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Modeling Reactions Between Activated Sludge Fractions and Ozone to Optimize Biosolids Reduction Processes

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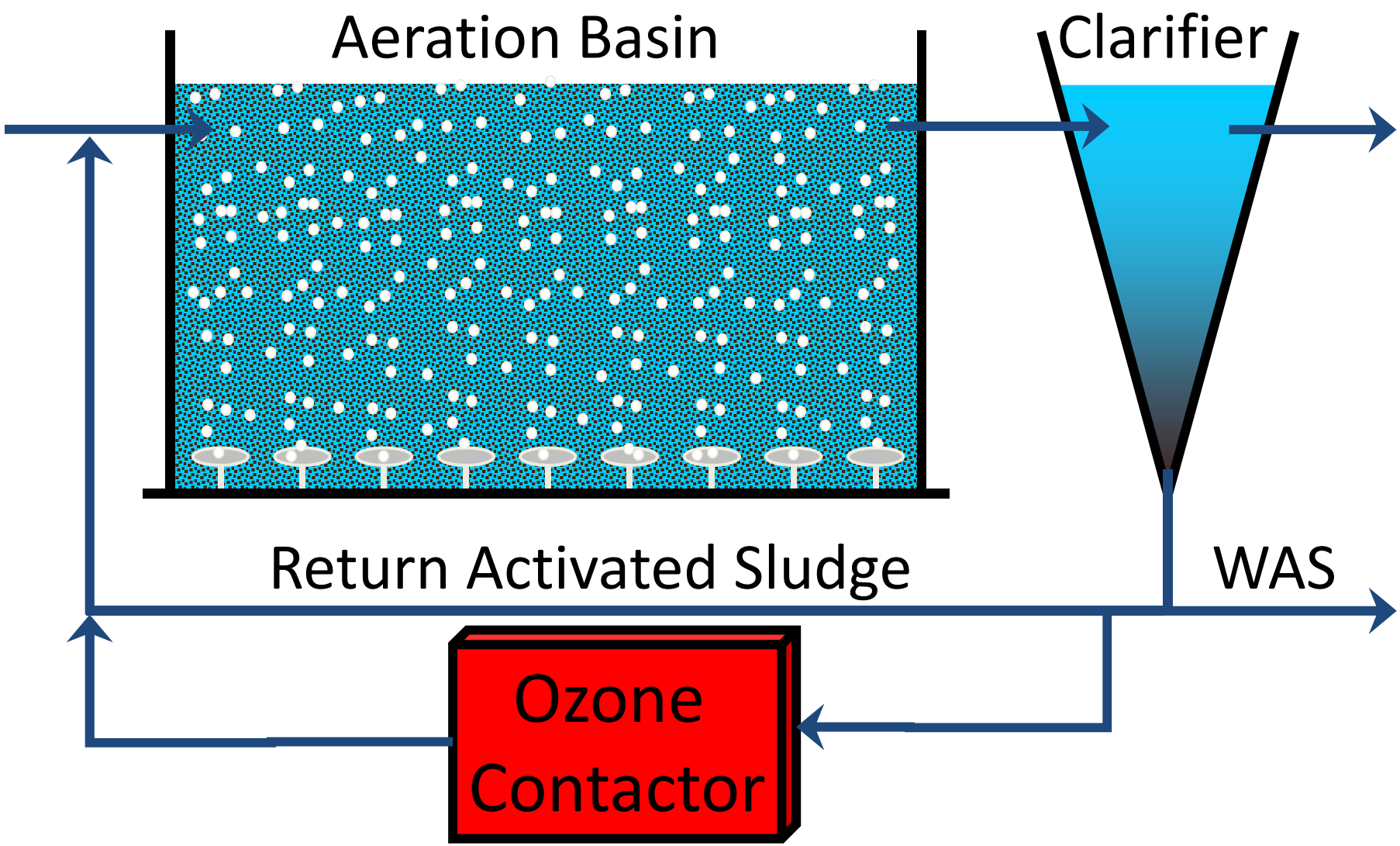
Introduction

- Cost of biosolids disposal is rising in North America due to disposal options and environmental taxes.
  - For our partner wastewater treatment facility, disposal cost more than doubled over the last 7 years.
- In some Canadian jurisdictions (e.g., Province of Quebec), landfilling of biosolids will be banned by 2020.

