

## 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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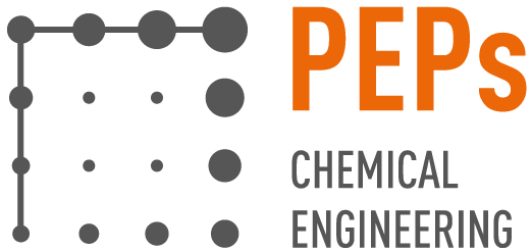
Products, Environment, and Processes (PEPs)

Department of Chemical Engineering

Université de Liège

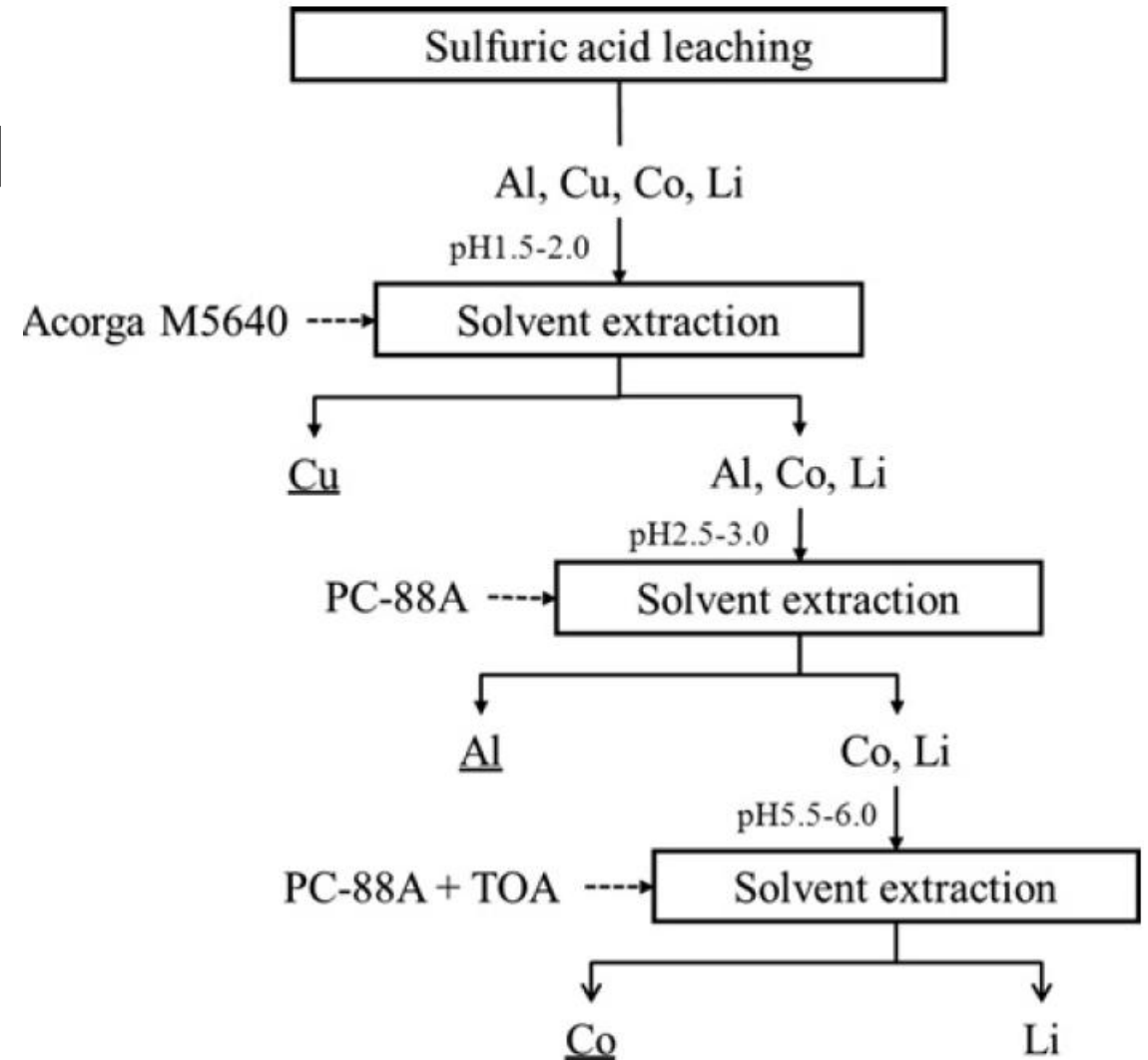
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# motivation

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

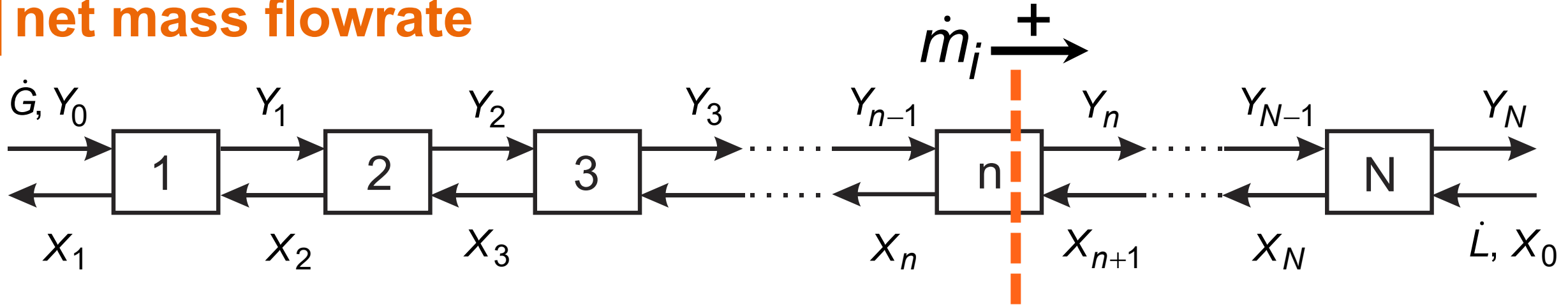


Suzuki, T., Nakamura T., Inoue, Y., Niinae, M., Shibata, J., 2012: A hydrometallurgical process for the separation of aluminum, cobalt, copper and lithium in acidic sulfate media. *Separation and purification technology*, 98, 396-401.

## process idea

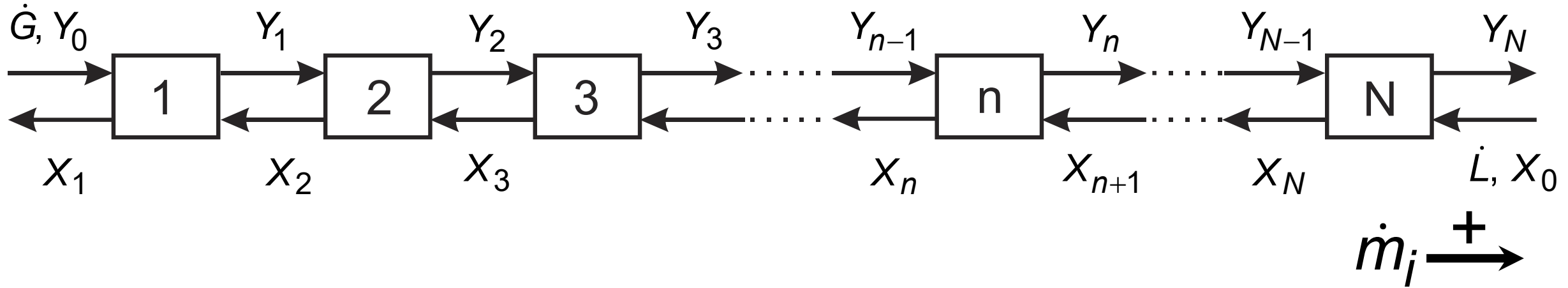
- **objective:** single-process to separate a **multi-component** mixture into **several product streams** of **arbitrary purity** and at **high concentration**  
→ **SisClever process**
- **idea:** create **accumulation zones**, one for each component, by controlling the **partition coefficients**

