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# Liquid-Liquid Two-Phase Flow Patterns and Mass Transfer Characteristics in glass microreactors

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Master Project / Presentation SGVC

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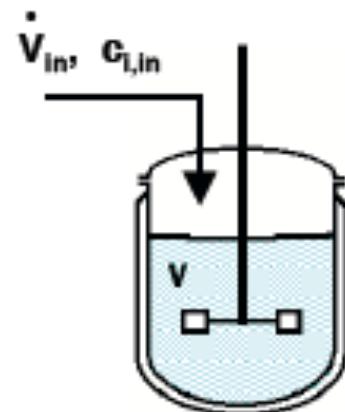
Group of catalytic reaction engineering, EPFL

- Dr. Laurent Cavin

Givaudan SA, Geneva

# Motivation of the Study (I)

- ✓ Liquid-liquid two-phase reactions: nitration, cyclization, ...
  - Fast and very exothermic
  - Semi-batch stirred tanks to control temperature
- ✓ Problem: very long reaction time



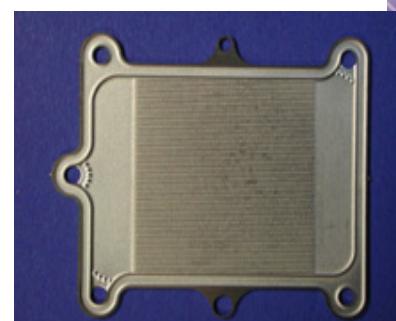
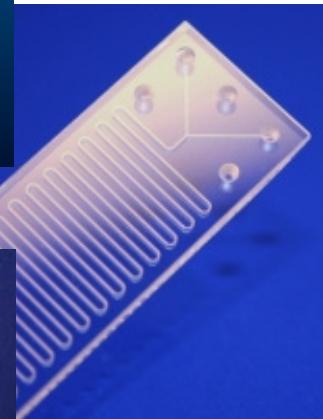
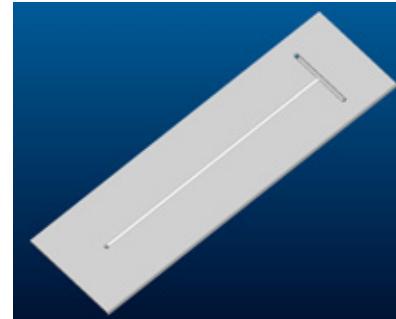
# Motivation of the Study (II)

- ✓ New technology : microreactors

Channel diameter: 20 - 500  $\mu\text{m}$

Channel length: 1 - 50 mm

S/V: 10'000 – 50'000  $\text{m}^2/\text{m}^3$



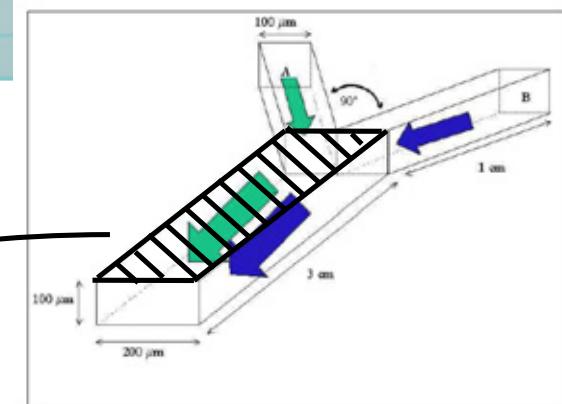
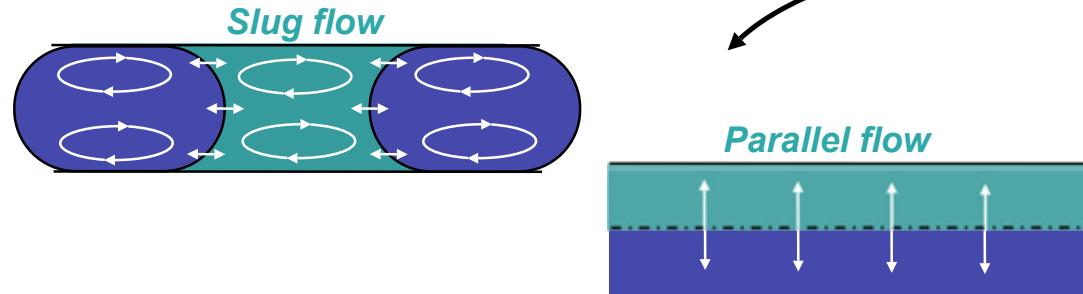
Courtesy of: J. C. Schouten, Eindhoven