➢ Thus, facilities want to reduce biosolids production.

- Air Liquide tries to open the North American market, but imprecision in performance predictions remain an obstacle.
- New Canadian laws require proper nitrification even during winter (water temperature <<10°C)
  - Is nitrification affected by RAS-ozonation?

Schematics of RAS Ozonation Unit

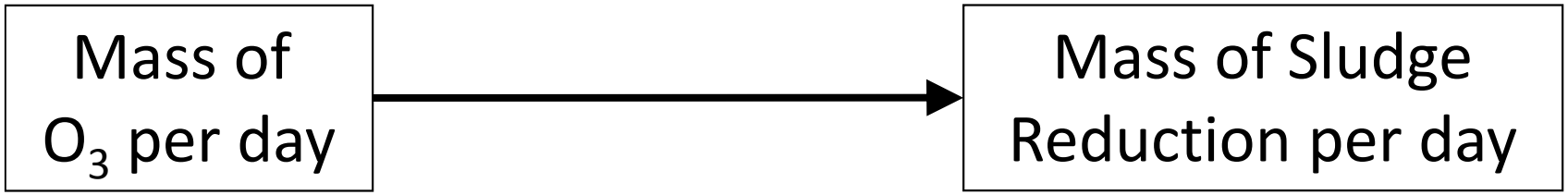


Objectives

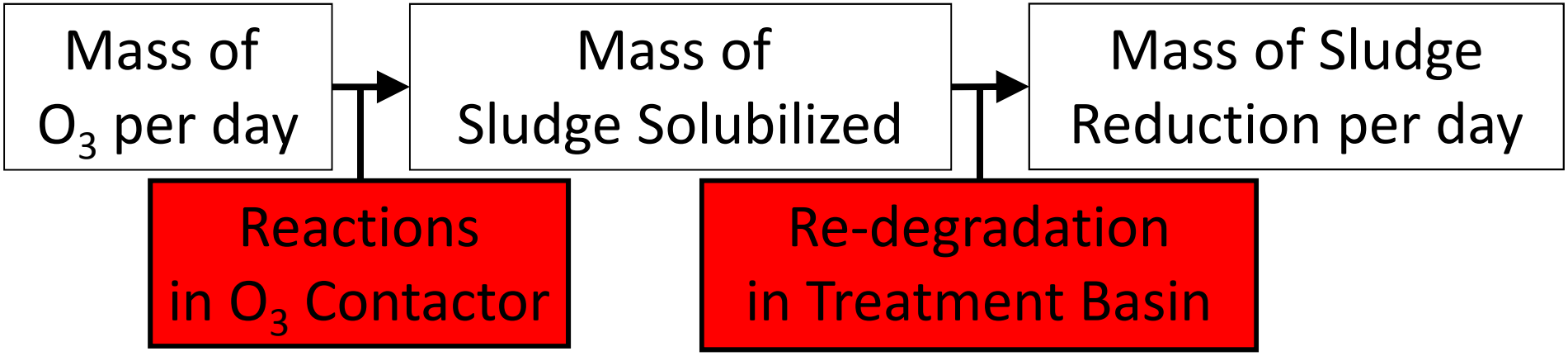
- Develop and validate a mathematical model to improve performance predictions.
- Perform a global sensitivity analysis to understand the impact of biological processes on biosolids reduction.
- Perform a scenario analysis on nitrification stability to identify threatening operation conditions.

