FOOD STRUCTURE AND FUNCTIONALITY FORUM SYMPOSIUM

FROM MOLECULES TO FUNCTIONALITY

30 MARCH - 2 APRIL 2014, AMSTERDAM, THE NETHERLANDS

# From micrometre scale insights to novel process design

March 31st 2014, Karin Schroën

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# Overview

- Emulsions and emulsification methods
  - Energy
  - Product properties
- Findings in the field of membranes & micro technology
  - Cross-flow membrane emulsification
  - Spontaneous emulsification (EDGE)
  - (Hybrid) pre-mix emulsification
- How to match these findings with large scale production?

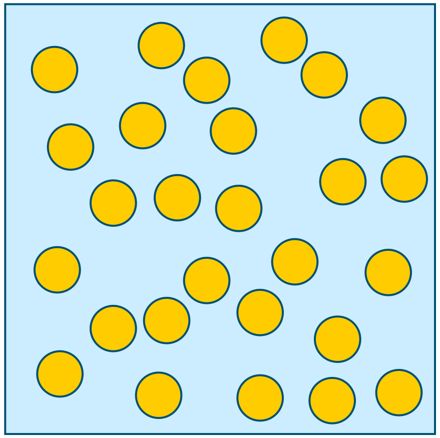
- Conclusions and link to conference theme

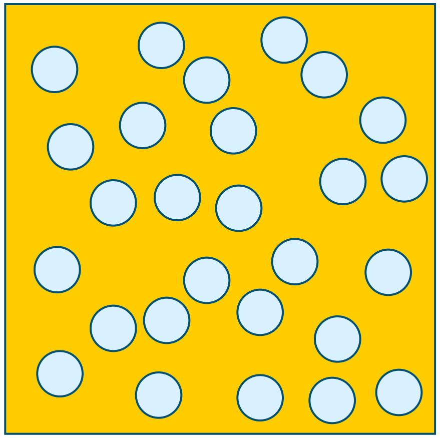
# Emulsions

- Dispersion of one immiscible (fluid) phase into another

- Oil in water
- Water in oil

- Gas and water or oil: foam / droplets



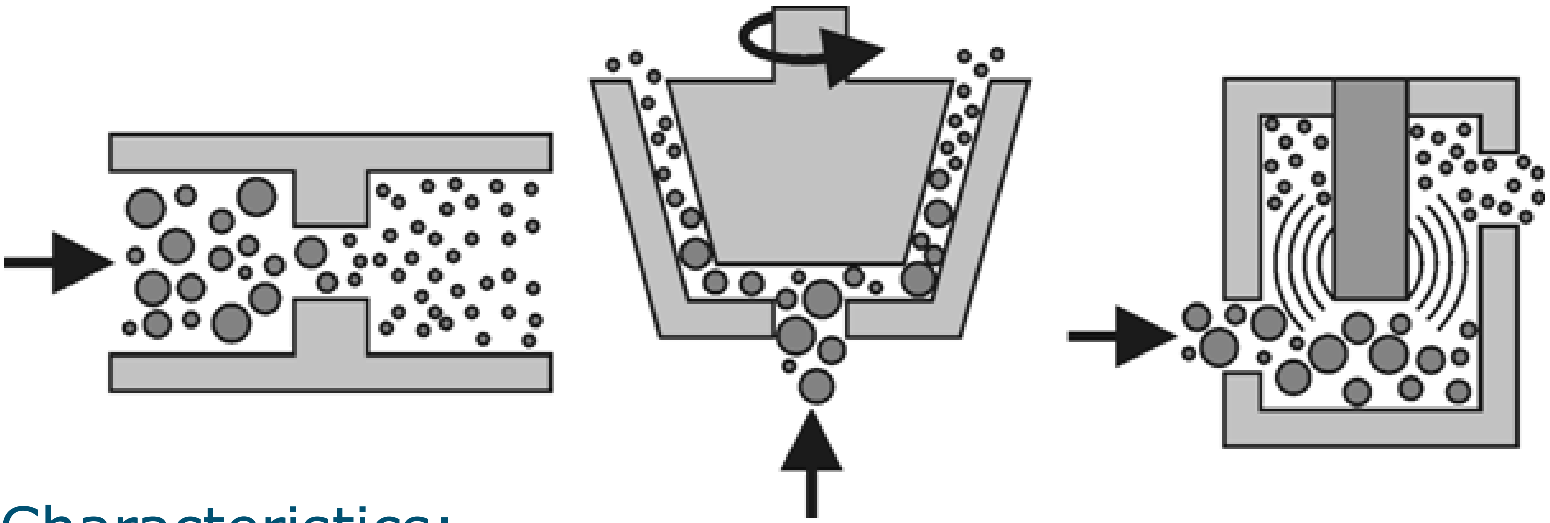


# Emulsions

- Paint
- Bitumen
- Mayonnaise
- Salad dressing
- Egg yolk
- Sausage
- Beer
- Milk
- Butter, margarine
- Bread
- Cream
- Ice cream

# Emulsification

- Mechanical methods
  - High-pressure homogenisers
  - Rotor-stator systems
  - Ultra sonifiers

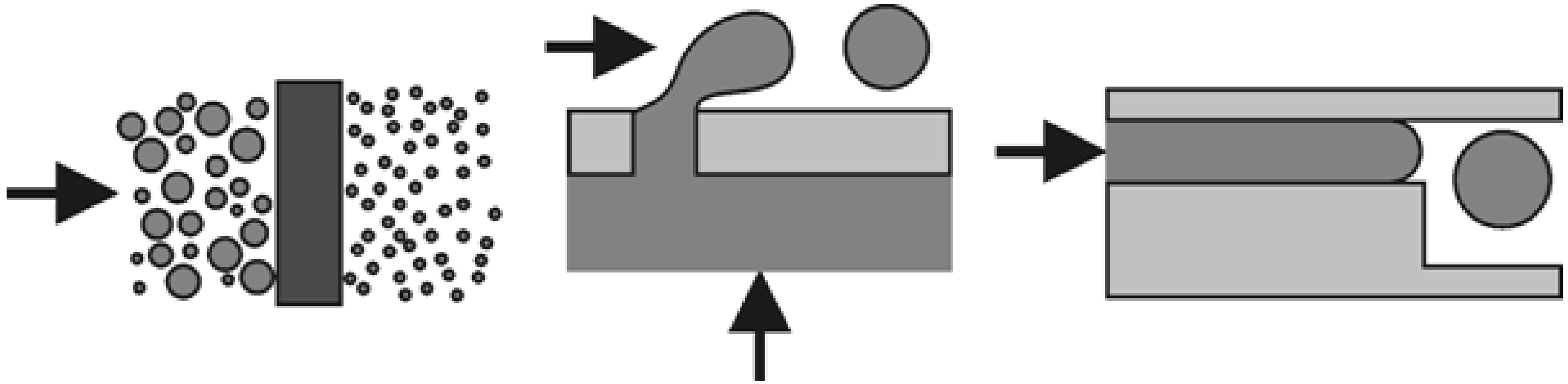


Characteristics:

High energy input, Temperature effects, Multiple passes

# Microstructured systems

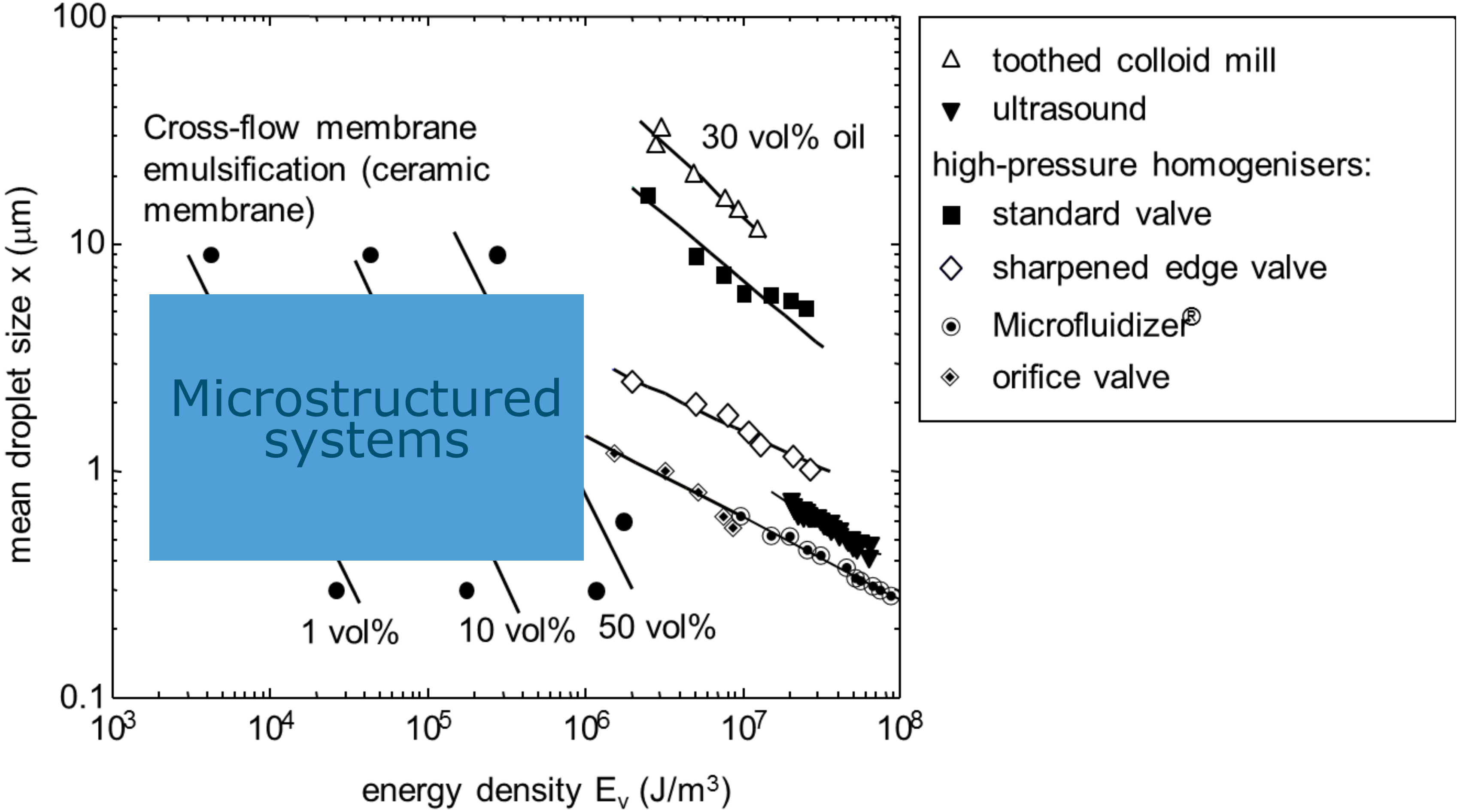
- Premix membrane emulsification
- Cross-flow (membrane or microchip)
- Spontaneous emulsification



Characteristics:

Low energy input, No temperature effects, Single pass

# Comparison of emulsification techniques

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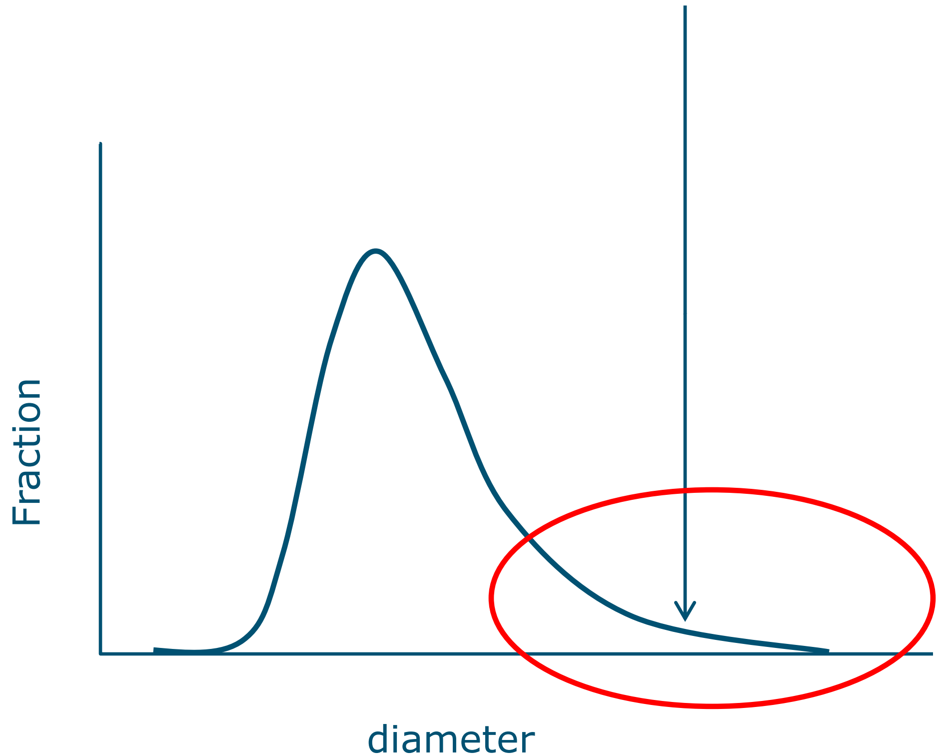
*V. Schröder. 1999. PhD thesis, Technische Hochschule Karlsruhe, Germany.*

# ‘Industrial’ demands put on alternative technology

- High through-put
- Small particle size (narrow size distribution)
- Cheap!