# net mass flowrate



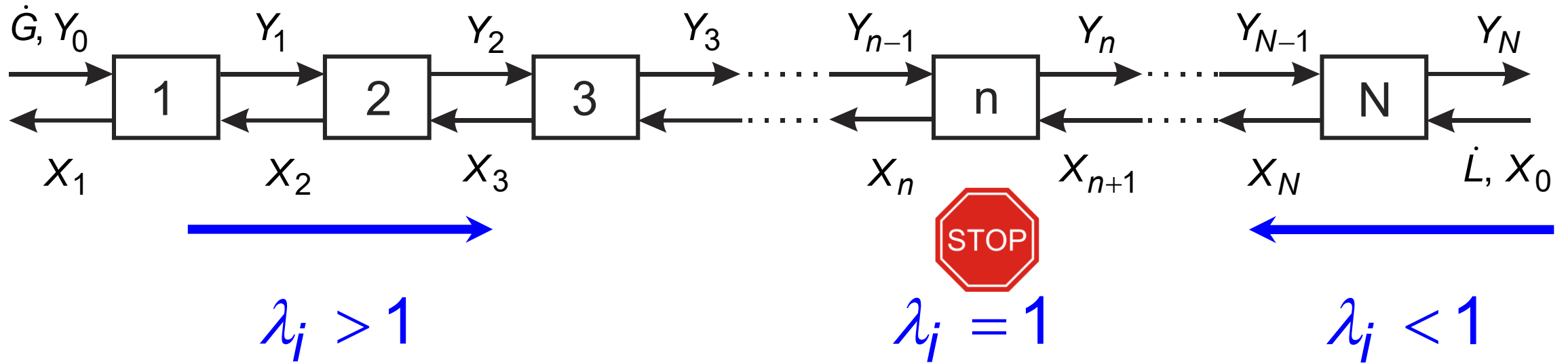
- net mass flowrate:  $\dot{m}_i = \dot{G}Y_i - \dot{L}X_i$
  - partition coefficient:  $K_i = \frac{Y_i}{X_i}$
  - extraction factor:  $\lambda_i = \frac{\dot{G}Y_i}{\dot{L}X_i} = \frac{\dot{G}}{\dot{L}}K_i$
- $$\left. \begin{array}{l} \dot{m}_i = \dot{G}Y_i - \dot{L}X_i \\ K_i = \frac{Y_i}{X_i} \\ \lambda_i = \frac{\dot{G}Y_i}{\dot{L}X_i} = \frac{\dot{G}}{\dot{L}}K_i \end{array} \right\} \dot{m}_i = \dot{L}X_i (\lambda_i - 1)$$

# direction of flow depends on $\lambda_j$



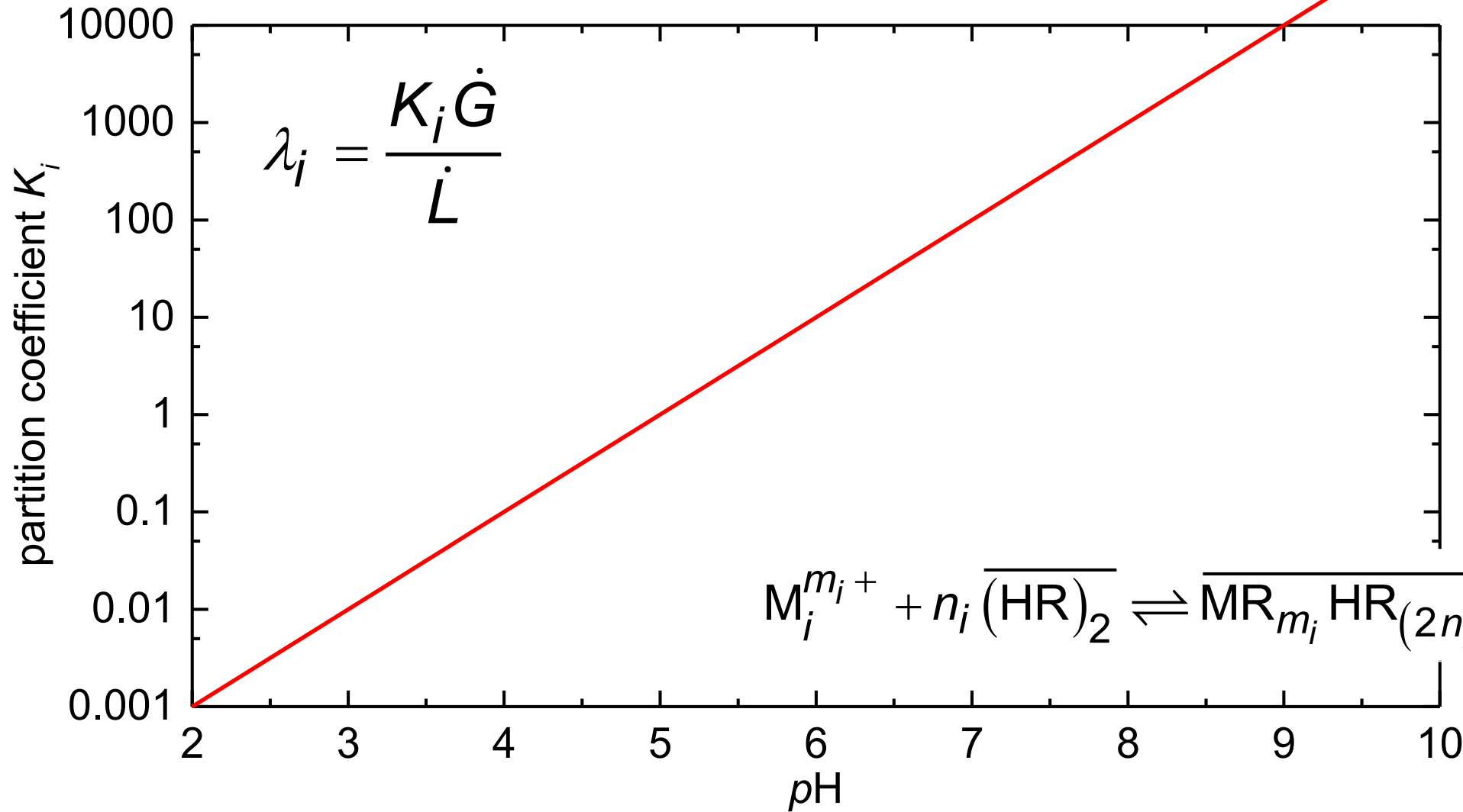
$$\dot{m}_j = \dot{L}X_j (\lambda_j - 1) \implies \dot{m}_j \begin{cases} > 0 & \text{for } (\lambda_j - 1) > 0, & \lambda_j > 1 & \longrightarrow \\ = 0 & \text{for } (\lambda_j - 1) = 0, & \lambda_j = 1 & \text{STOP} \\ < 0 & \text{for } (\lambda_j - 1) < 0, & \lambda_j < 1 & \longleftarrow \end{cases}$$