Concept of Ozone Unit Performance

- Technical/economic performance



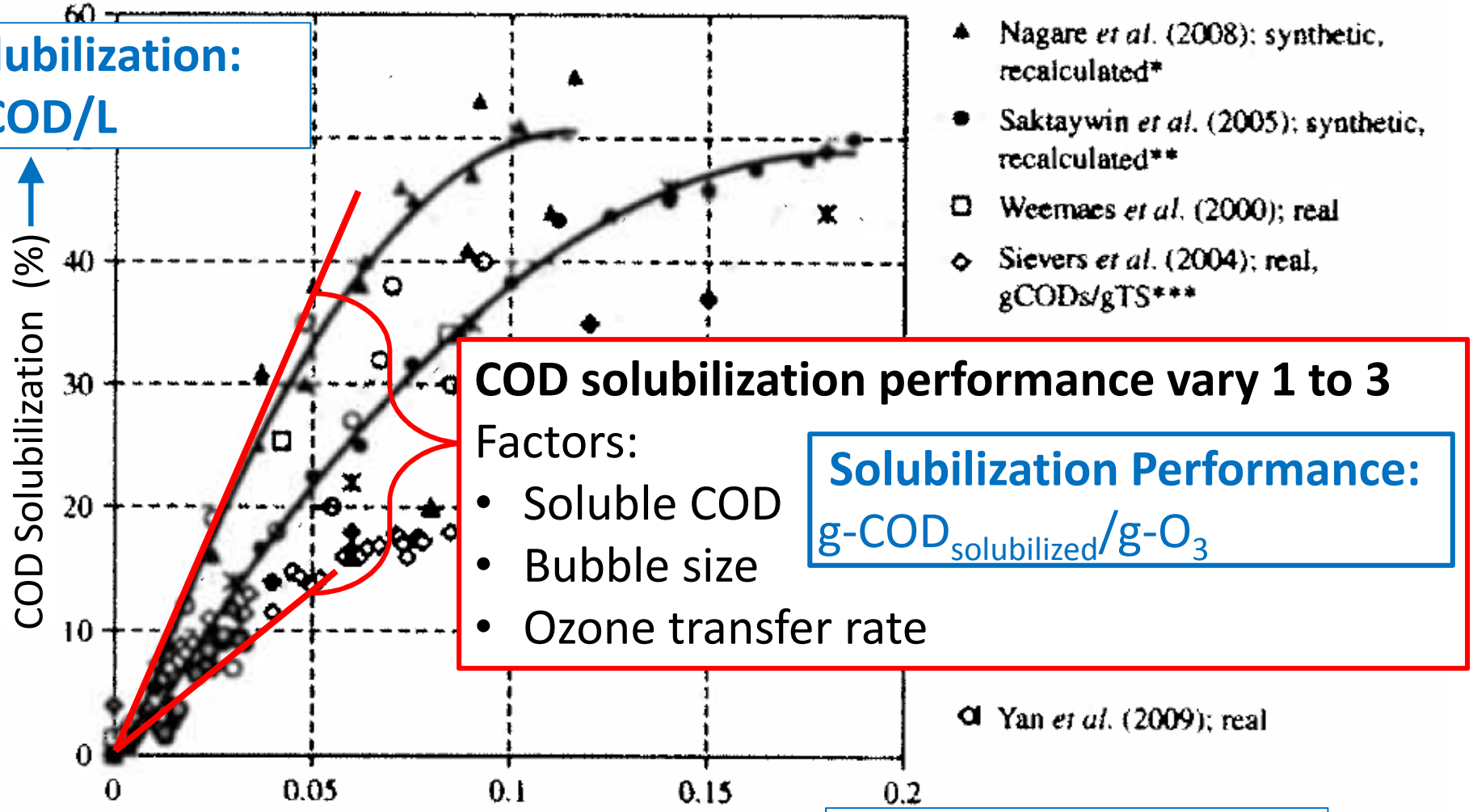
- True performance evaluation steps



O_3 Contactor Performance by COD Solubilization

Note: total COD and total suspended solids (TSS) are related

Solubilization: g-COD/L



COD solubilization performance vary 1 to 3

Factors:

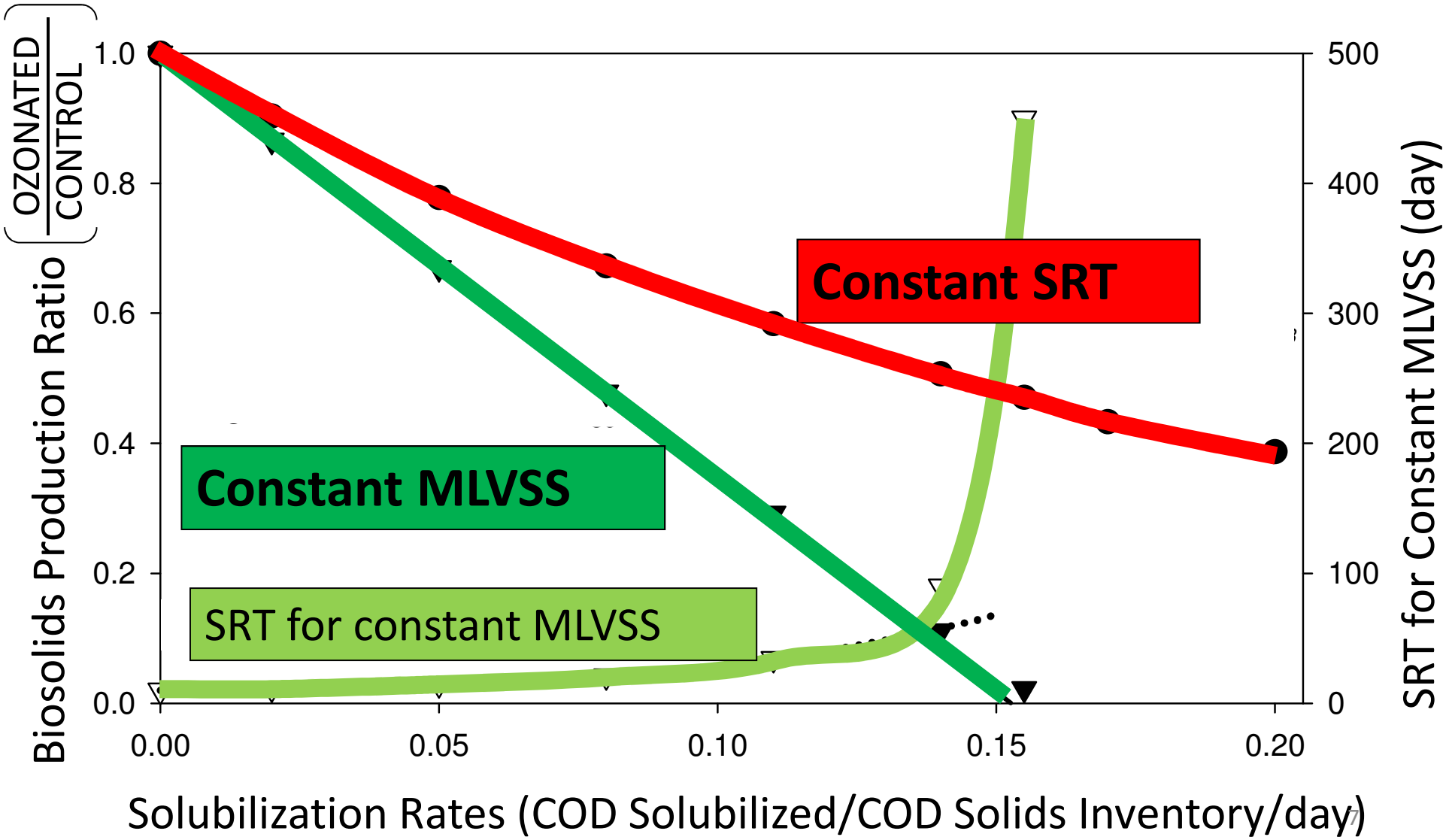
- Soluble COD
- Bubble size
- Ozone transfer rate

