

Annual Meeting of the DECHEMA/VDI Groups Interface-determined Systems and Processes,
Mixing Processes and Extraction 2026
Frankfurt, 26/02/2026

SisClever Process

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

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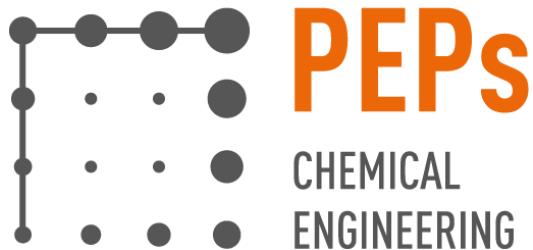
Products, Environment, and Processes (PEPs)

Department of Chemical Engineering

Université de Liège

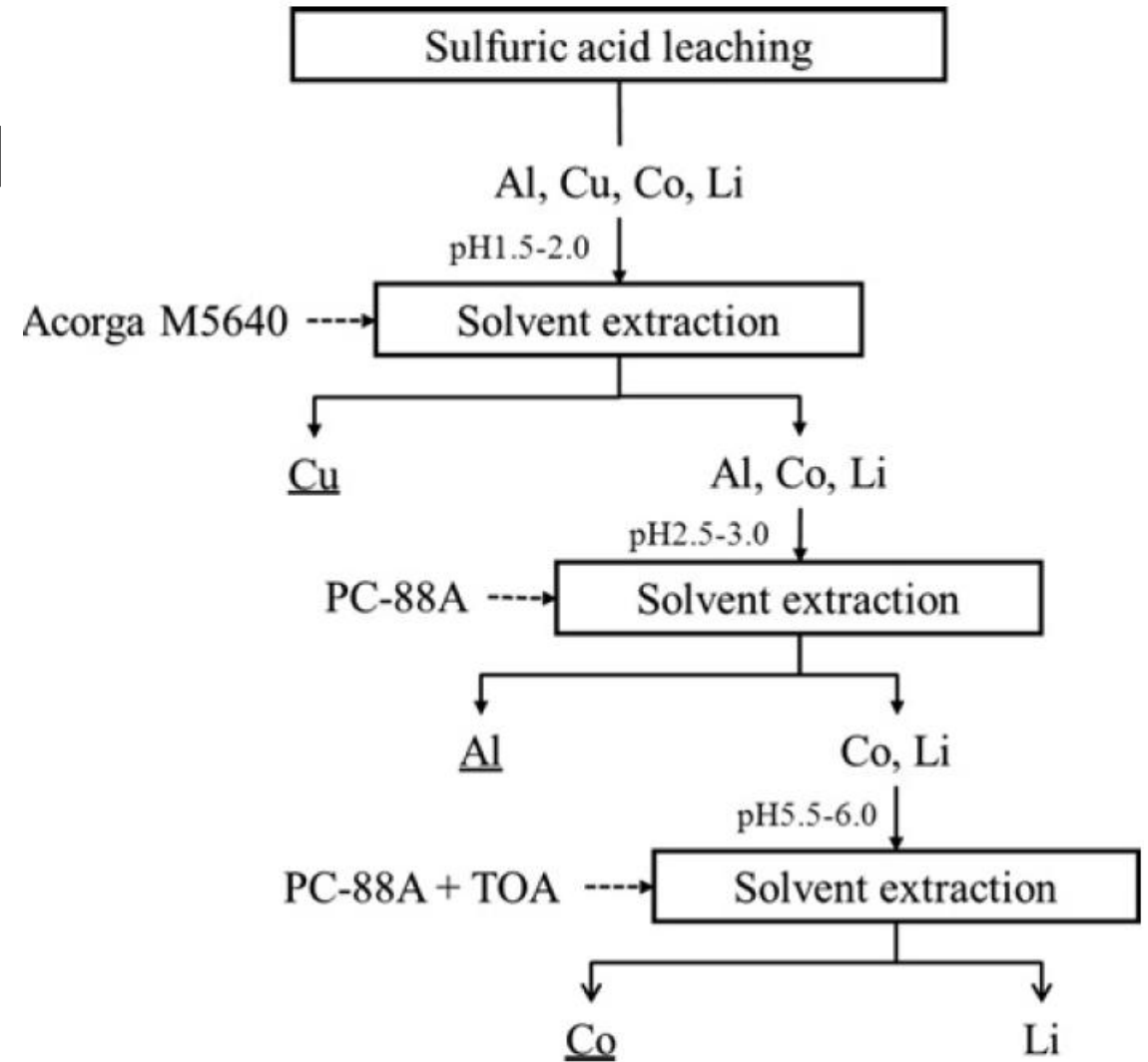
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motivation

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

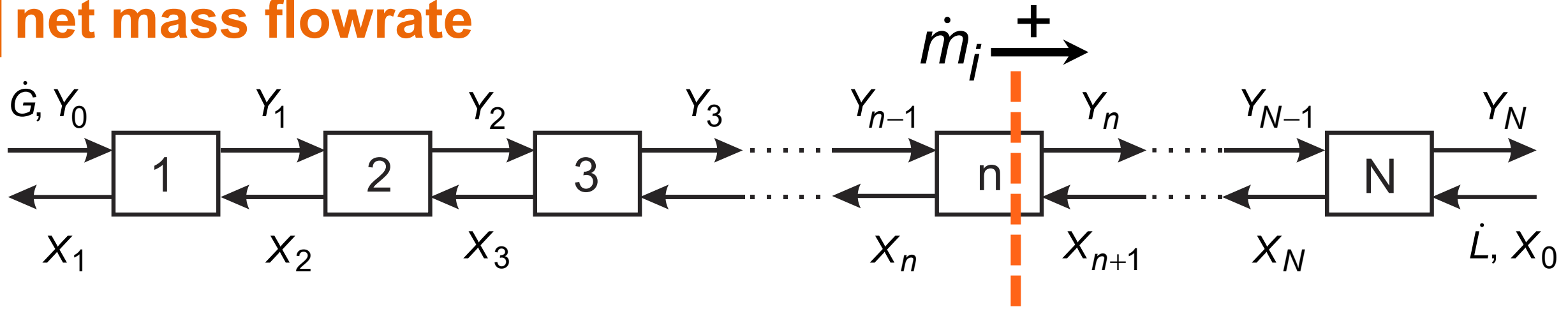


Suzuki, T., Nakamura T., Inoue, Y., Niinae, M., Shibata, J., 2012: A hydrometallurgical process for the separation of aluminum, cobalt, copper and lithium in acidic sulfate media. *Separation and purification technology*, 98, 396-401.

process idea

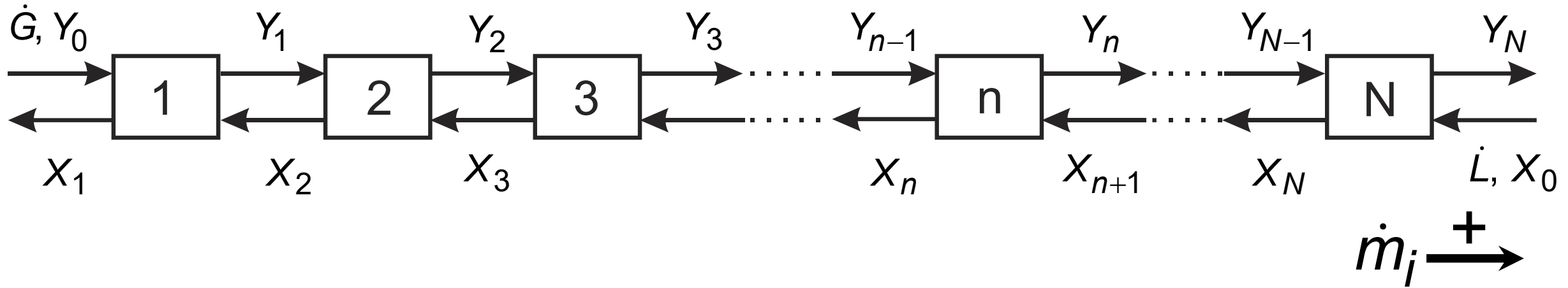
- **objective:** single-process to separate a **multi-component** mixture into **several product streams** of **arbitrary purity** and at **high concentration**
→ **SisClever process**
- **idea:** create **accumulation zones**, one for each component, by controlling the **partition coefficients**

