Nutrient recovery treatment train set-up using a new model library and global sensitivity analysis

RR2015

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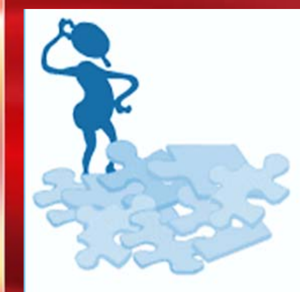
Presentation outline

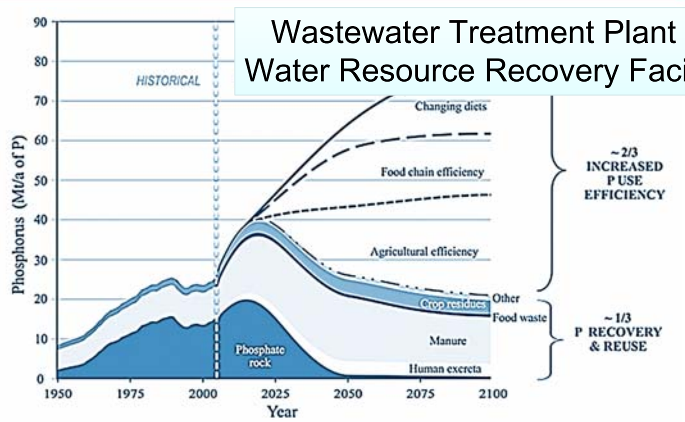
- Problem statement
- Objectives
- Model development and validation
- Global sensitivity analysis and process optimization
- Conclusions and recommendations

PROBLEM STATEMENT



Problem statement

Wastewater Treatment Plant → Water Resource Recovery Facility



Cordell et al. (2011)

OBJECTIVES

Nutrient recovery processes

- Precipitation → struvite, calciumphosphates
- Ammonia stripping → NH_3
- Acidic air scrubbing → ammonium sulphates
- Membrane filtration → H_2O, N-K concentrates
- Biomass production and harvest → biomass
- …

⇒ Mainly physicochemical unit processes !

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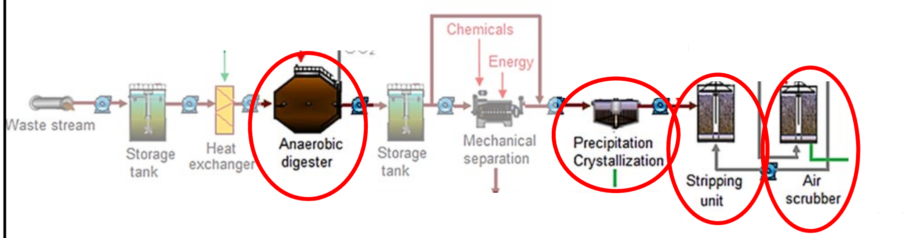
Potential flow diagram of WRRF for nutrient and energy recovery



Potential flow diagram of WRRF for nutrient and energy recovery

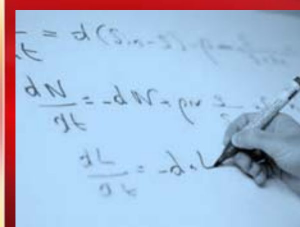
<u>Problem</u>: Optimal combination different for each waste flow

<u>Research question</u>: What is the optimal combination of unit processes and their operational conditions?

- Given: Particular waste stream
- Optimal:
  - Maximal resource recovery (nutrients, energy)
  - Minimal energy and chemical requirements

Approach = Mathematical models

MODEL DEVELOPMENT



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Generic nutrient recovery model (NRM) library

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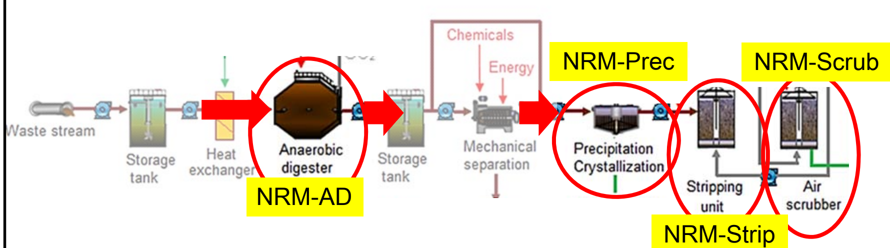

