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SisClever Process
simultaneous recovery of metals from ore or waste to high purity and high concentration via solvent extraction – principle and applications

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PEPs CHEMICAL ENGINEERING

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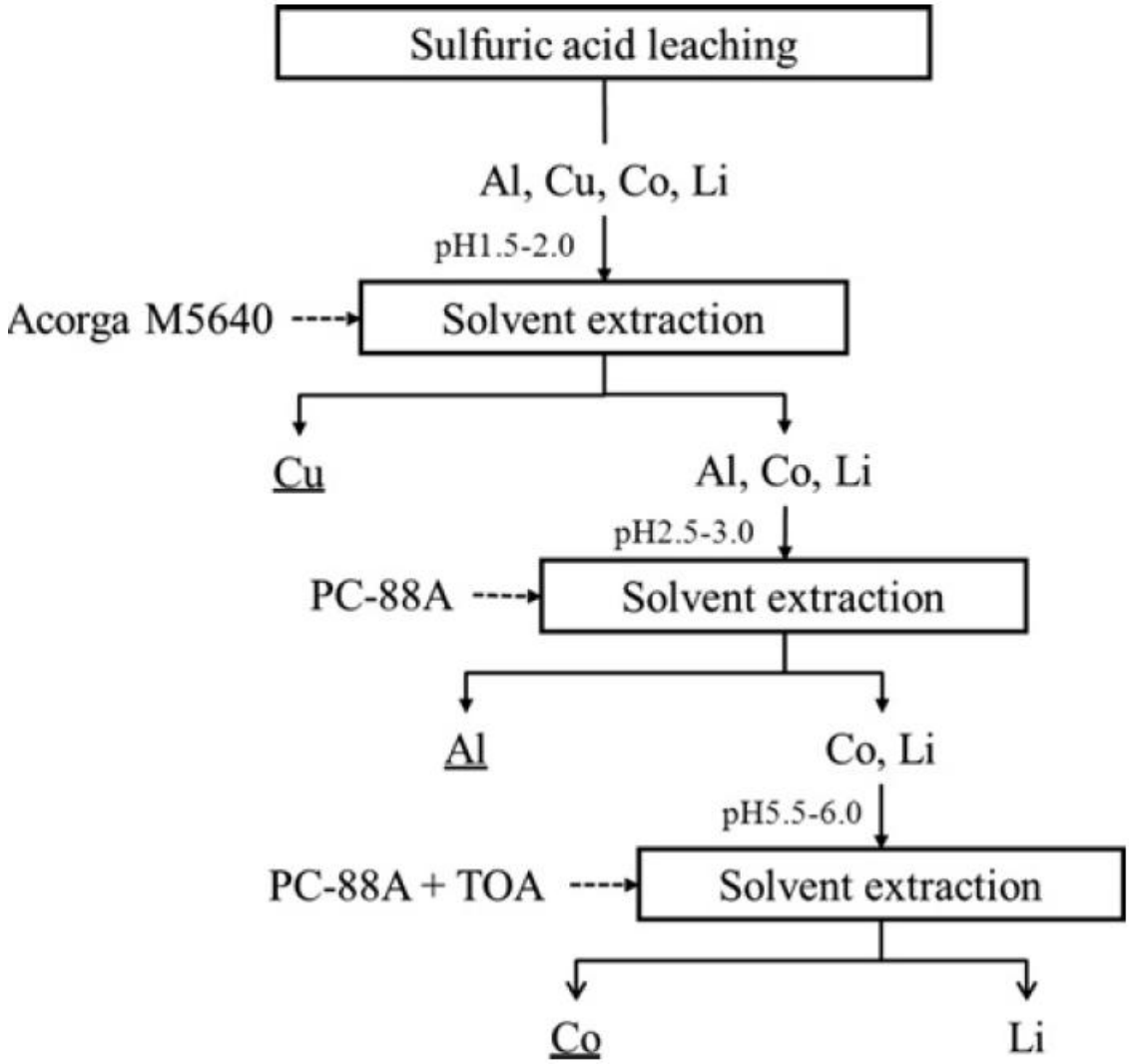
motivation

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

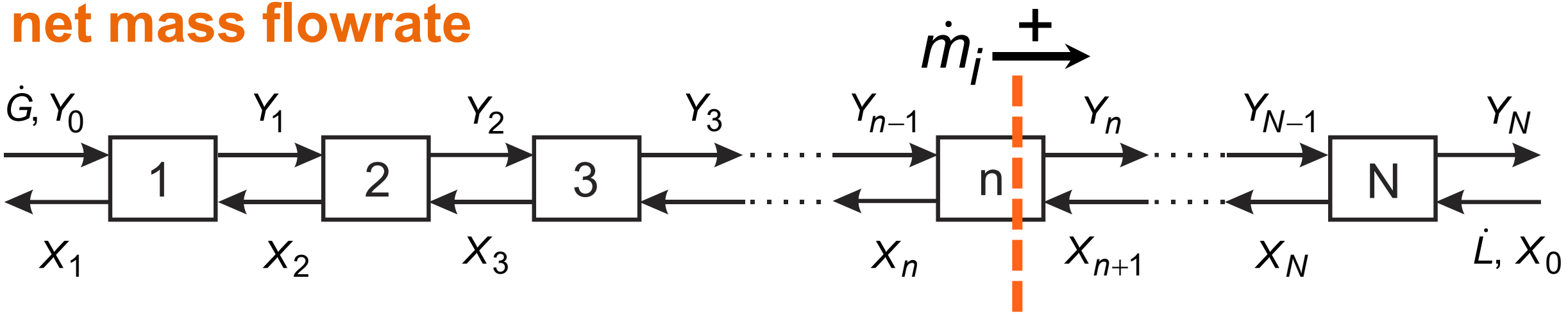


Suzuki, T., Nakamura T., Inoue, Y., Niinae, M., Shibata, J., 2012: A hydrometallurgical process for the separation of aluminum, cobalt, copper and lithium in acidic sulfate media. *Separation and purification technology*, 98, 396-401.

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**

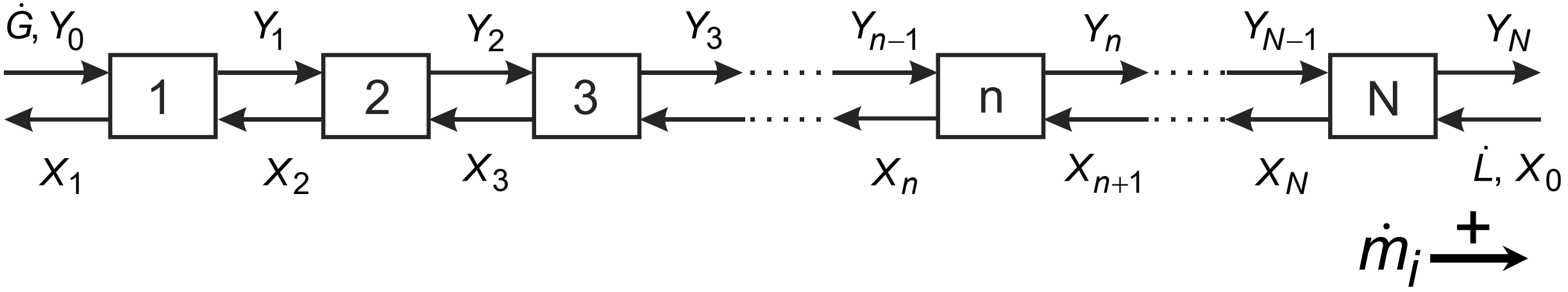
net mass flowrate



- 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: $\lambda_i = \dfrac{\dot{G}Y_i}{\dot{L}X_i} = \dfrac{\dot{G}}{\dot{L}}K_i$