net mass flowrate



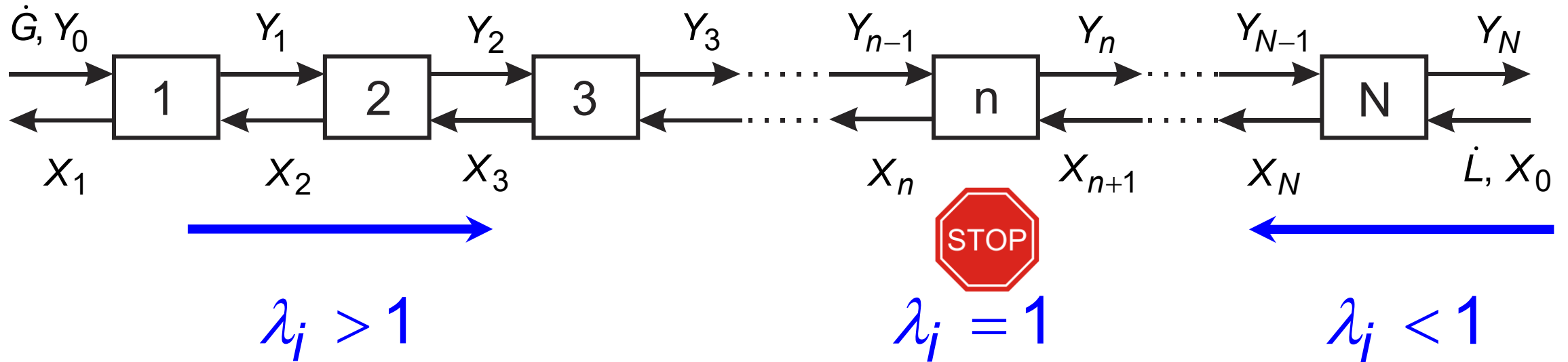
- net mass flowrate: $\dot{m}_i = \dot{G}Y_i - \dot{L}X_i$
 - partition coefficient: $K_i = \frac{Y_i}{X_i}$
 - extraction factor: $\lambda_i = \frac{\dot{G}Y_i}{\dot{L}X_i} = \frac{\dot{G}}{\dot{L}}K_i$
- $$\left. \begin{array}{l} \dot{m}_i = \dot{G}Y_i - \dot{L}X_i \\ K_i = \frac{Y_i}{X_i} \\ \lambda_i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

direction of flow depends on λ_j

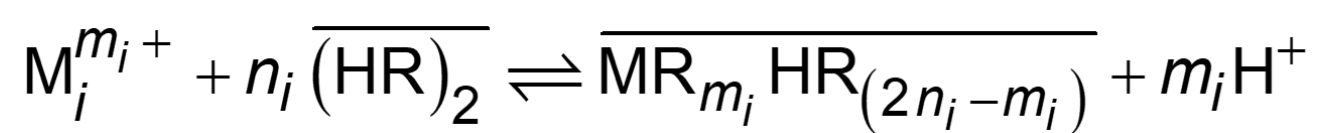


$$\dot{m}_j = \dot{L}X_j (\lambda_j - 1) \implies \dot{m}_j \begin{cases} > 0 & \text{for } (\lambda_j - 1) > 0, & \lambda_j > 1 & \longrightarrow \\ = 0 & \text{for } (\lambda_j - 1) = 0, & \lambda_j = 1 & \text{STOP} \\ < 0 & \text{for } (\lambda_j - 1) < 0, & \lambda_j < 1 & \longleftarrow \end{cases}$$

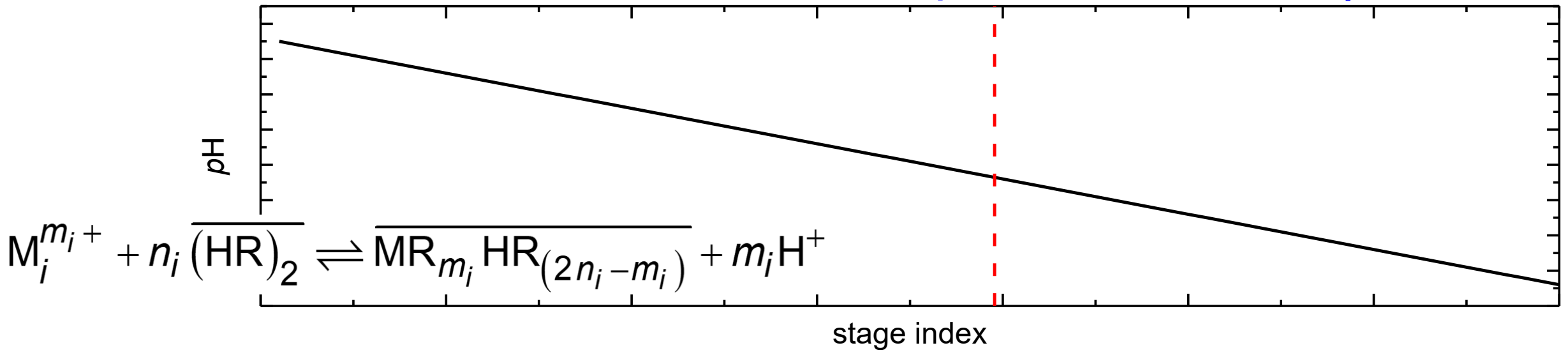
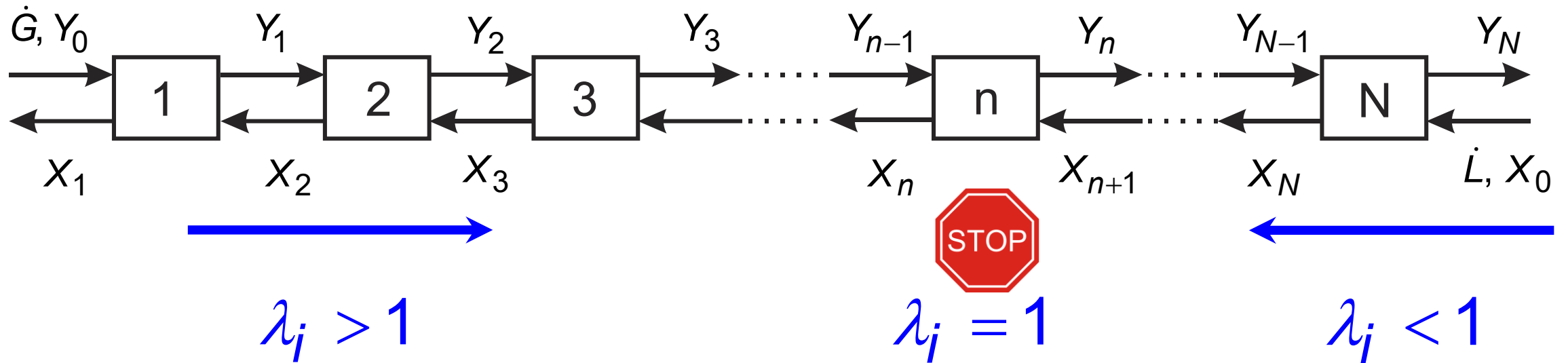
counter-current process



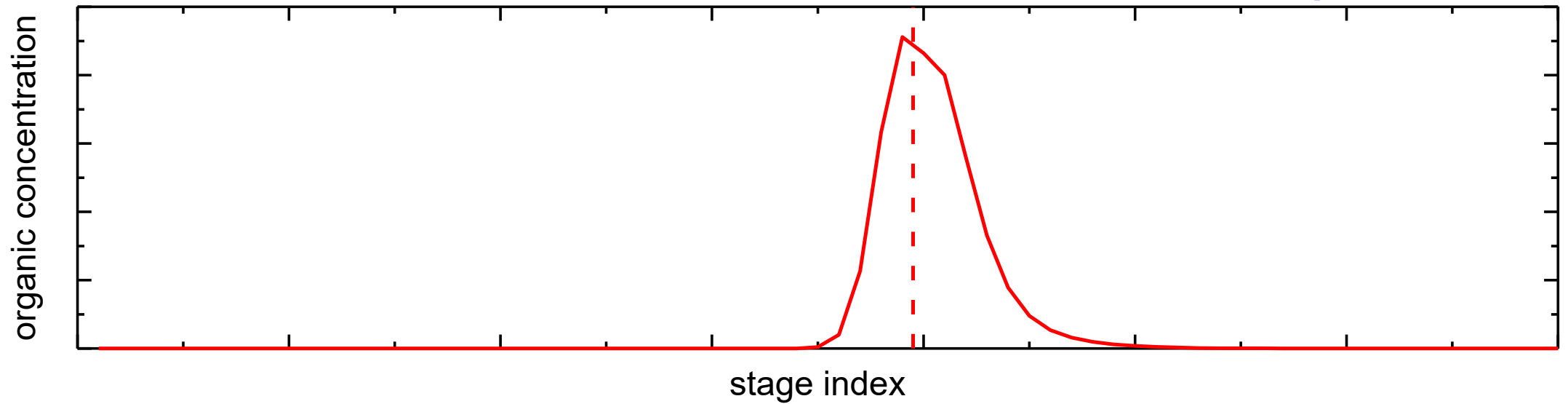
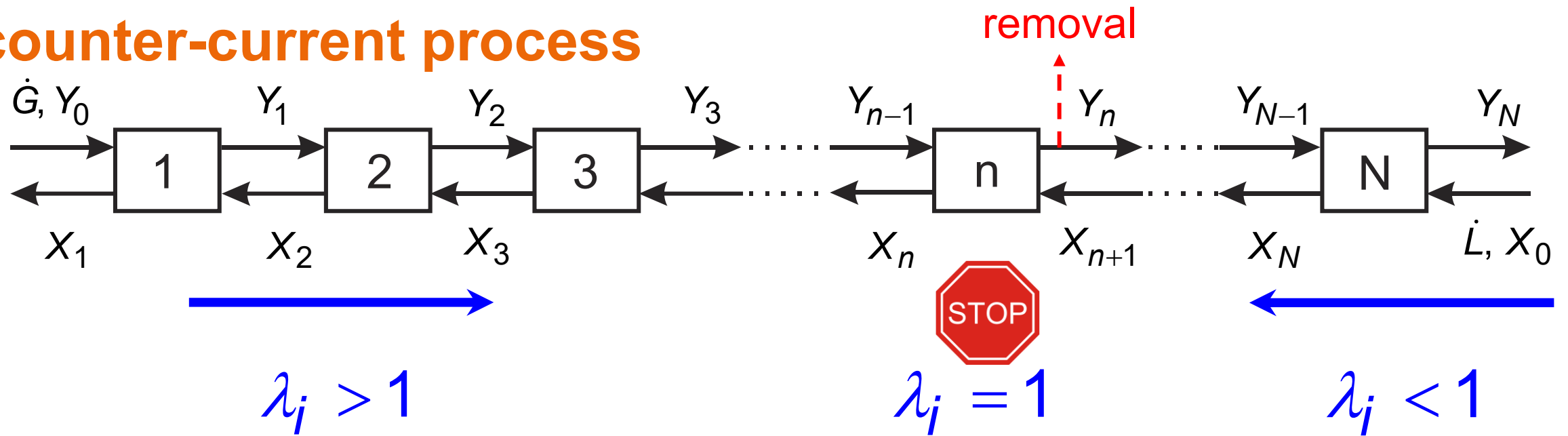
$$\lambda_j = K_j \frac{\dot{G}}{\dot{L}}$$



