Annual meeting of DECHEMA / VDI Group Extraction 2025
Aachen, 19/02/2025

SisClever Process

Simultaneous recovery of metals from ore or waste to high purity and high concentration via solvent extraction

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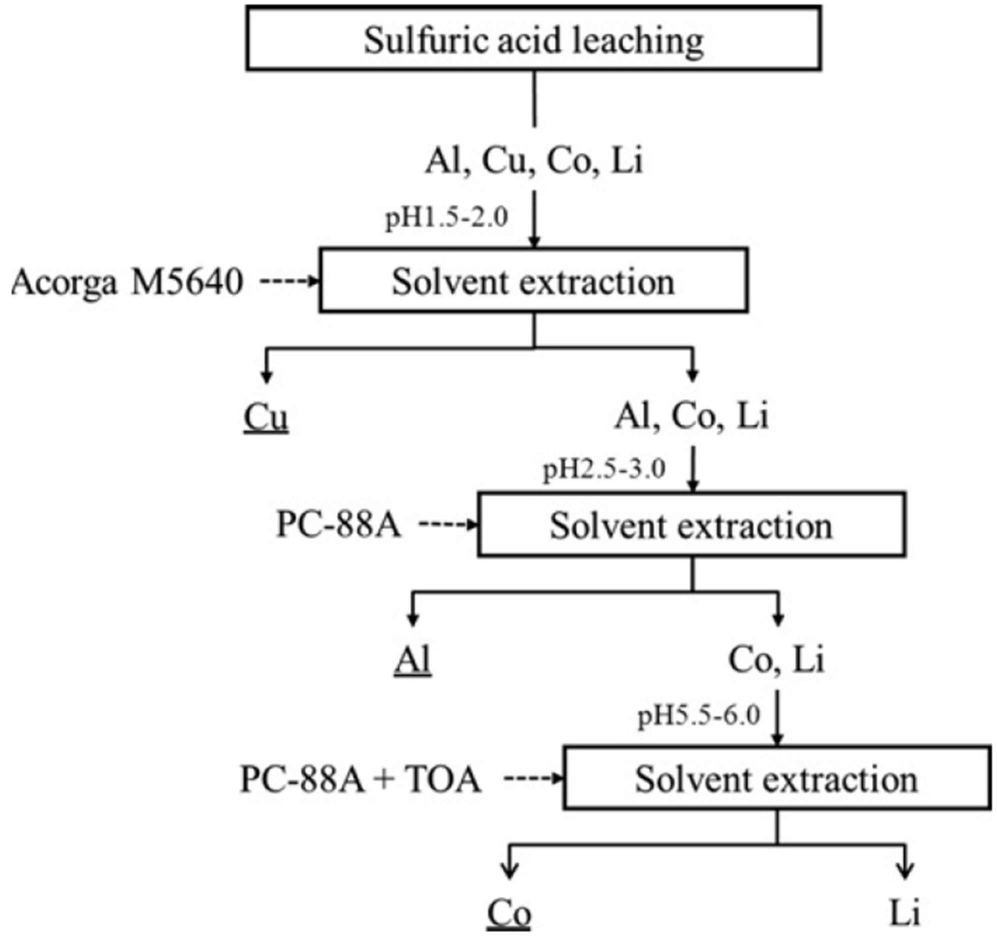
motivation

- separation of metals dissolved in an aqueous phase
- several unit operations
- different extractants



Suzuki, T., Nakamura T., Inoue, Y., Niinae, M., Shibata, J., 2012: A hydrometallurgical process for the separation of aluminum, cobalt, copper and lithium in acidic sulfate media. *Separation and purification technology*, 98, 396-401.

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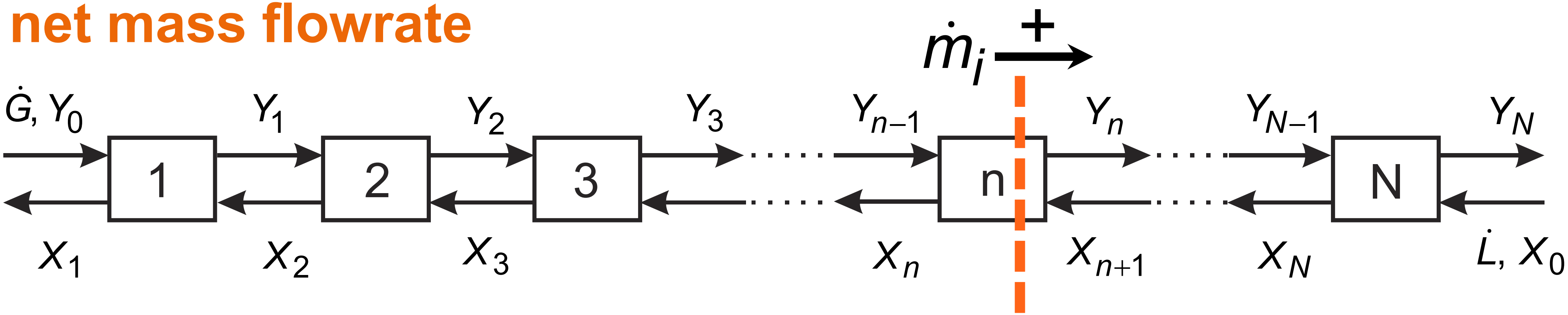
process idea

- **objective:** **single-process** to separate a **multi-component** mixture into **several product streams** of **arbitrary purity** and at **high concentration**
  → **SisClever process**
- **idea:** create **accumulation zones**, one for each component, by controlling the **partition coefficients**

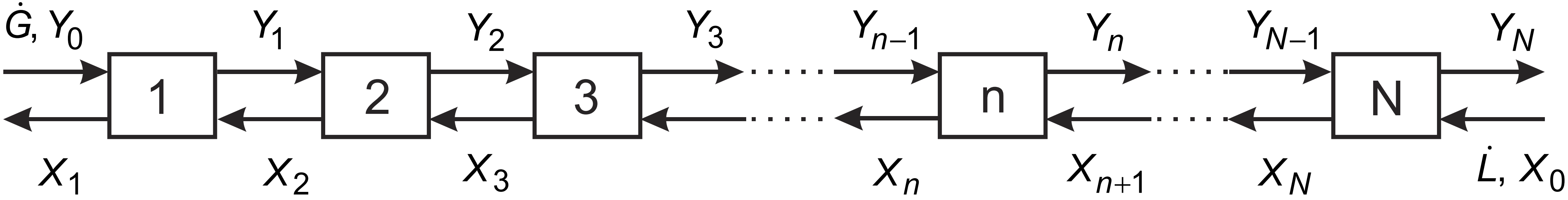
net mass flowrate



- net mass flowrate: $\dot{m}_i = \dot{G}Y_i - \dot{L}X_i$
- partition coefficient: $K_i = \dfrac{Y_i}{X_i}$
- extraction factor: $\lambda_i = \dfrac{\dot{G}Y_i}{\dot{L}X_i} = \dfrac{\dot{G}}{\dot{L}}K_i$

