DECHEMA FORSCHUNGSINSTITUT

Chemical Technology

Determination of mixing efficiency of micro structured mixers by isothermal heat balance calorimetry

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Project idea

Use the enthalpy of mixing ($h_{E,id}$) as a reference point for determination of mixing efficiency (G) of micro mixing devices

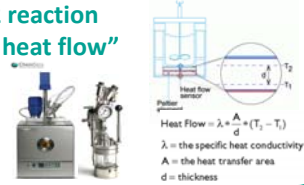
$$G = h_{E,eff} / h_{E,id}$$

$h_{E,id}$
- Measure for ideal mixing of two fluids on molecular scale
- Available in databases
- Accessible by isothermal calorimetry

$h_{E,eff}$
- Obtained from continuous heat balance calorimetry for the case when mixing takes place inside a micro mixing device

The instrument

ChemiSens® CPA202 reaction calorimeter - "true heat flow" principle
- real time measurement
- factory pre calibrated
- stable baseline

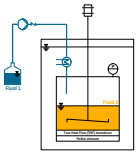


Types of experiments

BATCH / $h_{E,id}$

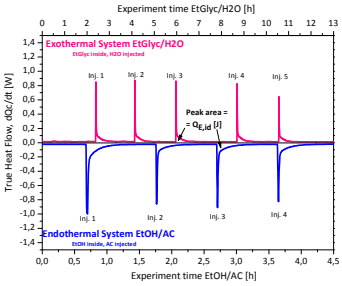
Model substances
- ethanol / acetone
- ethylene glycol / water

Injection
- gas tight syringe
- syringe pump



Reference point
- T = 25 °C

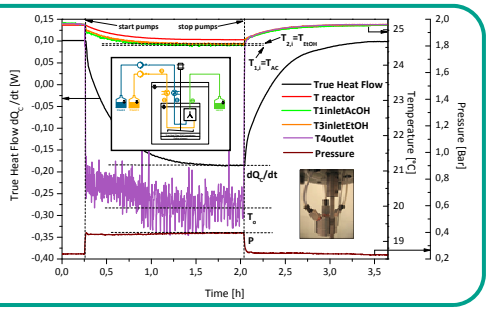
$$h_{E,id}\left[J \cdot mol^{-1}\right] = -\int dQc/dt \Big/ (n_1 + n_2) = -Q_{E,id}/(n_1 + n_2)$$



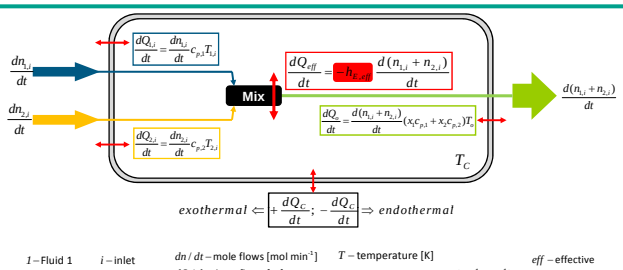
CONTINUOUS / $h_{E,eff}$

Parameter set: effect of flow rate
- $F_{EtOH}=F_{AC}$; x_{EtOH}= 0.5
- F_{EtGlyc} = F_{H2O} ; x_{EtGlyc}= 0.25

Parameter set: effect of stoichiometry
- F_{EtOH} + F_{AC} = 2 [ml min^{-1}]
- F_{EtGlyc} + F_{H2O} = 2 [ml min^{-1}]



Heat balance of continuous mixing



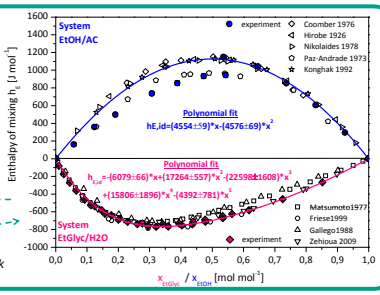
1 – Fluid 1 | i – inlet | dn/dt – mole flows [mol min^{-1}] | T – temperature [K] | eff – effective
2 – Fluid 2 | o – outlet | dQ/dt – heat flows [W] | c_p – molar heat capacity [J K^{-1} mol^{-1}] | c – calorimeter

