Measuring and Modeling the Residence Time Distribution of Gas Flows in Microreactors

W. Wibel, E. Anuriew, J. J. Brandner, R. Dittmeyer

Theory
- Residence time distribution $E$ estimated by the dispersion model:
  \[ E(\tau) = \frac{1}{4\tau_0} \exp\left(\frac{3}{4\tau_0} \right) \]
- Model parameters: $\tau_0$, $\sigma^2$

Modelling: Residence time distribution of microreactors
- Unequal flow distribution to a microchannel array
- Dispersion model applied to device: $E(\tau) = \frac{1}{t_0} \exp\left(-\frac{3}{t_0} \right)$
- inlet and outlet connections total residence time distribution including connections: $E = E_{input} \ast E_{mod} \ast E_{output}$

Experimental Technique
- Nitrogen ($N_2$) is used as carrier gas flow
- Insertion of Helium (He) as tracer into $N_2$ flow (time $t=0$)
- Measurement of He concentration at in- and outlet of microreactor by a special TCD sensor
- Determination of residence time distribution $E$ by correlation of in- and outlet sensor signal

Detection of Helium concentration by Thermal Conductivity Detectors (TCD)
- Similar to hotwire anemometry: here: integral measurement (cross-sectional)
- 15 µm platinum (Pt) wires, arranged in parallel in gas flow in front / back of microstructure
- Pt wire electrically heated ($U = 12$ V, T=70°C)
- Electrical resistance of Pt wire is temperature dependent
- Significantly different heat conductivity of carrier and tracer gas:
  \[ \Lambda_{Pt} = 0.026 \Lambda_{He} \rightarrow \Lambda_{Pt} = 0.154 \Lambda_{He} \]
- Change of Pt wire temperature / resistance when He concentration is increased

Results
- Switching of solenoid valve at $t=0$ (generation of (non ideal) step function by injecting He as tracer into $N_2$ flow)

Summary
- 26 different microstructured devices tested (reactors, heat exchangers, mixers)
- Most of the devices were provided by industry partners
- Materials of devices: stainless steel, plastic, ceramics and glass
- More than 200 measurements evaluated

Sources:

KIT – University of the State of Baden-Württemberg and National Research Center of the Helmholtz Association