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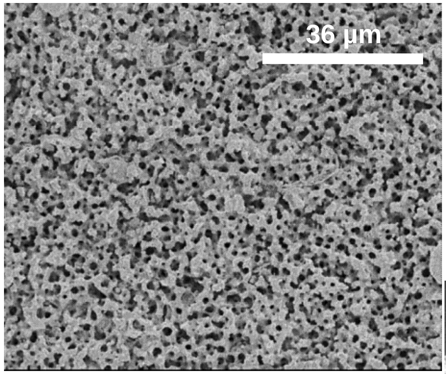
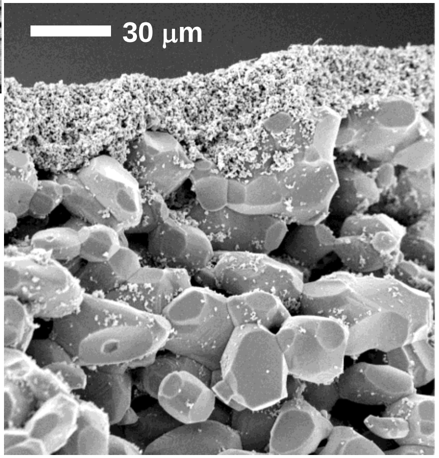
# Microstructures starting point: membranes

- Shirazu porous glass (SPG)




- Ceramics




➢ Pore size distribution

- Microsieves

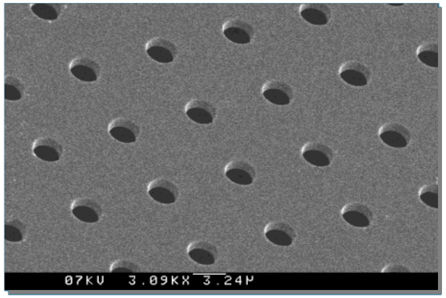



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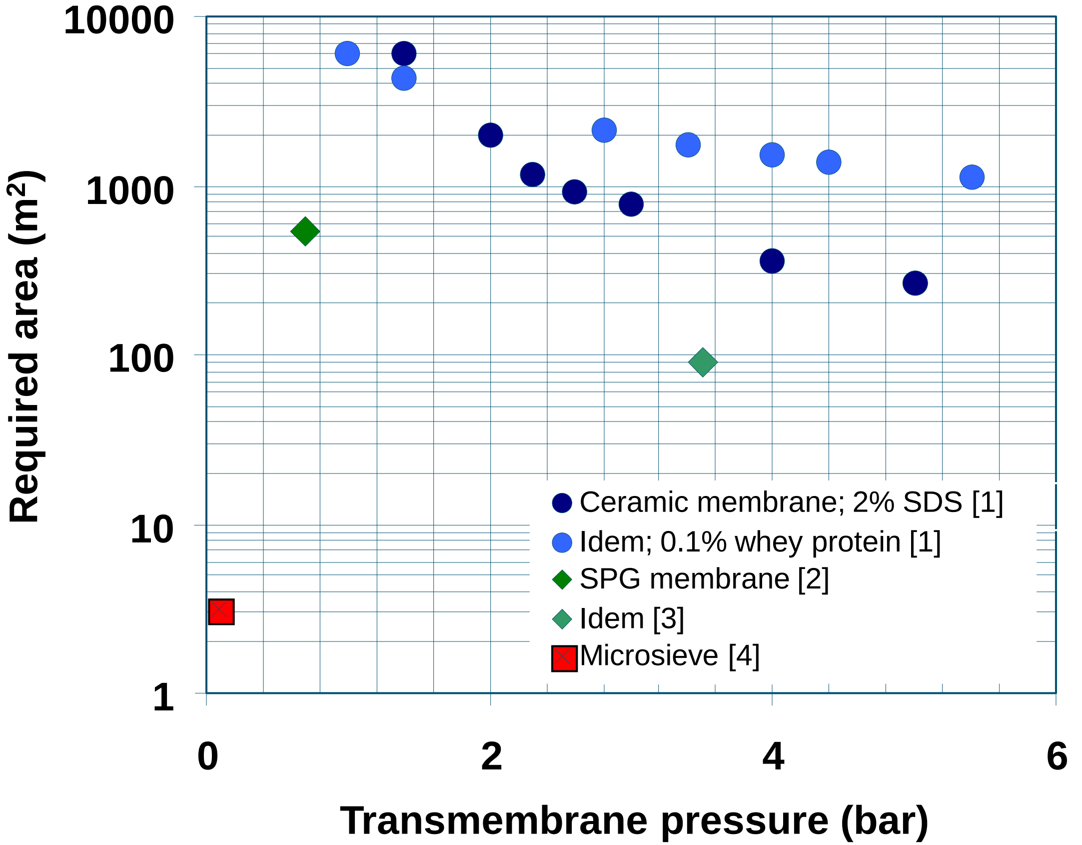
*Image courtesy of Aquamarijn Micro Filtration BV*