Solubilization Performance: $g\text{-}COD_{solubilized}/g\text{-}O_3$

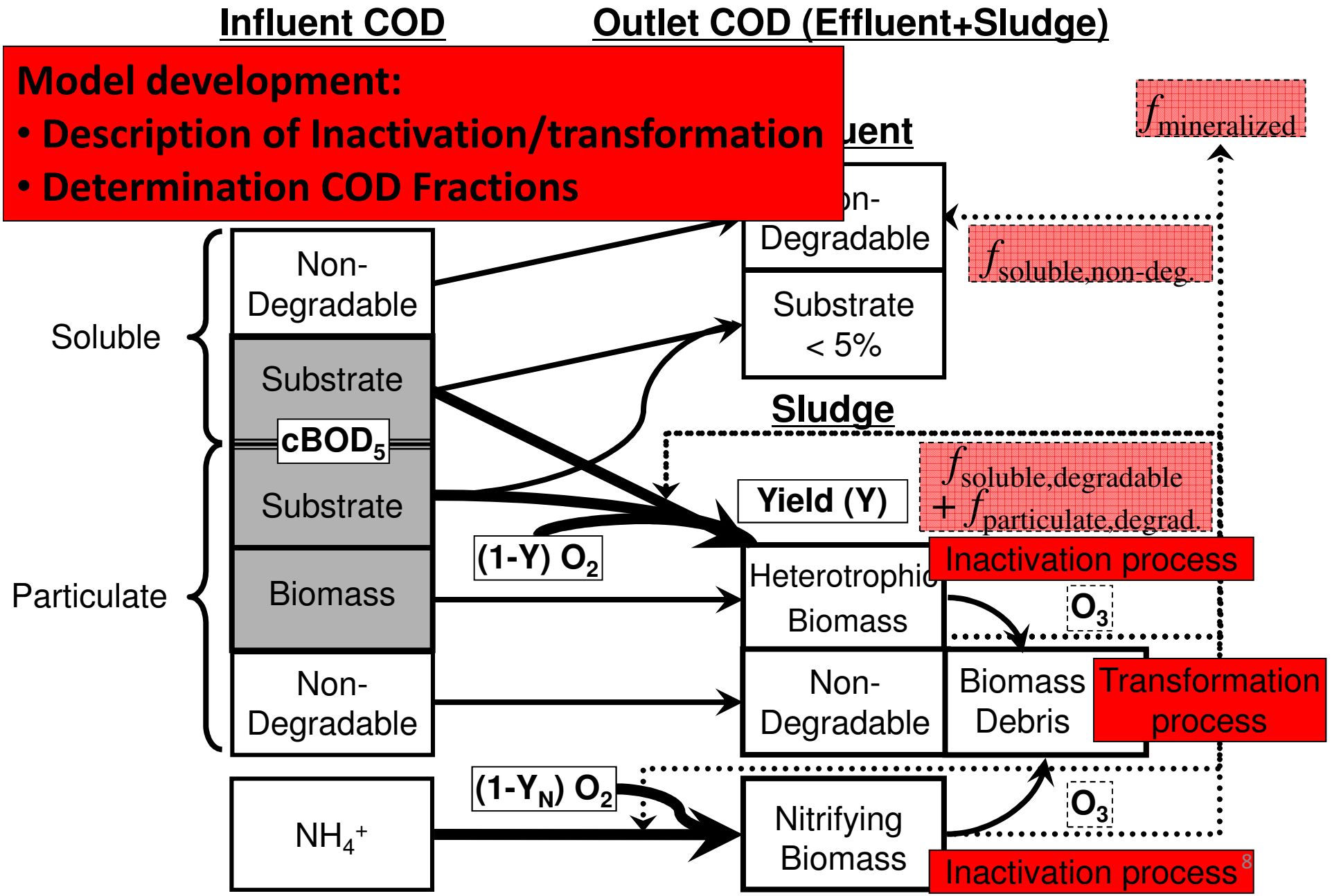
Ozone dose: $g\text{-}O_3/L$

Folodari, Andreottola and Ziglio (2010) Sludge Reduction Technologies in Wastewater Treatment Plants

