Jahrestreffen der ProcessNet Fachgruppen Extraktion, Phytoextrakte und Membrantechnik, Frankfurt, May 23 to 24, 2022

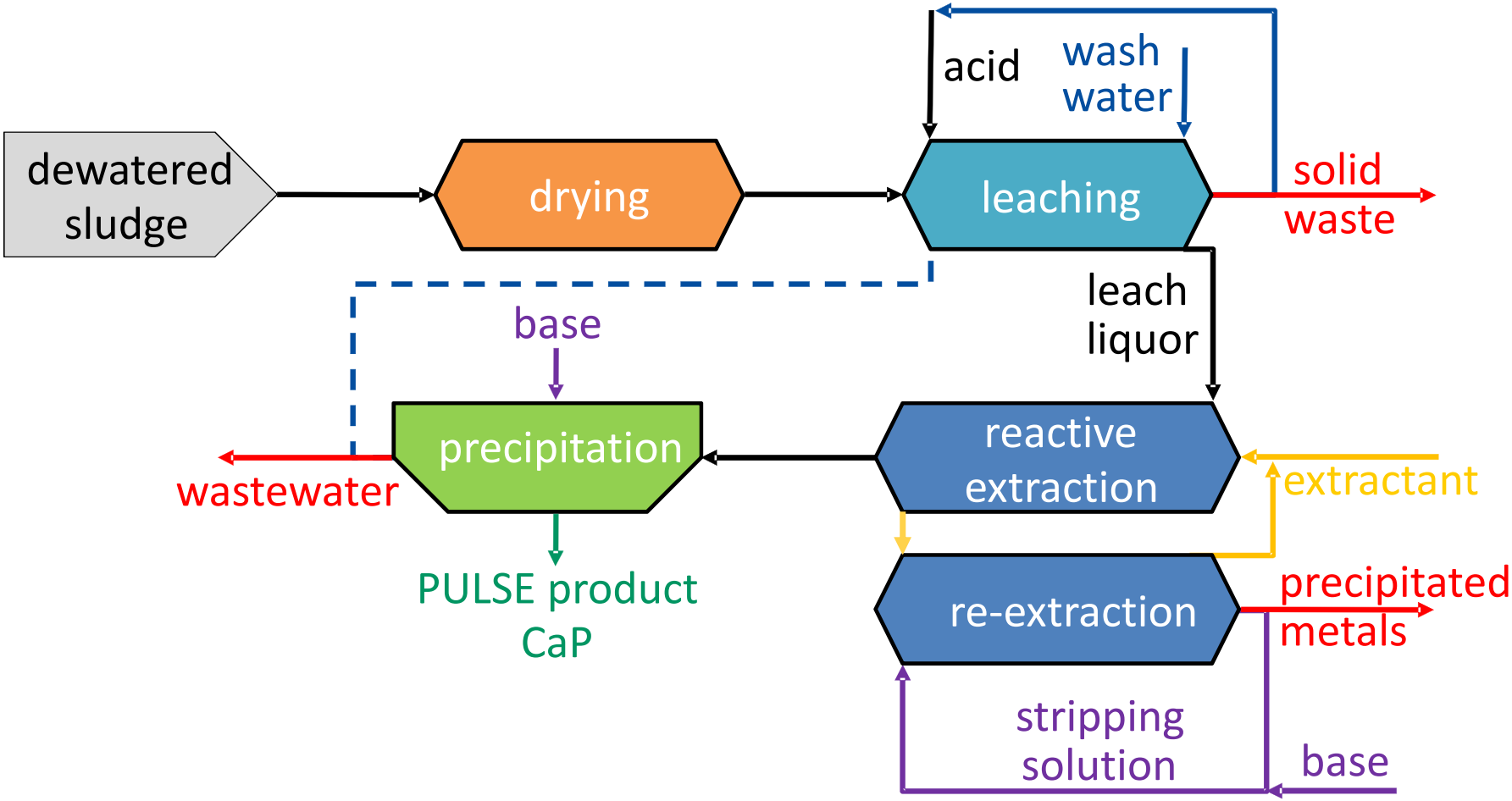
Model-Based Optimization and Pilot-Scale Validation of Phosphorous Recovery from Sewage Sludge

Z.A. Shariff, D. Leleu, A. Pfennig
andreas.pfennig@uliege.be
Products, Environment, and Processes (PEPs)
Department of Chemical Engineering
University of Liège
https://www.chemeng.uliege.be

agenda

- PULSE process and pilot
- solid-liquid-liquid equilibrium tool
- results: pilot trials and simulation
- summary

PULSE (Phosphorus University of Liege Sludge Extraction)