counter-current process



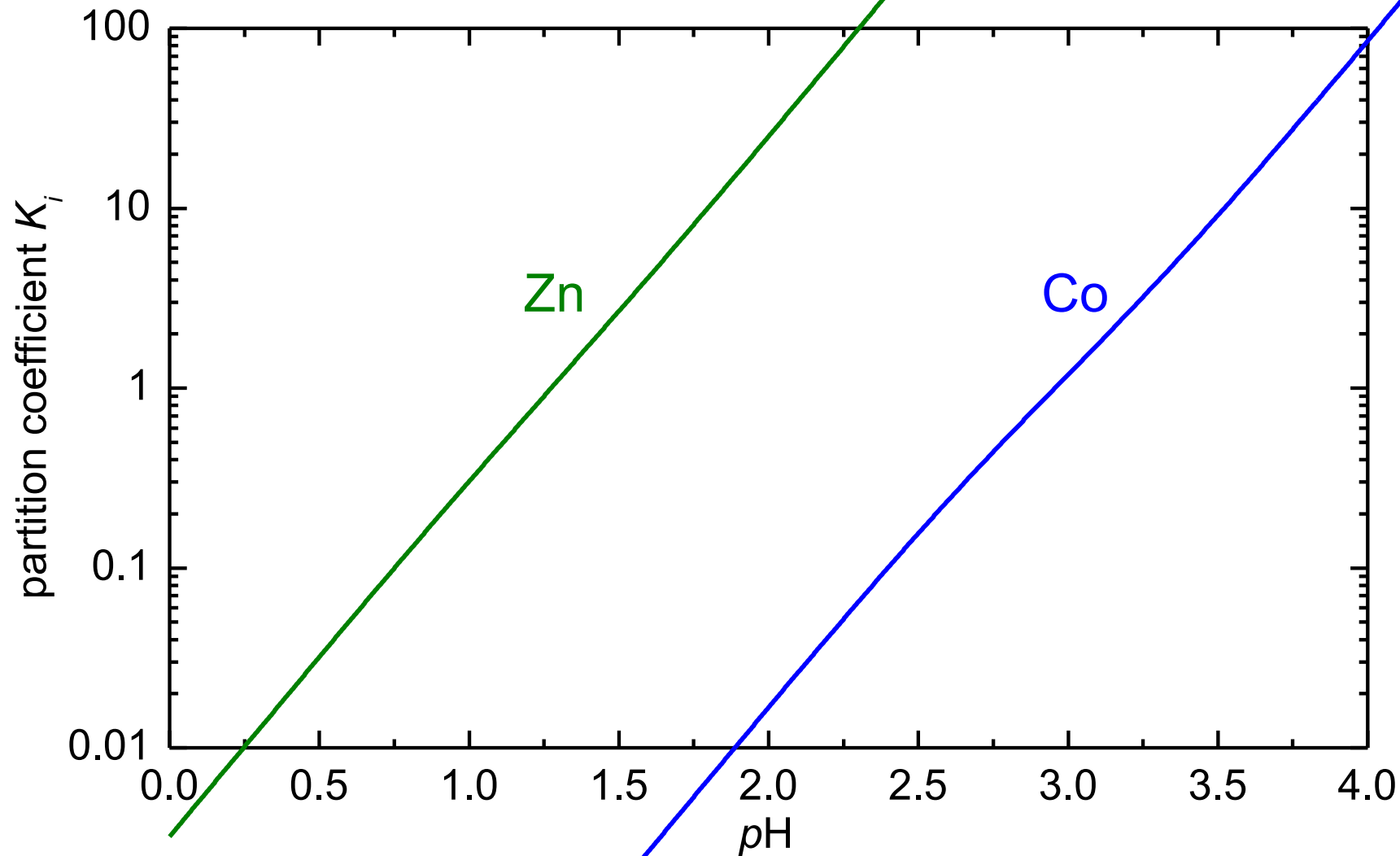
counter-current process



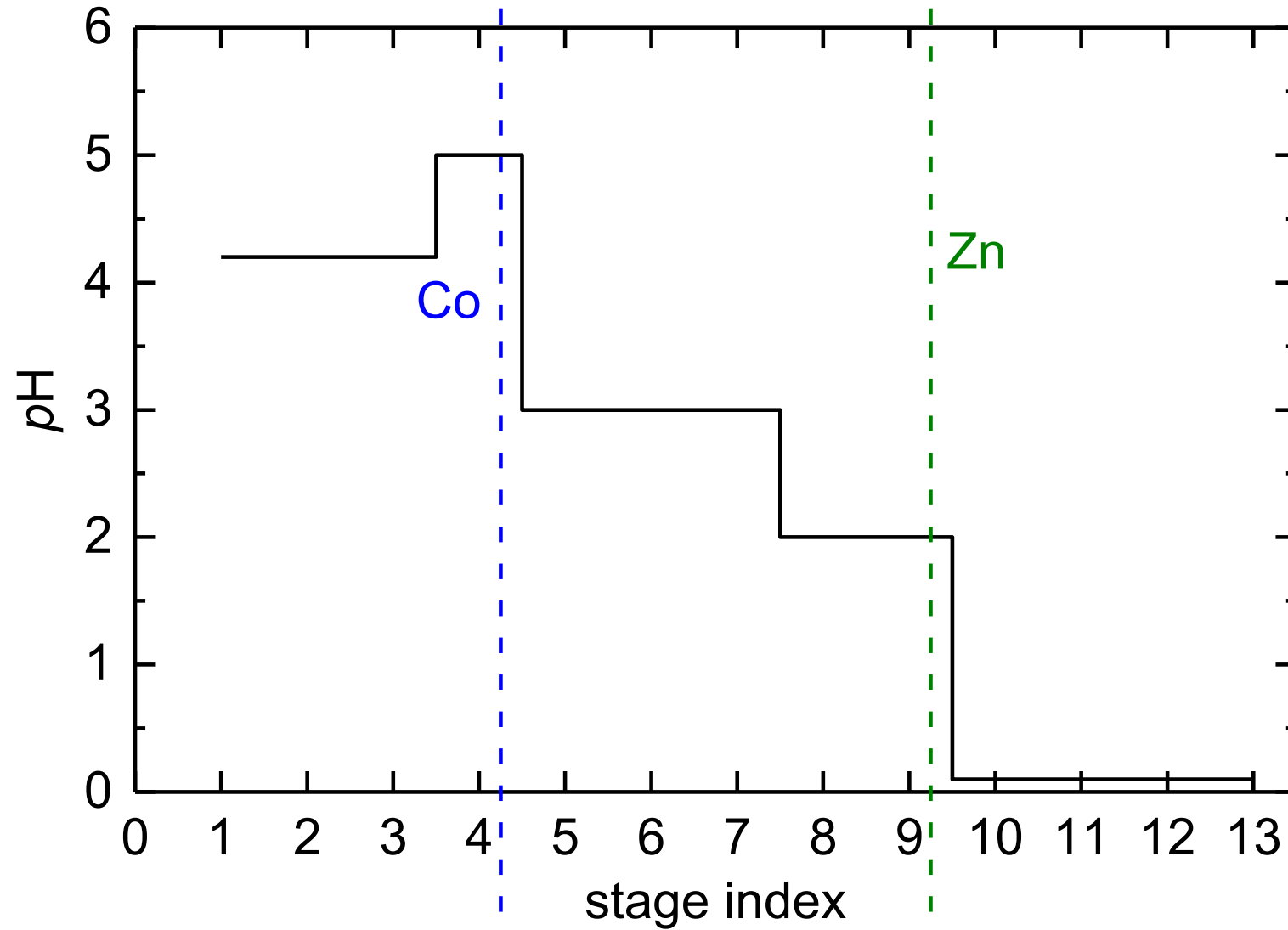
separation of 2 metals

extractant: D2EHPA

T = 25°C



