L. Sengen [1,2], R. Kuwertz [1], J. Heck [1], M. Grünewald [2];
[1] Ehrfeld Mikrotechnik BTS GmbH, 55234 Wendelsheim, D
[2] Ruhr-University Bochum, Laboratory of Fluid Separations, 44801 Bochum, D

RUHR UNIVERSITÄT BOCHUM

RUB

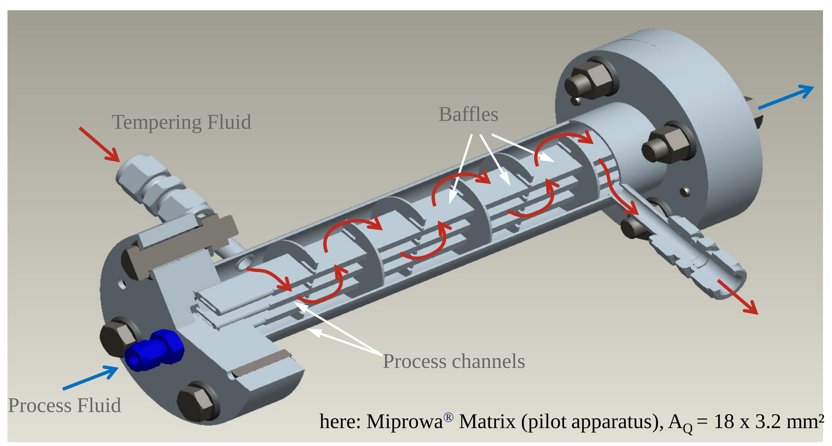
Design of a Modularized, Intensified Milli-Reactor for Production Scale

EHRFELD Mikrotechnik BTS

Motivation

Miprowa® Technology:

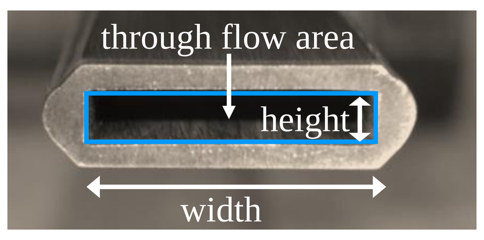
Continous tube-bundle like reactor with milli-scaled structures with two main design aspects:



1. Flat rectangular product channels
   → High surface-to-volume ratios

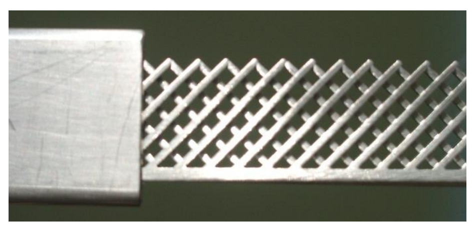
Miprowa® Matrix: *740 m²/m³*

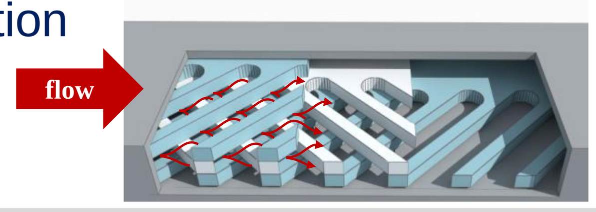
1 inch tube: *160 m²/m³*



2. Static mixing inserts (SM) are exchangeable
   → Intensified heat exchange capacity
   → Forced convection over the entire reactor length
   → Narrow and defined residence time distribution
   → Homogenous reaction conditions