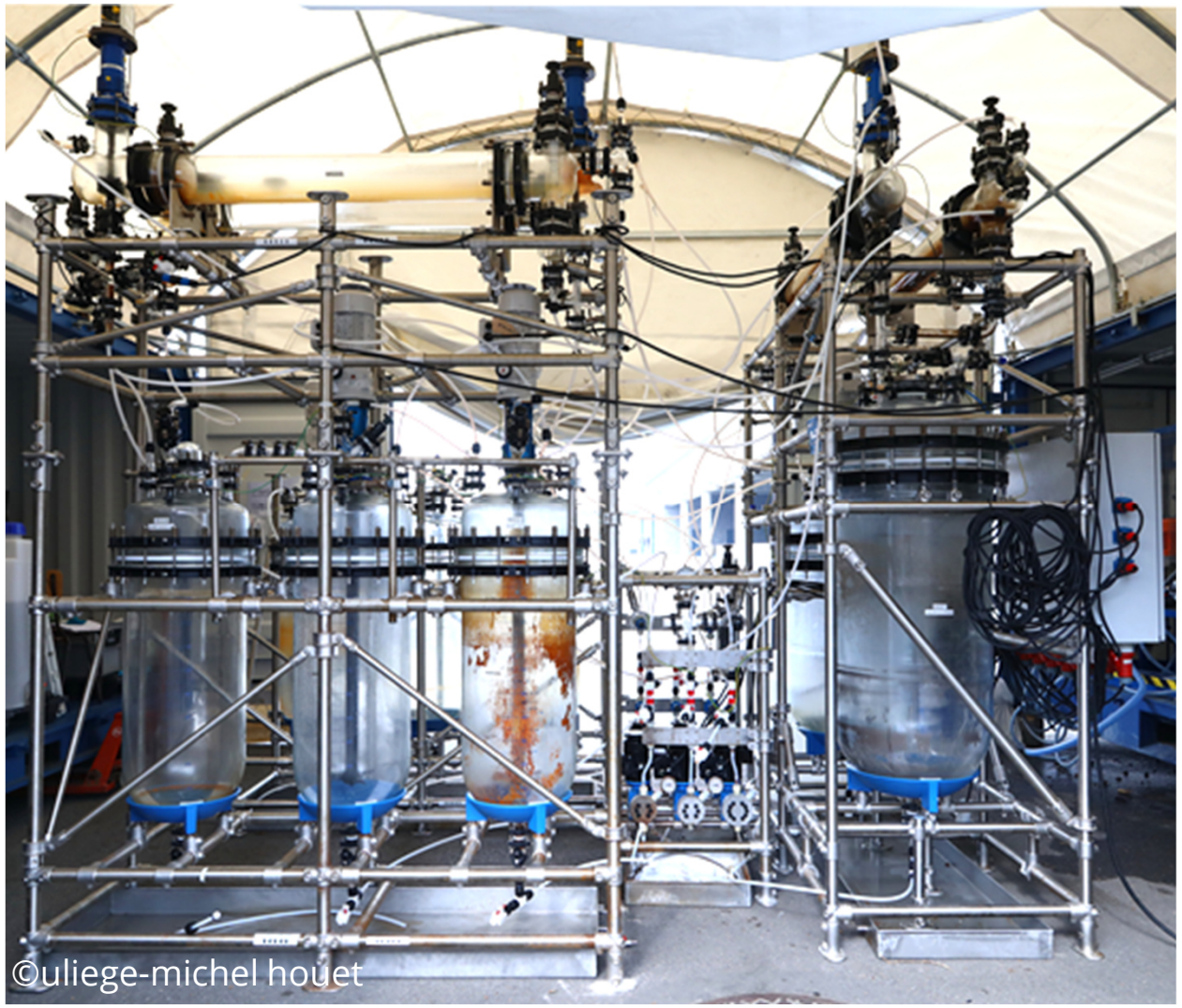


PULSE demonstrator

©uliege-michel houe

PULSE demonstrator

- mobile unit
- capacity to treat up to 80 kg of dewatered sludge per batch
- 5 horizontal mixer-settlers
- locations:
  ULiège
  Oupeye WWTP
  Bo'ness, Scotland



reactions in PULSE process (examples)

- leaching of P and metals from sludge

$$FePO_4 + 3HCl \leftrightarrow Fe^{3+} + H_3PO_4 + 3Cl^-$$

$$K_l = \frac{c_{Fe^{3+}}\, c_{H_3PO_4}\, c_{Cl^-}^3}{c_{FePO_4}\, c_{HCl}^3}$$

- speciation in aqueous solution

$$Fe^{3+} + 4Cl^- \leftrightarrow FeCl_4^-$$

$$K_a = \frac{c_{FeCl_4^-}}{c_{Fe^{3+}}\, c_{Cl^-}^4}$$

- reactive extraction of metals with organic extractant

$$\overline{R_3NHCl} + FeCl_4^- \leftrightarrow \overline{FeCl_4R_3NH} + Cl^-$$

$$K_e = \frac{c_{\overline{FeCl_4R_3NH}}\, c_{Cl^-}}{c_{\overline{R_3NHCl}}\, c_{FeCl_4^-}}$$