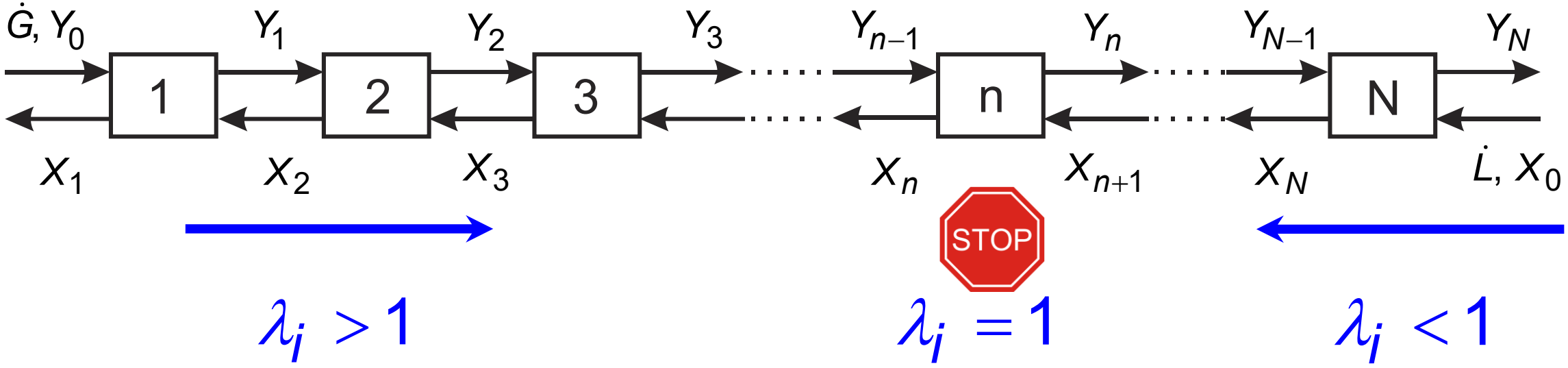
$$\dot{m}_i = \dot{L}X_i\left(\lambda_i - 1\right)$$