Corning S.A.S. - Fontainebleau Research Center

# State of the art + objectives

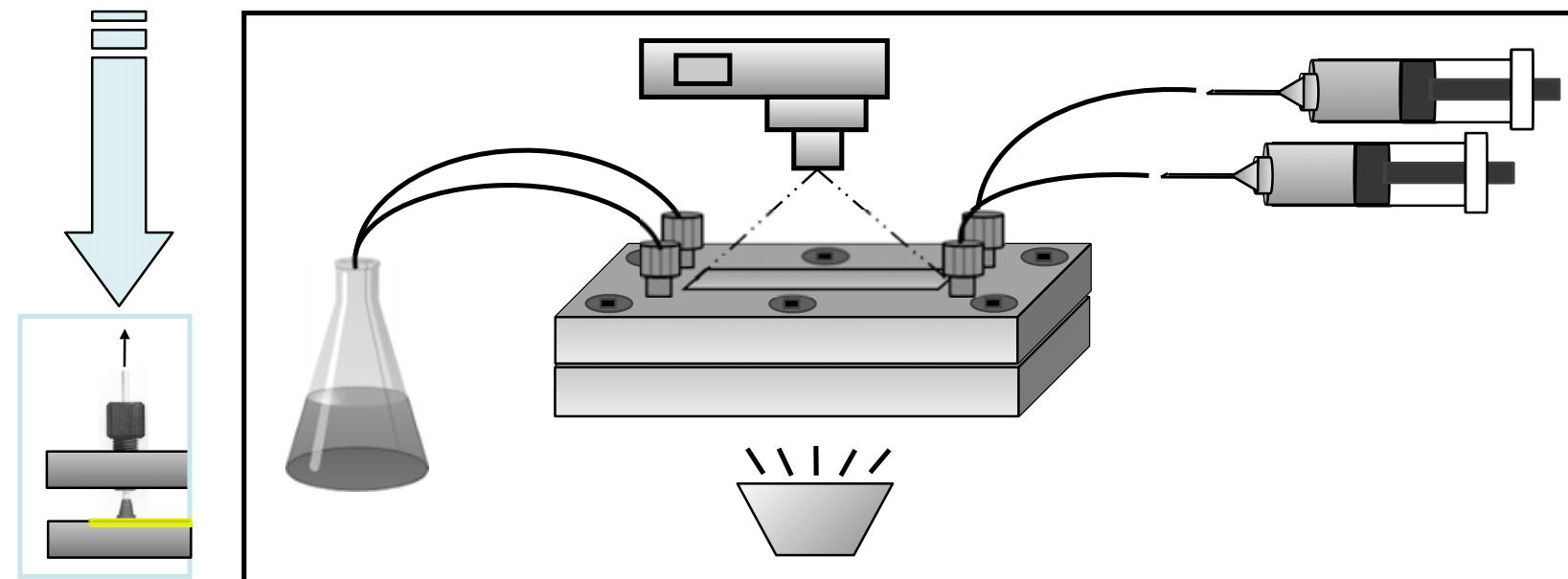
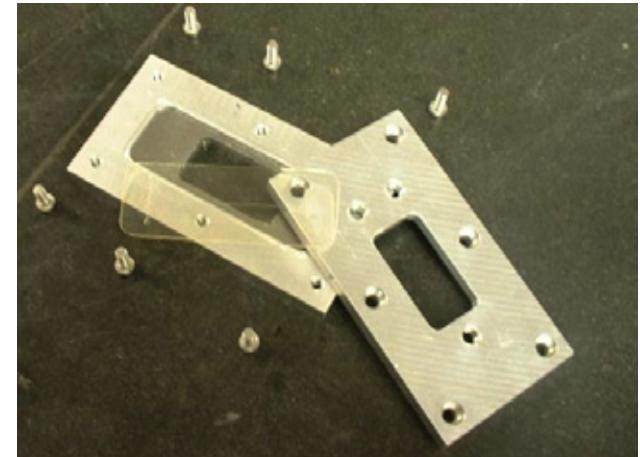
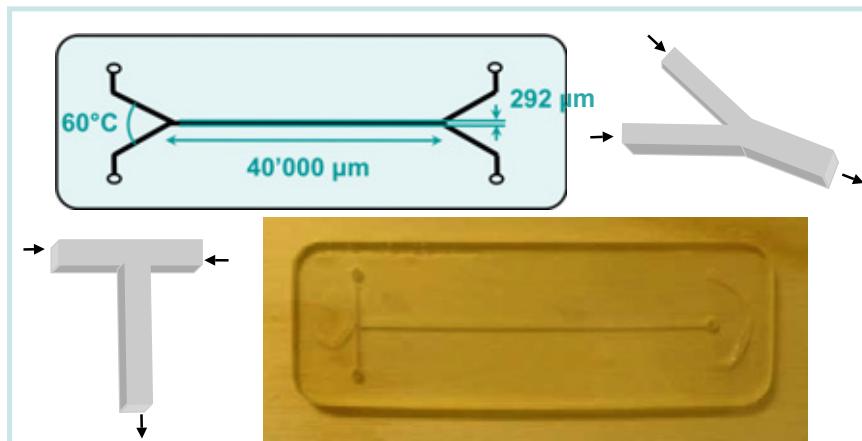
- ✓ Design and operation of two-phase systems
  - Knowledge of hydrodynamics