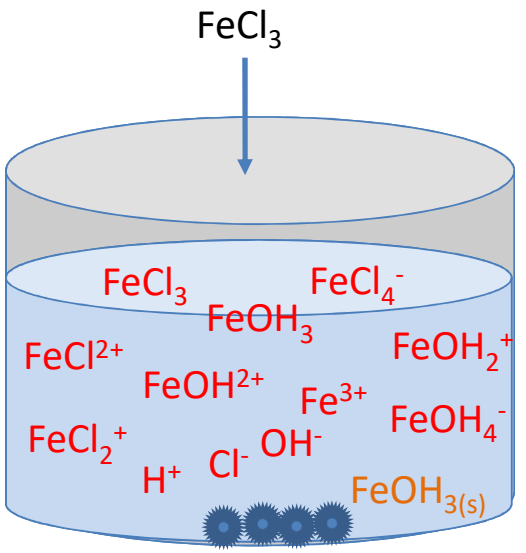
- precipitation of CaP

$$Ca^{2+} + HPO_4^{2-} \leftrightarrow CaH(PO_4)$$

$$K_p = \frac{1}{c_{Ca^{2+}}\, c_{HPO_4^{2-}}}$$

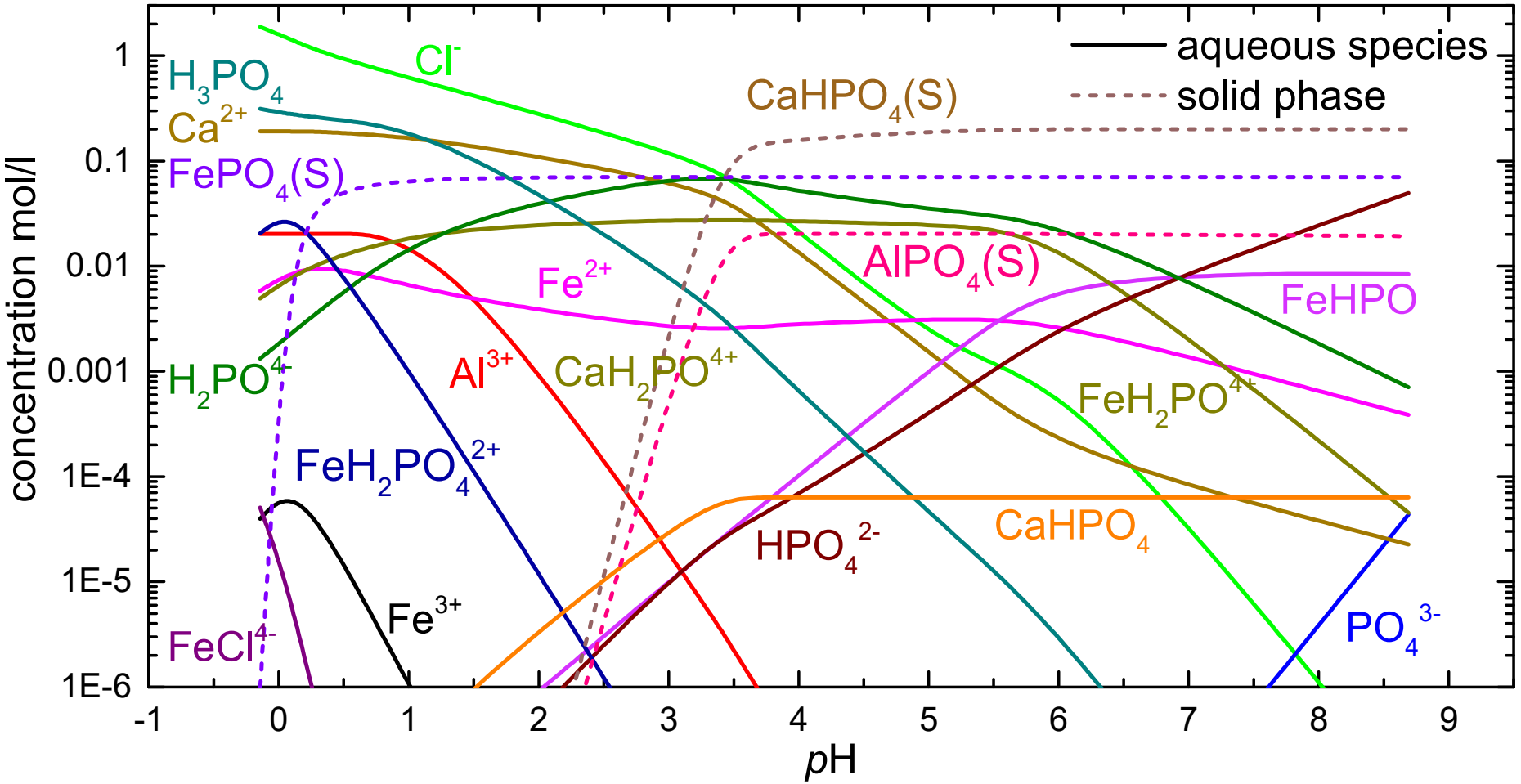
Solid-Liquid-Liquid Equilibrium tool

- charge balance
  - $0 = \sum_{i=0}^{n} c_i z_i$
- mass balances
  - $c_{tot,j} = \sum_{i=0}^{n} \nu_{i,j} c_i$
- law of mass action
  - $log K_m = \sum_{i=0}^{n} \nu_{i,r} \, log \, a_i$
- Ion Activity Product: $IAP = a_A^{\nu_1} a_B^{\nu_2}$
- Saturation Index: $SI = \log IAP - log \, K_{sp}$