# Literature/experimental studies




- Culinary cream
- 30% volume fraction fat
- Vegetable oil
- 20 $m^3/h$


1. *V. Schroeder et al., J. Colloid Interf. Sci., 202 (1998) 334,*
2. *T. Nakashima et al., Key Eng. Mater., 61 & 62 (1991) 513; 3*
3. *T. Fuchigami et al., J. Sol-Gel Sci. Tech., 19 (2000) 337;*
4. *A.J. Abrahamse et al., J. Membrane Sci., 204 (2002) 125*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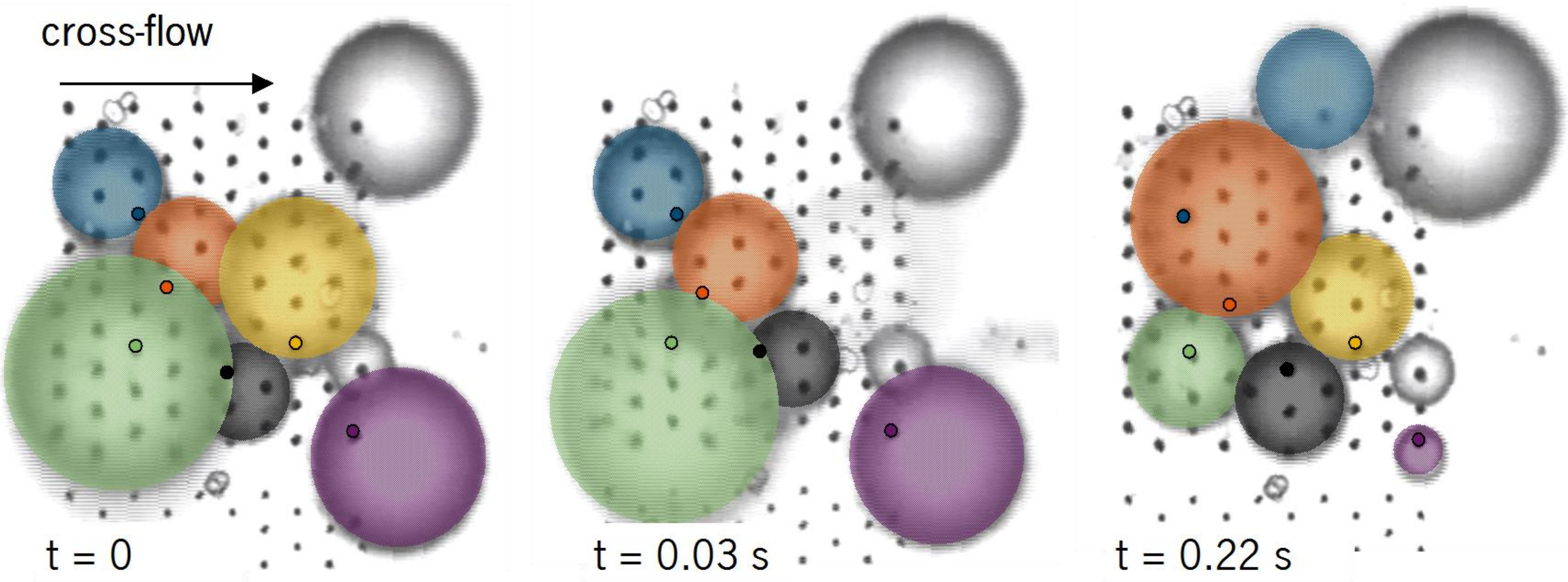
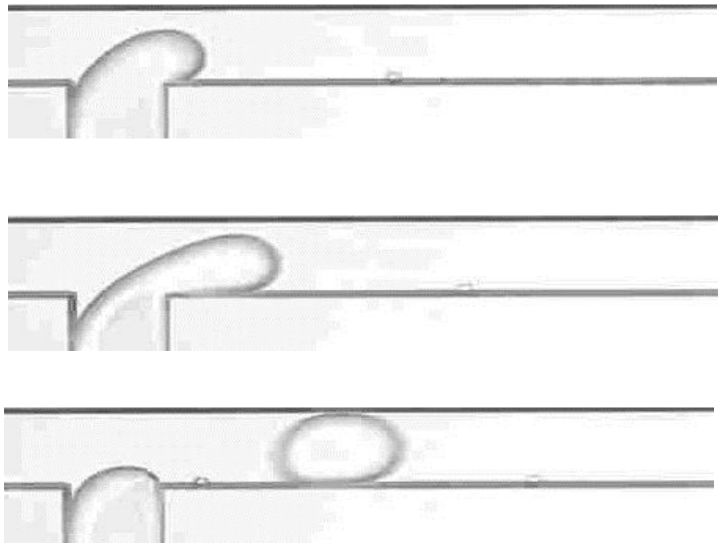
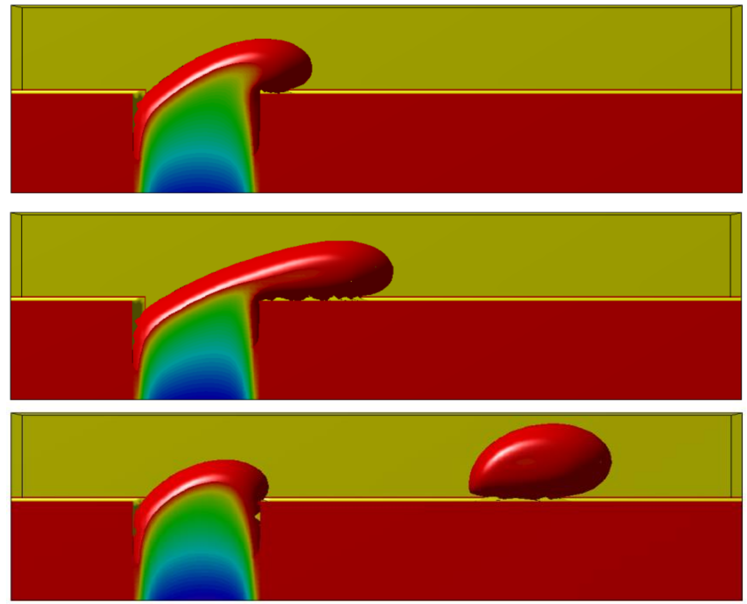
# Microsieves in practice: no monodispersity




- Highly porous membrane: steric interaction (exaggerated because of low flow rates)
- Not all pores are active! Cross-talk.

# Cross-flow mechanism





Scaling relation:

$$V_{droplet} = V_{crit,ref}\, Ca^{-0.75} + t_{neck,ref} Ca^{-0.75}\, \varphi_d \qquad Ca = \frac{\gamma_{sh}\, r_h\, \eta}{\sigma}$$

Two steps: *Interfacial tension, viscosity, shear rate, design!*

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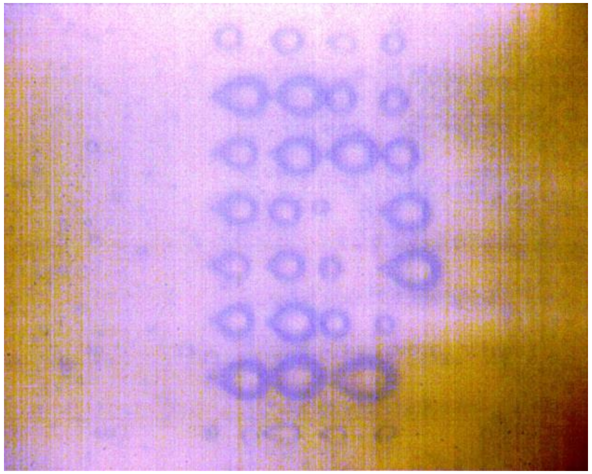
# Shear-based microfluidics

- Design of the sieves

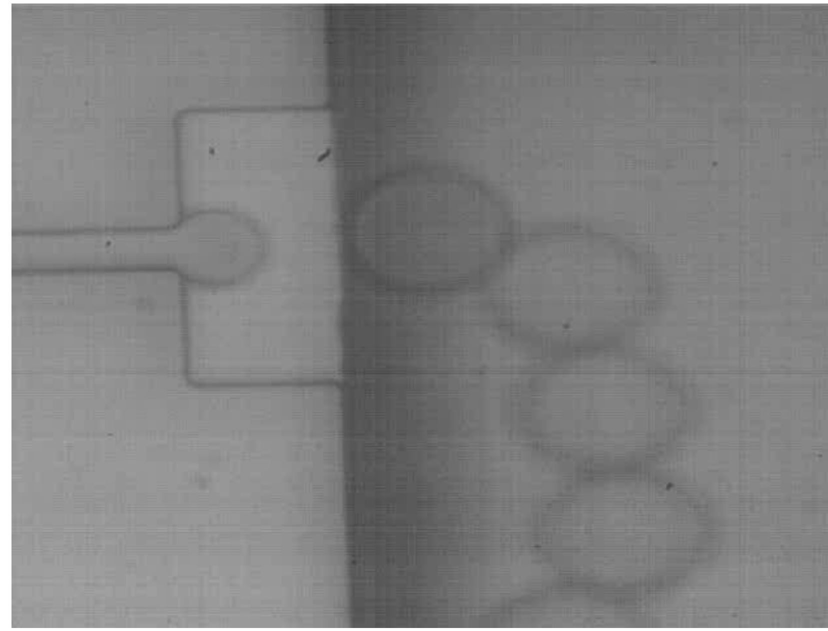
  thickness to prevent cross-talk

  pore positioning
- Control on continuous phase + dispersed phase needed
- Pore size distribution!