# counter-current process

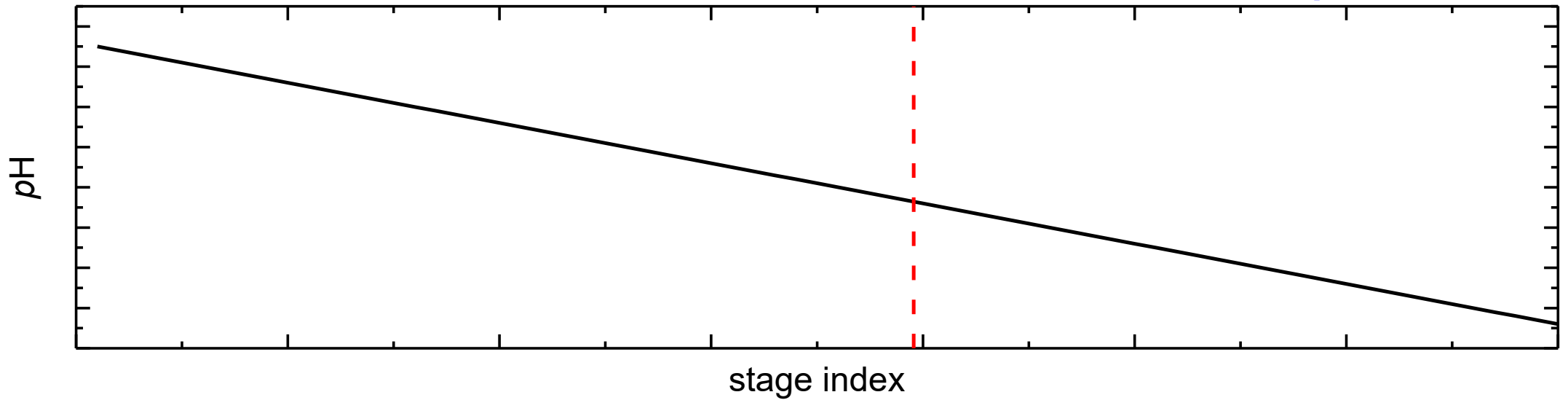
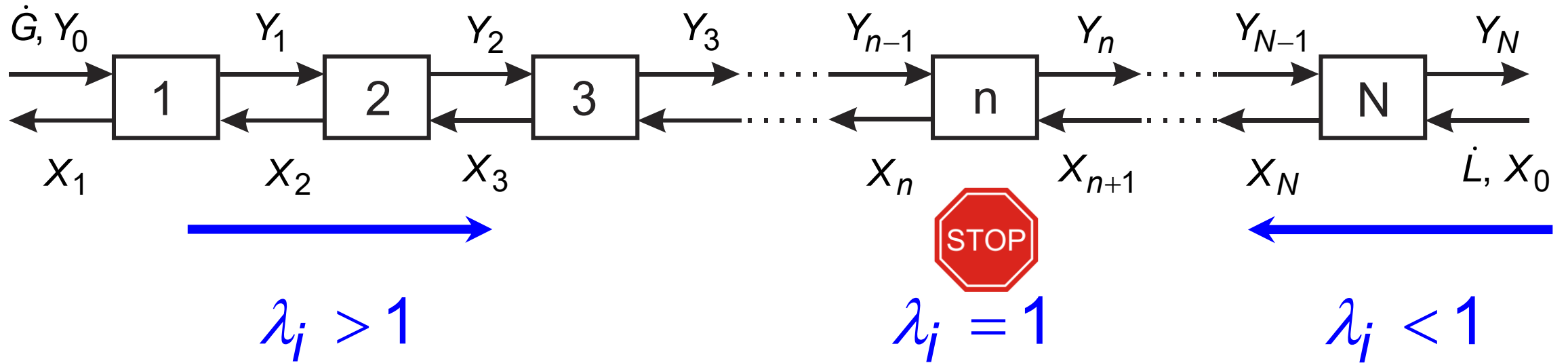


$$\lambda_j = K_j \frac{\dot{G}}{\dot{L}}$$

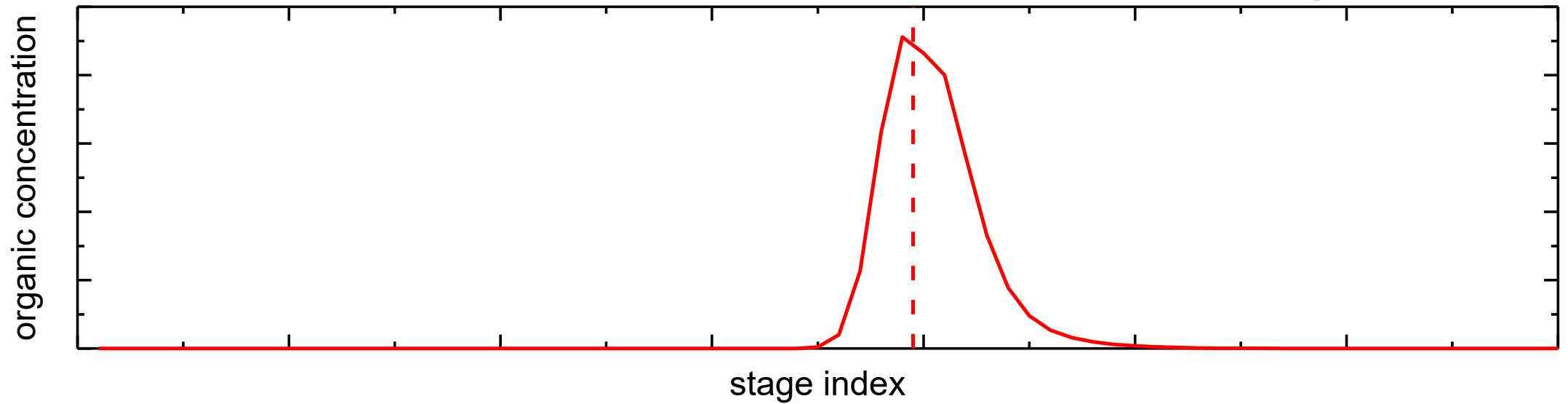
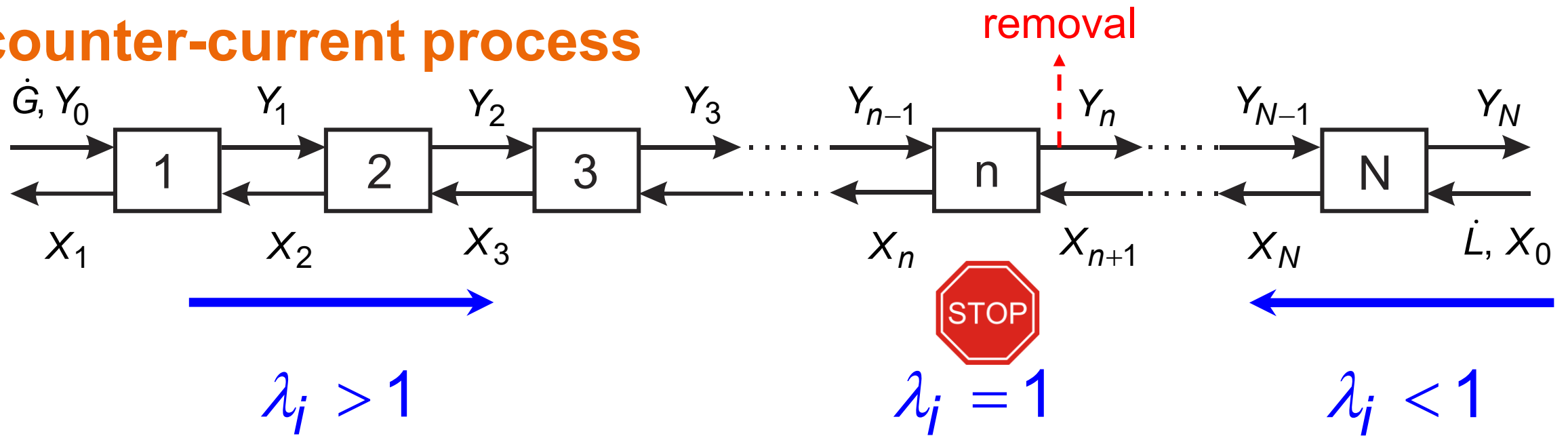
# partition coefficient vs. pH in reactive extraction