optimal pH-profile



experimental set-up

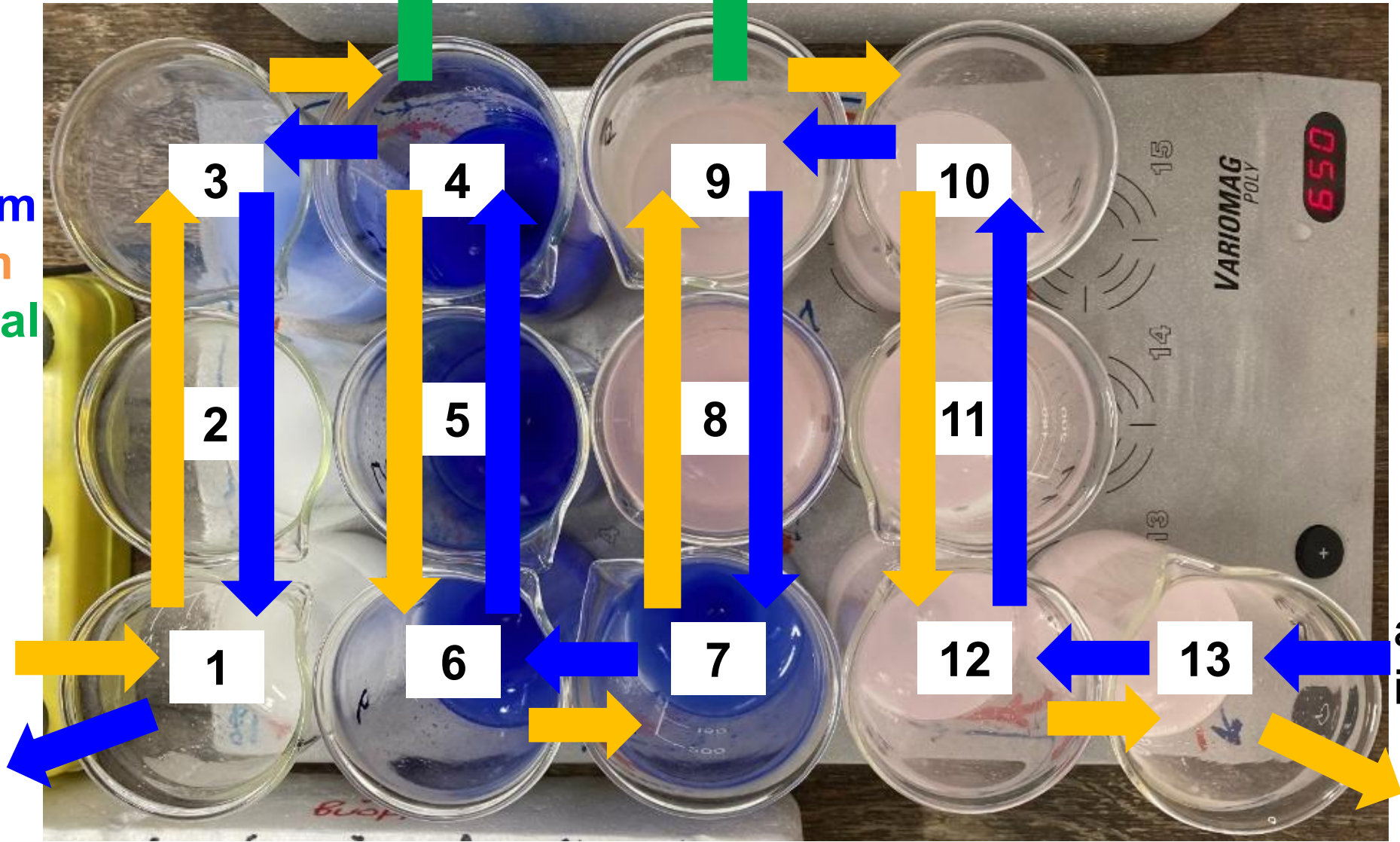
Co removal

Zn removal

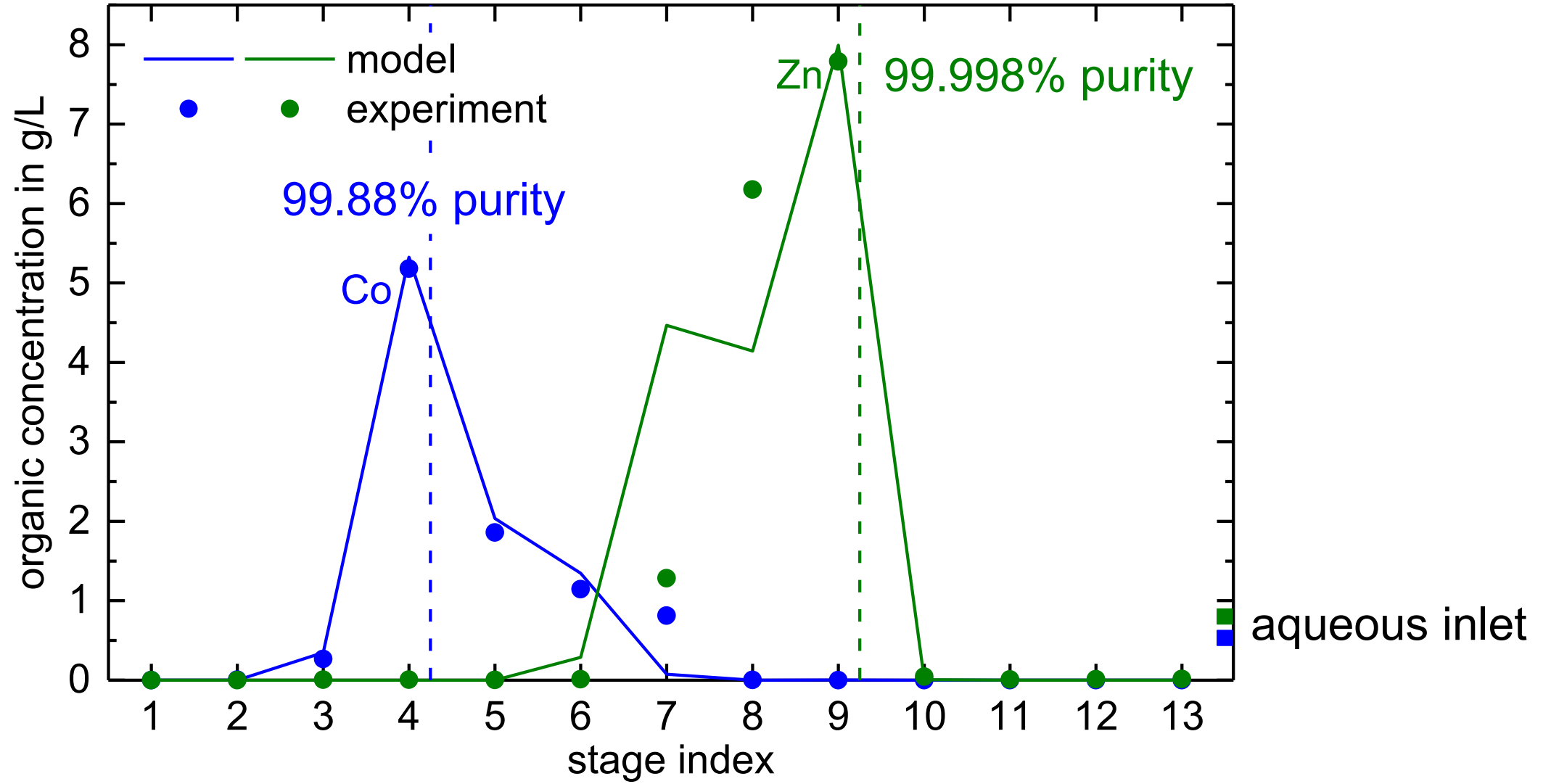
aqueous stream
organic stream
organic removal