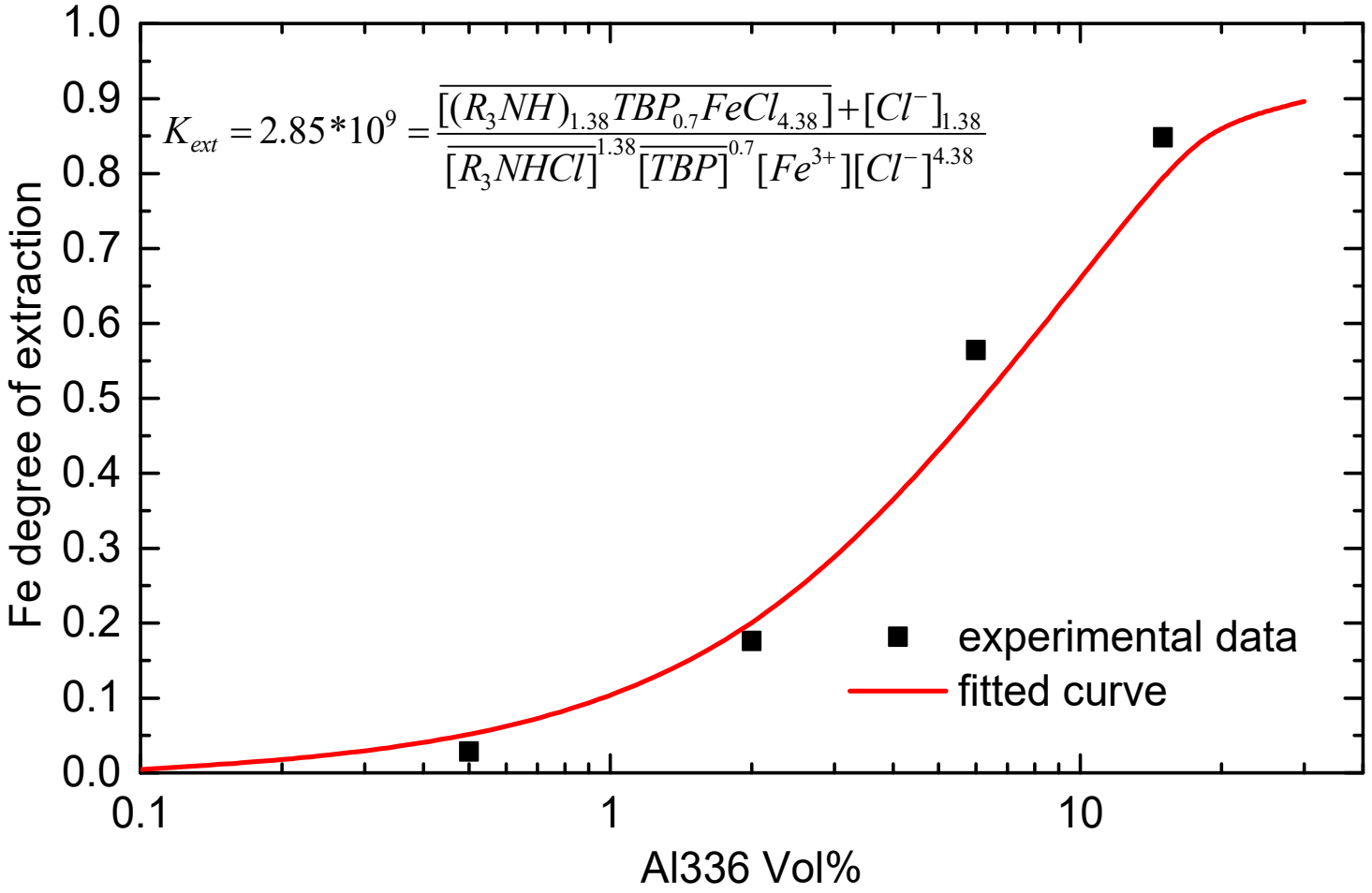


$a_i = \gamma_i c_i$ *(activity)*
$\gamma_i =$ activity coefficient
$c_i =$ concentration
$i =$ species
$j =$ master species