*Difficult to control droplet size!*

# Spontaneous droplet generation



Laplace pressure differences

Dispersed phase, terrace design

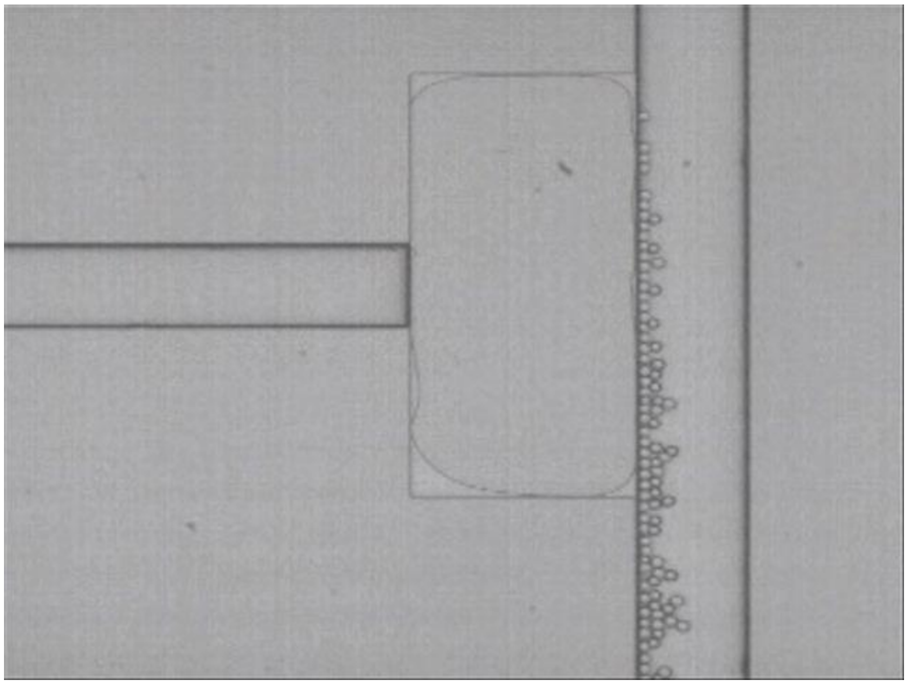
*Up-scaling?*

# Edge-based Droplet GEneration (EDGE)

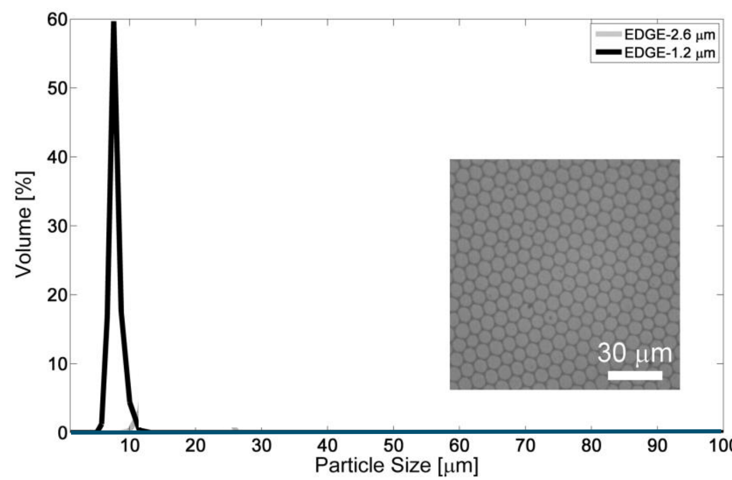
Simultaneous formation of droplets from **one** microstructure

Droplet ~ 6-8 x plateau depth

Dispersed phase flow



slowed down 100x

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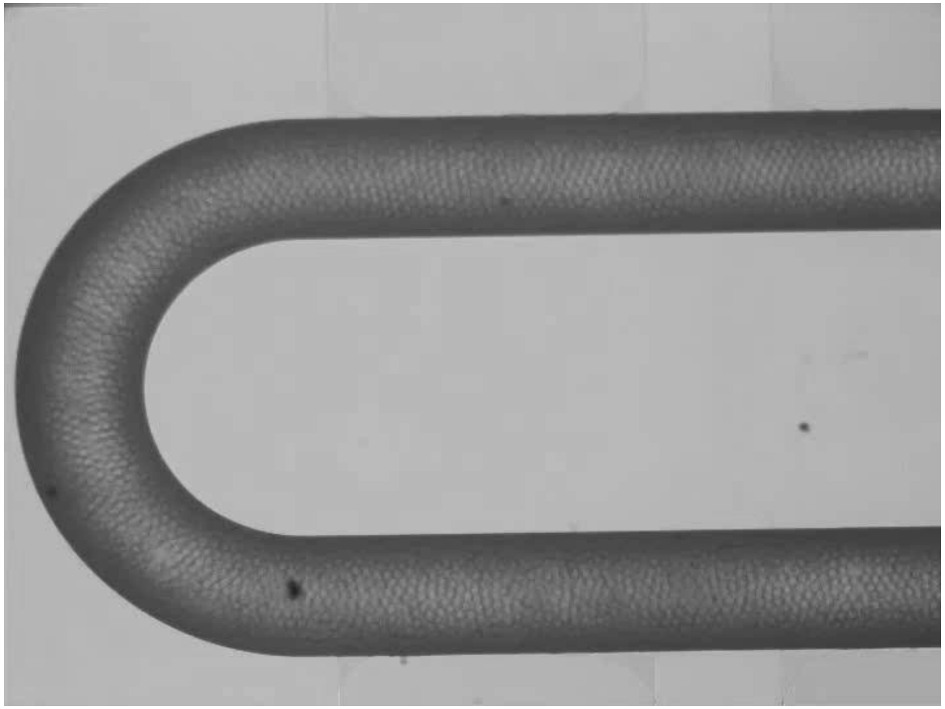
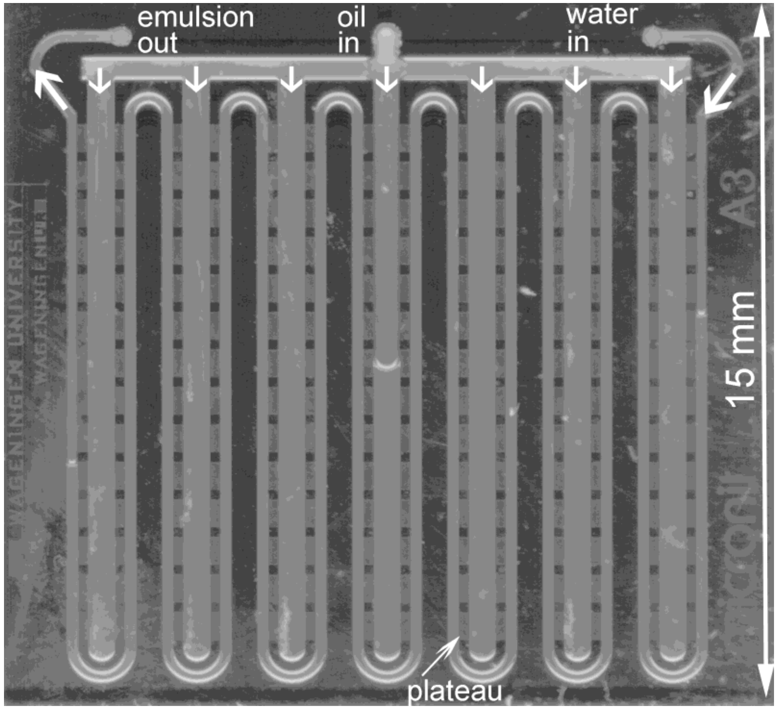
# 'Up scaled' EDGE system