direction of flow depends on λ_i



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

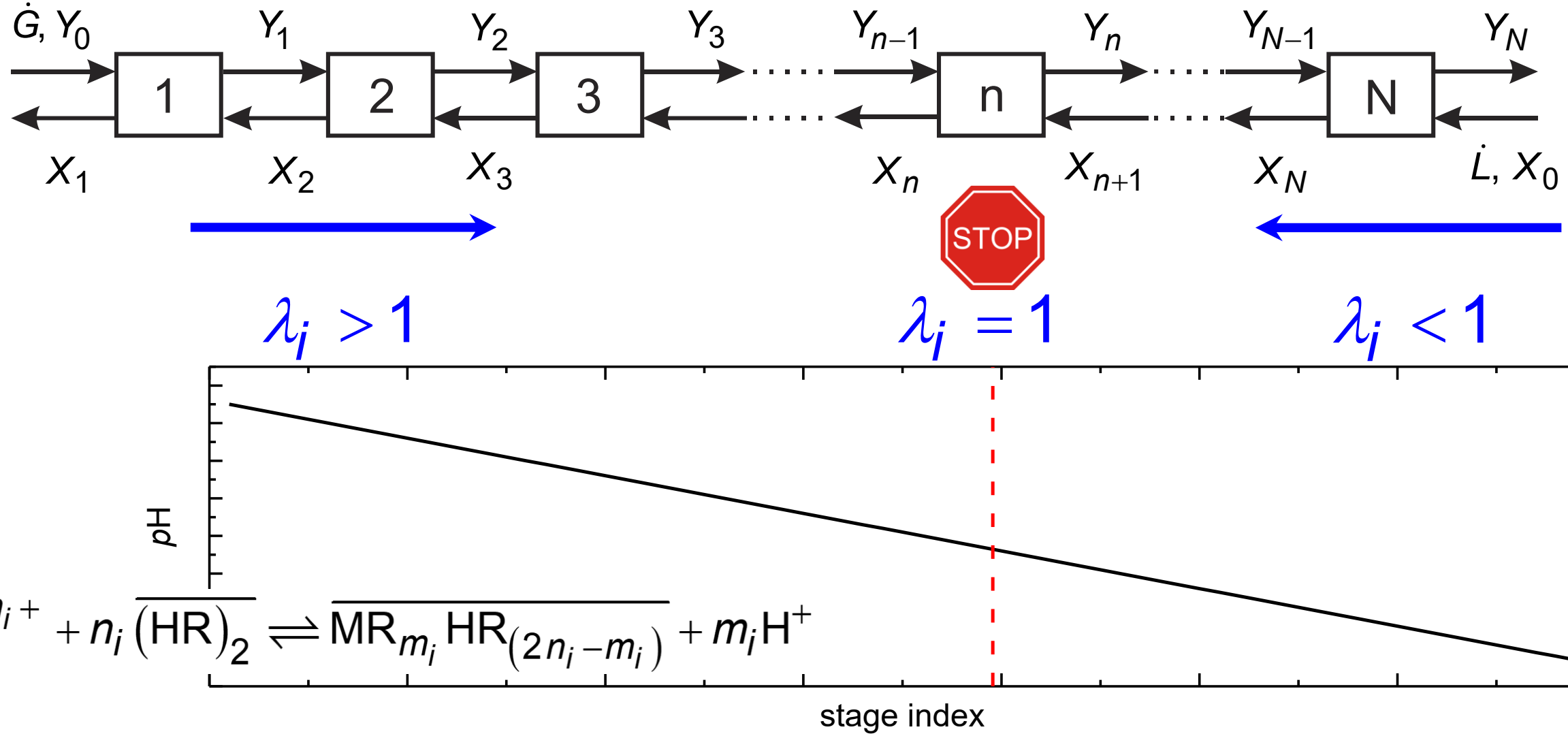
counter-current process



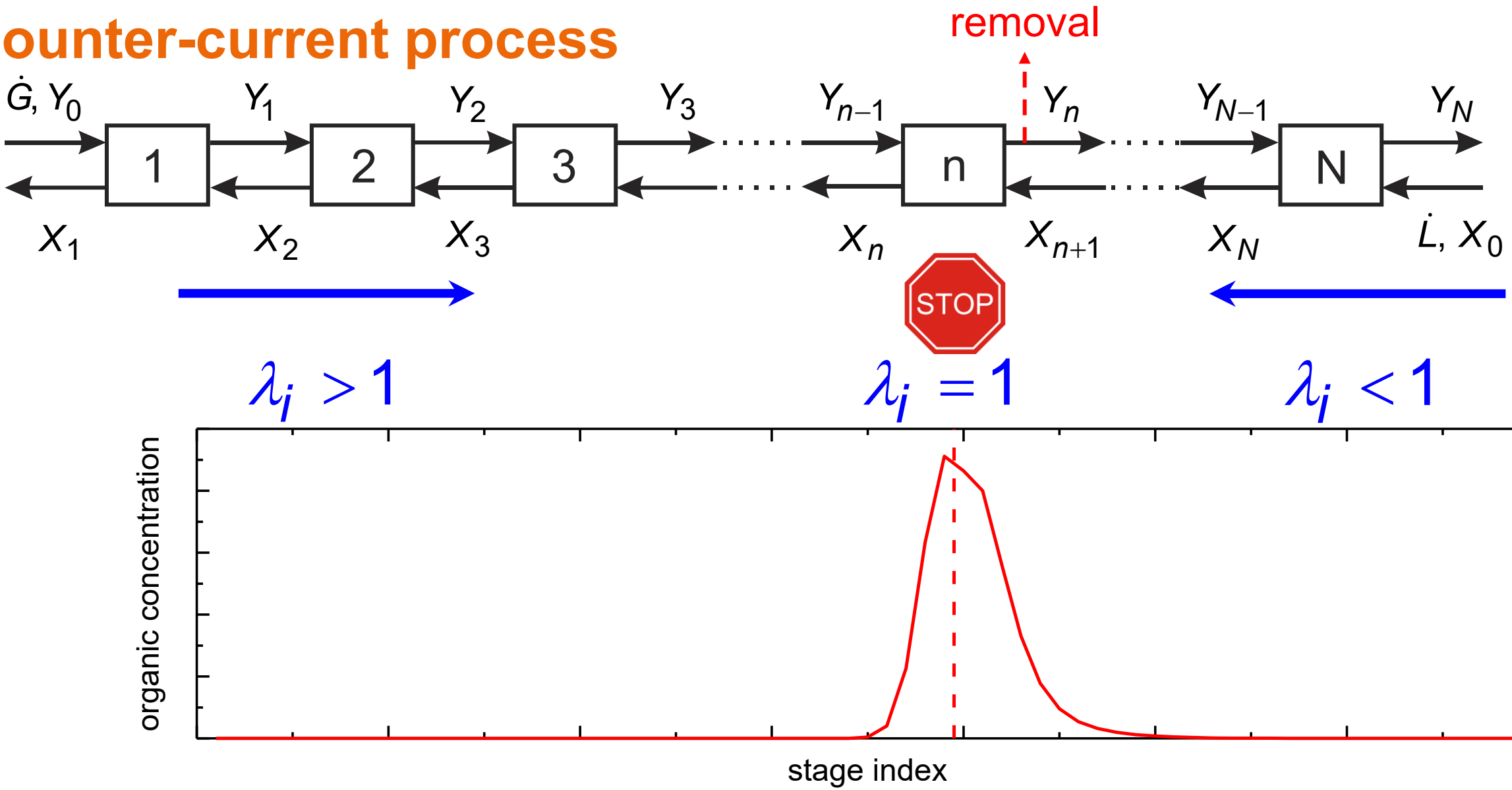
$$\lambda_i = K_i \frac{\dot{G}}{\dot{L}}$$

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

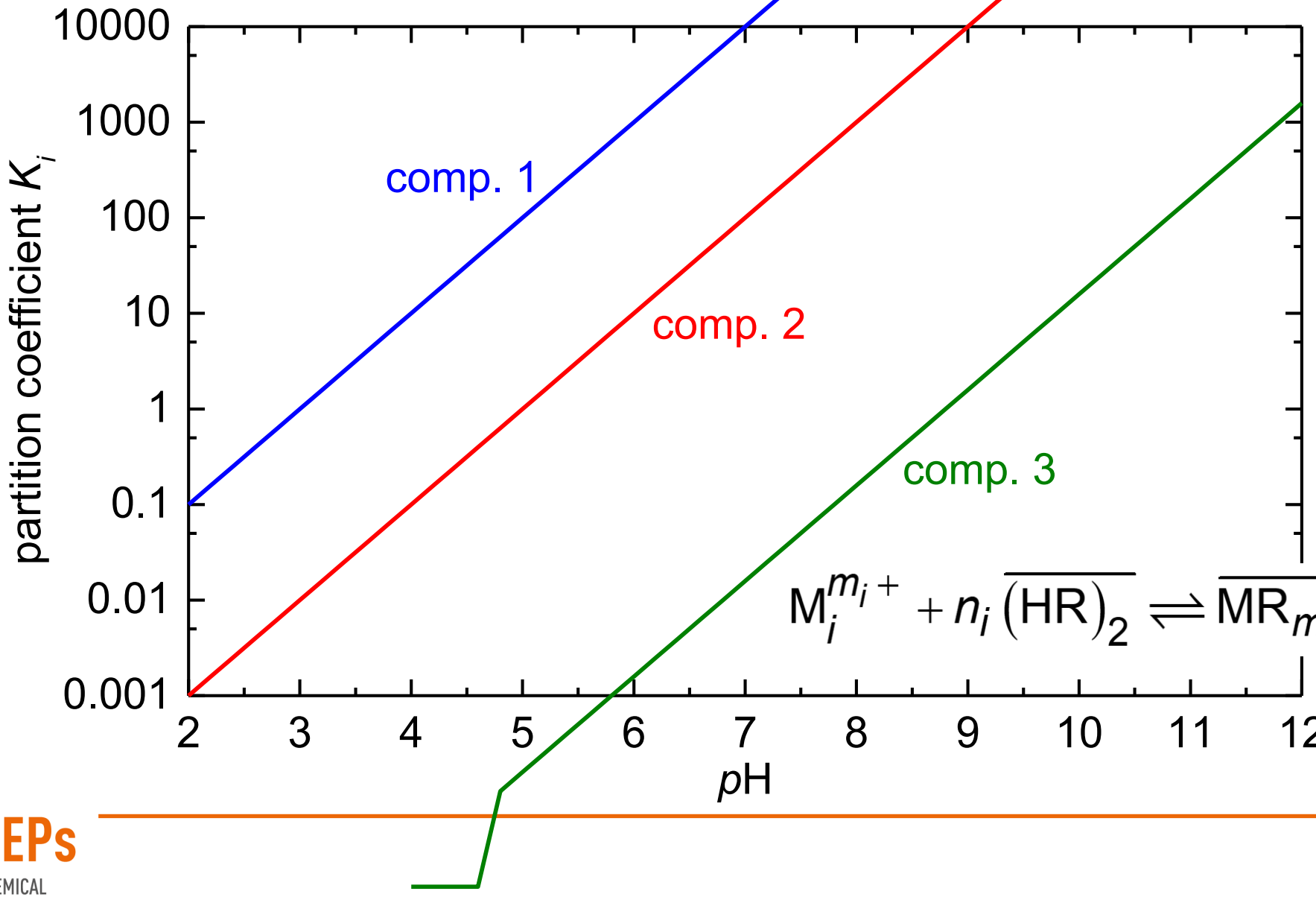
counter-current process



counter-current process



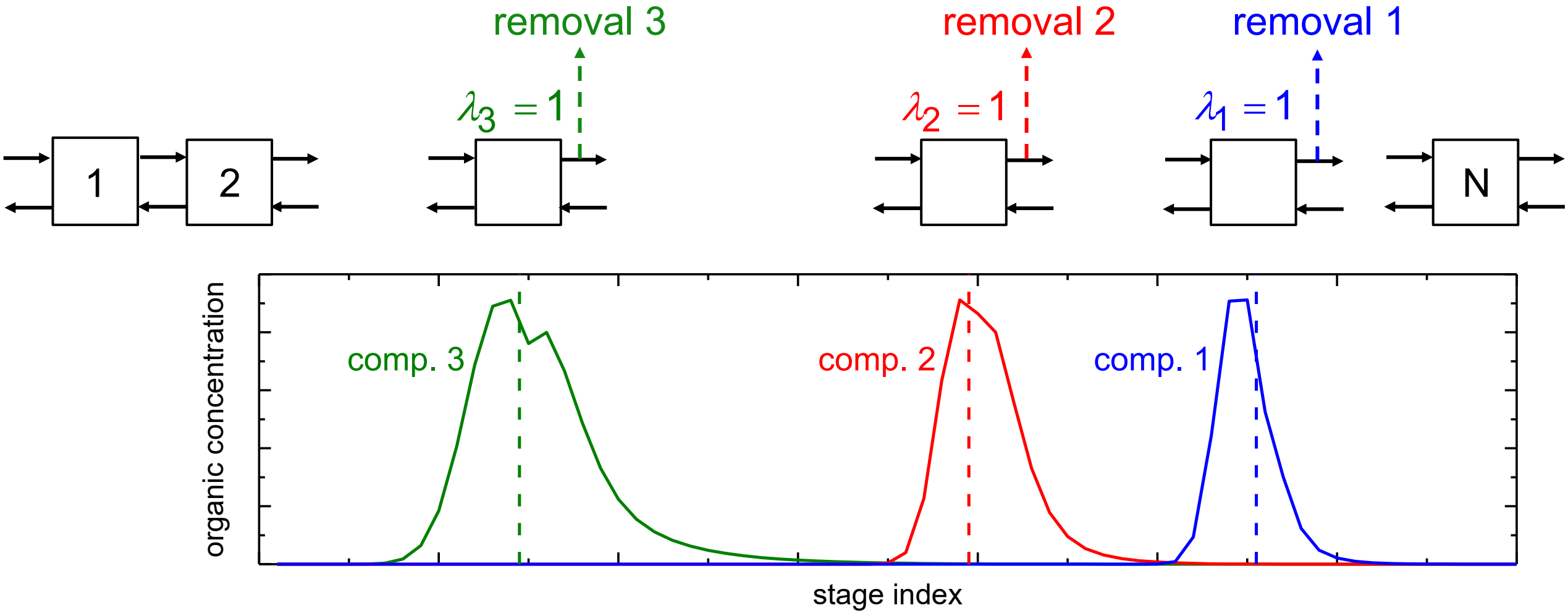
partition coefficient vs. *p*H in reactive extraction