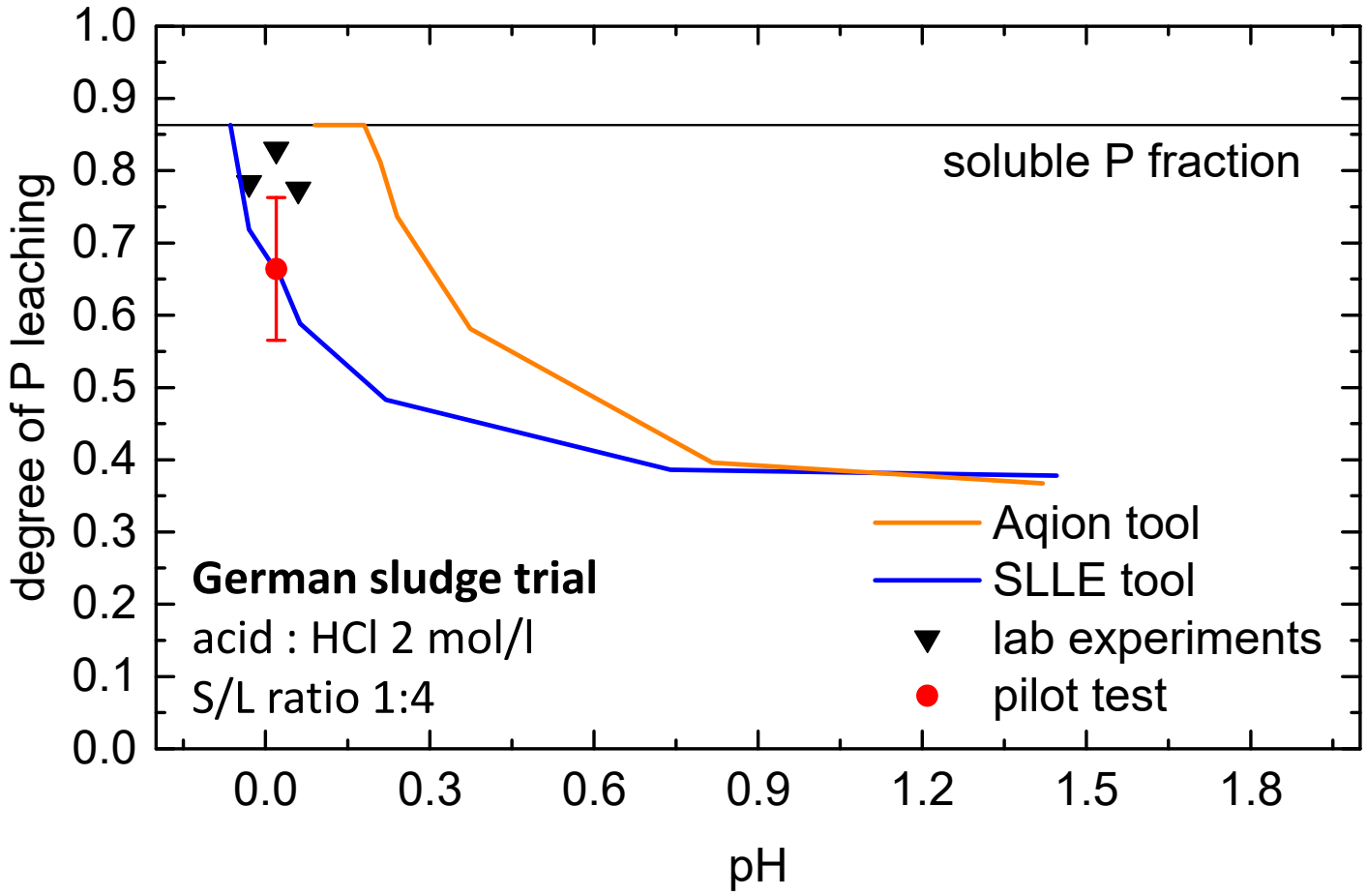
SLLE tool simulation



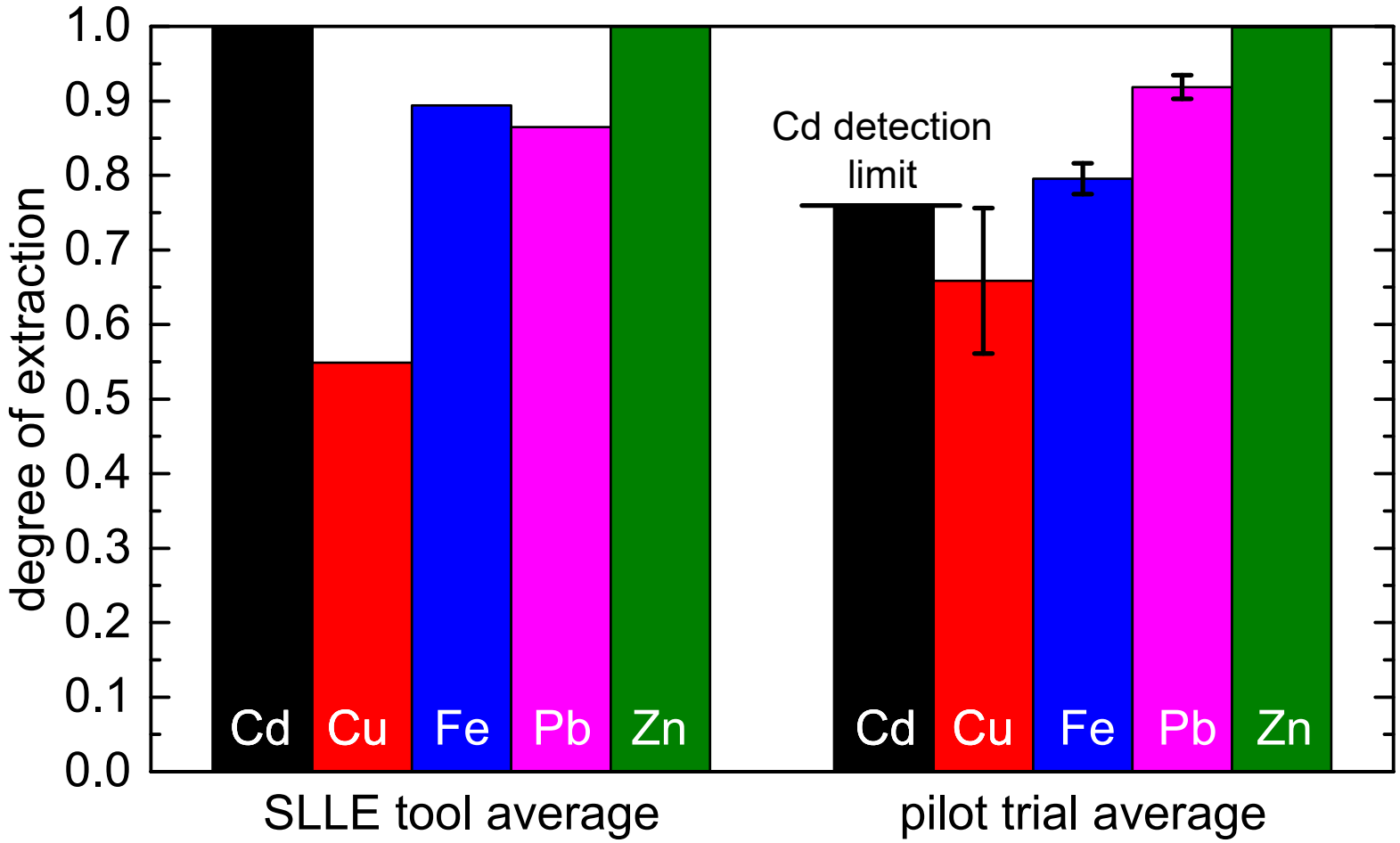
parameter fitting with SLLE tool