organic inlet

aqueous inlet

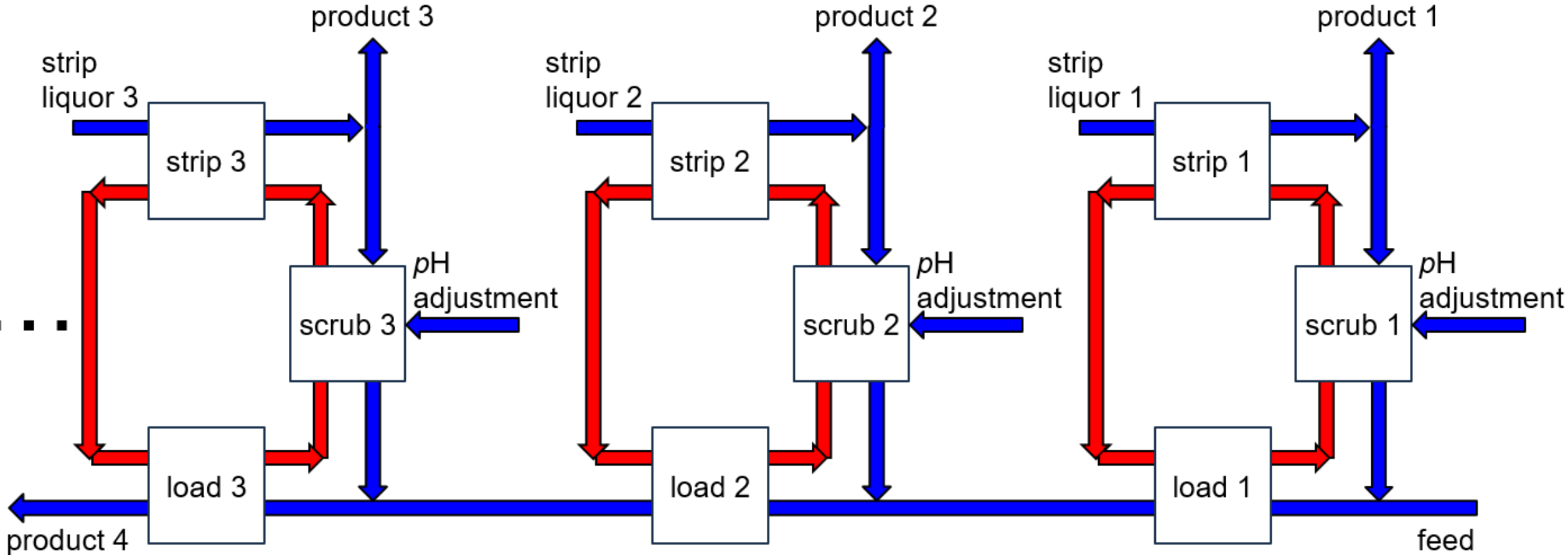


experimental validation



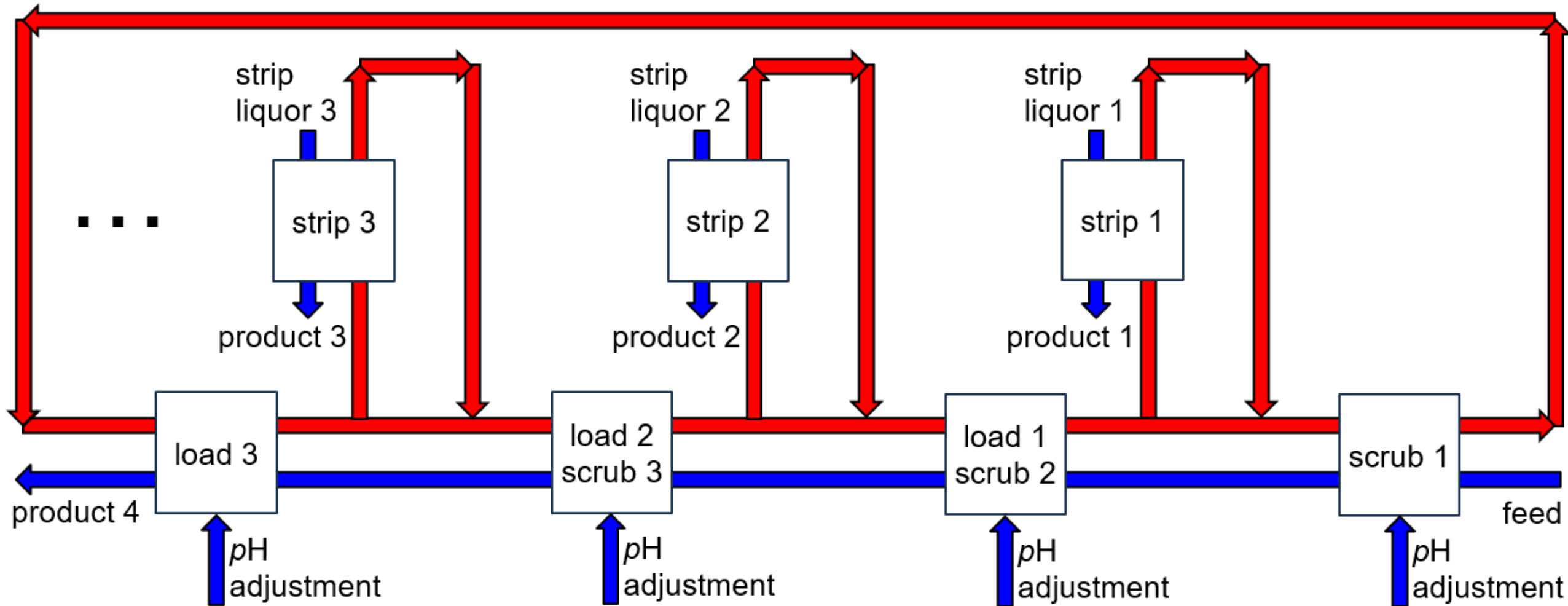
conventional processes

aqueous
organic



SisClever process

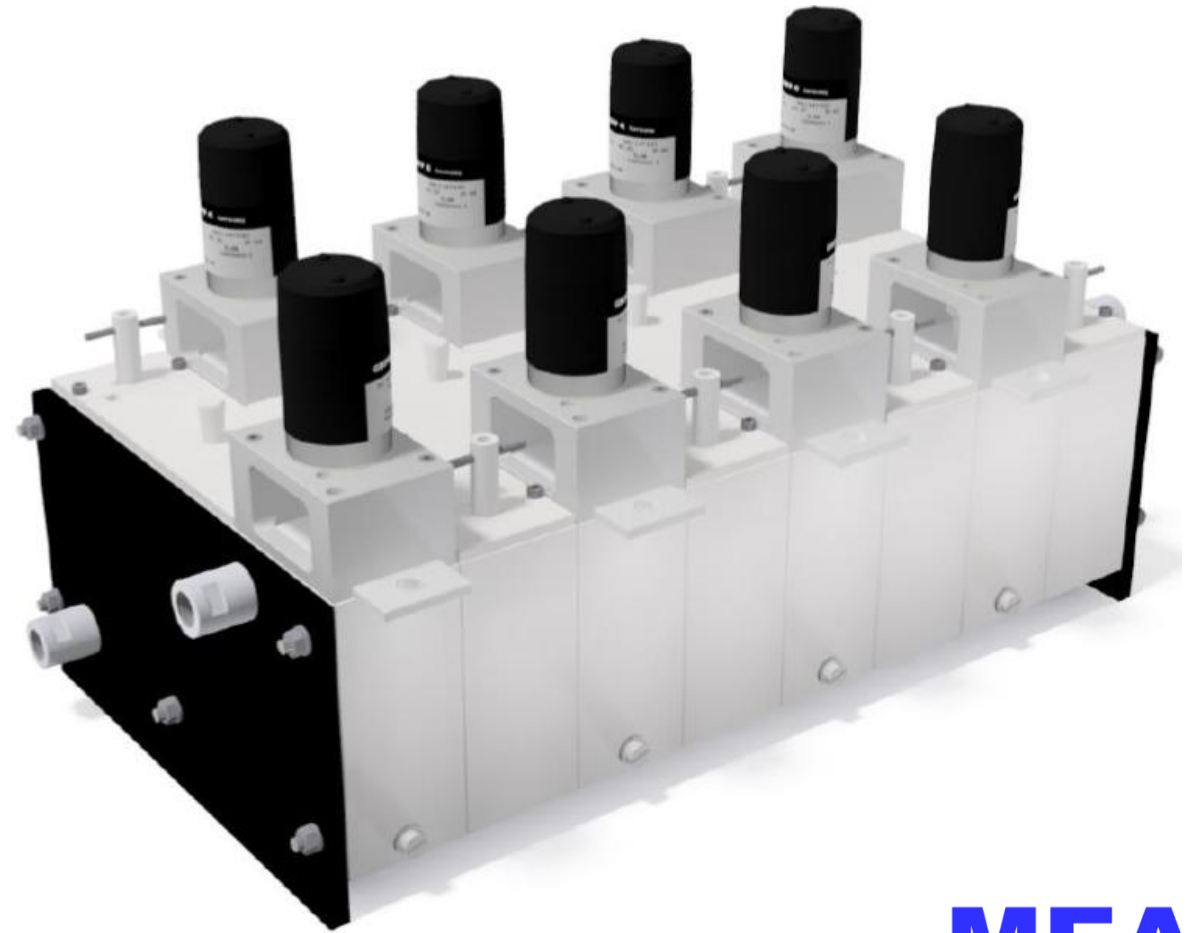
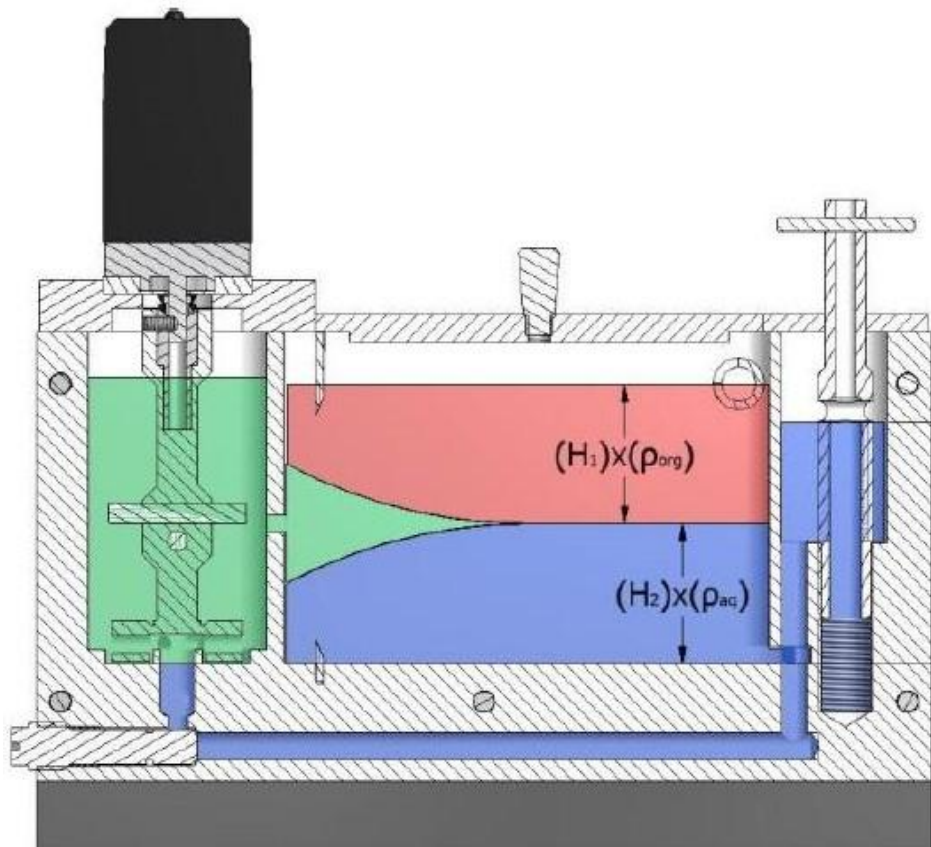
aqueous
organic