$$\dot{m}_i = \dot{L}X_i\left(\lambda_i - 1\right)$$

net mass flowrate

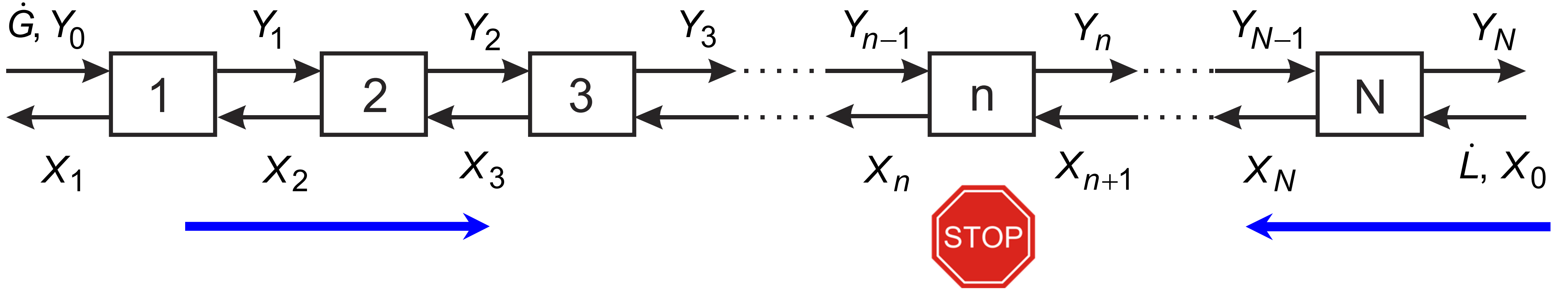


$$\dot{m}_i \xrightarrow{+}$$

- direction of flow dependent on λ_i

$$\dot{m}_i = \dot{L} X_i \left(\lambda_i - 1\right) \Longrightarrow \dot{m}_i \begin{cases} >0 \quad \text{for} \quad \left(\lambda_i - 1\right) > 0, \quad \lambda_i > 1 \quad \longrightarrow \\ =0 \quad \text{for} \quad \left(\lambda_i - 1\right) = 0, \quad \lambda_i = 1 \quad \text{STOP} \\ <0 \quad \text{for} \quad \left(\lambda_i - 1\right) < 0, \quad \lambda_i < 1 \quad \longleftarrow \end{cases}$$

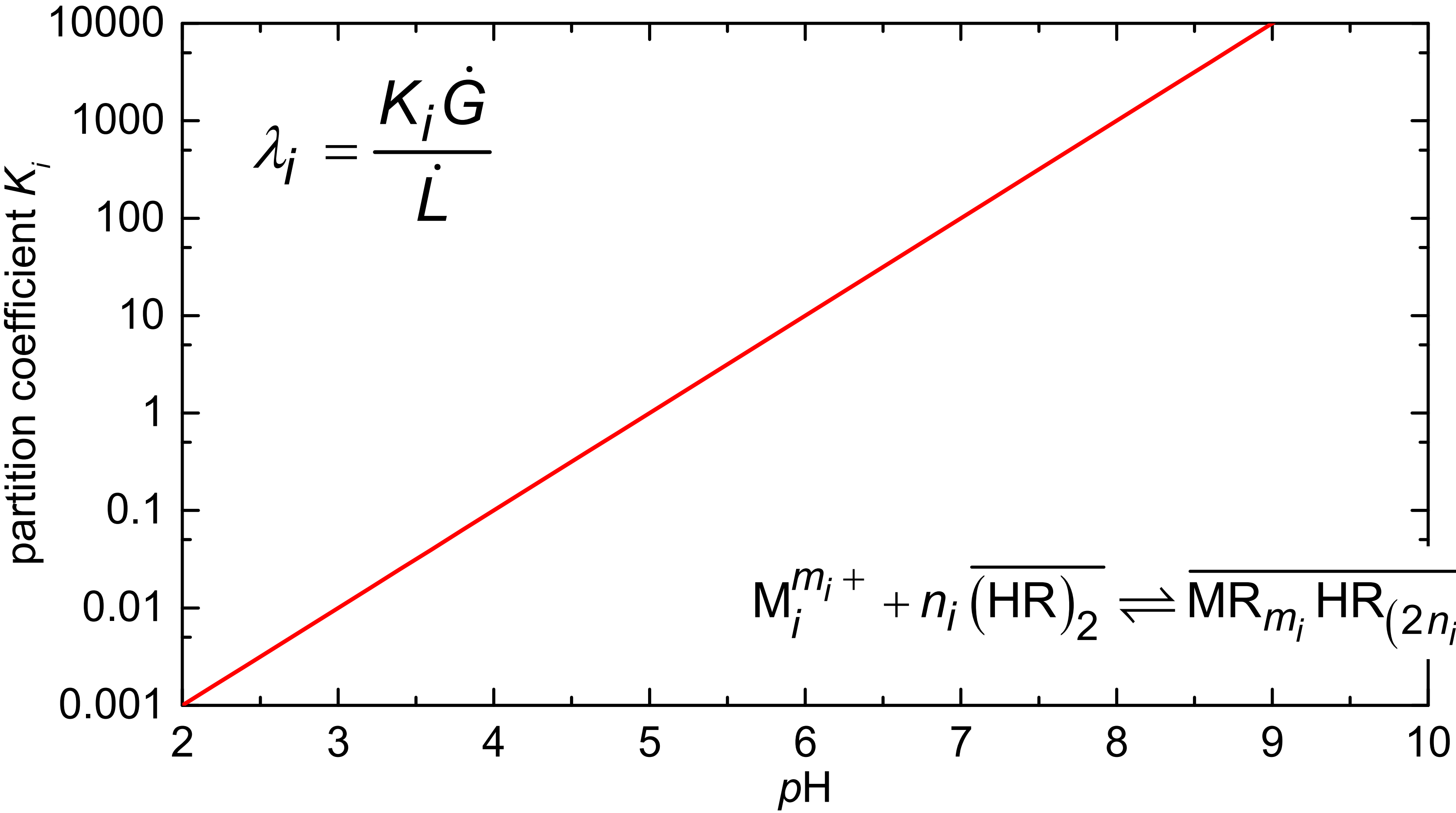
counter-current process



$\lambda_i > 1$ $\lambda_i = 1$ $\lambda_i < 1$

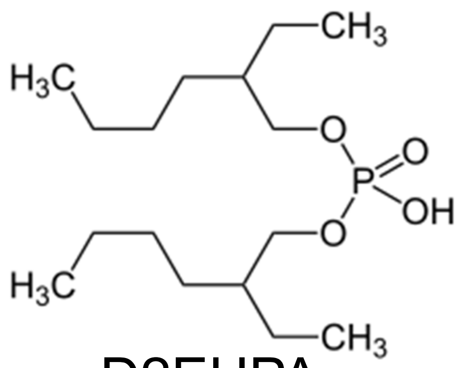
$$\lambda_i = K_i \frac{\dot{G}}{\dot{L}}$$