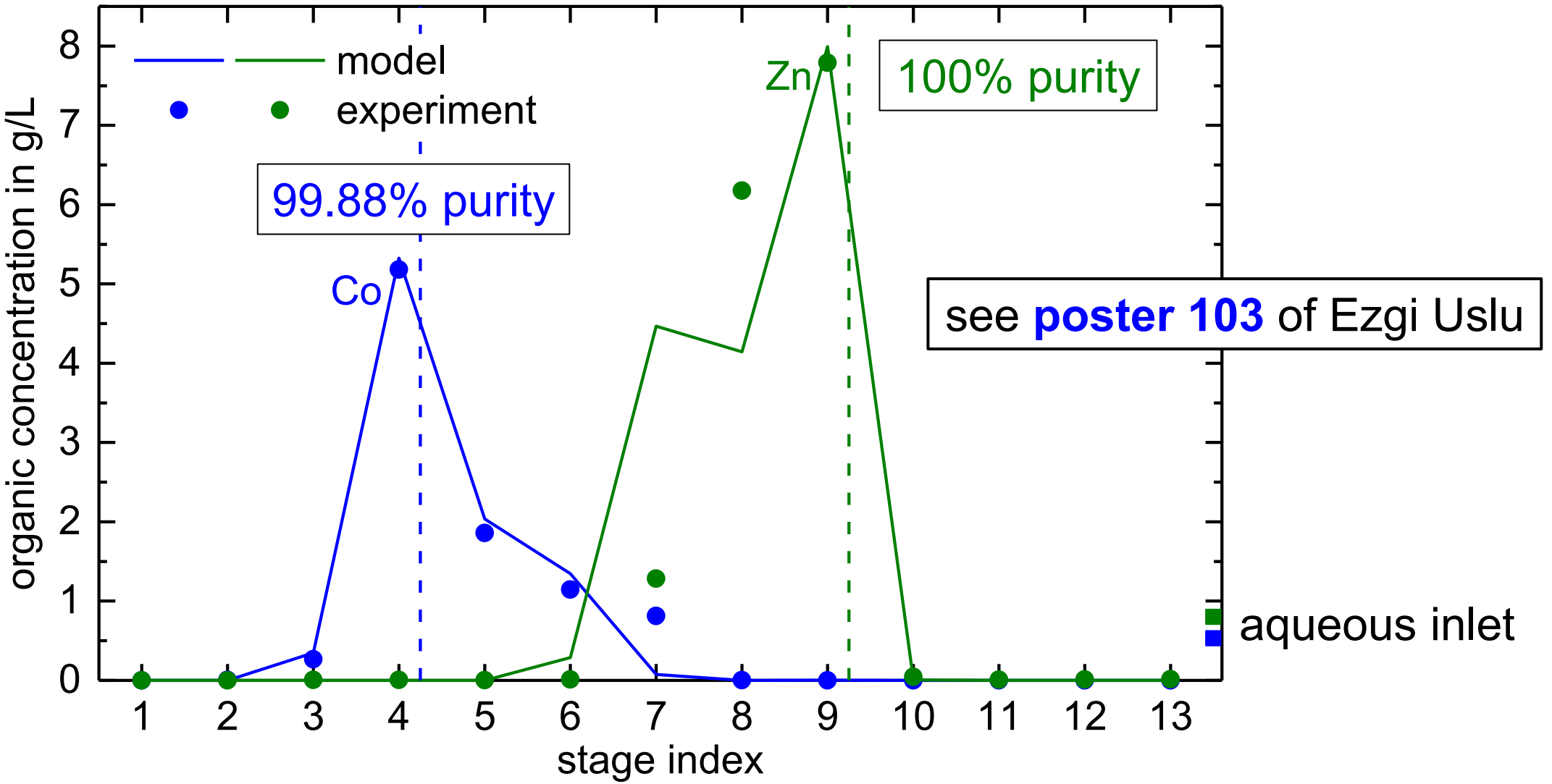
$$\lambda_i = \frac{K_i \dot{G}}{\dot{L}}$$