competitive advantages

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

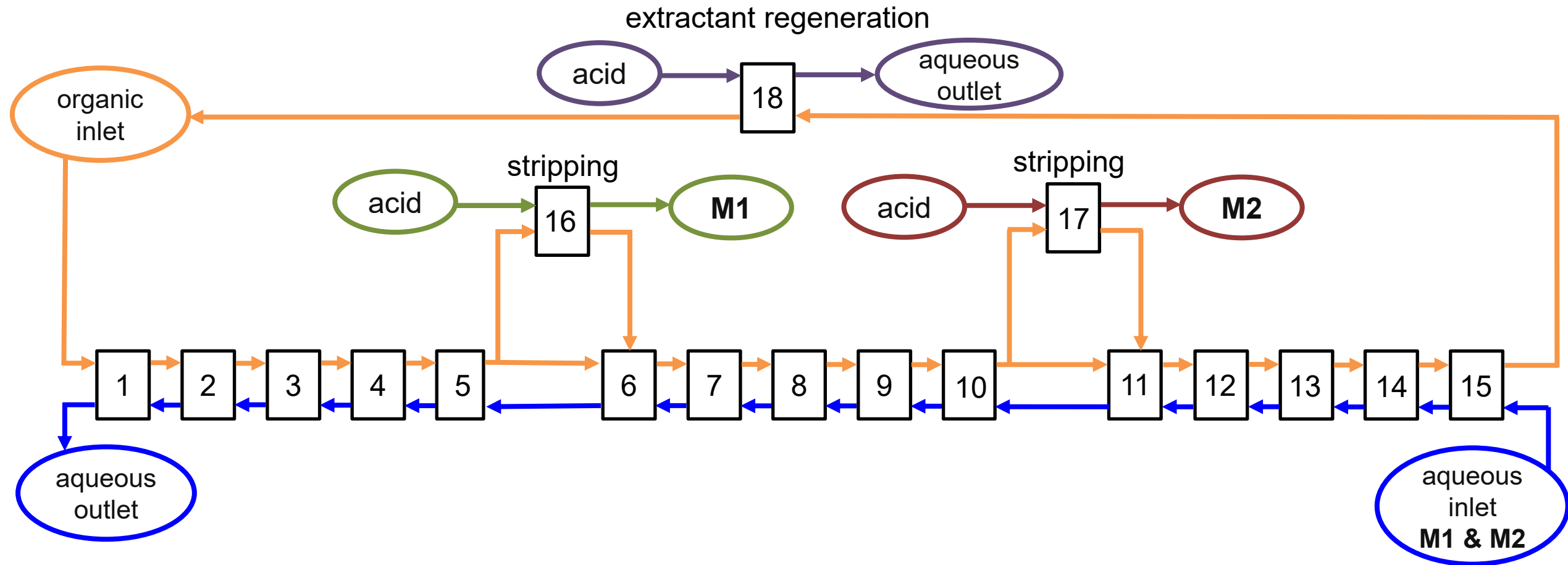
continuous experiments



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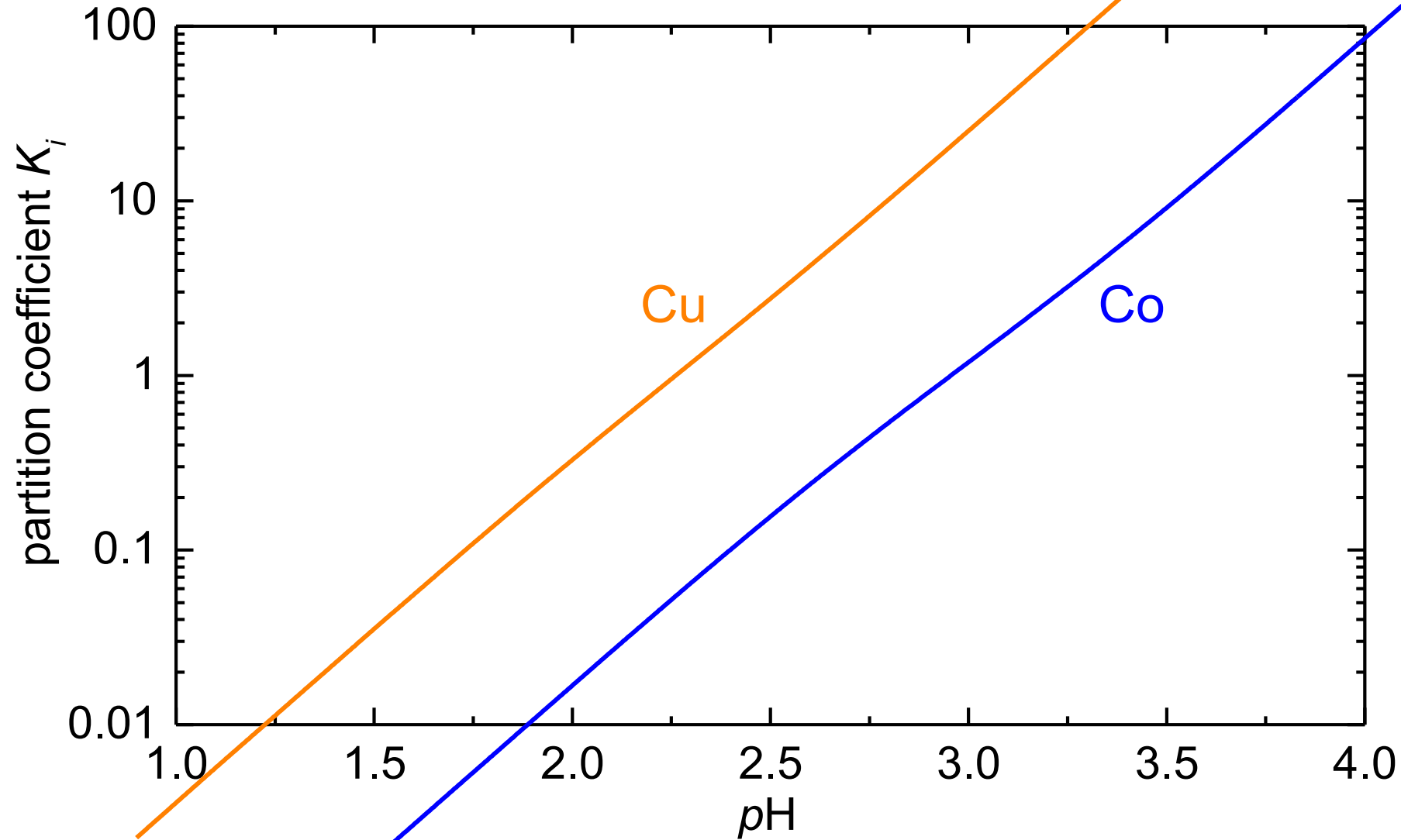
continuous experiments