Heat flow balance[1]

$$0 = \left[\left(\frac{dQ_{1,i}}{dt} + \frac{dQ_{2,i}}{dt}\right) - \frac{dQ_o}{dt}\right] - \frac{dQ_C}{dt} + \frac{dQ_{eff}}{dt}$$

$$G = \frac{h_{E,eff}}{h_{E,id}} = \frac{-\frac{dQ_{eff}}{dt} \Big/ \frac{d(n_{1,i}+n_{2,i})}{dt}}{h_{E,id}}$$

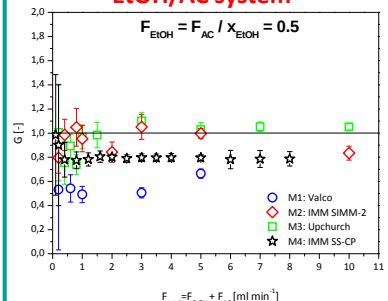
Polynomial fit of batch data

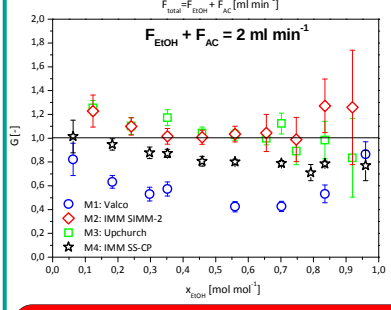


[2] based on M. Baerns, H. Hofmann, A. Renken, *Chemische Reaktionstechnik Band I*, 3. Auflage (1999) Georg Thieme Verlag Stuttgart p. 270-271

Mixer characterisation

EtOH/AC system



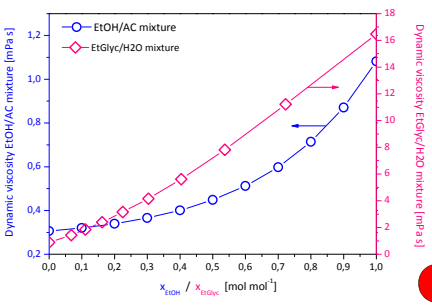


Characterised static micro mixers

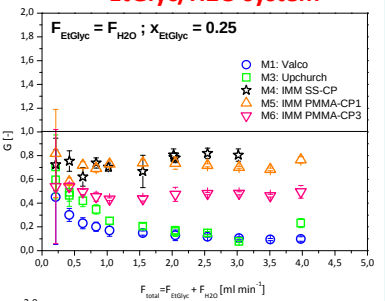
Multi-lamination (ML) principle
- **M1:** T-piece SS (Valco Inst.)
- **M2:** SIMM-2 SS (Fraunhofer ICT-IMM)
- **M3:** T-mixer PEEK (Upchurch /Idex Corp.)

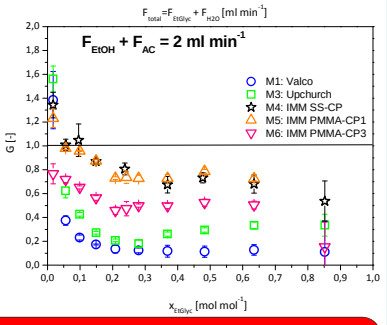
Split And Recombine (SAR) principle
- **M4:** Caterpillar mixer SS (Fraunhofer ICT-IMM)
- **M5:** Caterpillar mixer PMMA 180° (Fraunhofer ICT-IMM)
- **M6:** Caterpillar mixer PMMA 90° (Fraunhofer ICT-IMM)

Viscosity change



EtGlyc/H2O system





Efficiency ranking: M3 > M2 > M4 >> M1

Efficiency ranking: M4 ≈ M5 > M6 > M3 > M1

Summary

- G is suitable for qualitative assessment of mixing efficiency
- Well defined reference point / High reproducibility
- No need for optically transparent devices
- No need for knowledge of mixer channel geometry
- Wide variation of fluid viscosity possible

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