→ Continuous dispersion of two-phase systems





Methods

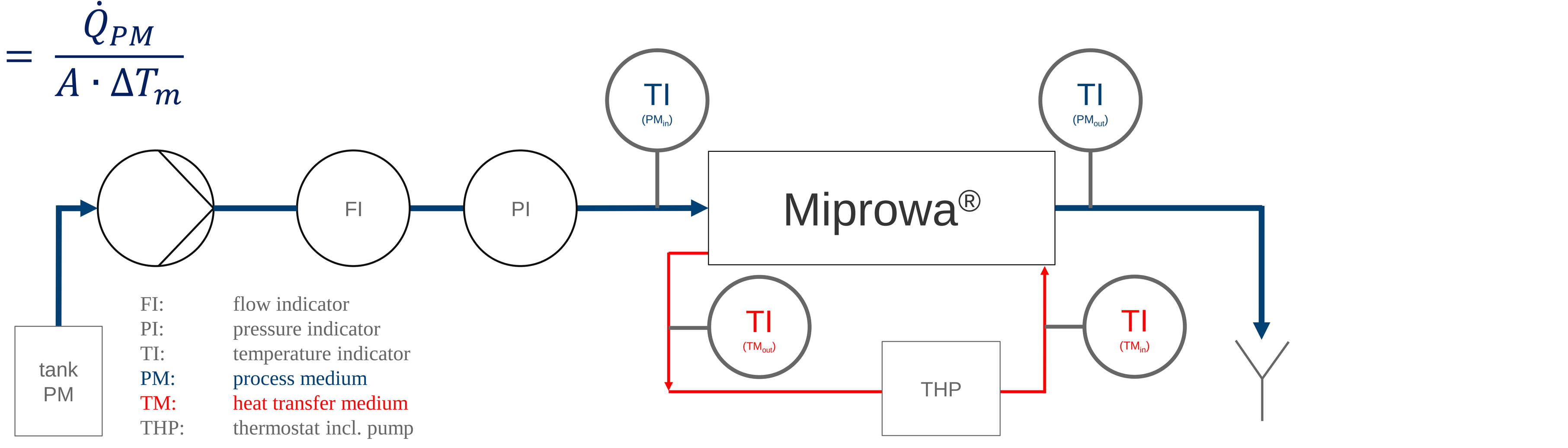
Heat and Mass Transfer Experiments

Experimental setup for heat and mass transfer experiments

→ Measurement of in- and outlet temperatures of process and heat transfer medium

→ Overall heat transfer coefficient calculated using the logarithmic mean temperature difference:

$$k = \frac{\dot{Q}_{PM}}{A \cdot \Delta T_m}$$



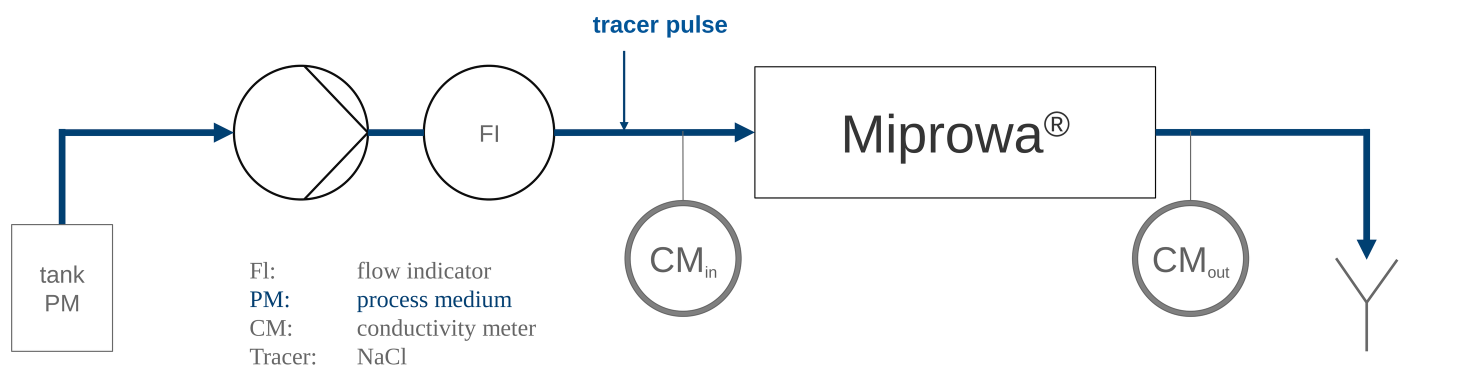
Residence Time Behavior

Experimental setup to investigate the residence time

→ Measurement and comparison of conductivity at the in- and outlet using a pulse tracer (NaCl) in the process medium