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

counter-current process

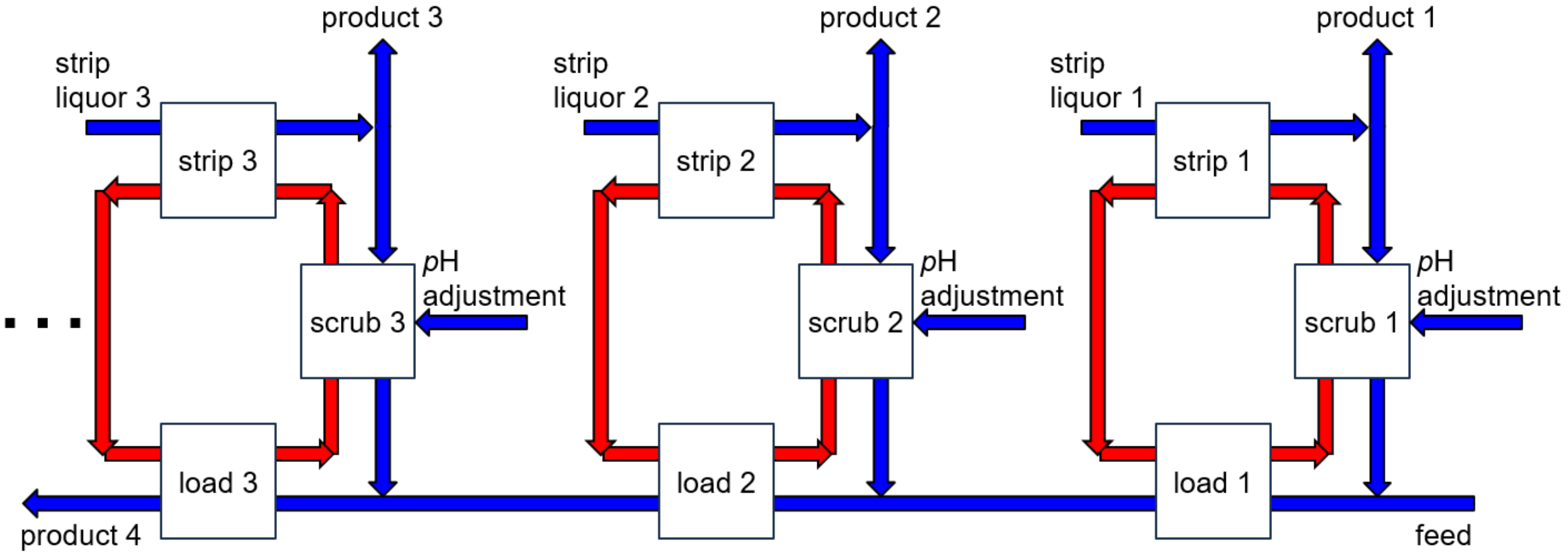


experimental validation



conventional processes

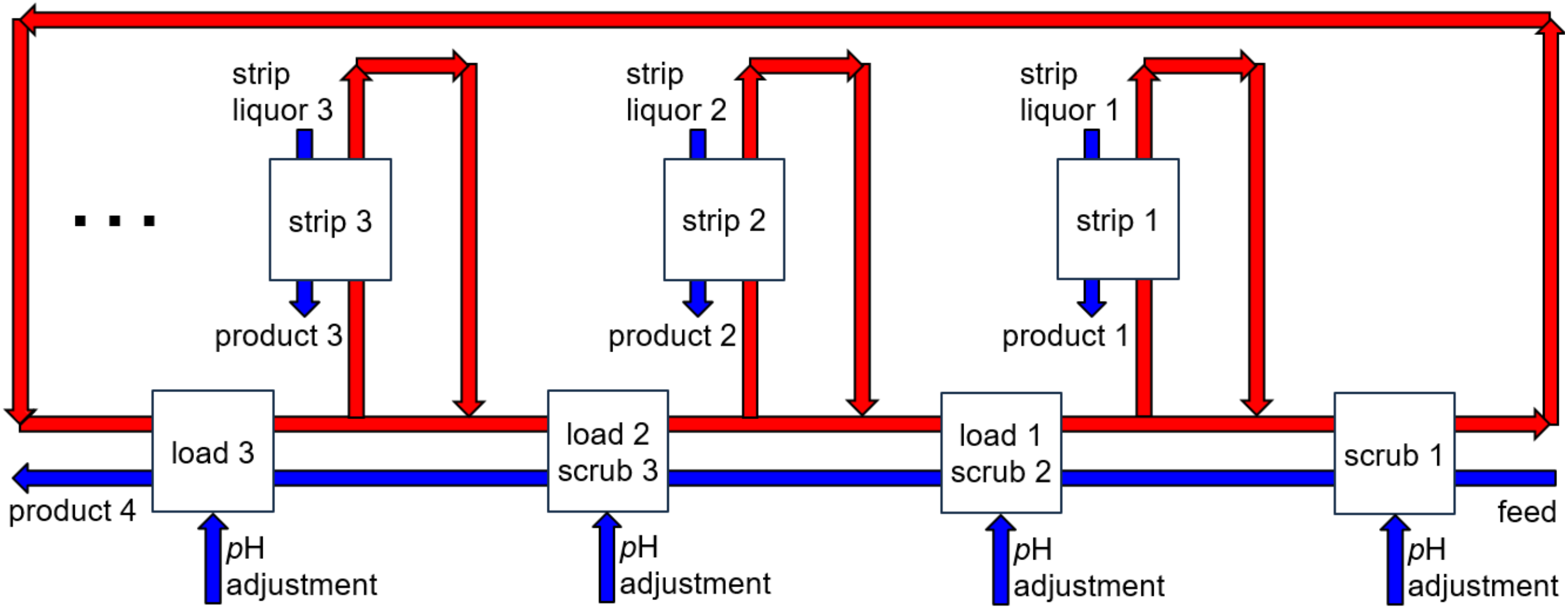
aqueous
organic



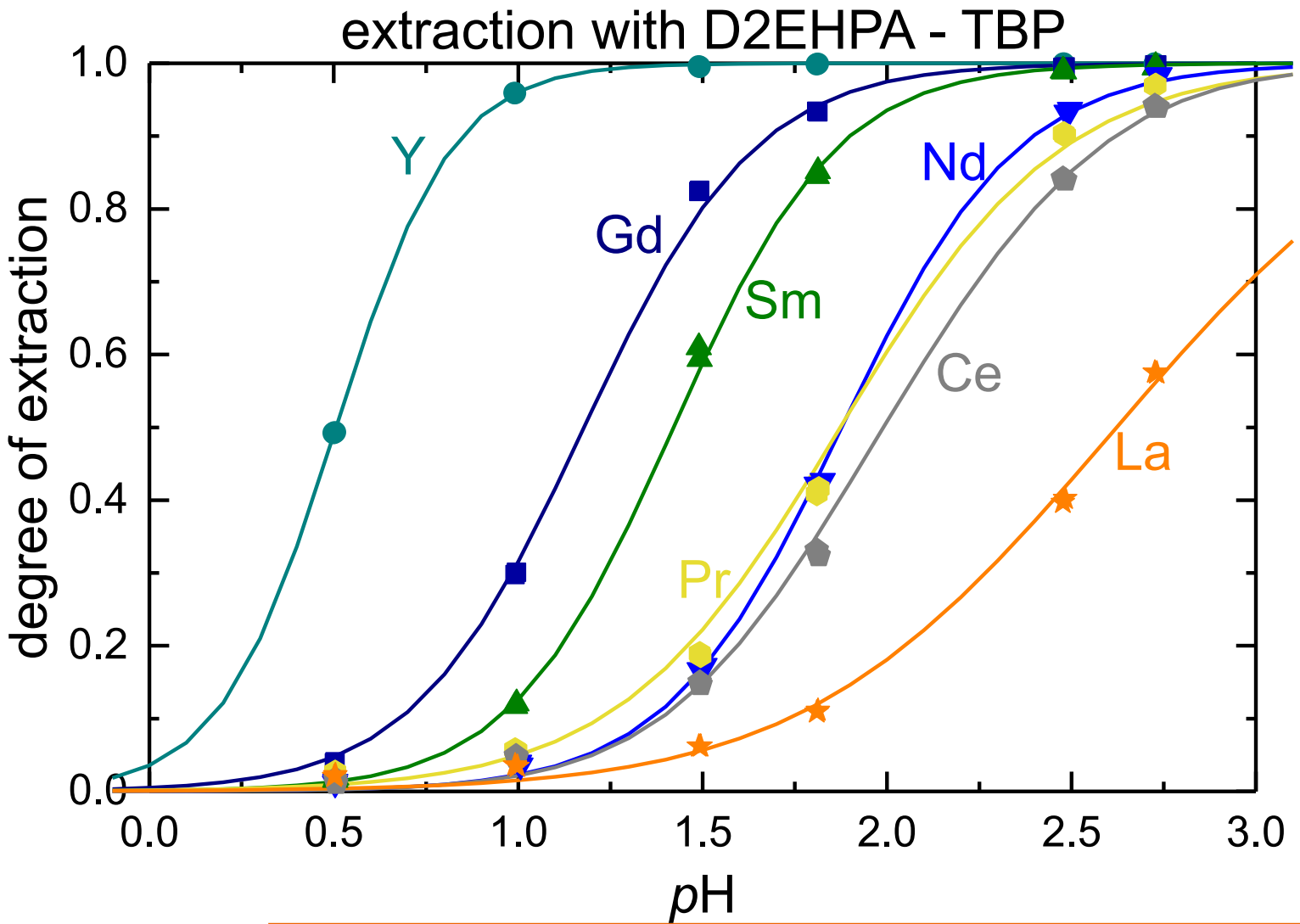
Bart HJ (2001) Reactive Extraction. Springer 1-16
doi: 10.1007/978-3-662-04403-2_1