Biosolids Reduction with Increasing Solubilization Rate (COD Solubilized/Solids Inventory/day)

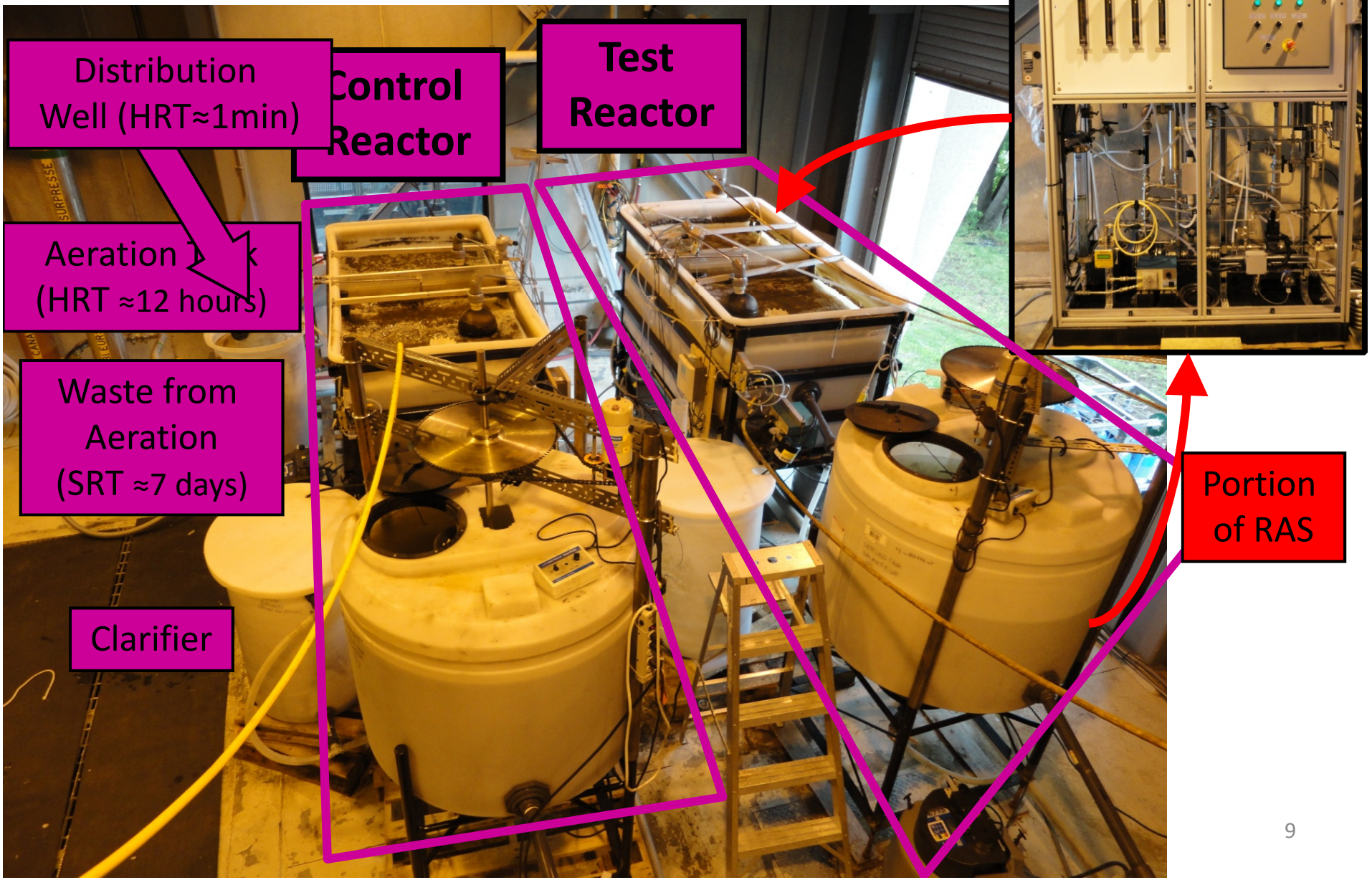


Model of Activated Sludge + RAS-Ozonation



Pilot-Scale Parallel Reactors

(1 m^3 Aeration Tank)