phosphorus leaching from sludge

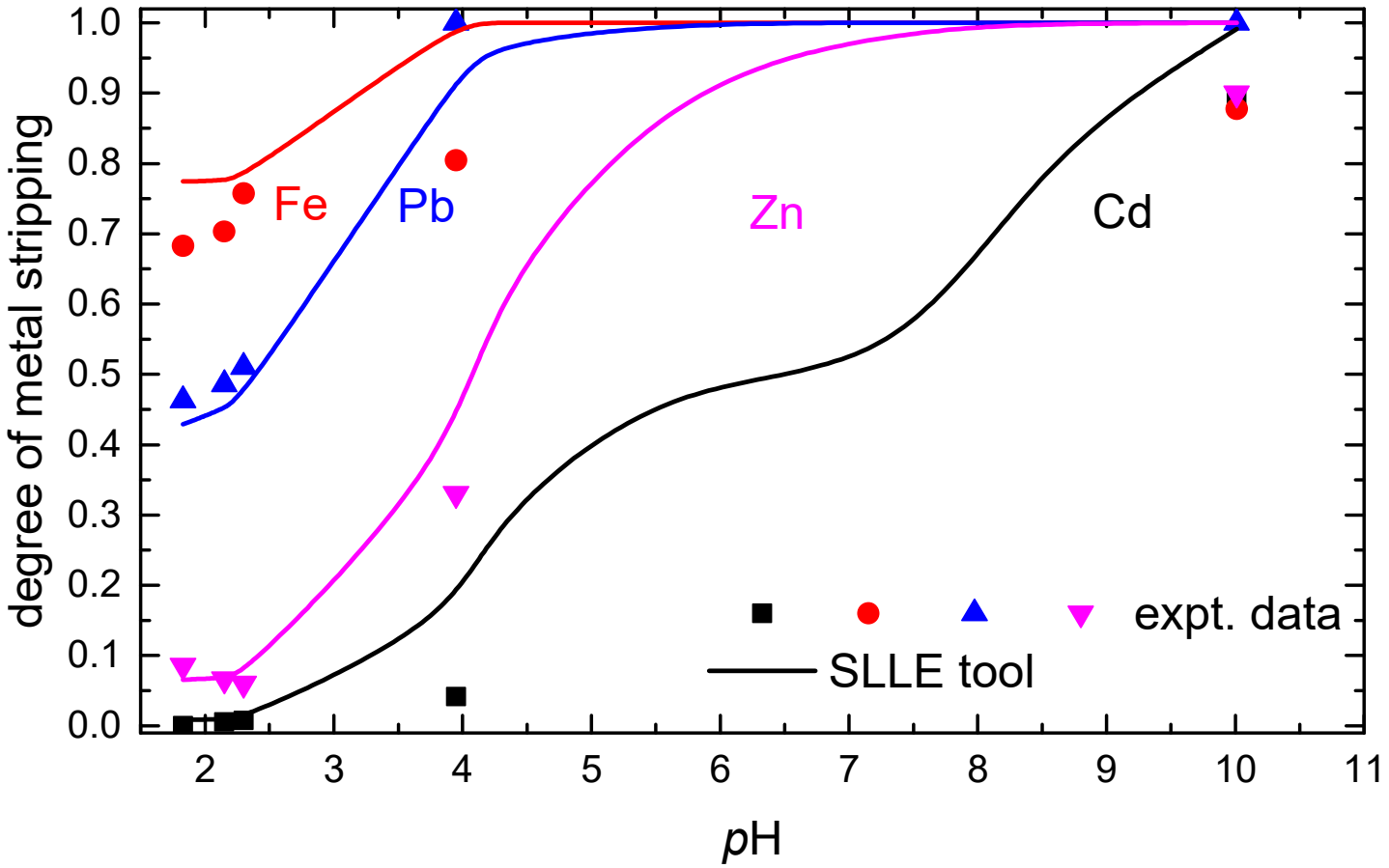


reactive extraction of metals