partition coefficient vs. *p*H in reactive extraction



$$\lambda_i = \frac{K_i \dot{G}}{\dot{L}}$$

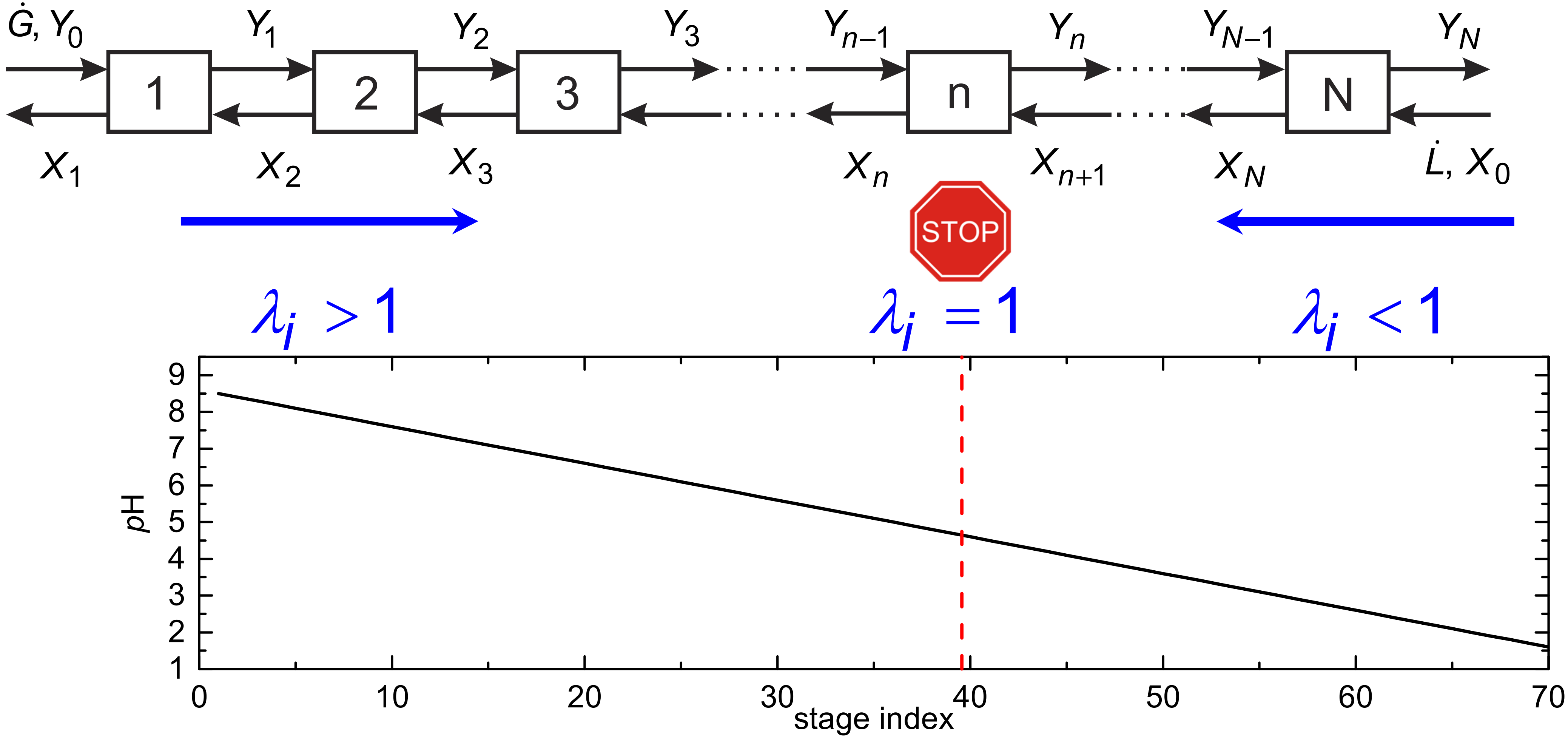
liquid-liquid ion exchange



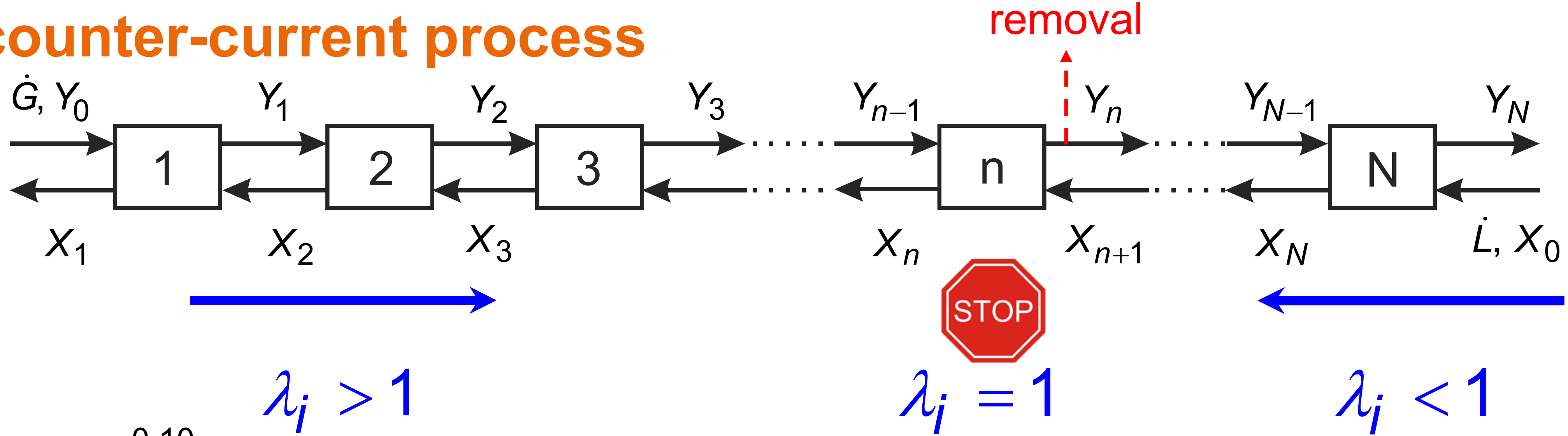
D2EHPA

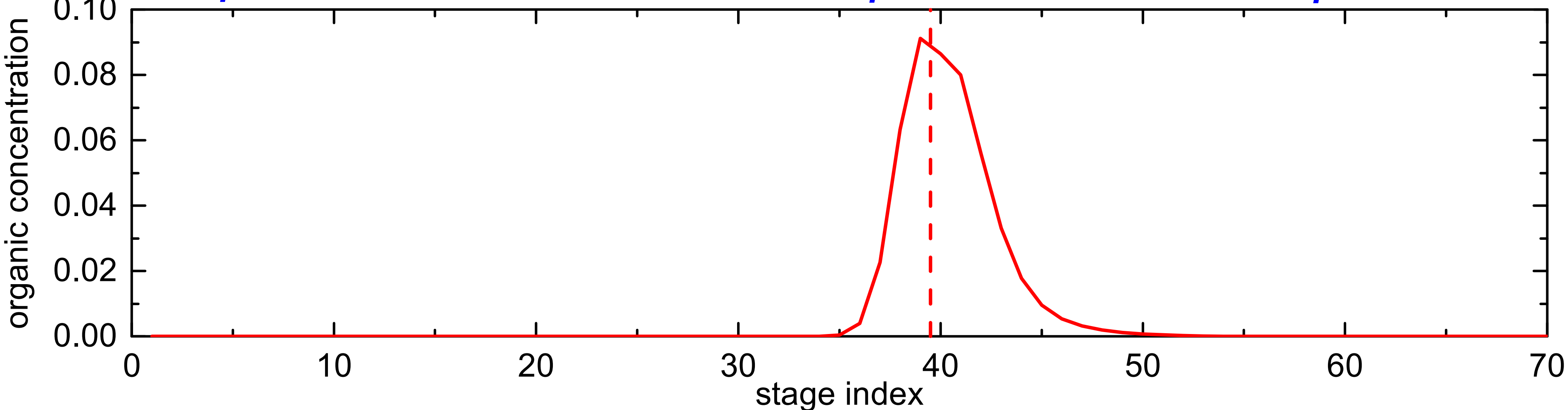