- ✓ Small droplets
- ✓ Food ingredients
- ✓ All plateaus fill
- Scaling: single chip

*Simple & stable!*






*Productivity?*

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# Pre-mix emulsification

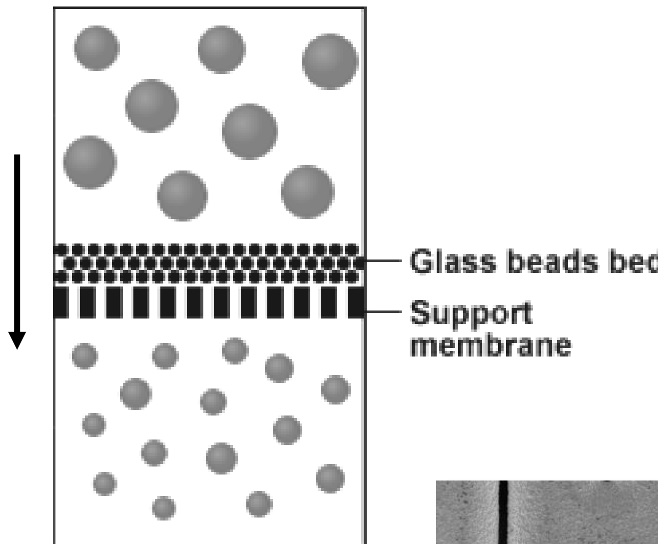
- Regular membranes: fouling → flux loss

➢ Dynamic membrane

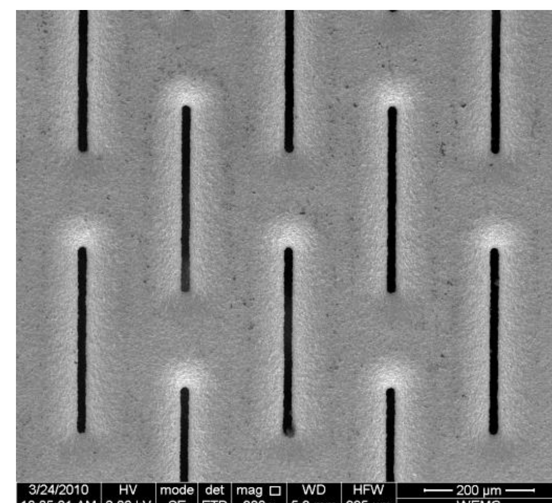
  Break-up bed

  Clean

  Use again




Support metal sieve (width ~10 micron)



*Sieves courtesy of Stork Veco*

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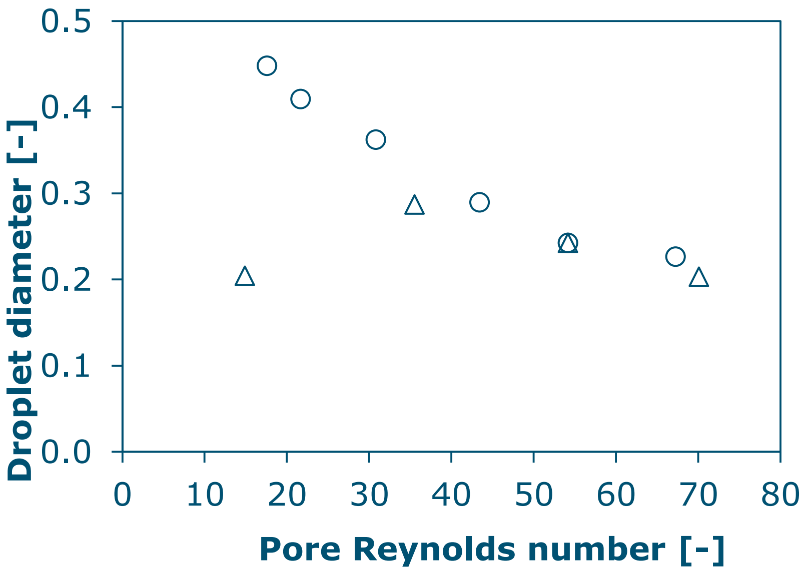
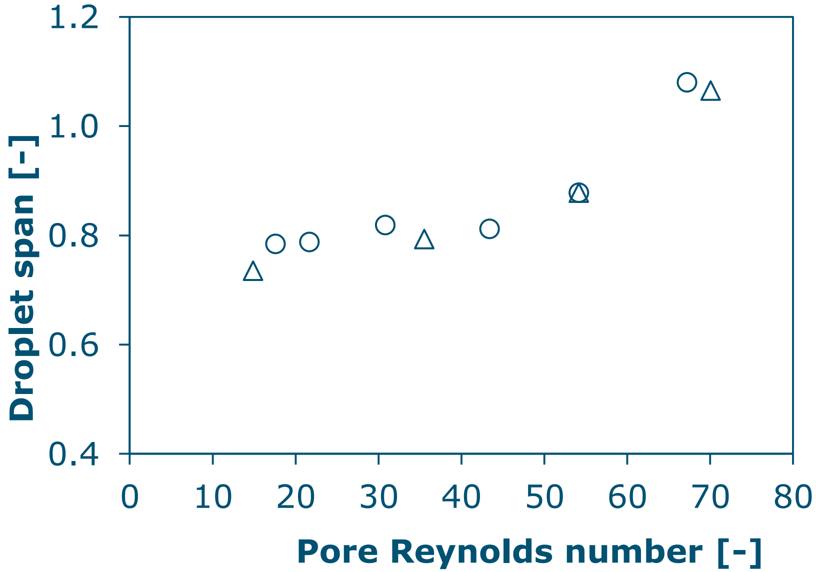
# Characterisation




Decreasing $d_p$

Increasing $H_{bed}$

Fluxes: 100-800 $m^3/m^2/h$

Reasonable monodispersity

'Droplets < voids'