Courtesy of: Fabien LADEVEZE, TOULOUSE

- ✓ Only few information available for **liquid-liquid** two-phase flow
  - Influence of fluid properties on flow patterns unknown  
= Objective I
  - Comparison of mass transfer performance slug flow/  
parallel flow never done  
= Objective II

# Experimental Set-up



# Flow Patterns: Main forces

- ✓ Objective I: Influence of fluid properties on flow patterns
- ✓ Fluid properties ↔ forces acting on the system
- ✓ Competition between forces dictates the observed flow patterns
- ✓ Theory which connects forces and flow patterns

<i>Force</i>	<i>Action</i>	<i>Flow Pattern</i>
interfacial tension	reduces interfacial area	slug flow
viscous stresses	extend and drag the interface downstream	parallel flow

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Reynolds number	$\frac{\text{inertial forces}}{\text{viscous forces}}$	$\text{Re} = \frac{\rho \cancel{x} u \cancel{x} d_H}{\mu}$
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Capillary number	$\frac{\text{viscous forces}}{\text{interfacial tension}}$	$\text{Ca} = \frac{\mu \cancel{x} u}{\sigma}$
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- ✓ Experiments to verify and clarify the theory

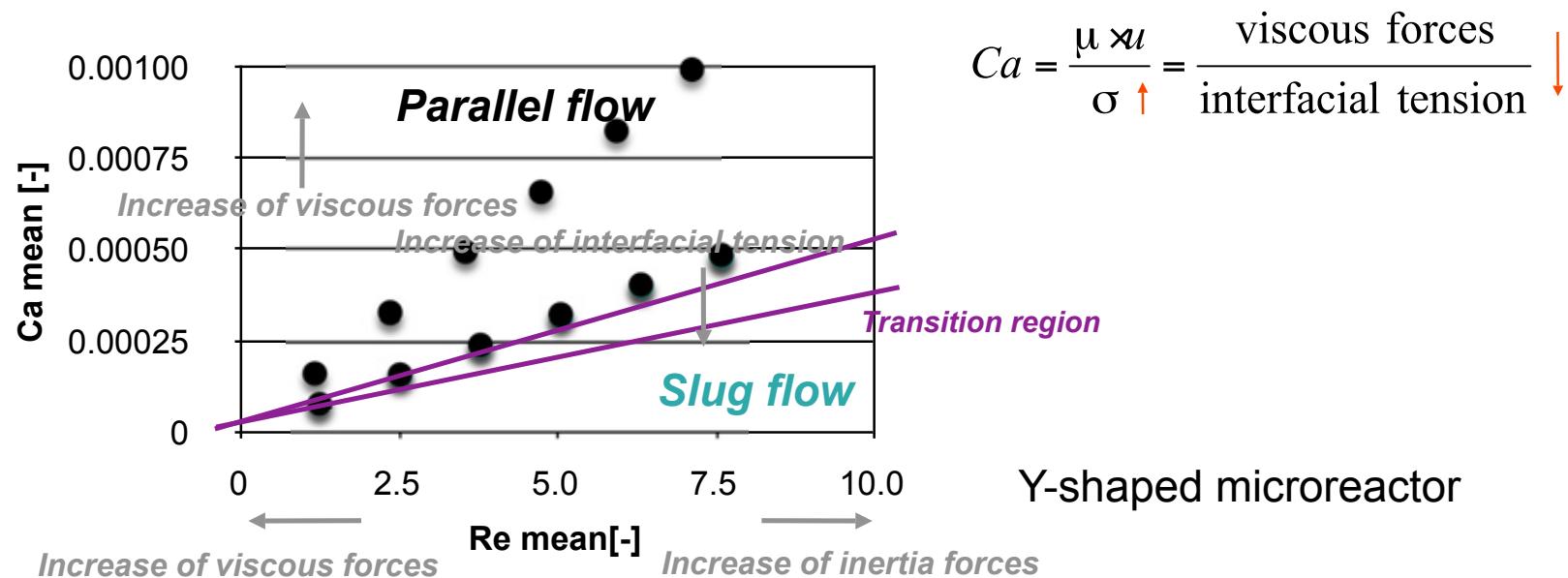
# Flow Patterns: Method + Results

We confirmed experimentally that the observed flow patterns can be explained by a competition between interfacial tension and viscous forces.

- ✓ Example (Y-shaped microreactor):

Water/toluene => parallel flow

Addition of NaOH in water => slug flow



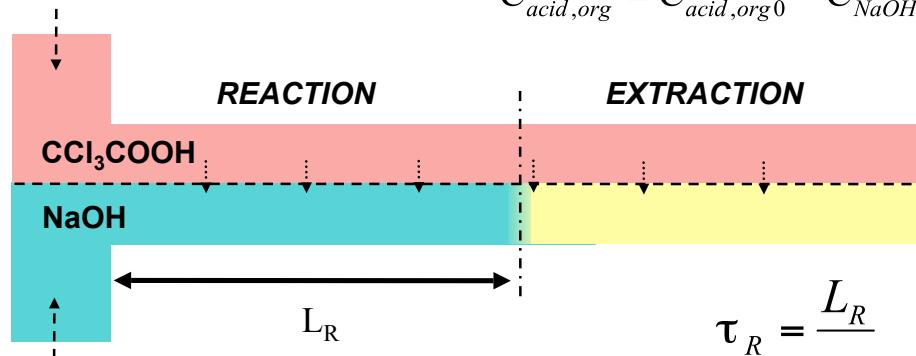
# Mass Transfer: Model reaction

- ✓ Objective II: Mass transfer performance slug flow / parallel flow

- ✓ Model reaction



*Organic phase*

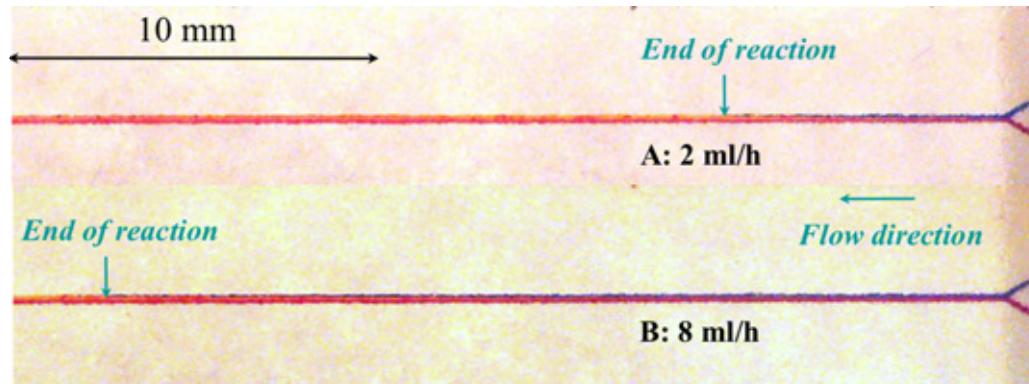


*Aqueous phase*

Series	$C(NaOH)$	$C(CCl_3COOH)$	Total flow rate	Flow ratio
1	0.1 M	0.6 M	2-12 ml/h	1:1
2	0.15 M	0.6 M	2-12 ml/h	1:1
3	0.2 M	0.6 M	2-12 ml/h	1:1