NRM = Nutrient Recovery Model

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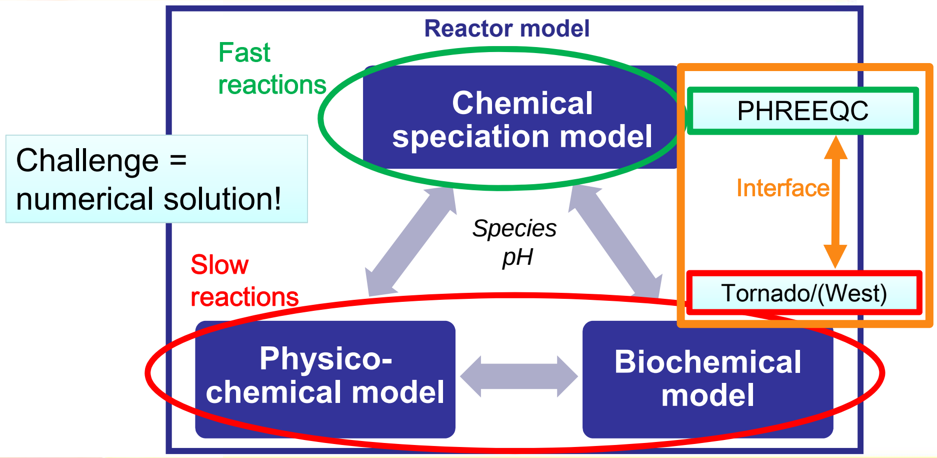
Combined three-phase physicochemical-biological models



Important findings & contributions

- Geochemical databases incomplete:
  - ➔ Extended database for nutrient recovery, e.g. $(NH_4)_2SO_4$, $AlPO_4$, NaH_2PO_4, ...
- Speed-up of model simulations:
  - Selective database reduction (> 3000 to 77 species)
    - ⇒ Speed-up of 5
  - Tight model coupling (software development)
    - ⇒ Speed-up of 10

Biochemical transformation model (NRM-AD)

BIOCHEMICAL	PHYSICOCHEMICAL
• ADM 1 (19): Disintegration, hydrolysis, acidogenesis, acetogenesis, methanogenesis *Batstone et al. (2002)*	• Acid-base systems (9)
• Extension 1 (8): Sulfurgenesis *Knobel & Lewis (2002)*	• Ion-pairing (43)
• Extension 2: Inclusion of new components in stoich. matrix ADM 1 (P, K, S)	• Precipitation-dissolution (23)
• Extension 3 (4): EBPR sludge (*Ikumi, 2011)*	• Gas-liquid exchange (7)

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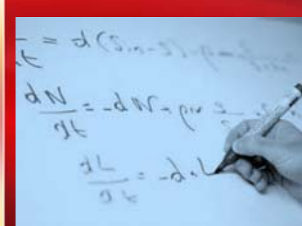
MODEL VALIDATION



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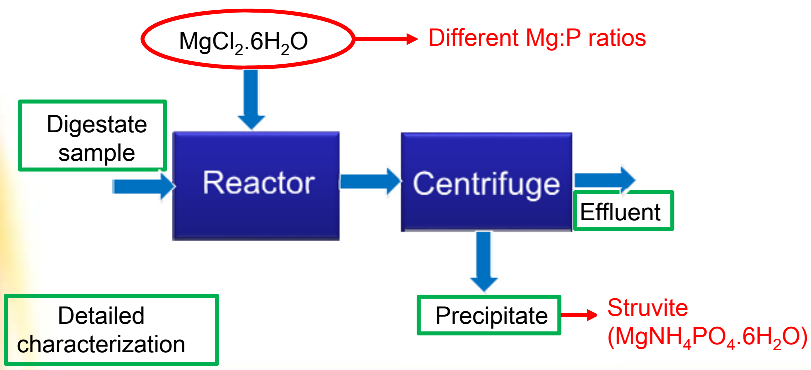
Model validation: example NRM-Prec

- Lab-scale experiments P-precipitation



Model validation: NRM-Prec

- Experimental vs. simulation results (after 12h)

Mg:P	Digestate 1 % P-recovery			Digestate 2 % P-recovery	
	Experim.	Original PHREEQC	Extended PHREEQC	Experim.	Extended PHREEQC
1:1	41	95.60	41.32	28	27.76
2:1	44	97.91	43.62	29	29.29

NaH_2PO_4

⇒ Good agreement with experimental results at steady state

⇒ Importance of a detailed chemical solution speciation and input characterization!