$$M_i^{m_i+} + n_i \overline{(HR)_2} \rightleftharpoons \overline{MR_{m_i} HR_{(2n_i - m_i)}} + m_i H^+$$

counter-current process

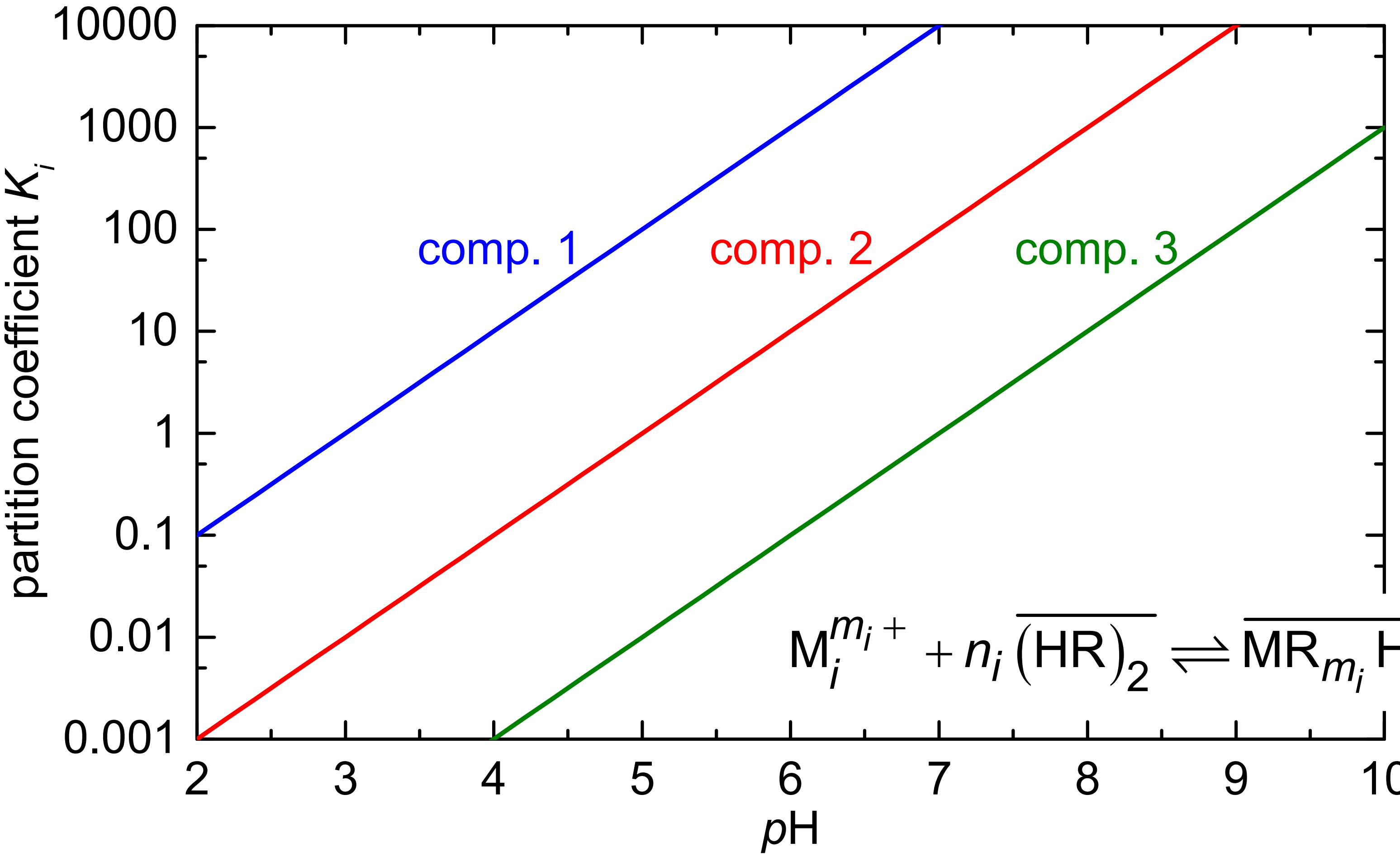


counter-current process





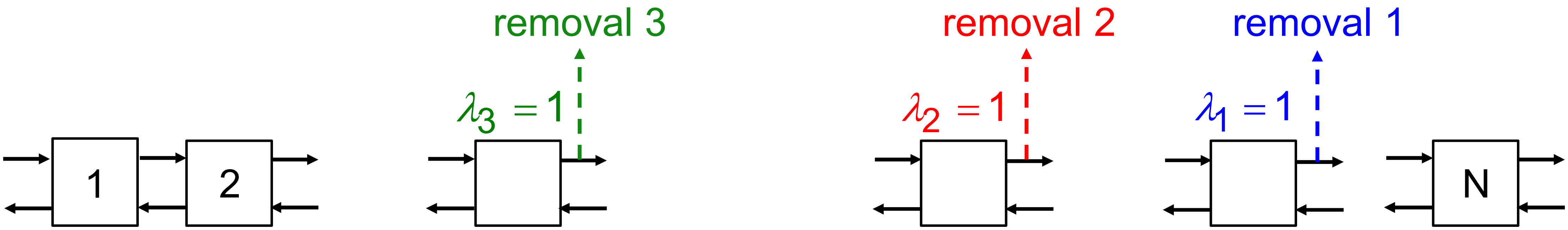
partition coefficient vs. *p*H in reactive extraction