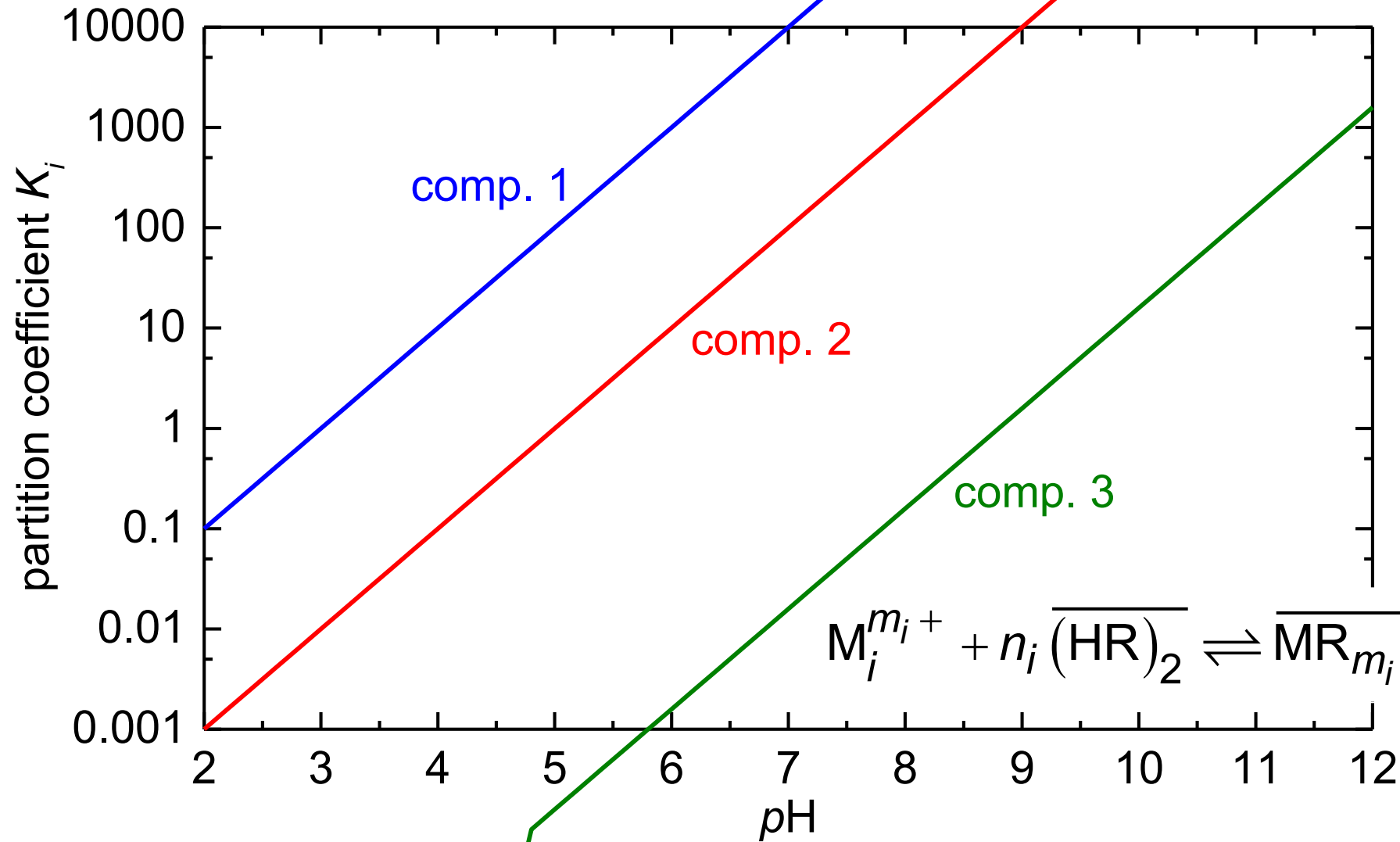
# counter-current process



# counter-current process



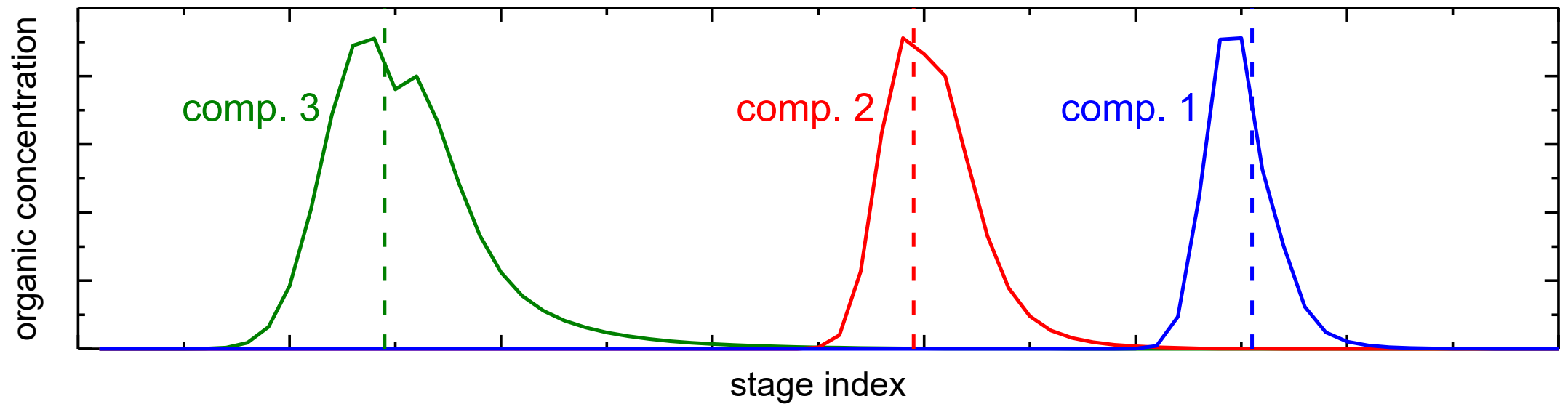
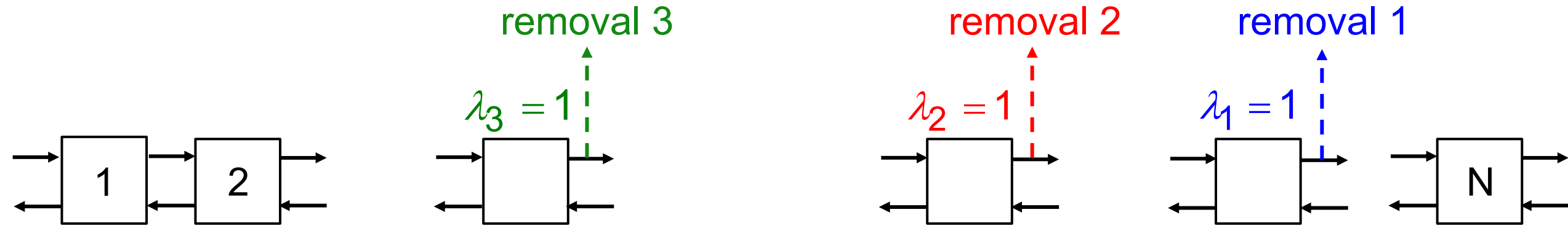
# partition coefficient vs. pH in reactive extraction