→ Mathematical treatment of the conductivity signals

→ Narrow residence time distribution can be used as a measure of the mixing quality in single-phase systems



Results

Influence of the static mixing inserts on the overall heat transfer

→ Calculation of the gain factor Nu/Nu_0 [1,2]

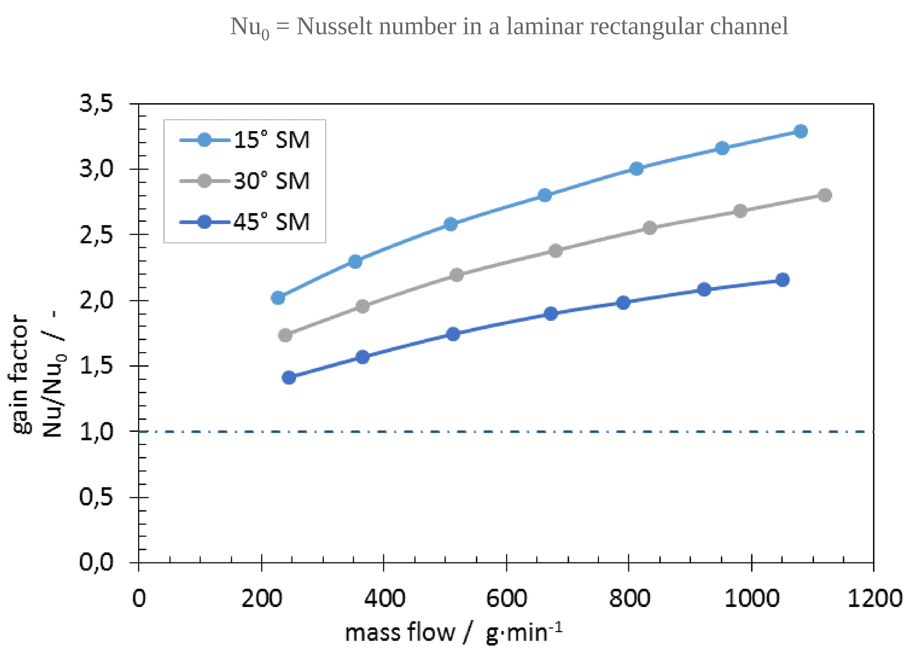
- Derivation of the product-side heat transfer coefficient from the overall heat resistance

$$\frac{1}{k \cdot A} = \frac{1}{\alpha_i \cdot A_i} + R_W + \frac{1}{\alpha_o \cdot A_o} \qquad Nu = \frac{\alpha_i d_h}{\lambda}$$

experimental data, calculated data, geometric parameter
i: inner, w: wall, o: outer

→ Comparison of different SM shows the influence of the inclination angle of the comb structure on the heat transfer

- Significant intensification of convective heat transfer in channels with the comb layers compared to the empty channel