GLOBAL SENSITIVITY ANALYSIS AND PROCESS OPTIMIZATION

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Global sensitivity analysis (GSA)

- Selection of factors with highest impact on model outputs (= objective for further study)

Acquired understanding

Optimal treatment train configuration

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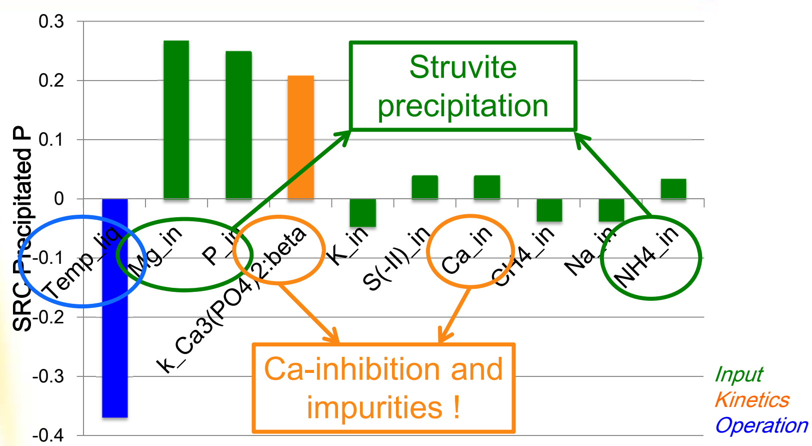
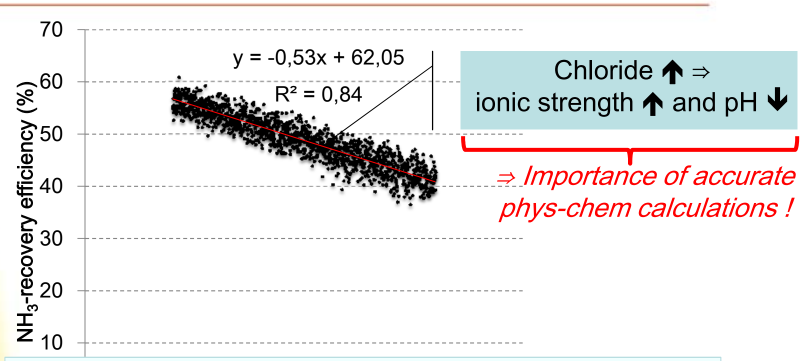
NRM-Prec: Factor ranking

SRC Precipitated P manure



NRM-Strip: Example GSA results

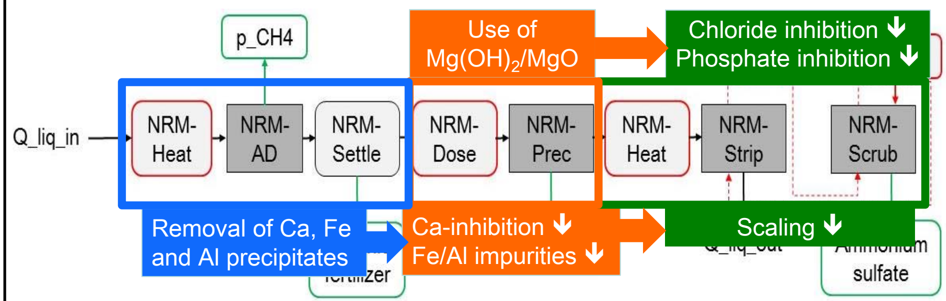
Impact chloride on NH_3-recovery efficiency



⇒ Practical implication for treatment train:
If preceding P-precipitation
use $Mg(OH)_2$/MgO instead of $MgCl_2$

Treatment train configuration
Target = struvite + ammoniumsulfate

OPTIMAL OPERATING CONDITIONS



Consumables → Costs | *Recovered products → Revenues*

CONCLUSIONS AND RECOMMENDATIONS

Main conclusions

- Generic nutrient recovery model (NRM) library created
- Default parameters + proper input characterization
  ➔ good agreement
  with steady state experimental results
- Global sensitivity analysis
  ➔ optimal treatment train configuration
- Model-based treatment train optimization
- PhD available from http://modeleau.fsg.ulaval.ca

Acknowledgements