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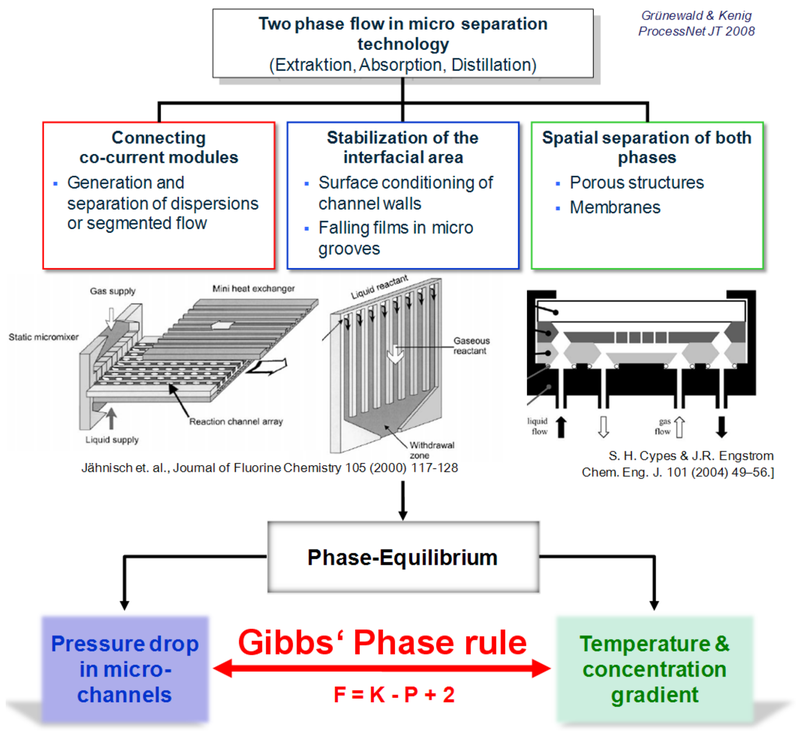
Process design for micro-structured distillation devices

Motivation



Micro-distillation devices presented in the last years:

- single channel (dispersed phases)
- two fluid channels (interface stabilized by surface forces)
- two fluid channels (interface stabilized by capillary forces)

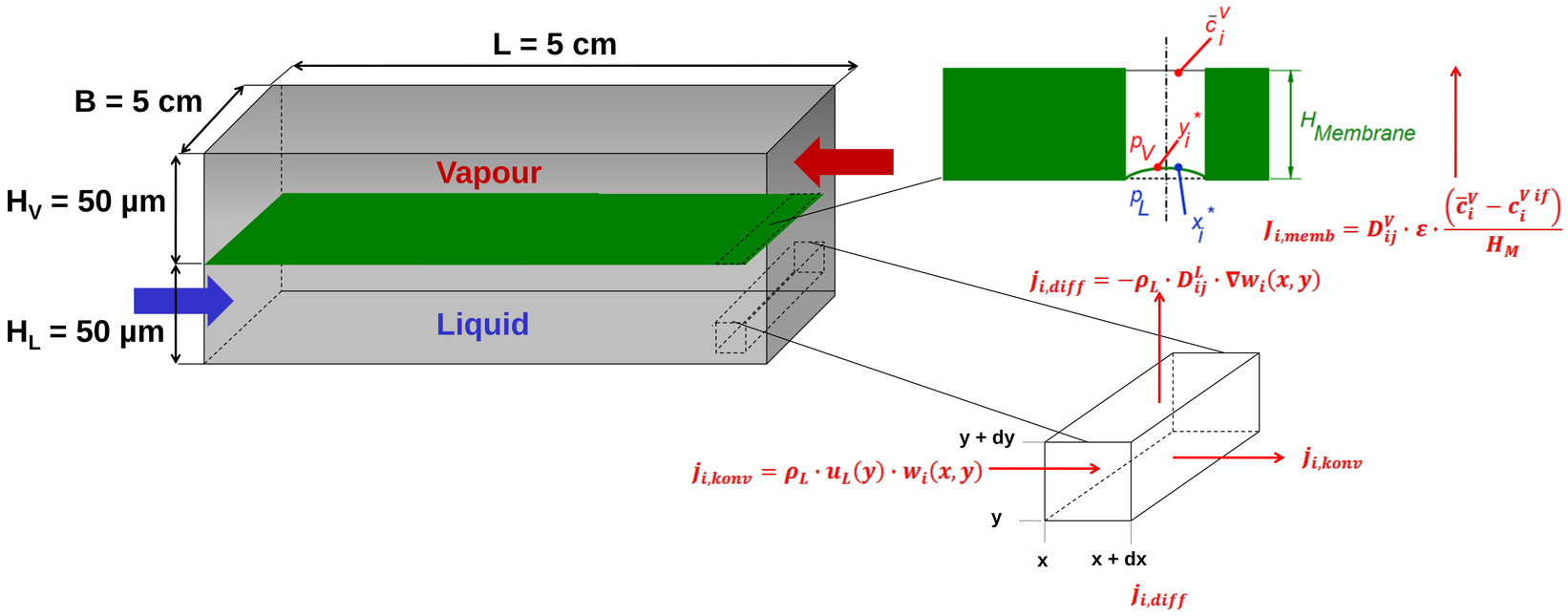
Advantages of micro-structured devices:

- high efficiency
- small hold-up
- modularity

Questions not answered:

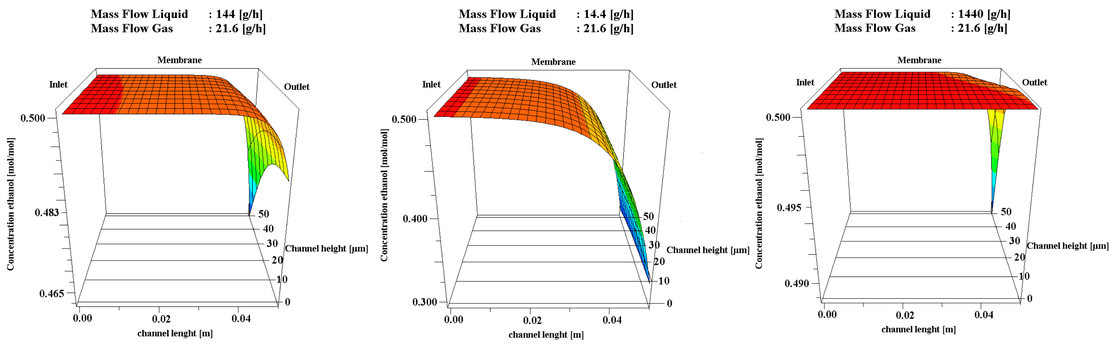
- operating limitations
- mass transport limitations

Simulation



Rigorous process model:

- mixture of two substances
- steady state calculation
- laminar flow in both channels
- no-slip condition
- adiabatic conditions
  → temperature gradient along membrane
  → similar evaporation enthalpy
  → constant total mole flow



Limitations for liquid flow:

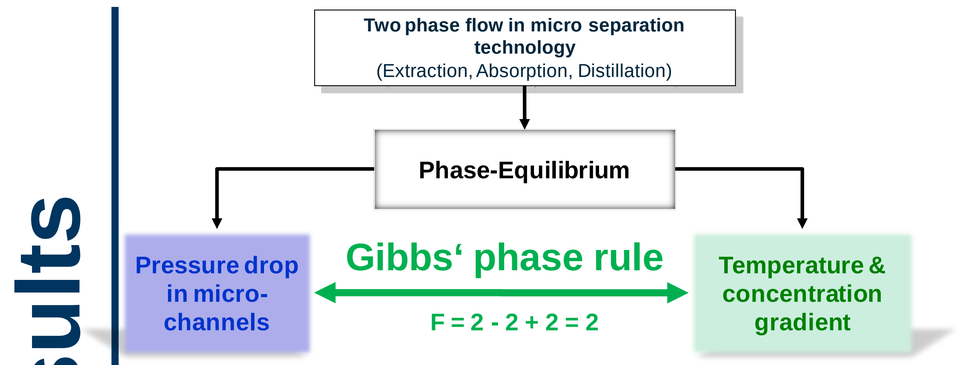
- small temperature rise → no limitation
- upper bound
  → residence time (diffusion vs. channel height)
  → utilisation of membrane length
- lower bound
  → economic efficiency (throughput vs. capital cost)

$\dot{m}_{L\,in}$ [g/h]	288	288	288	288
$\dot{m}_{V\,in}$ [g/h]	21,6	64,8	108	216
$\dot{m}_{membran\,EtOH}$ [g/h]	4,19	12,19	19,50	31,69
ΔT [K]	1,26	3,73	6,56	16,82
$\Delta p_{membran\,max}$ [bar]	0,25	0,36	0,47	0,82

Limitations for vapour flow:

- upper bound
  → temperature rise (max. ΔT of device)
  → pressure drop (Δp vs. capillary pressure of membrane)

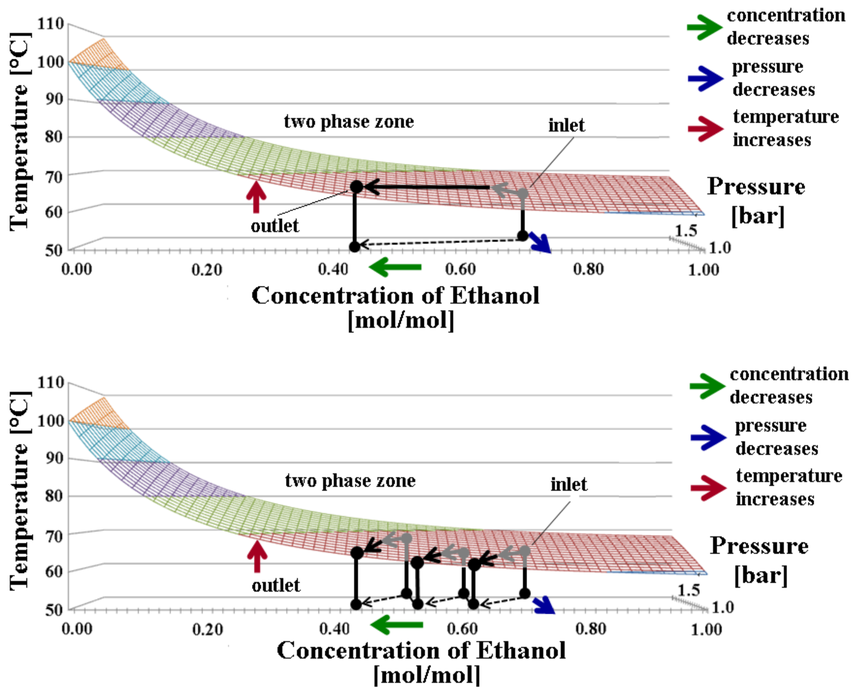
Results



Phase-equilibrium at membrane:

- pressure drop fixed by channel geometrie
- concentration fixed by mass transfer
- temperature fixed by Gibbs' phase rule

→ no degree of freedom



Consequences for process design:

- pressure drop limits mass transfer
- pressure drop depends on geometries
- pressure drop per module limited

→ stepwise increase of pressure for defined distillation task

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