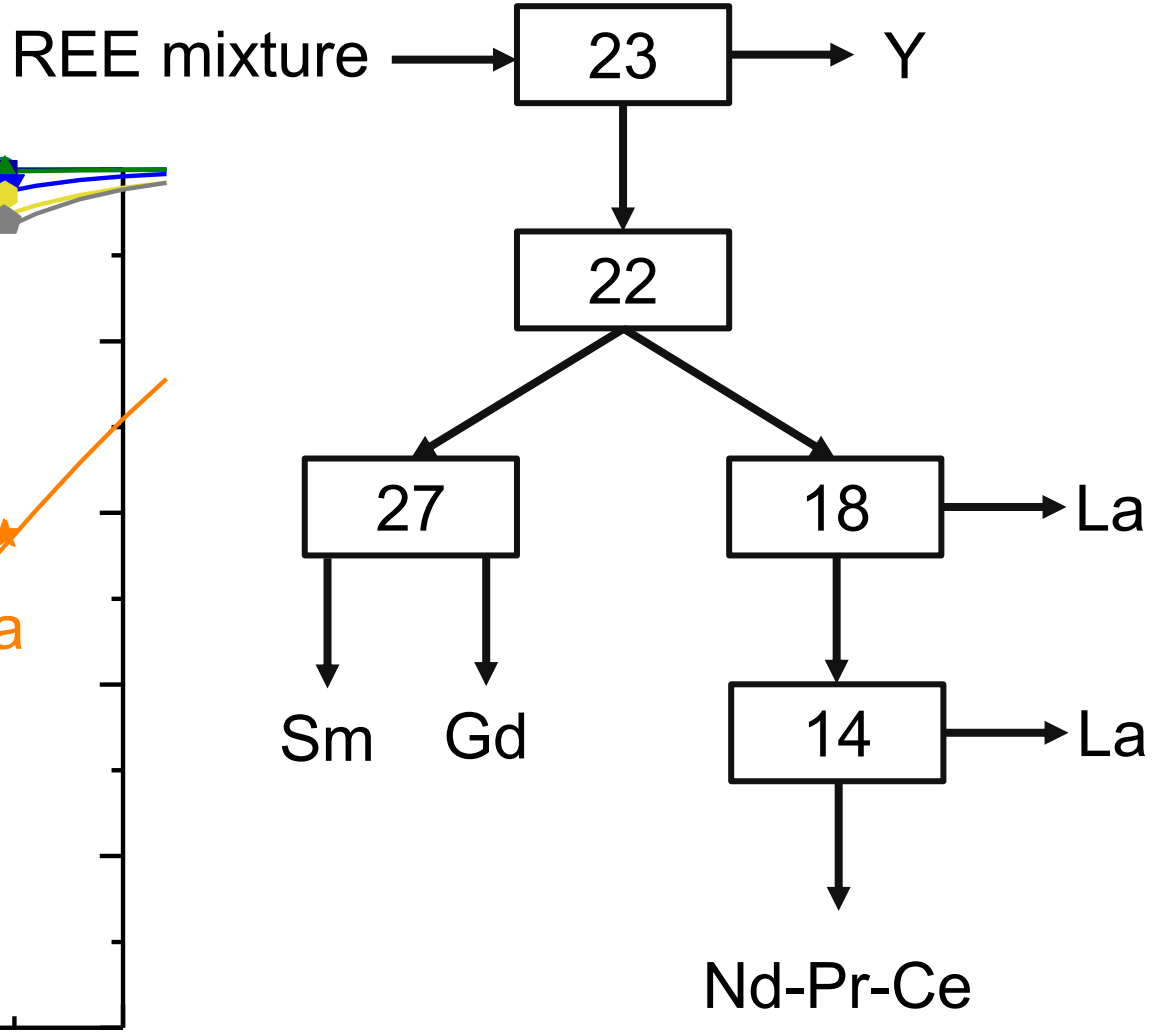
SisClever process

aqueous
organic



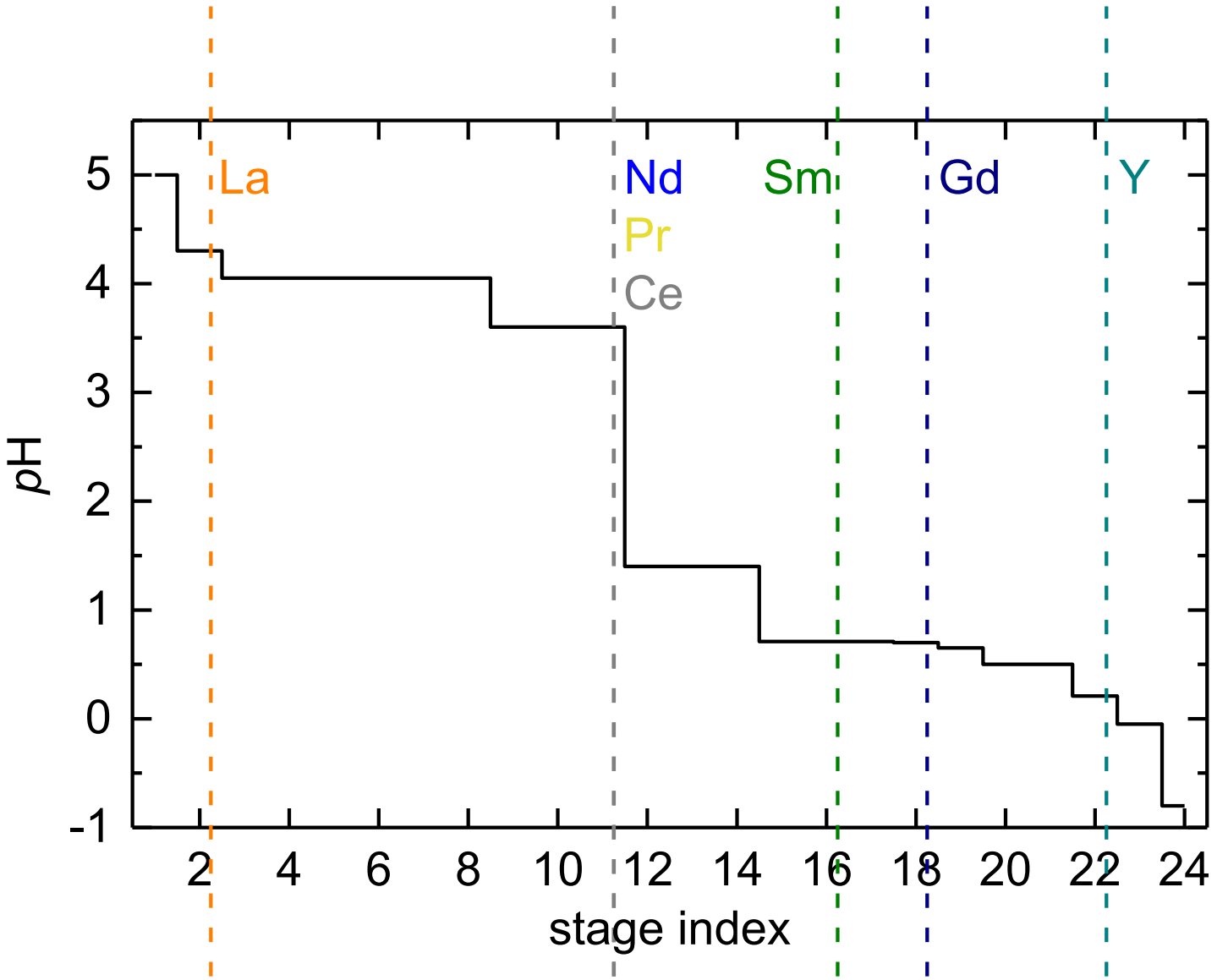
REE separation simulations



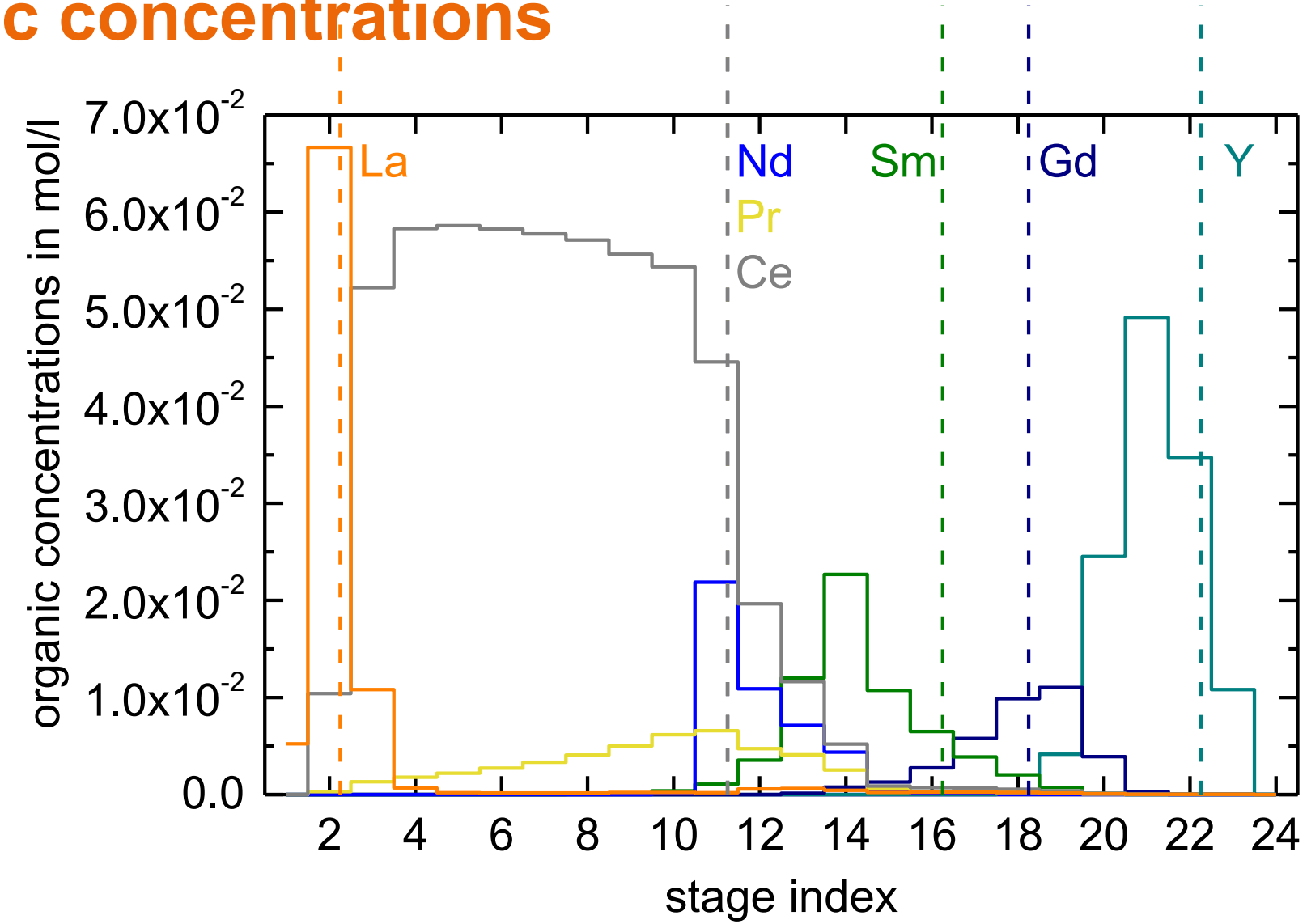


104 stages

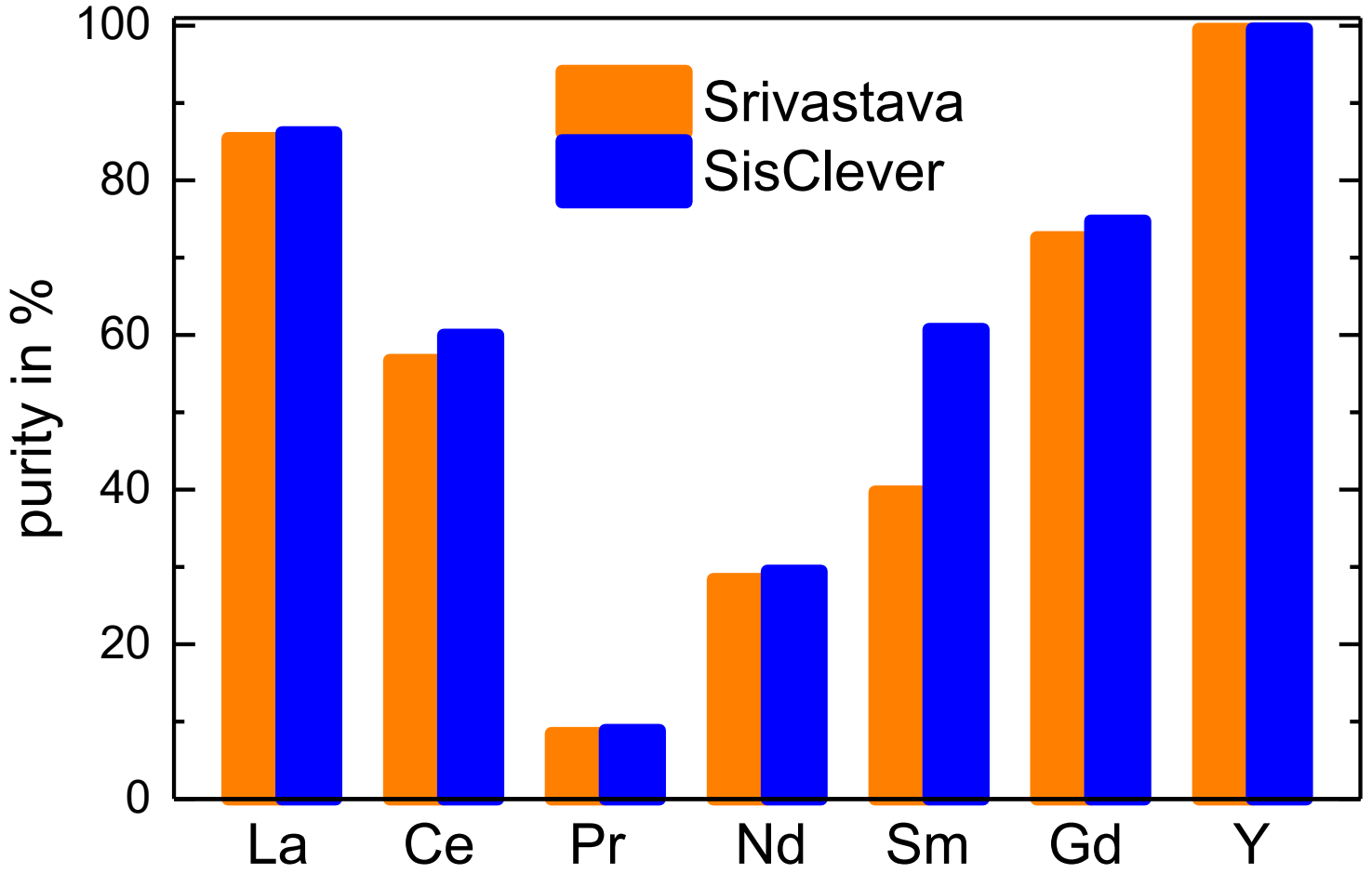
*p*H-profile


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

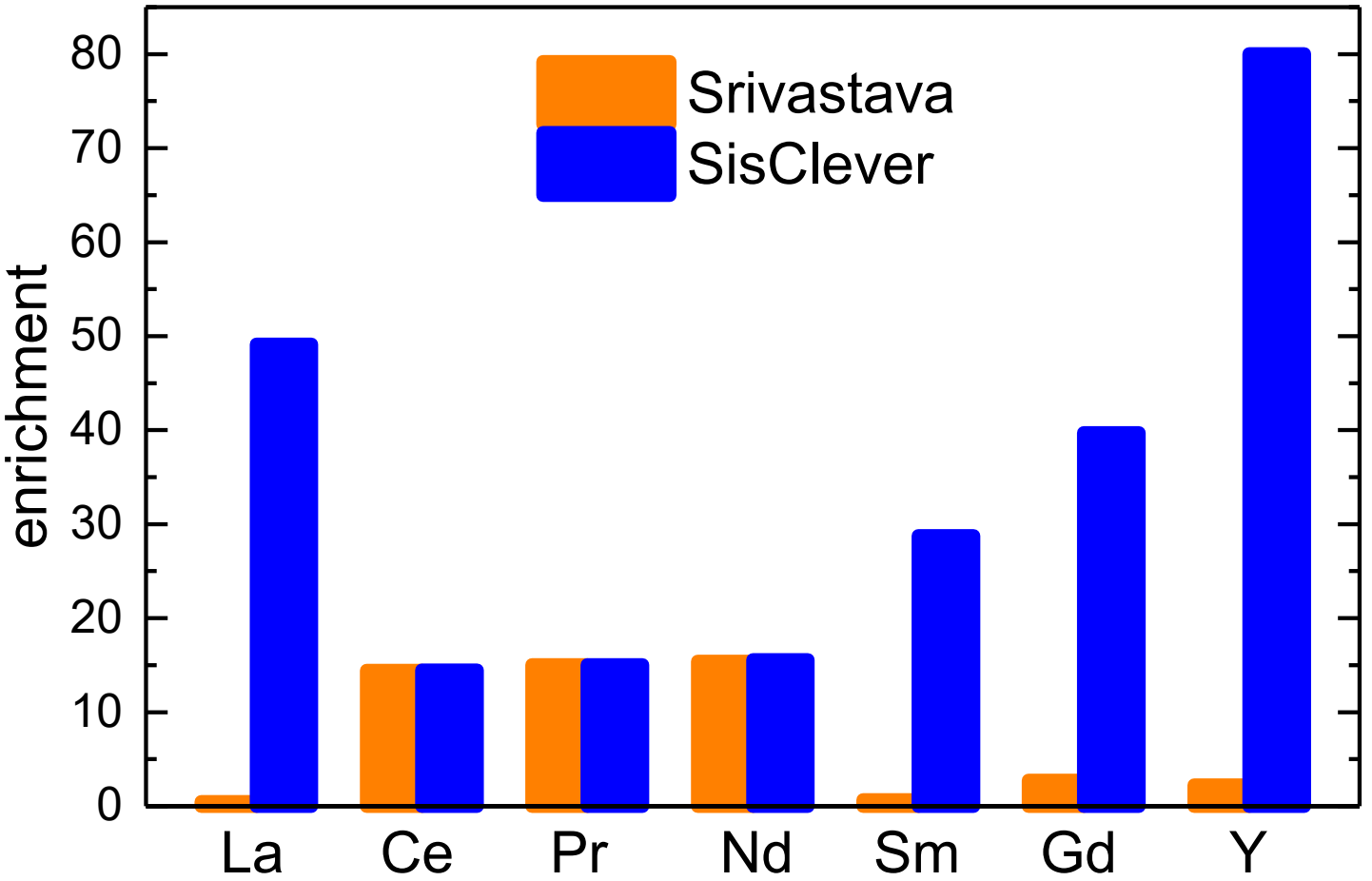
organic concentrations



product purities



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