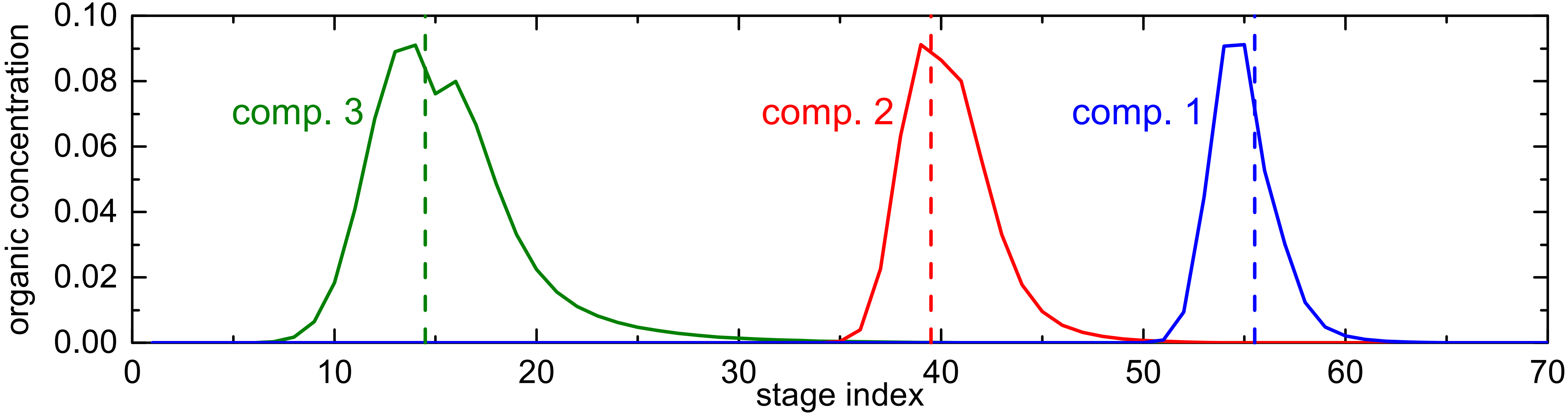


$$\lambda_i = \frac{K_i \dot{G}}{\dot{L}}$$

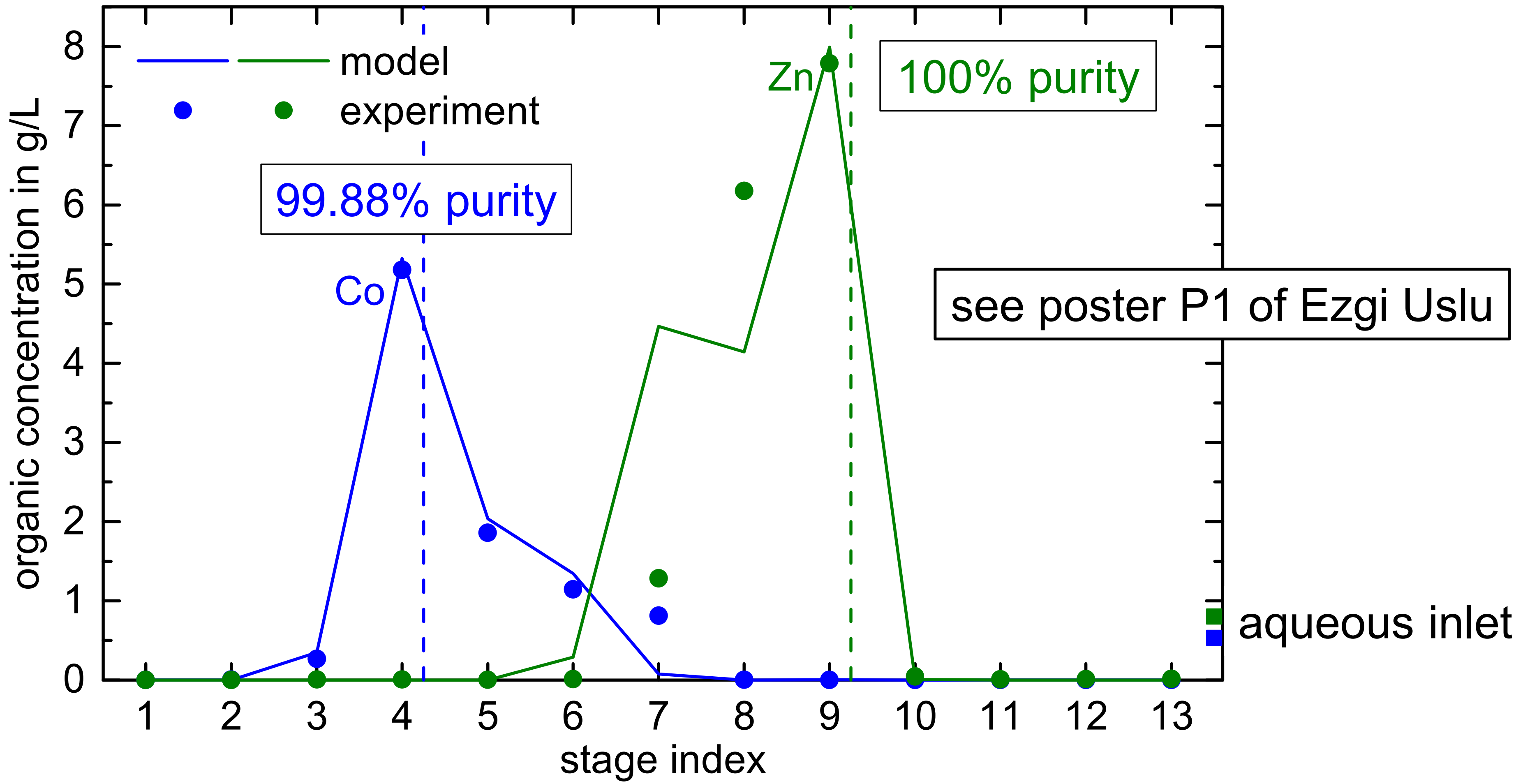
$$M_i^{m_i+} + n_i \overline{(HR)_2} \rightleftharpoons \overline{MR_{m_i} HR_{(2n_i - m_i)}} + m_i H^+$$