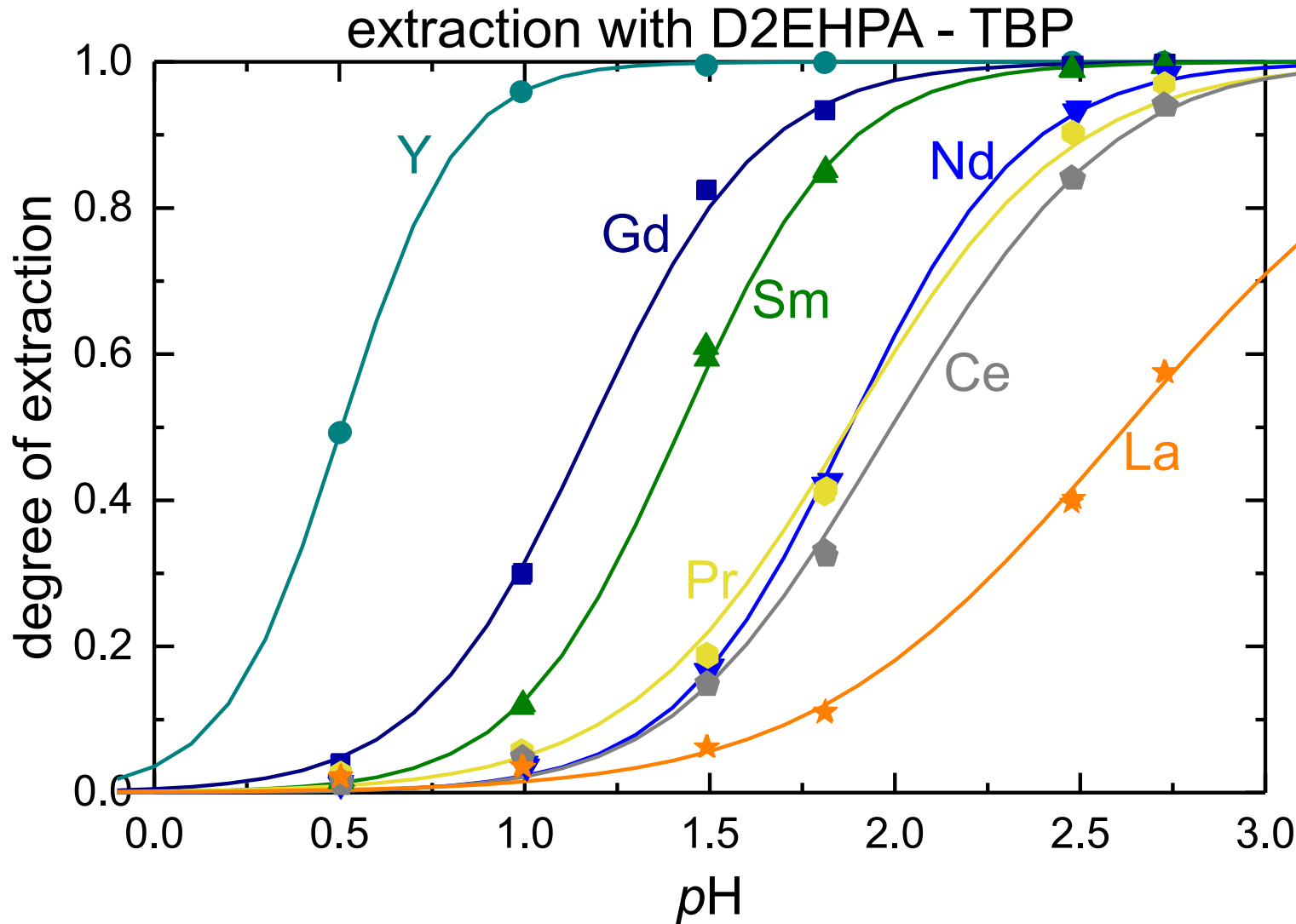
$$\lambda_i = \frac{K_i \dot{G}}{\dot{L}}$$