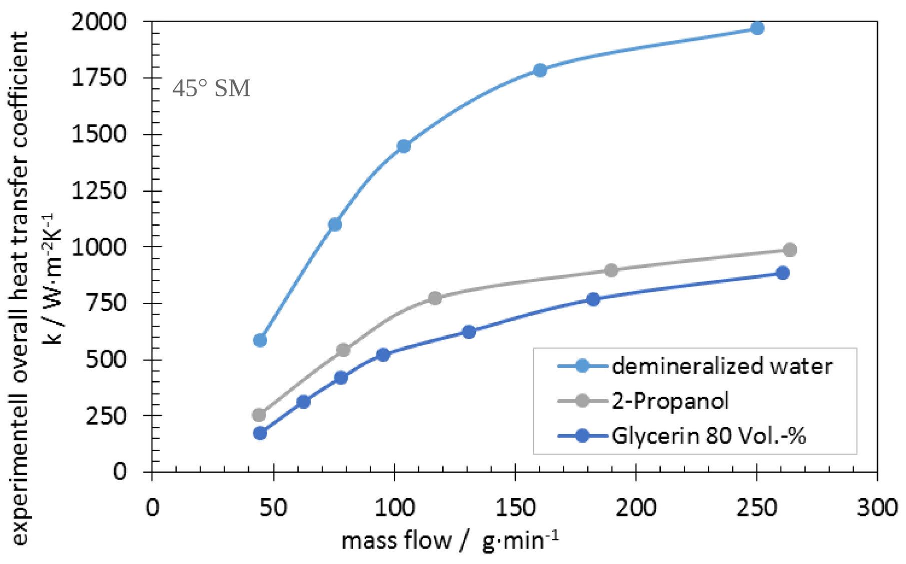


Heat transfer for different process media

→ Influence of heat capacity (c_p), density (ρ) and viscosity (η) on the overall heat transfer of different process fluids

$$c_{p,Wasser} > c_{p,Isopropanol} > c_{p,Glycerin}$$
$$\rho_{Glycerin} > \rho_{Wasser} > \rho_{Isopropanol}$$
$$\eta_{Glycerin} \gg \eta_{Isopropanol} > \eta_{Wasser}$$

- For low-viscosity fluids with high specific heat capacity the heat transfer coefficient is up to $k \approx 2000\ W \cdot m^{-2}K^{-1}$
- For a glycerin water mixture (80 Vol.-%) and Isopropanol $k \approx 1000\ W \cdot m^{-2}K^{-1}$

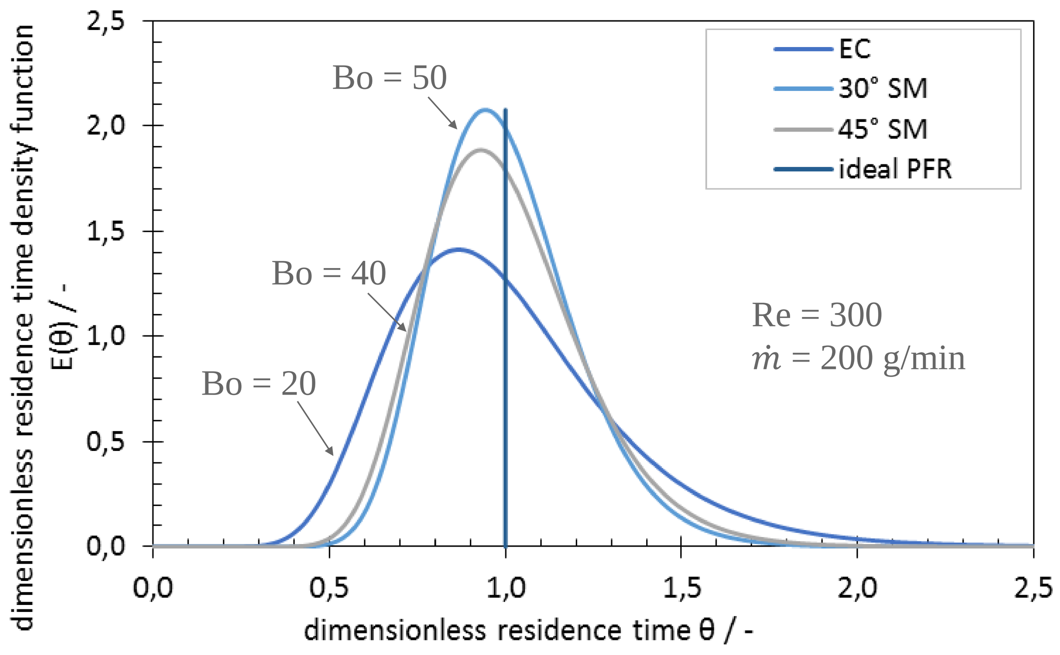


Influence of the static mixing inserts on the residence time distribution

→ Calculation of the dimensionless residence time density function E(θ)

Channel with SM:

- Homogenization of the velocity profile
- Residence time density function is more symmetric
- Less tailing