High volume fractions are possible

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# Comparison characteristics microsystems

| | *Shear based* | *Spontaneous* | *Hybrid systems* |
|---|---|---|---|
| *High through-put* | reasonable | no(t yet) | yes! |
| *Small particle size /* | $d_d > d_p$ | $d_d = 6h_p$ | $d_d < d_p$ |
| *Narrow size distribution* | reasonable | yes | reasonable |

For 1 micro droplets, design reaches limits of microfluidics resolution shear / spontaneous

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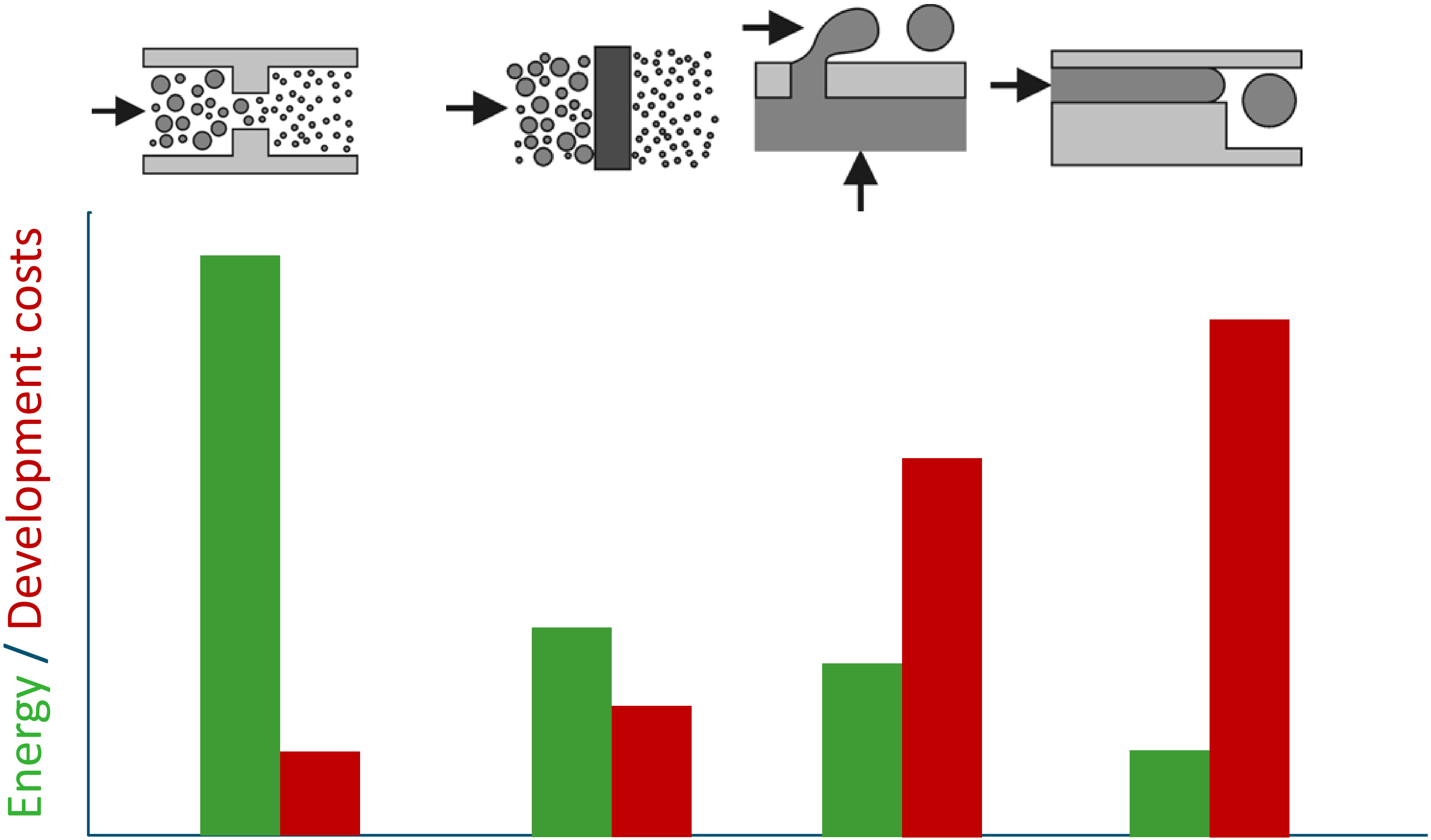
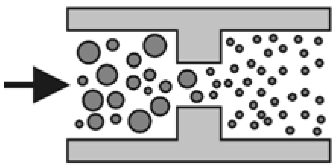
# Comparison with large scale demands

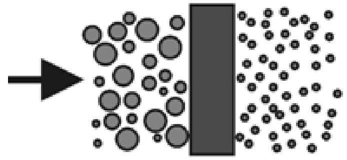


# Which applications?



Various oil fractions

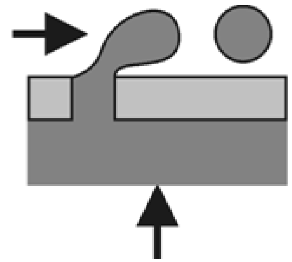
Specialty / bulk product



Various oil fractions

Shear / temperature sensitive ingredients

Specialty / bulk product



Max 10%

Shear / temperature sensitive ingredients

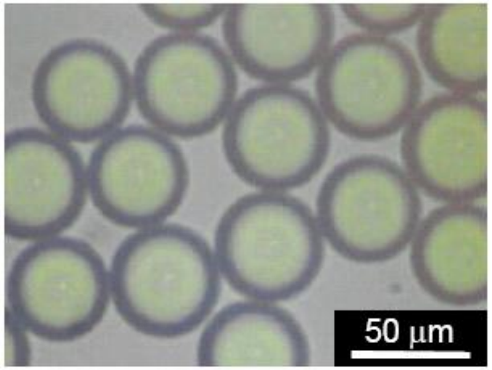
Specialty product

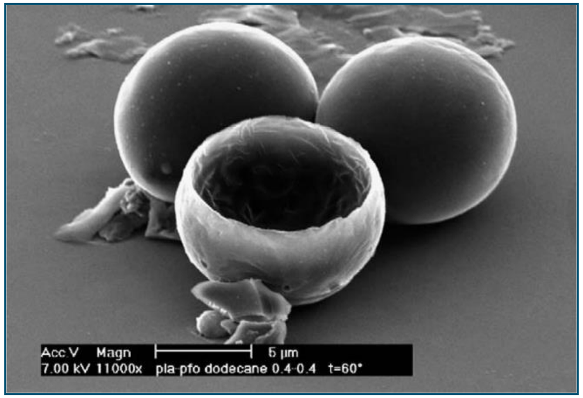
Various oil fractions

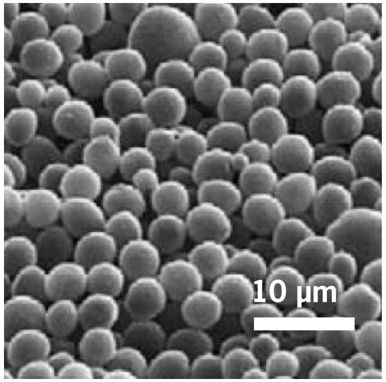
Shear / temperature sensitive ingredients