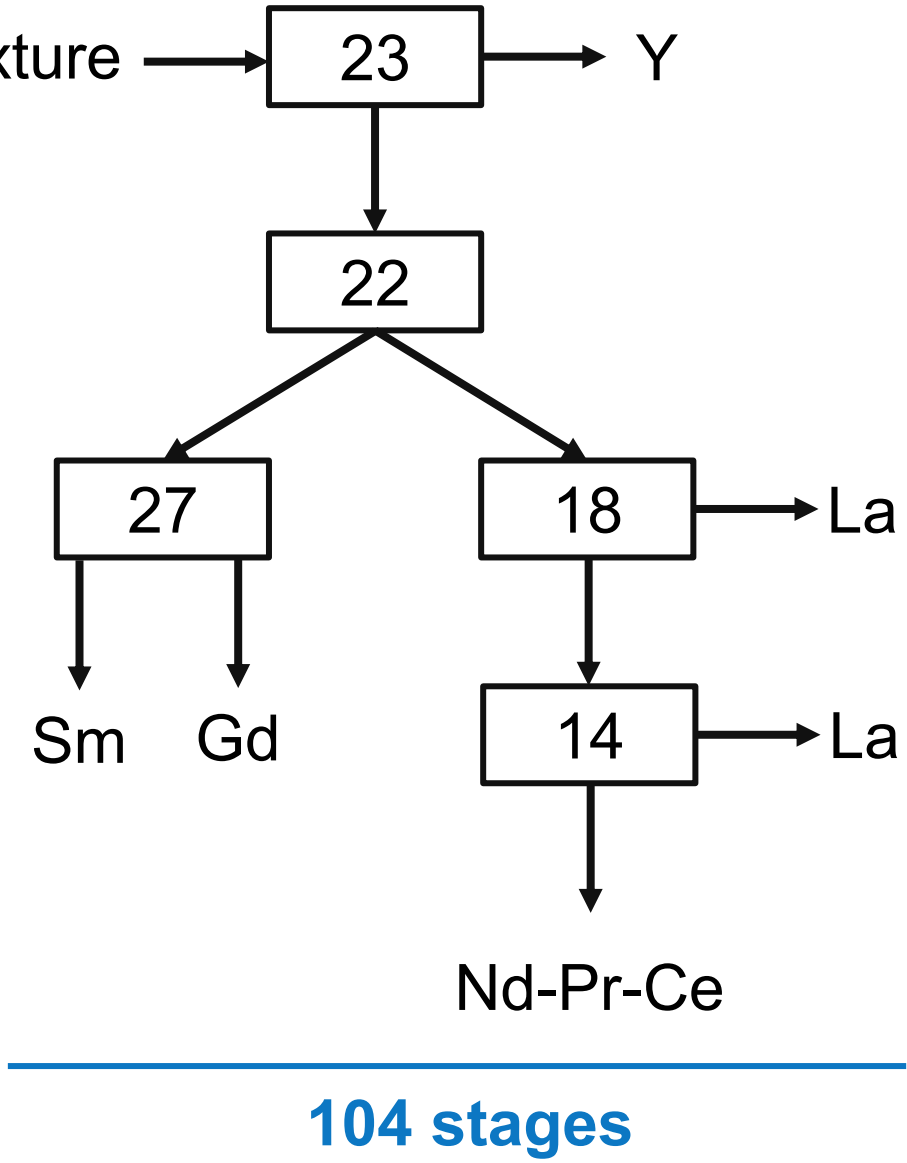
# counter-current process



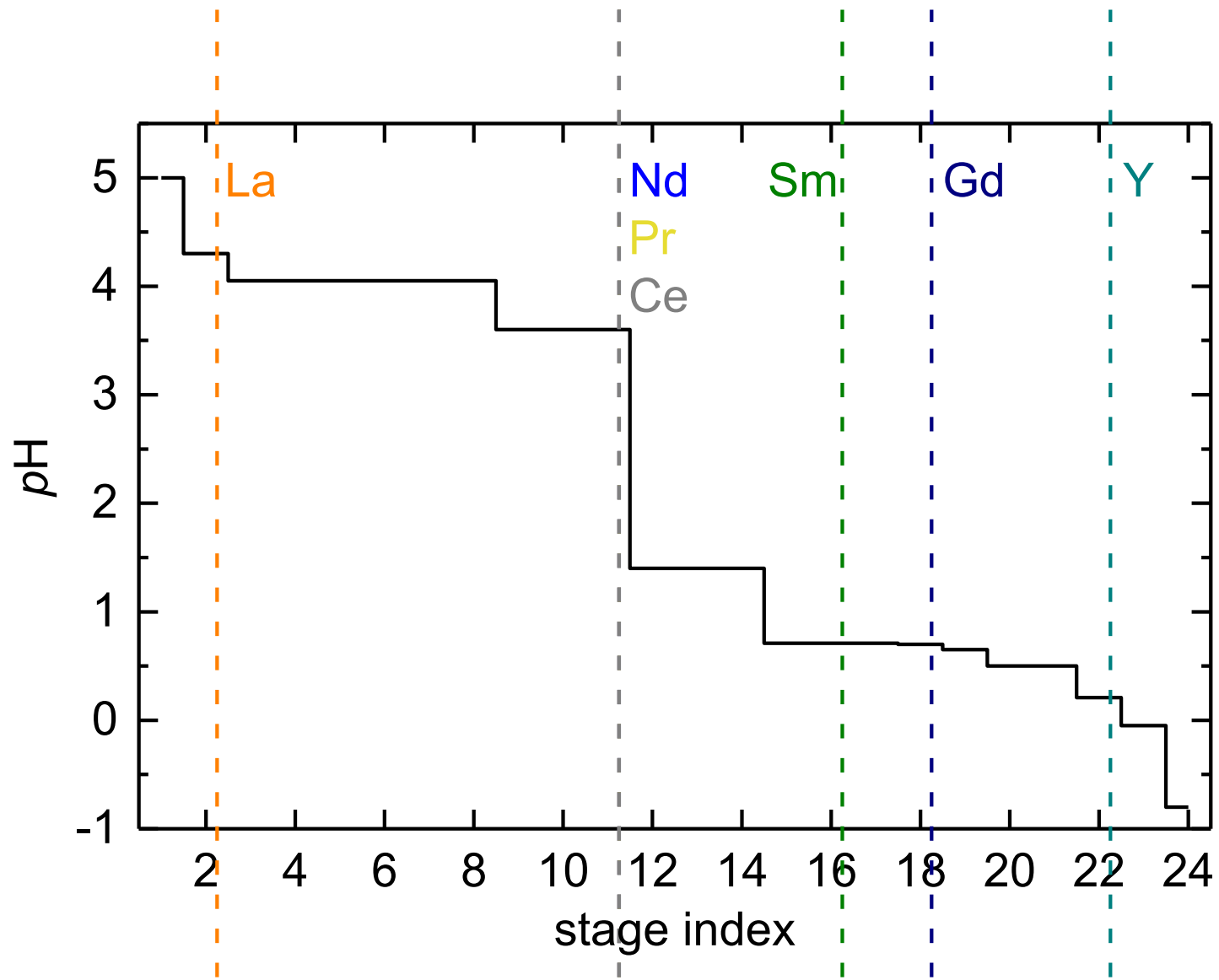
# REE separation simulations



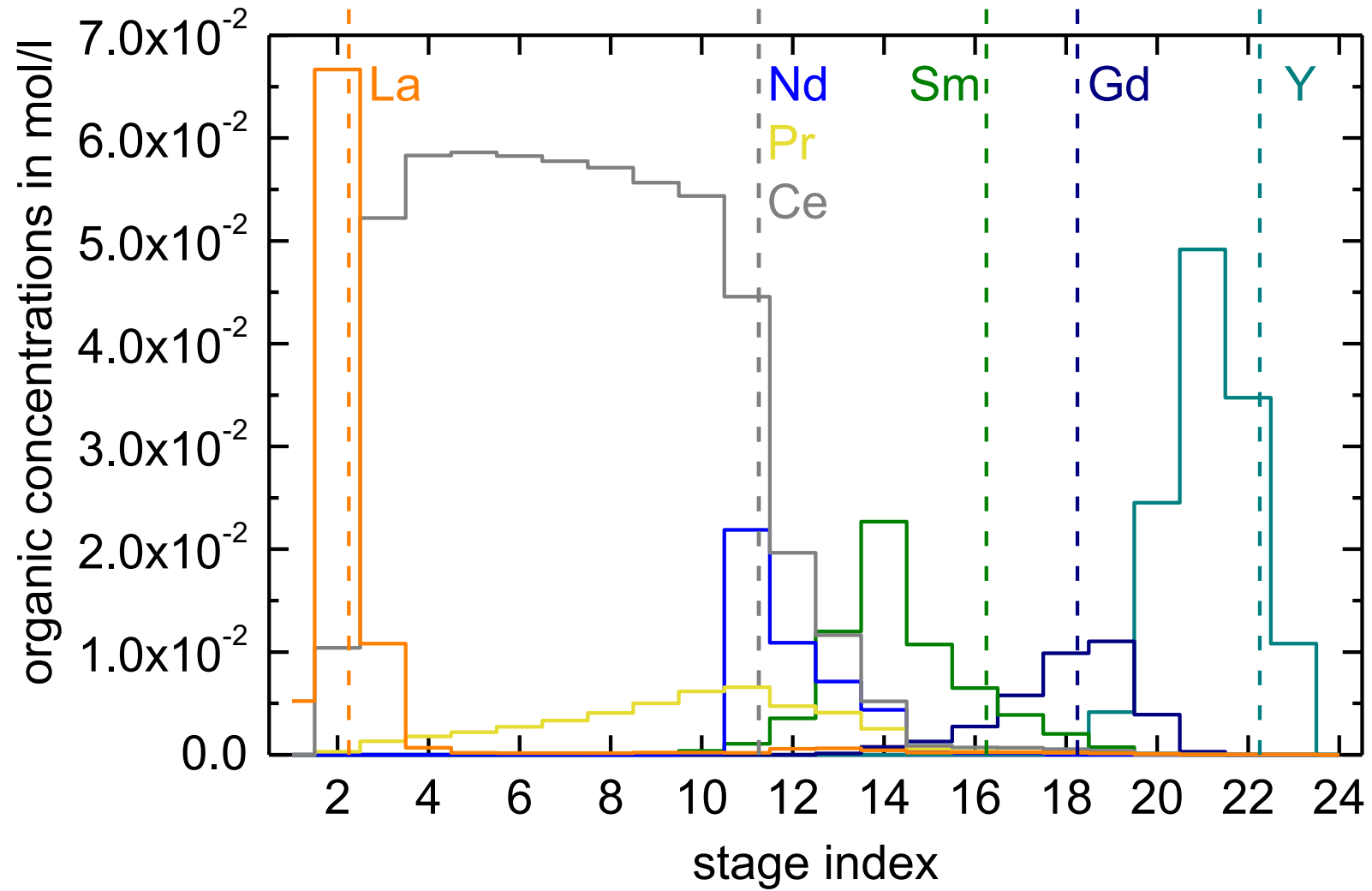
REE mixture →



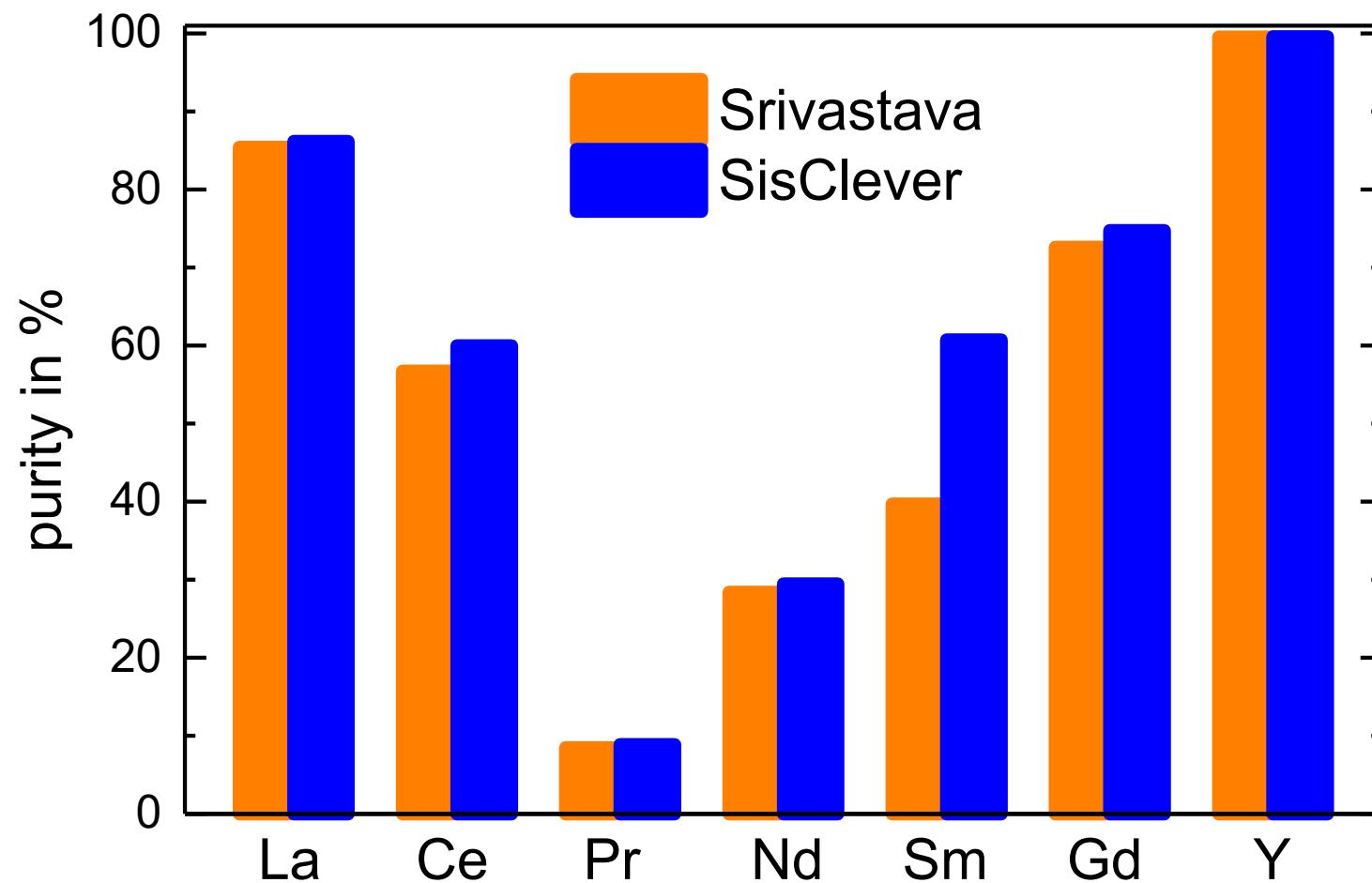
# pH-profile



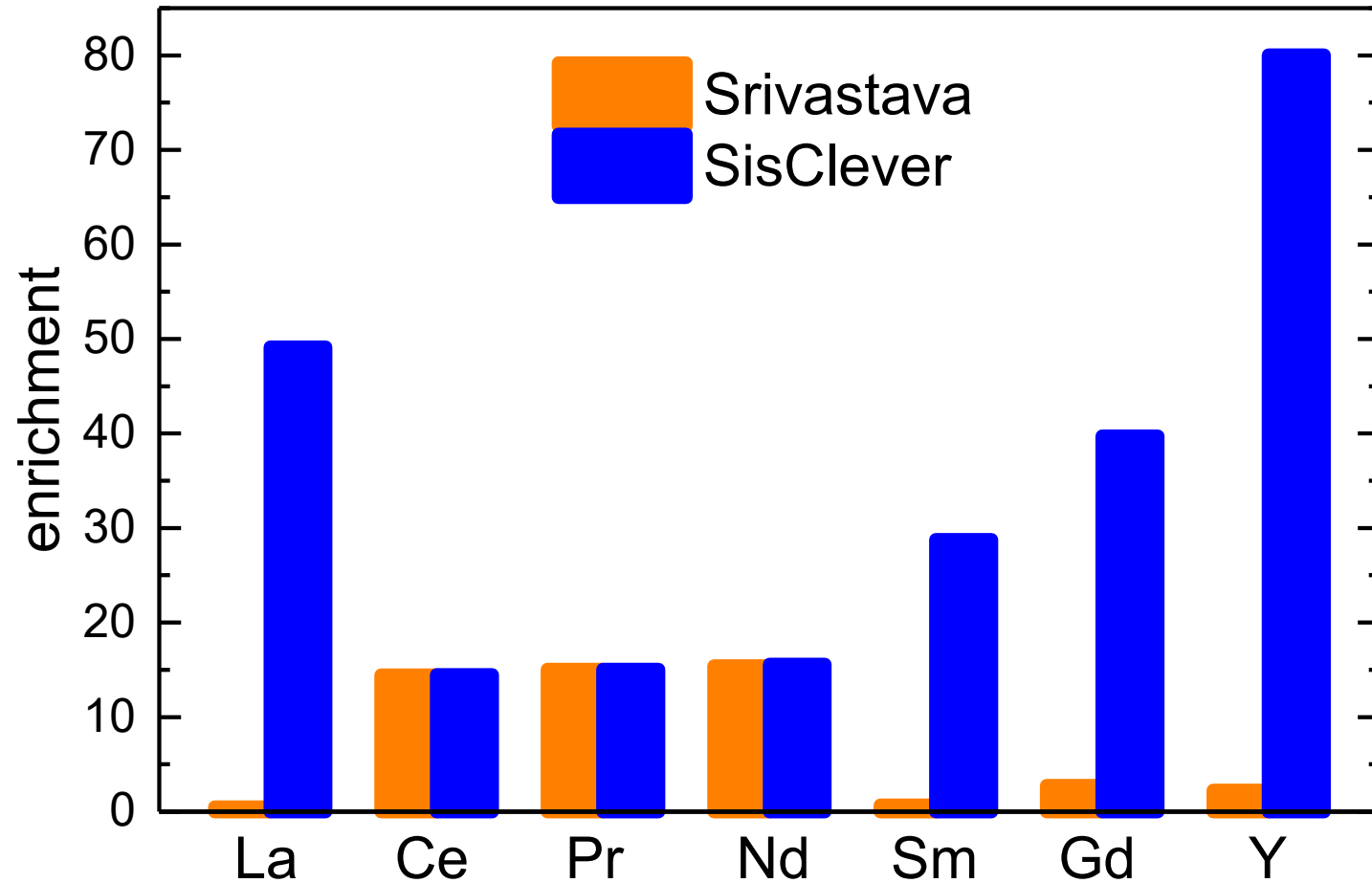