counter-current process





experimental validation



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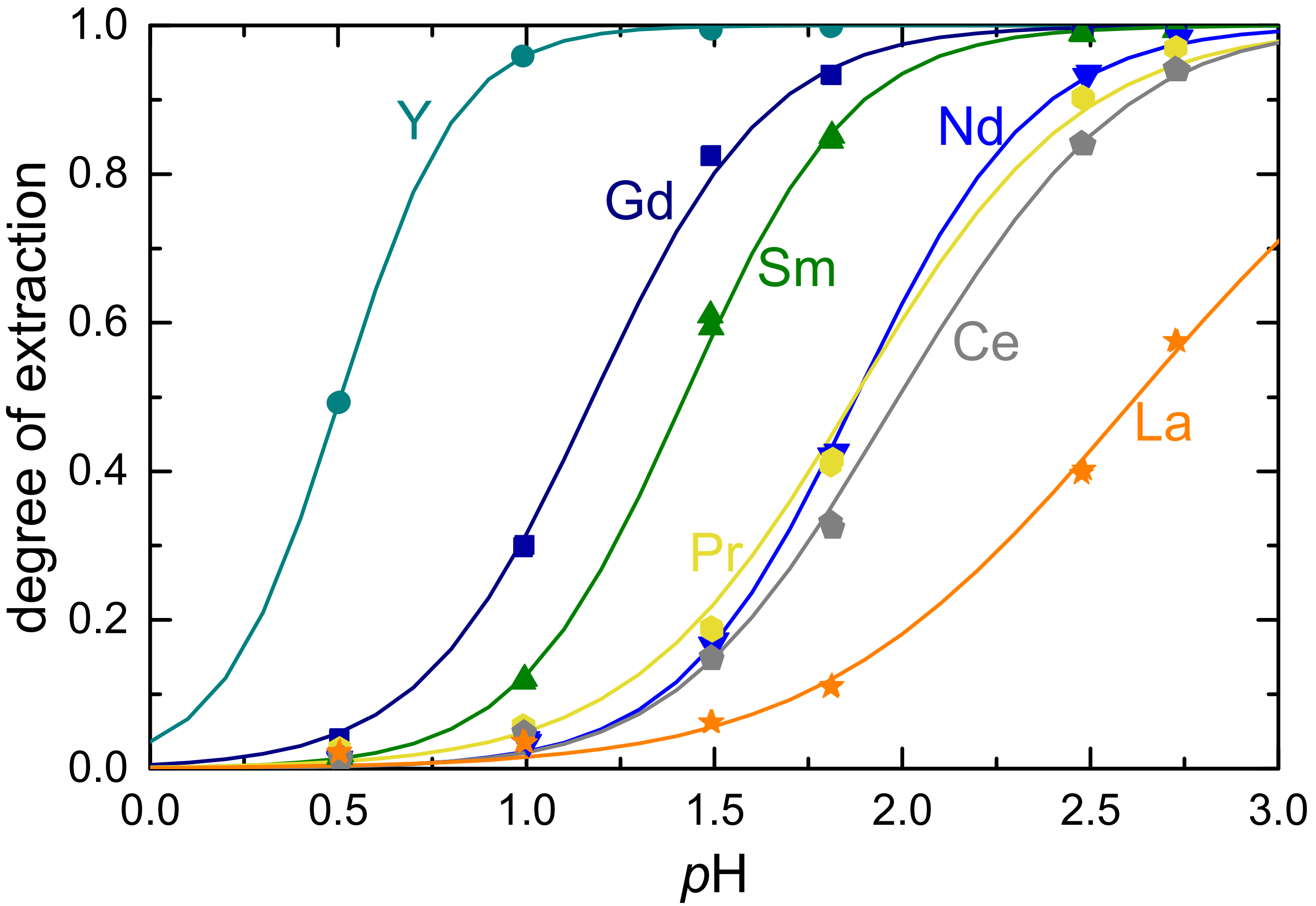
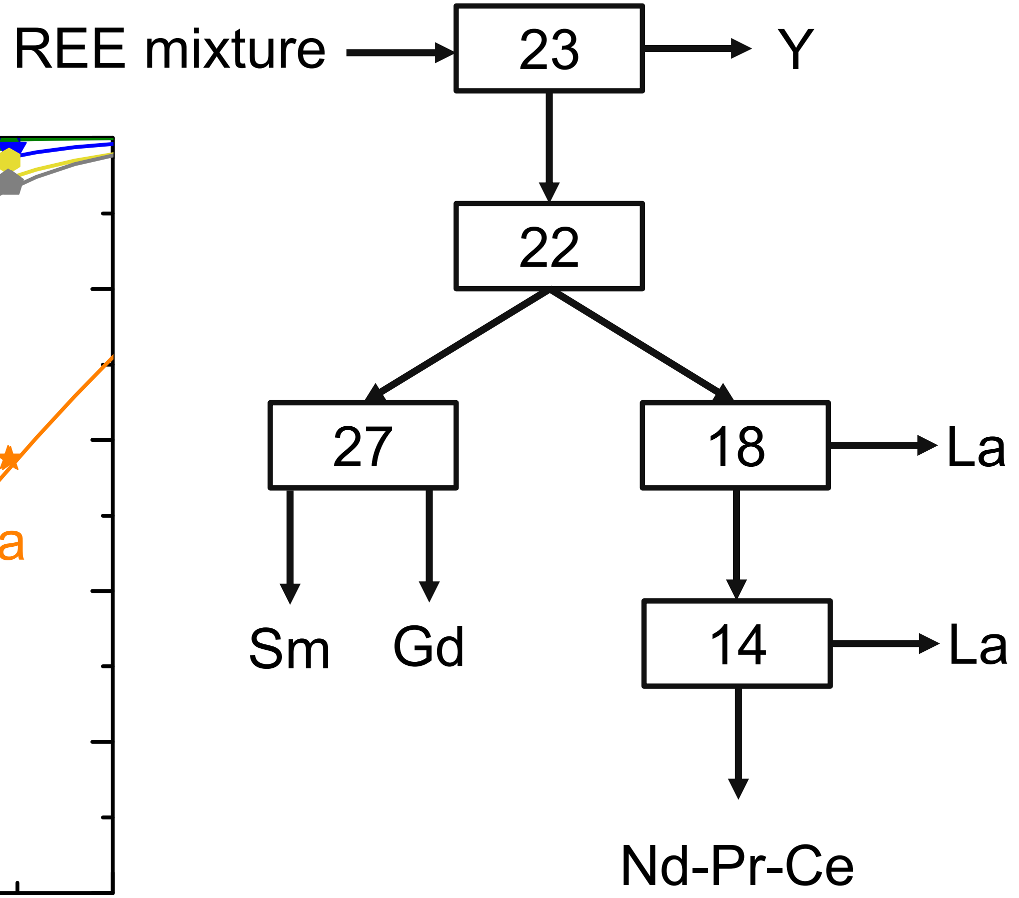
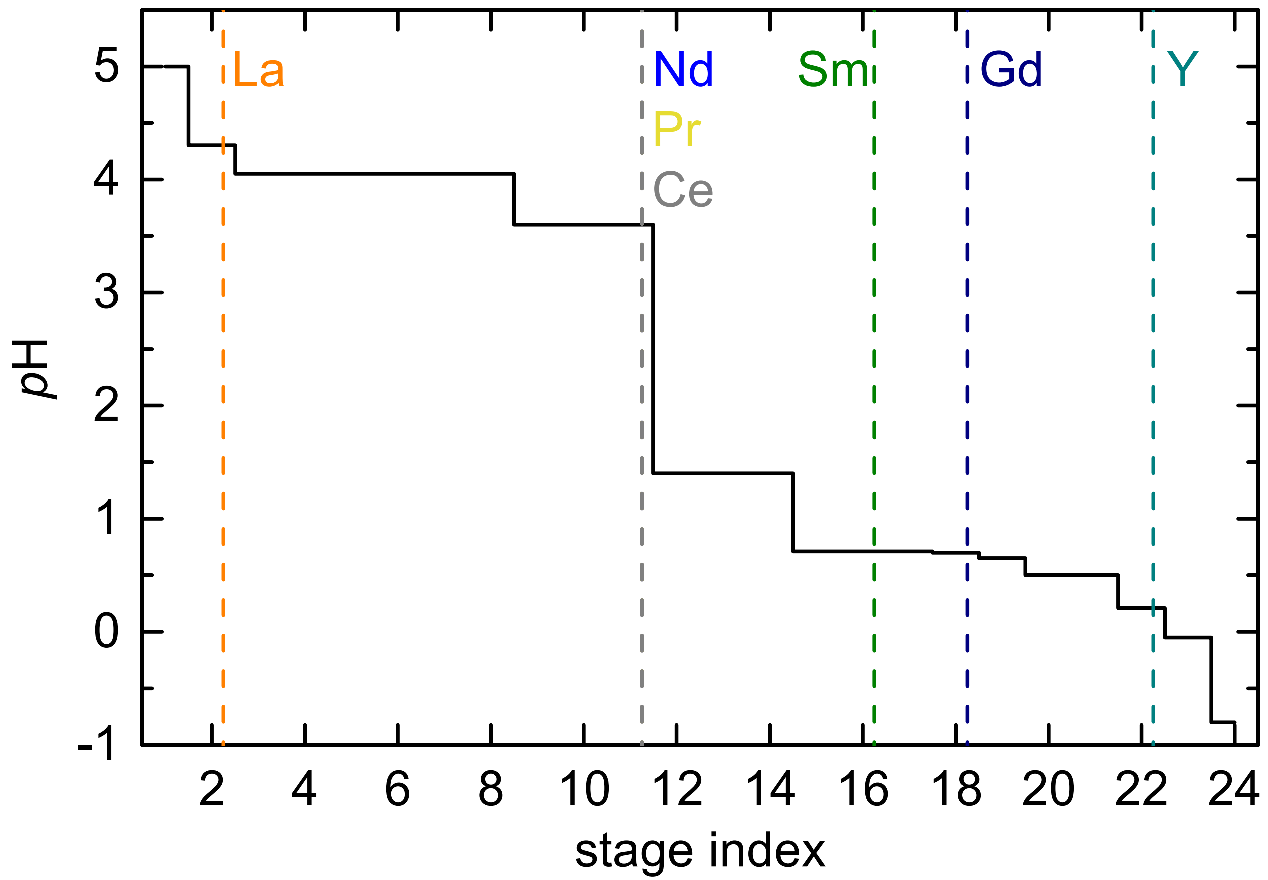
REEE separation simulations





