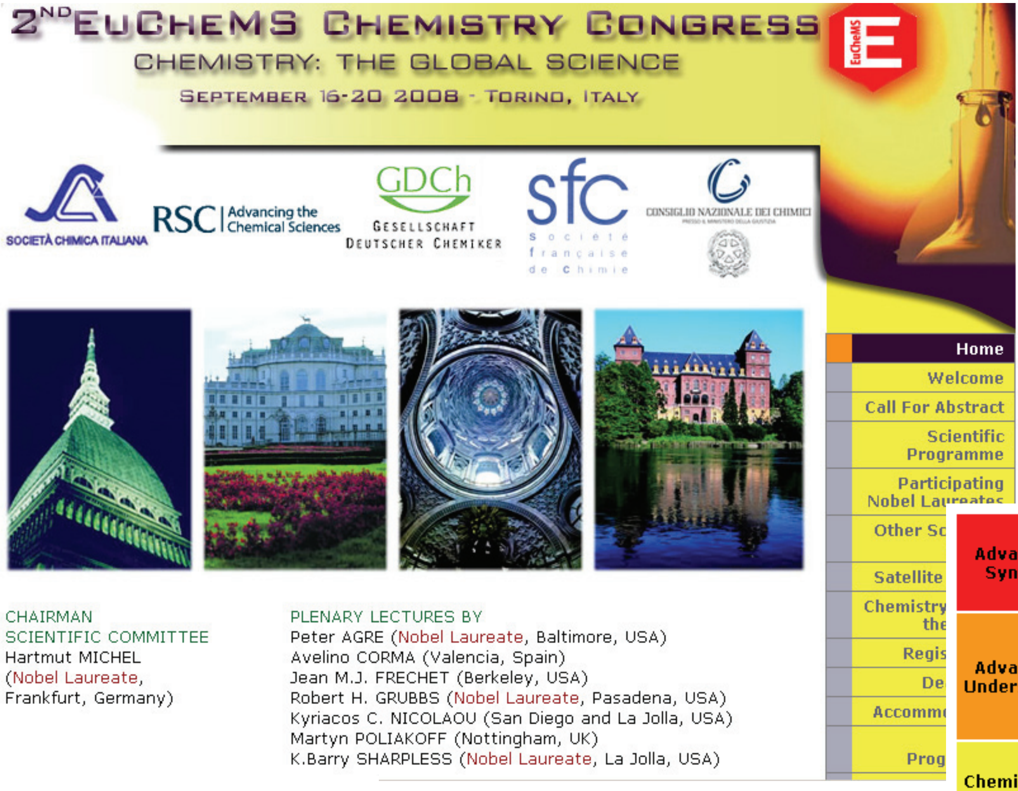
Plenary Lectures

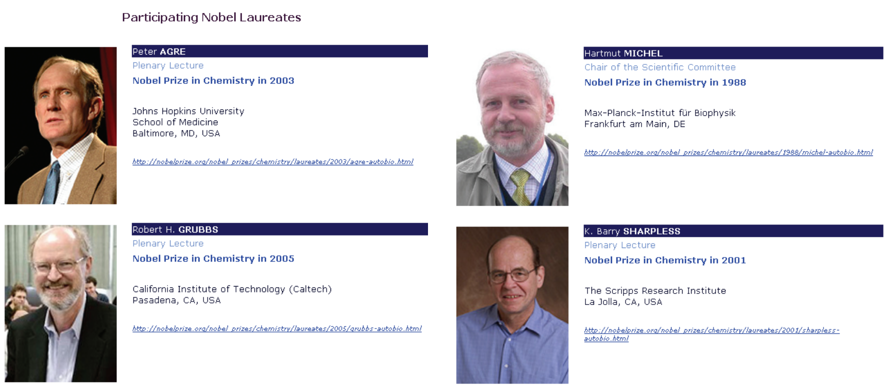
Steven V. Ley, University of Cambridge, United Kingdom
New Tools for Molecule Makers

Michael Matlosz, E.N.S.I.C, Nancy, Fance
Microprocess engineering, process intensification and multiscale design

Syntop (Ökologie): Lebewesen, die in einem bestimmten Biotop gemeinsam vorkommen

CONGRESS OF THE EUROPEAN ASSOCIATION FOR CHEMICAL AND MOLECULAR SCIENCES (EuCheMS), TURINO, SEPTEMBER 2008





Reactions under Novel Conditions

Convener: V. Hessel (NL/DE)

Keynote:

J.-i. Yoshida (Uni Kyoto)

Topic Lectures:

N. Kockmann (Lonza)
L. Magna (IFP)
H. Lehmann (Novartis)
W. Verboom (Uni Twente)
D. Kralisch (Uni Jena)

Advances in Synthesis	Organic Catalysis Convener: J.S. Siegel (CH)	Radical Reactivity in Transition Metal Chemistr… Convener: R. Poli (FR)	Reactions under Novel Conditions Convener: V. Hessel (NL/DE)
Advances in Understanding	Chemical Measurement Quality: Societal Impact Conveners: B. Magnusson (SE) E. Ferrara (IT)	Cutting Edge Chemistry with Computers Conveners: M. Yáñez (ES) T. Brinck (SE)	Food … Detection Limits down to Nothing Conveners: R. Battaglia (CH) R. Marchelli (IT)
Chemistry and Life Sciences	Biomolecular Interactions and Mechanisms Convener: J. Jiménez Barbero (ES)	Drug Targeting and Delivery Convener: K. Dawson (IE)	Metal Homeostasis Convener: H. Kozlowski (PL)
Energy and Industry	Biorefineries and Biotechnologies Convener: M. Penttilä (FI)	Energy Production & Storage Convener: C. Buess-Herman (BE)	New Trends for Agrochemicals Convener: C. Lamberth (CH)
Environment	Greening Chemistry Convener: G. Centi (IT)	Greenhouse Gases Convener: A.A. Jensen (DK)	Water Pollutants Conveners: S. Facchetti (IT) S. Herve (FI)
Materials and Devices	Branched Polymers - Smart Functional Materials Convener: D.K. Smith (UK)	Nanomaterials Convener: N. Champness (UK)	Porous Materials Convener: U. Müller (DE)