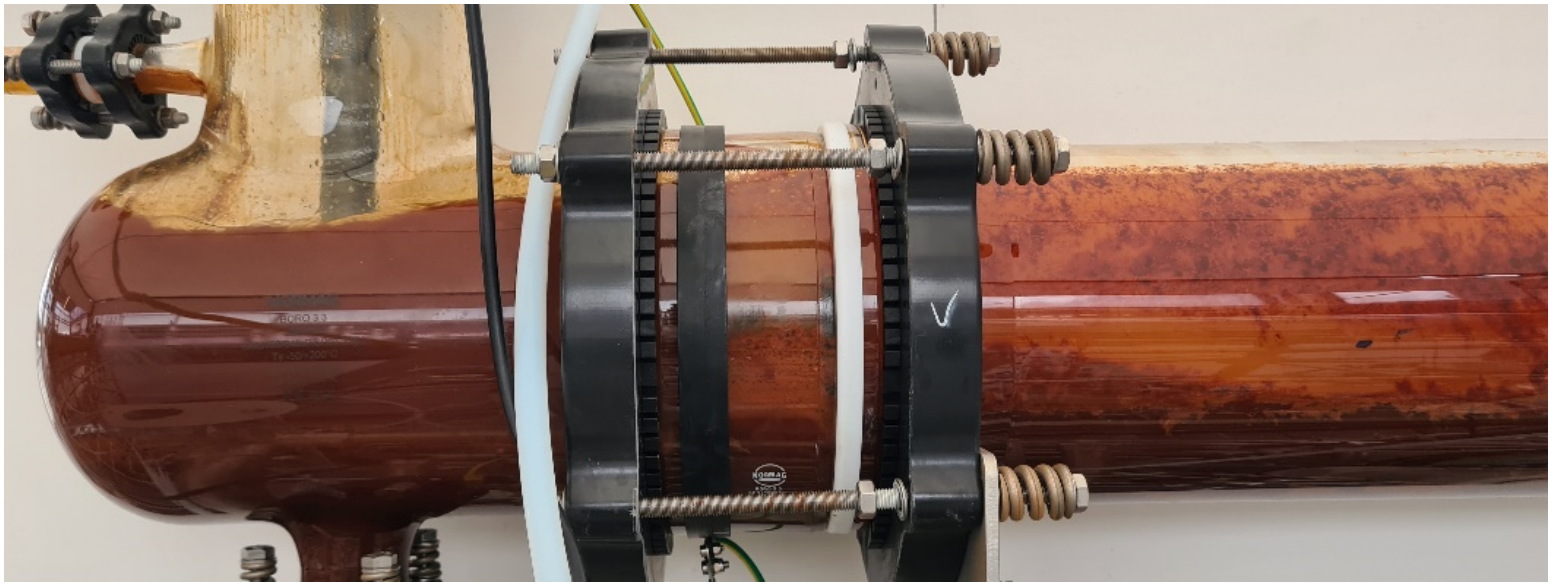


German sludge
solvent: Alamine 336,
TBP & Exxal 10,
Ketrul D80
o/a phase ratio: 1.5 to 3