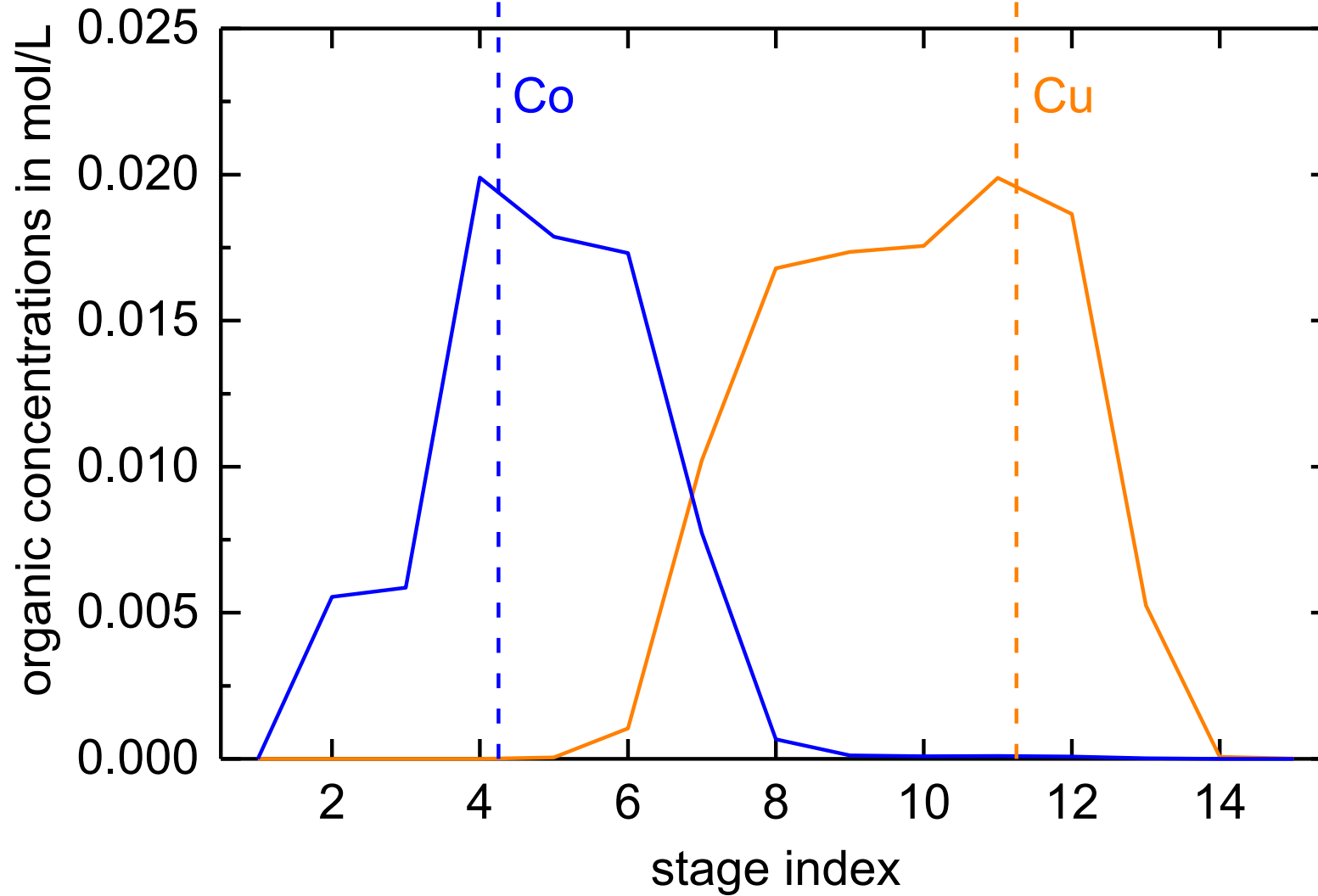
continuous experiments

extractant: D2EHPA

T = 25°C



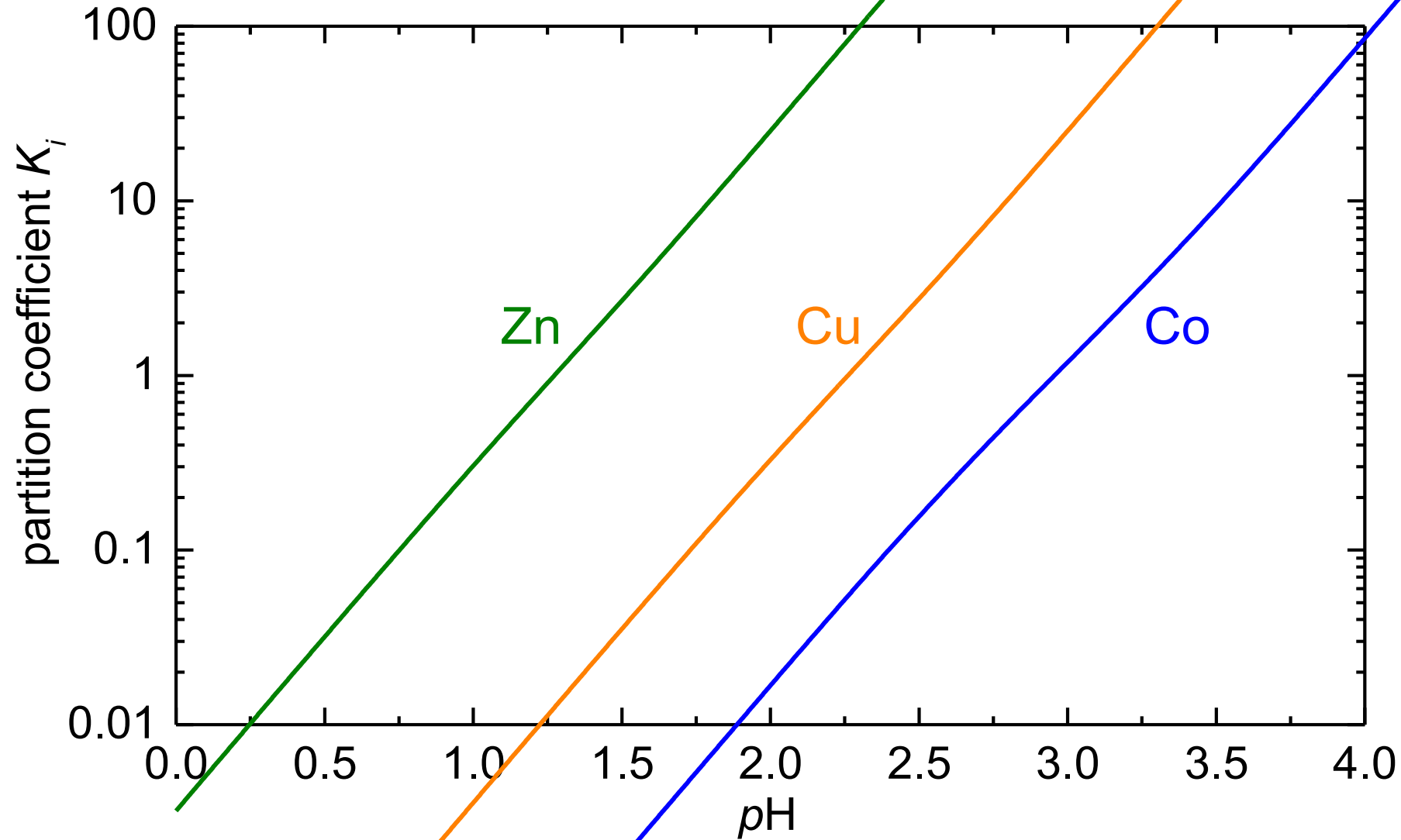
continuous experiments



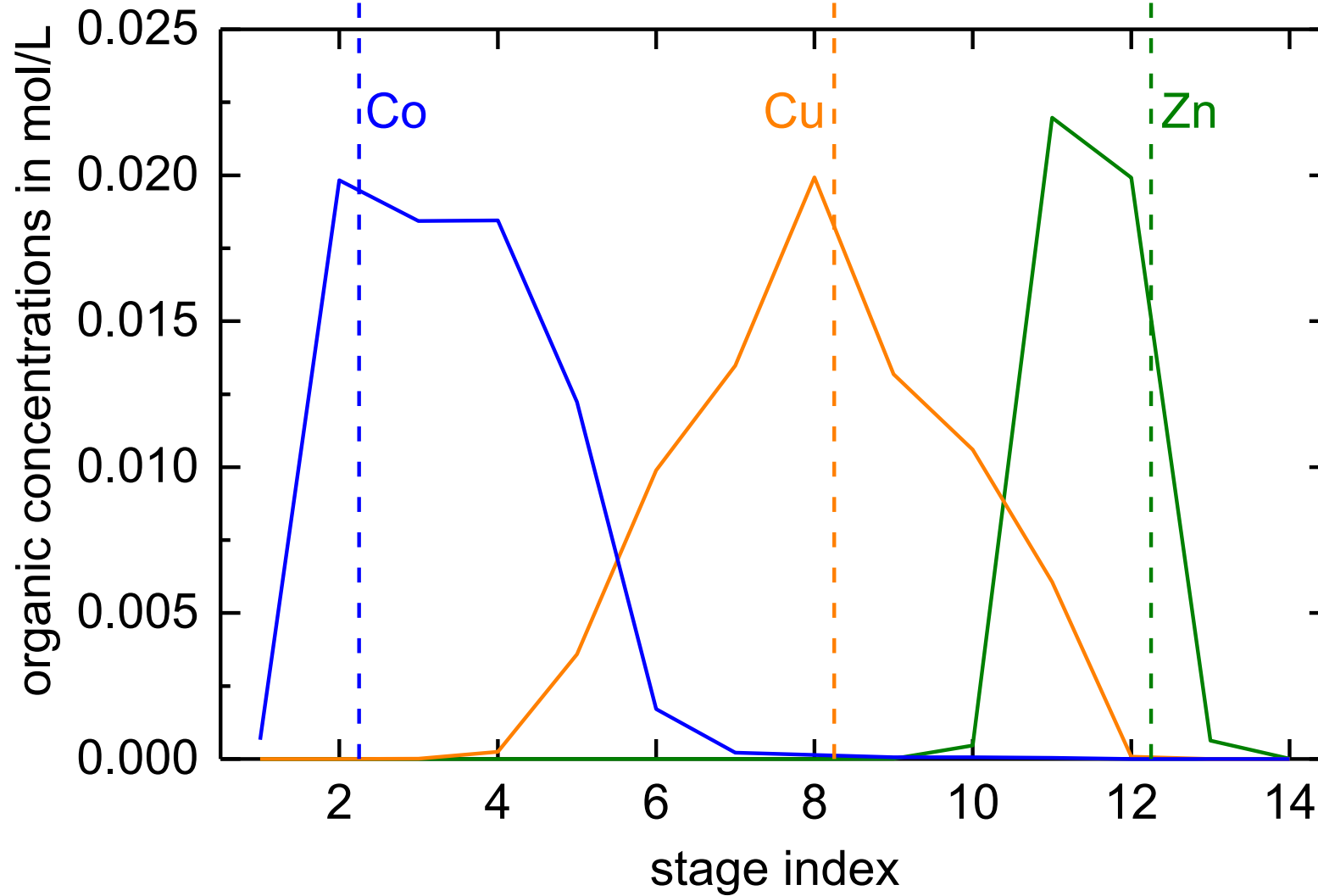
continuous experiments

extractant: D2EHPA

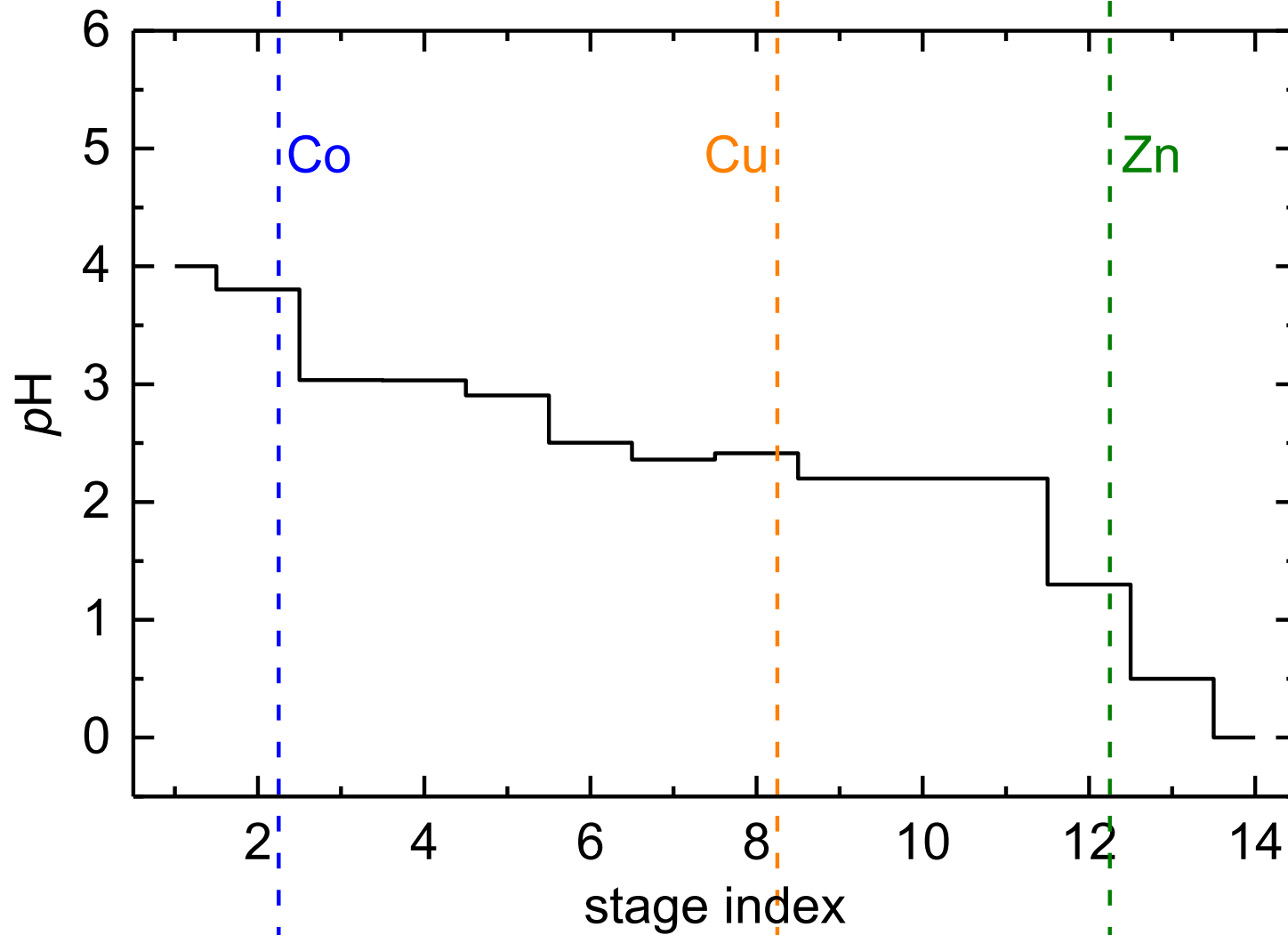