# organic concentrations



# product purities



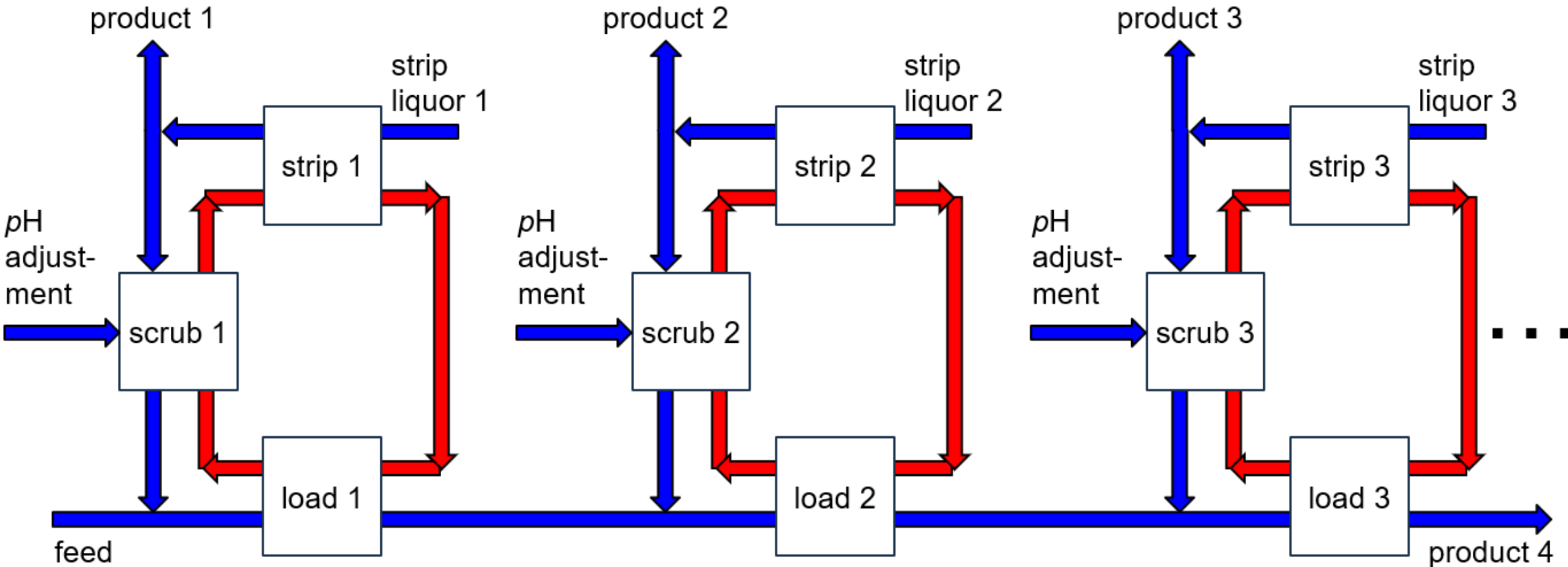
enrichment =  $C_{\text{product}} / C_{\text{inlet}}$



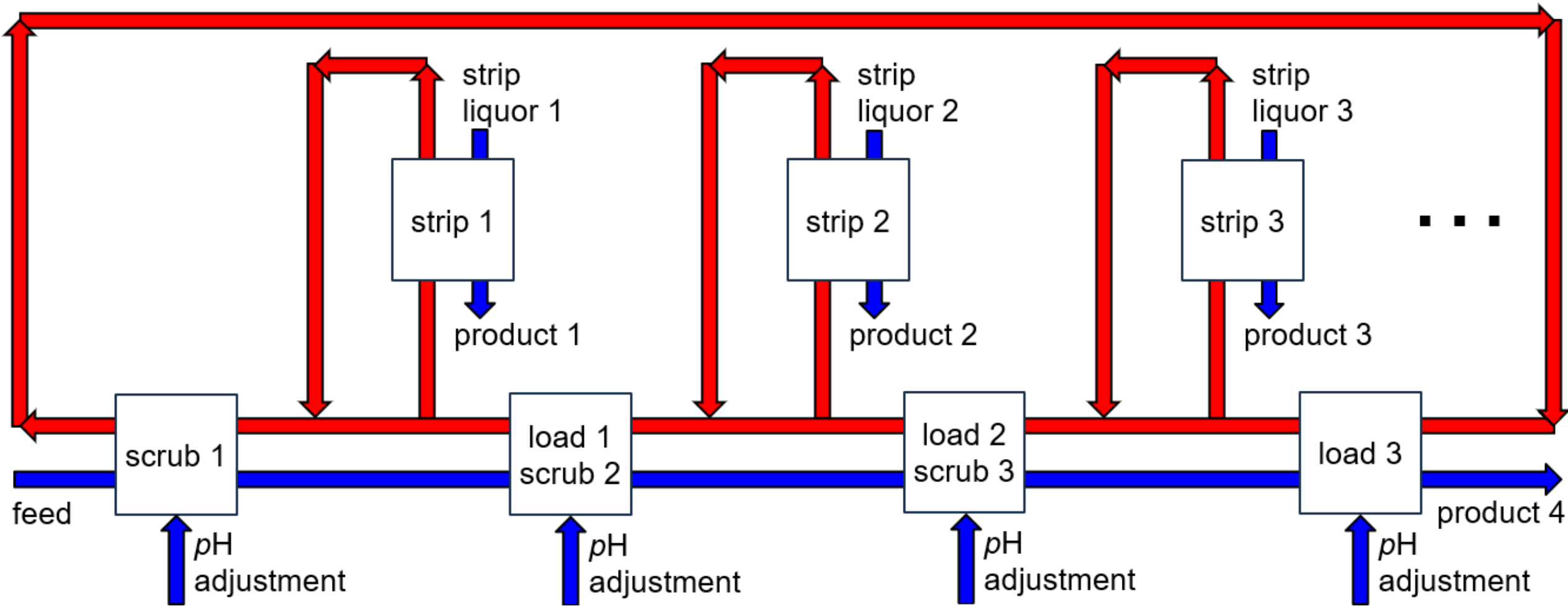
# comparison between SisClever and Srivastava

- SisClever:
  - 24 stages for extraction
  - 5 stages for stripping
  - 29 stages**
- Srivastava:
  - 104 stages
- at least same purities
- much higher enrichment for several metals

# conventional processes



# SisClever process



# 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**
- 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
- **generic** for any 2-phase countercurrent process with suitable  **$K_i$  variability**

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