solvent stripping with Ammonia solution

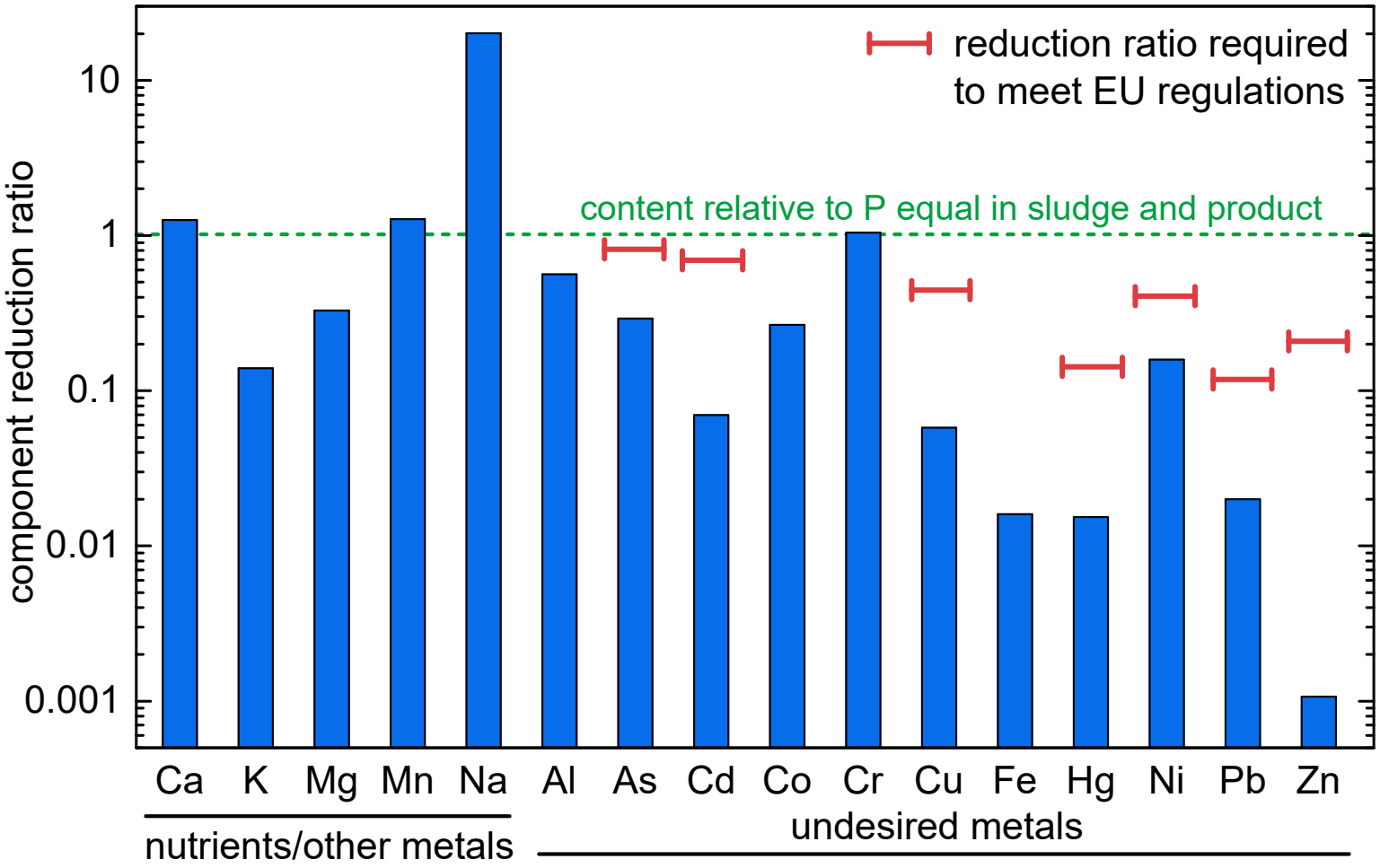


challenges and opportunities



- precipitation during extractant regeneration → challenge in phase separation
- precipitated and dissolved metals obtained during solvent regeneration can be further separated and valorized

metal depollution



final product after precipitation

dried filter cake

granulation of ground product

pilot trials summary

	German sludge	Belgian sludge	Scottish sludge
sludge source wwtp	Dortmund Deusen	Oupeye	Sterling
sludge	digested 25% DM	undigested 17 to 20% DM	digested 25% DM
P removal	Fe salt precipitation	Bio P	Bio P
operation site	at ULiège	at wwtp	Bo'ness testing facility
quantity treated	340 kg	280 kg	250 kg
P recovery	60 to 65%	60 to 65%	48 to 52%
P_2O_5	33 %	31 %	29 %

summary

- pilot trials conducted with different sludges at different sites
- use of SLLE simulation tool for optimization at each site
  - reduction in experimental work
  - optimization of resource consumption
- solvent extraction → Fe, Cd, Cu, Hg, Pb and Zn extracted
- product analysis and granulation by Prayon → sufficient P_2O_5 content and good granulation, low metal content
- good plant availability of P confirmed by pot trials from UGhent

acknowledgements

- Interreg North-West Europe and Région Wallonne SPW
- BTC Europe GmbH – BASF for providing samples of Alamine336
- TOTAL Belgium for providing samples of Ketrul D80
- Exxon Belgium for providing samples of Exxal 10
- UGhent and Prayon Belgium for ICP analyses

Jahrestreffen der ProcessNet Fachgruppen Extraktion, Phytoextrakte und Membrantechnik, Frankfurt, May 23 to 24, 2022

Model-Based Optimization and Pilot-Scale Validation of Phosphorous Recovery from Sewage Sludge

Z.A. Shariff, D. Leleu, A. Pfennig
andreas.pfennig@uliege.be
Products, Environment, and Processes (PEPs)
Department of Chemical Engineering
University of Liège
https://www.chemeng.uliege.be

References

- http://www.nweurope.eu/projects/project-search/phos4you-phosphorus-recovery-from-waste-water-for-your-life/
- Doetsch, P., Pinnekamp, Johannes, Montag, D., Rath, W., Grömping, M., 2010. Rückgewinnung von Pflanzennährstoffen, insbesondere Phosphor aus der Asche von Klärschlamm (Abschlussbericht PASCH). Institut für Siedlungswasserwirtschaft der RWTH Aachen, Aachen.
- Bednarz, A., Rüngeler, B. and Pfennig, A. (2014), Use of Cascaded Option Trees in Chemical-Engineering Process Development. Chemie Ingenieur Technik, 86: 611-620. https://doi.org/10.1002/cite.201300115
- Morel, F., & Hering, J. G., 1993. Principles and applications of aquatic chemistry. New York (N.Y.): Wiley
- Bogdan, A.; Robles-Aguilar, A.A.; Liang, Q.; Pap, S.; Michels, E.; Meers, E. Substrate-Driven Phosphorus Bioavailability Dynamics of Novel Inorganic and Organic Fertilizing Products Recovered from Municipal Wastewater—Tests with Ryegrass. Agronomy 2022, 12, 292. https://doi.org/10.3390/agronomy12020292