T = 25°C



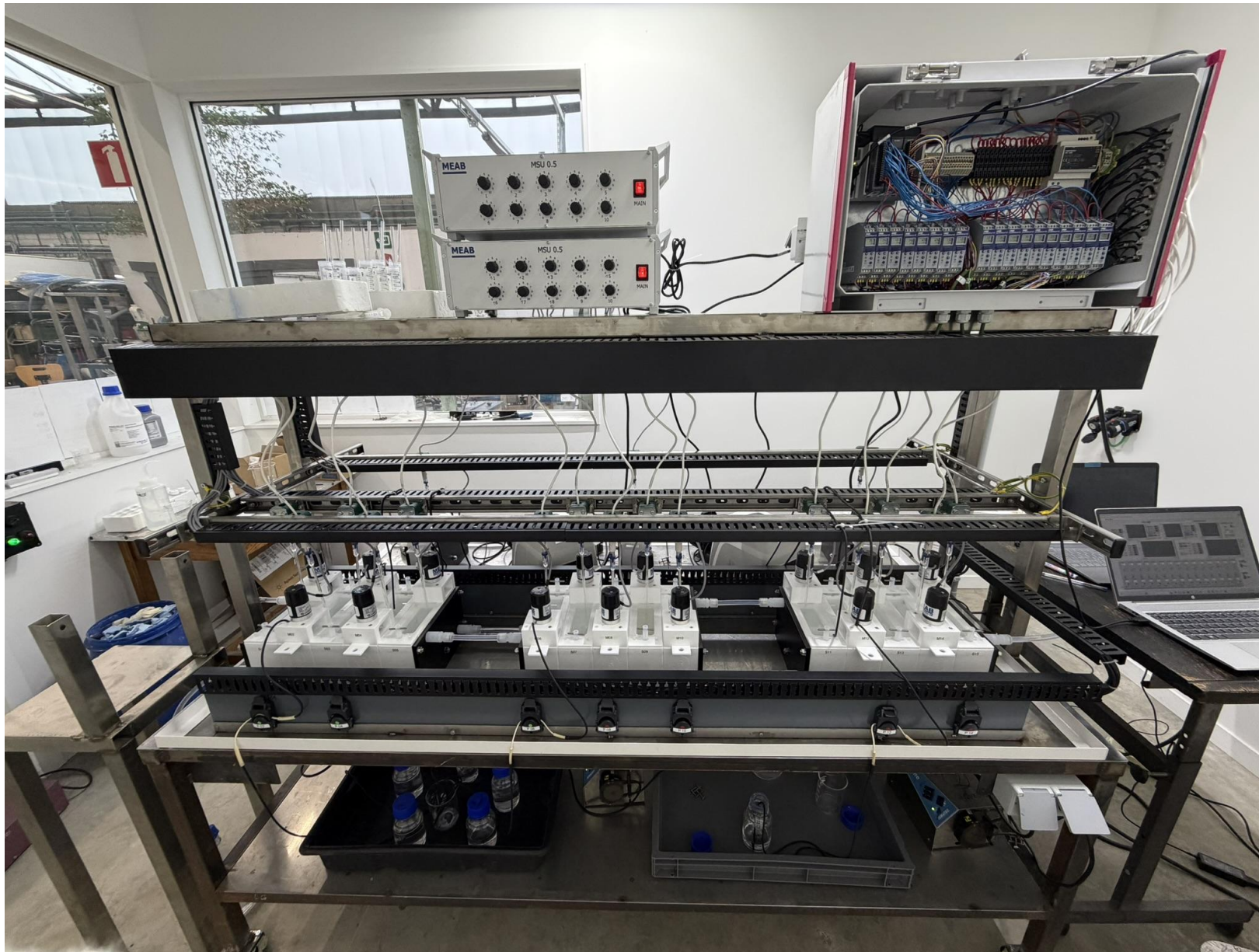
continuous experiments



pH-profile control



set-up



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**
- 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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