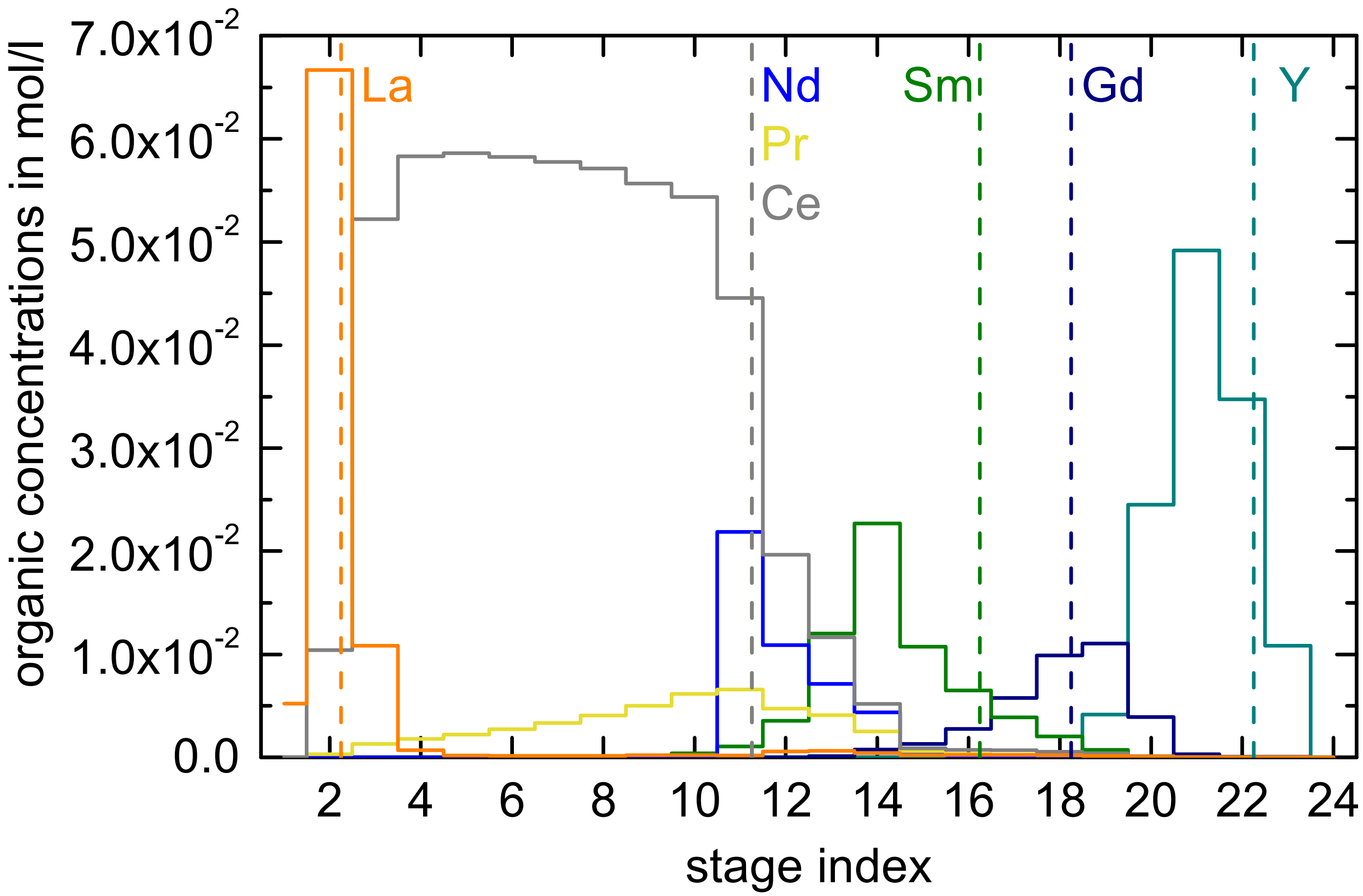
104 stages

*p*H-profile

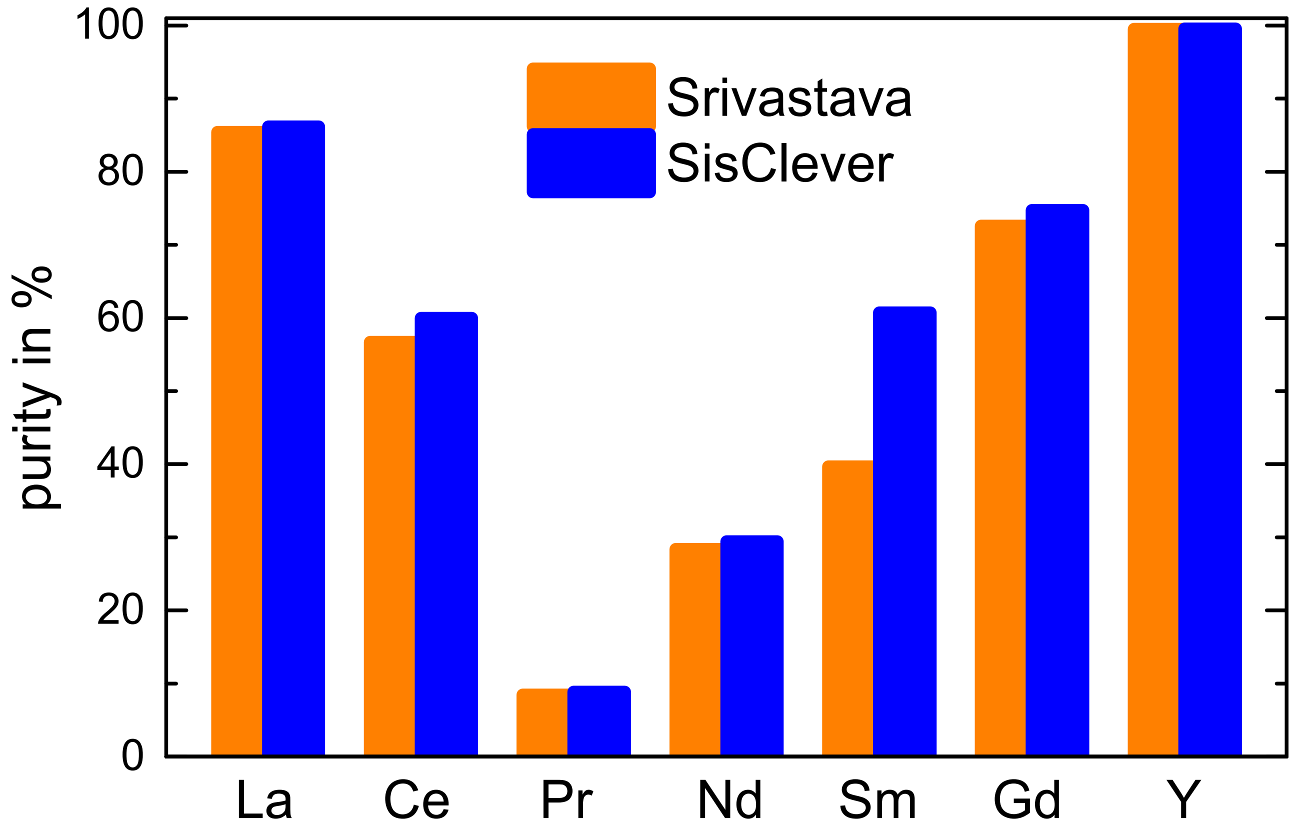


La
Nd
Pr
Ce
Sm
Gd
Y
5
4
3
2
1
0
-1
*p*H
2
4
6
8
10
12
14
16
18
20
22
24
stage index

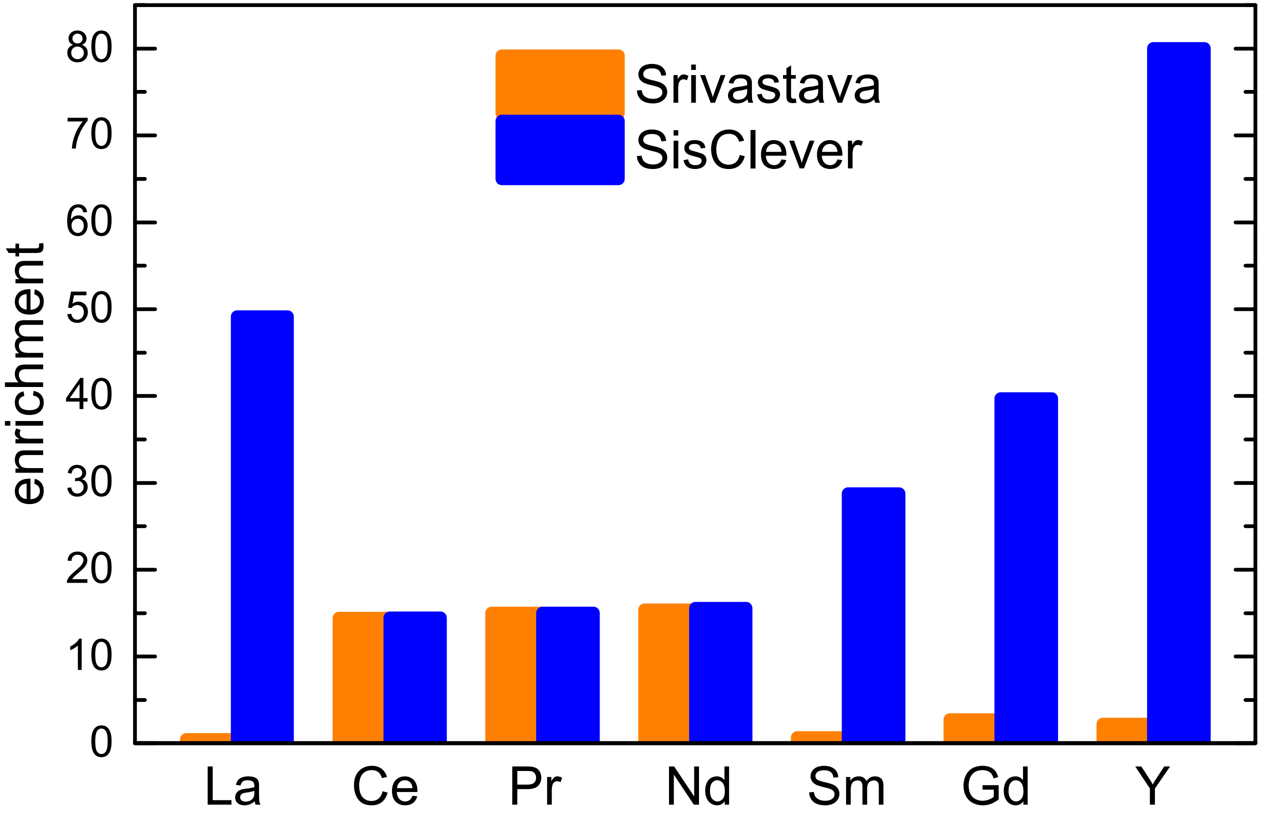
organic concentrations



product purities



enrichment = $C_{product}$ / C_{inlet}



comparison

- 24 stages for extraction
  5 stages for stripping
  29 stages < 104 stages
- at least same purities
- much higher enrichment for several metals

competitive advantages

- **high concentration** & **high purity**
- valorize **minor components** at **disparate feed** concentrations
- **flexible** process
- **constant** principal counter-current **flowrates**
- **costs** $\leq$ conventional processes

conclusions

- **SisClever process**: simultaneous separation of multiple components to a high level of recovery, in a **single process**
- **accumulation zones**, one per component, by controlling the **partition coefficients**
- process **simulations**, **validated experimentally** → **Ezgi Uslu P1**
- patent filed
- example applications
  - cation exchange: Li-ion batteries, Nd magnets, electronic scrap
  - anion exchange: amino acids, organic acids
  - bioprocesses: fermentation broth

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