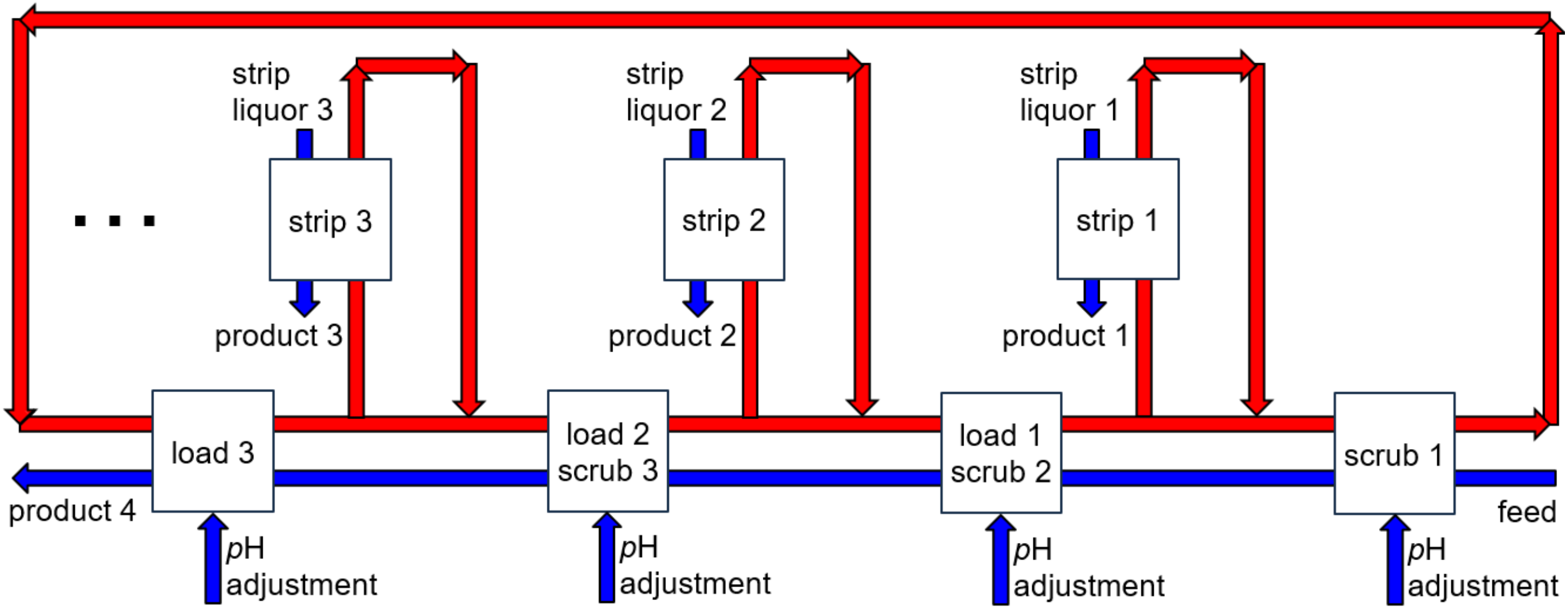


comparison between SisClever and Srivastava

- SisClever:
  24 stages for extraction
  5 stages for stripping
  29 stages

  Srivastava:
  104 stages
- at least same purities
- much higher enrichment for several metals

SisClever process



competitive advantages

- **high concentration** & **high purity**
- valorize **minor components** at **disparate feed** concentrations
- **flexible** process
- **constant** principal counter-current **flowrates**
- **costs** ≤ 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 P103**
- patent WO 2025/016946 A1
- example applications
  - cation exchange: Li-ion batteries, Nd magnets, electronic scrap
  - anion exchange: amino acids, organic acids
  - bioprocesses: fermentation broth
- next objectives: continuous operation & **collaboration with industry**

acknowledgement

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