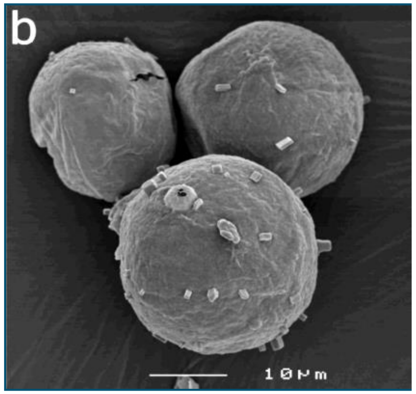
Specialty product

# Beyond emulsions and beyond food



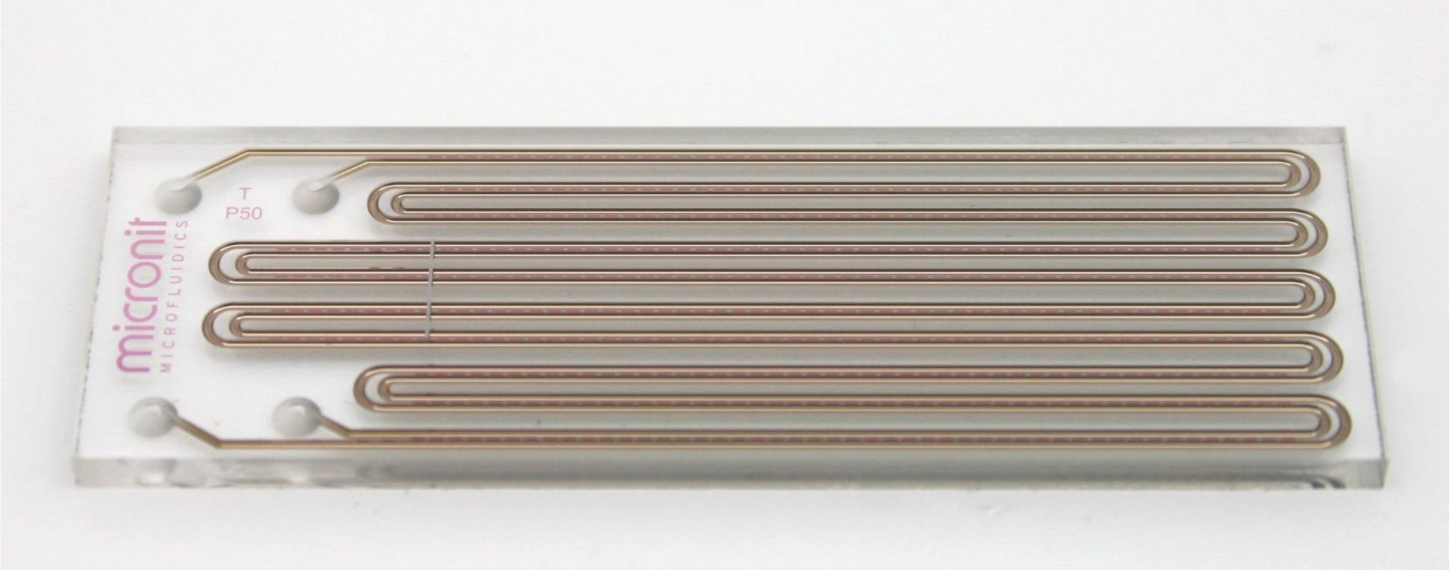



# Remaining industrial questions

- Construction materials: metal ideally steel
  - Roughness
  - Wettability (modification)
  - Construction limitations in microfluidics



# Conclusions:

New emulsification techniques:

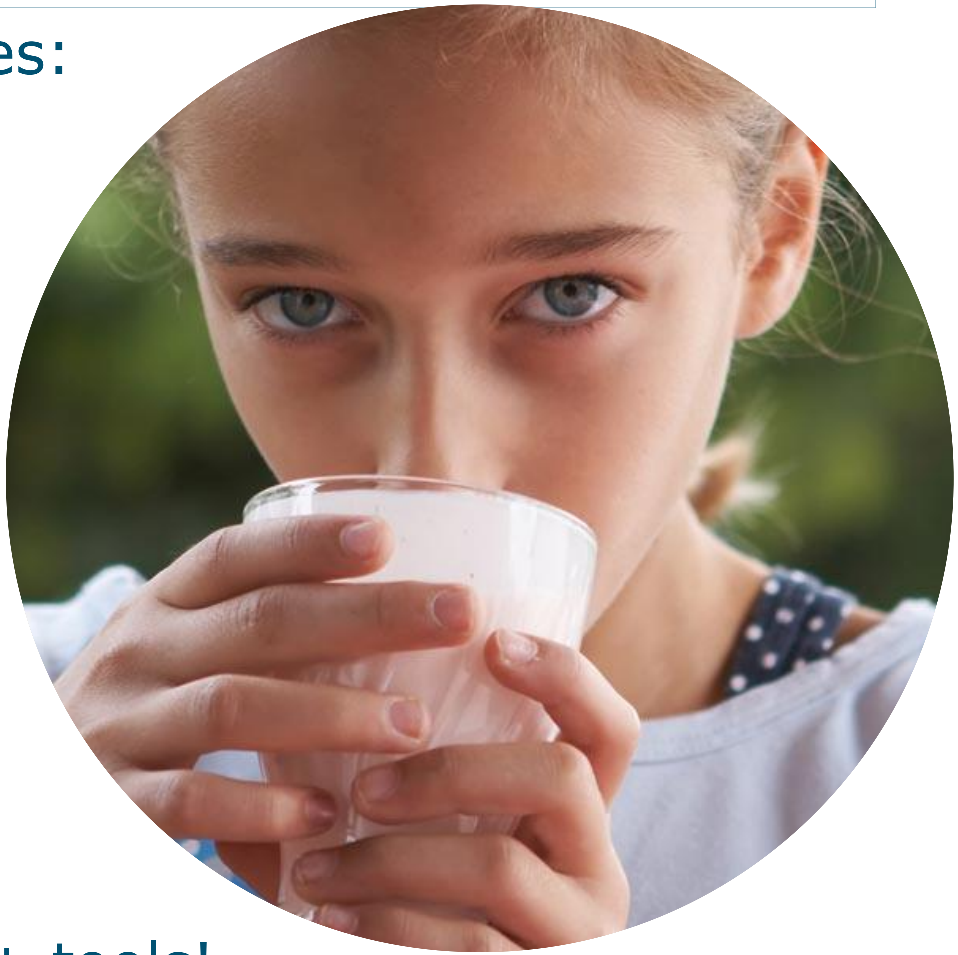
- Membranes
- Microfluidics (up-scaling)
- ✓ Hybrid systems (flux, energy & droplet size

Construction material:

- Metal (+ modification)

Combination with modelling

On-going: various products + tools!



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