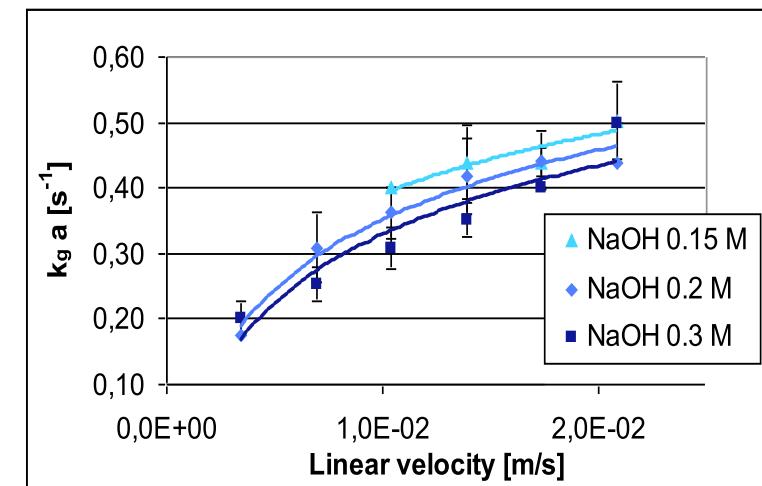
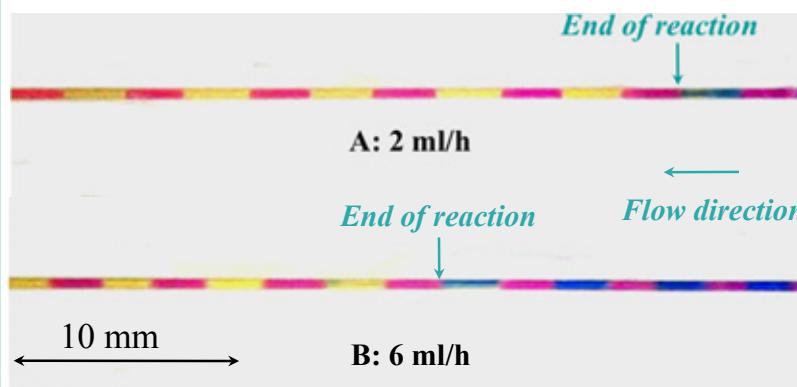
# Mass Transfer: Results

- ✓ Parallel flow in Y-shaped microreactor (Organic solvent = Toluene)



$C \text{ (NaOH)}$	$C(\text{CCl}_3\text{COOH})$
0.2 M	0.6 M

- ✓ Slug flow in T-shaped microreactor (Organic solvent = Hexane)



# Mass Transfer: Summary of the results

Type	$C$ (NaOH)	$k_g \cdot a$		$a$	$k_g$
Parallel flow	0.1-0.2 M	0.2-0.5 s <sup>-1</sup>		6'850 m <sup>-1</sup>	3·10 <sup>-5</sup> - 8·10 <sup>-5</sup> m/s
Slug flow	0.15-0.3 M	0.2-0.5 s <sup>-1</sup>		714-1176 m <sup>-1</sup>	2.5·10 <sup>-4</sup> - 4.5·10 <sup>-4</sup> m/s
				10'700-11'200 m <sup>-1</sup>	2·10 <sup>-5</sup> - 4.5·10 <sup>-5</sup> m/s

Burns et al. 2001

- ✓ Global volumetric mass transfer coefficient for slug flow corresponds to values for parallel flow

# Final conclusions

- ✓ Microreactors possess high mass transfer performance at low power dissipation.

Type	$k_g \cdot a [s^{-1}]$	$P/V [kW/m^3]$
Mechanical stirrer	0.005-0.8	0.5-10
<b>T and Y Microreactors</b>	<b>0.2-0.5</b>	<b>~ 0.7</b>

## Objective I: Influence of fluid properties on flow patterns

The flow patterns are controlled by interfacial tension and viscous forces and depend strongly on the set-up.

## Objective II: Mass transfer performance slug flow / parallel flow

The same mass transfer performance (except very diluted or concentrated solutions).

# ACKNOWLEDGEMENTS

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