→ High flow velocities and efficient cross mixing at laminar flow

→ Mixing inserts induce significant narrowing of the residence time density function and thus an intensification of convective heat transfer [3,4]

References

[1] Cengel: Heat and Mass Transfer. A practical approach. Third Edition. Singapure (u.a.): McGraw-Hill, 2006

[2] Rathore, Raul: Engineering Heat Transfer. Second Edition. Sudbury: Jones and Bartlett Publishers, Inc., 2009

[3] Lie et al. (1996): Hydrodynamics and heat transfer of rheologically complex fluids in a Sulzer SMC static mixer, Chemical Engineering Science 51 (10) 1947-1955

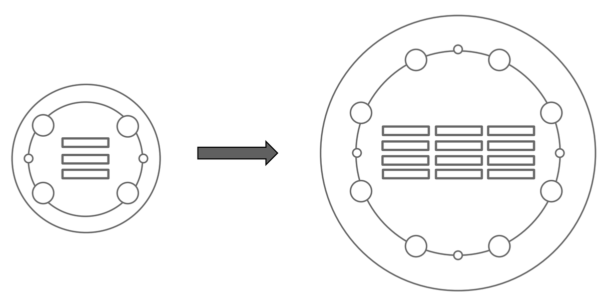
[4] Genetti (1982): Laminar flow heat transfer with inline mixers inserts. Chem. Eng. Commun. 14 (1) 47-57

Scale-Up

Quick and Reliable Scale-Up

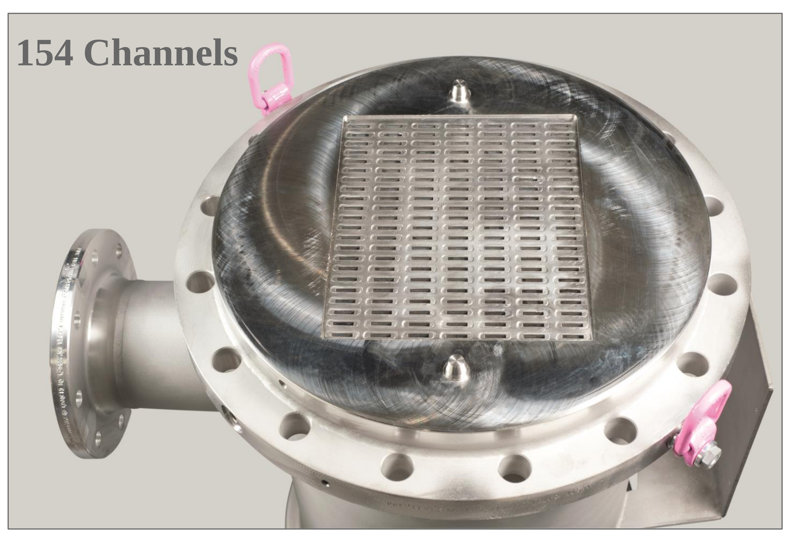
- Increasing the throughput by numbering-up of the product channels while keeping the channel cross section constant

⇨ Constant heat transfer capacities



Channel numbering-up

Development scale	Development + pilot scale	Production scale
Miprowa® Lab	Miprowa® Matrix	Miprowa® Production
- Use of up to 8 channels in a row (maximal 30 mL) - Extendable with dosing ports or temperature sensors	- Reactor to validate process parameters - Lab or production channel size, up to 3 channels and 2 different channel lengths available	- Reactor technology with more than 3 channels (in a row or in parallel) - Industrial application up to 10.000 L/h



R&D and kilo lab 0.6 – 15 L/h → Pilot scale 0.6 L/h – 150 L/h → Production Scale Up to 10,000 L/h

EHRFELD Mikrotechnik BTS

Ehrfeld Mikrotechnik BTS GmbH
+49 (0)6734 91930
info@ehrfeld.com
www.ehrfeld.com

FluidVT
www.fluidvt.rub.de

Name: Laura Sengen
Tel.: +49 (0)234 32 25908
Mail: laura.sengen@bayer.com