Modeling Development and Validation

- Description of inactivation
  - kinetics and stoichiometry
- Model prediction of pilot-scale experiments' data
  - Same installation studied in 3 different years

Modeling Effects of Ozone on RAS Biomass

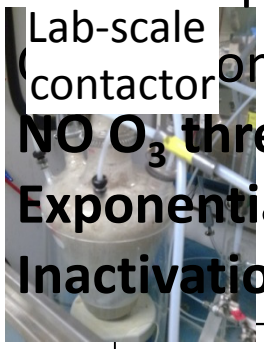
Is biomass inactivated at low O_3 dose?

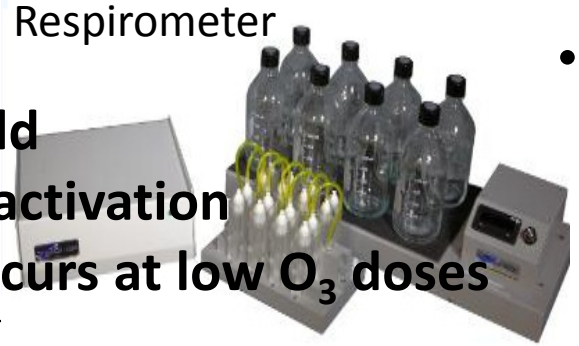
- Others reported dose threshold
- Others reported linear inactivation
- Our observation:

NO O_3 threshold

Exponential inactivation

Inactivation occurs at low O_3 doses

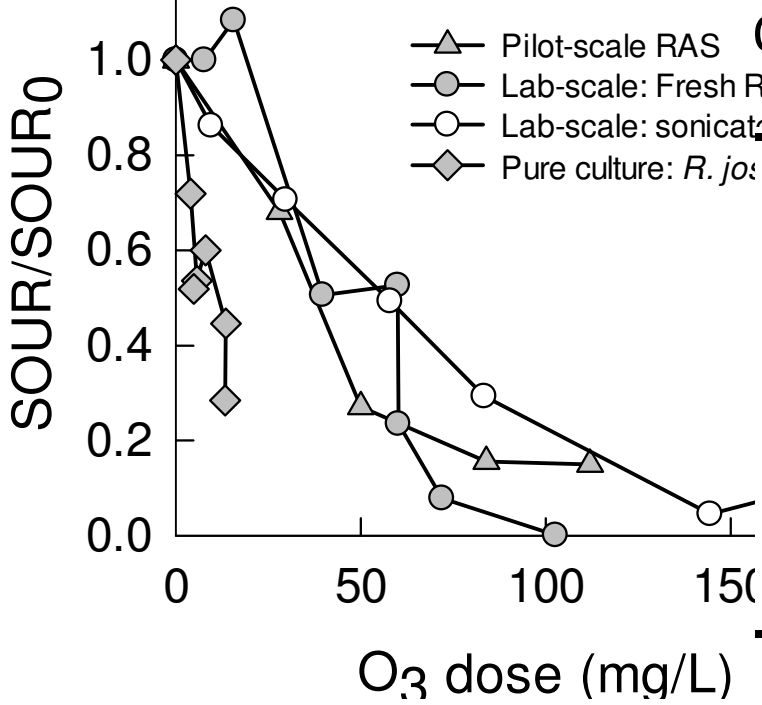




Does inactivation solubilize biomass?

- From literature: ozone solubilizes cellular content…
- Conclusion:

Little COD solubilization upon inactivation



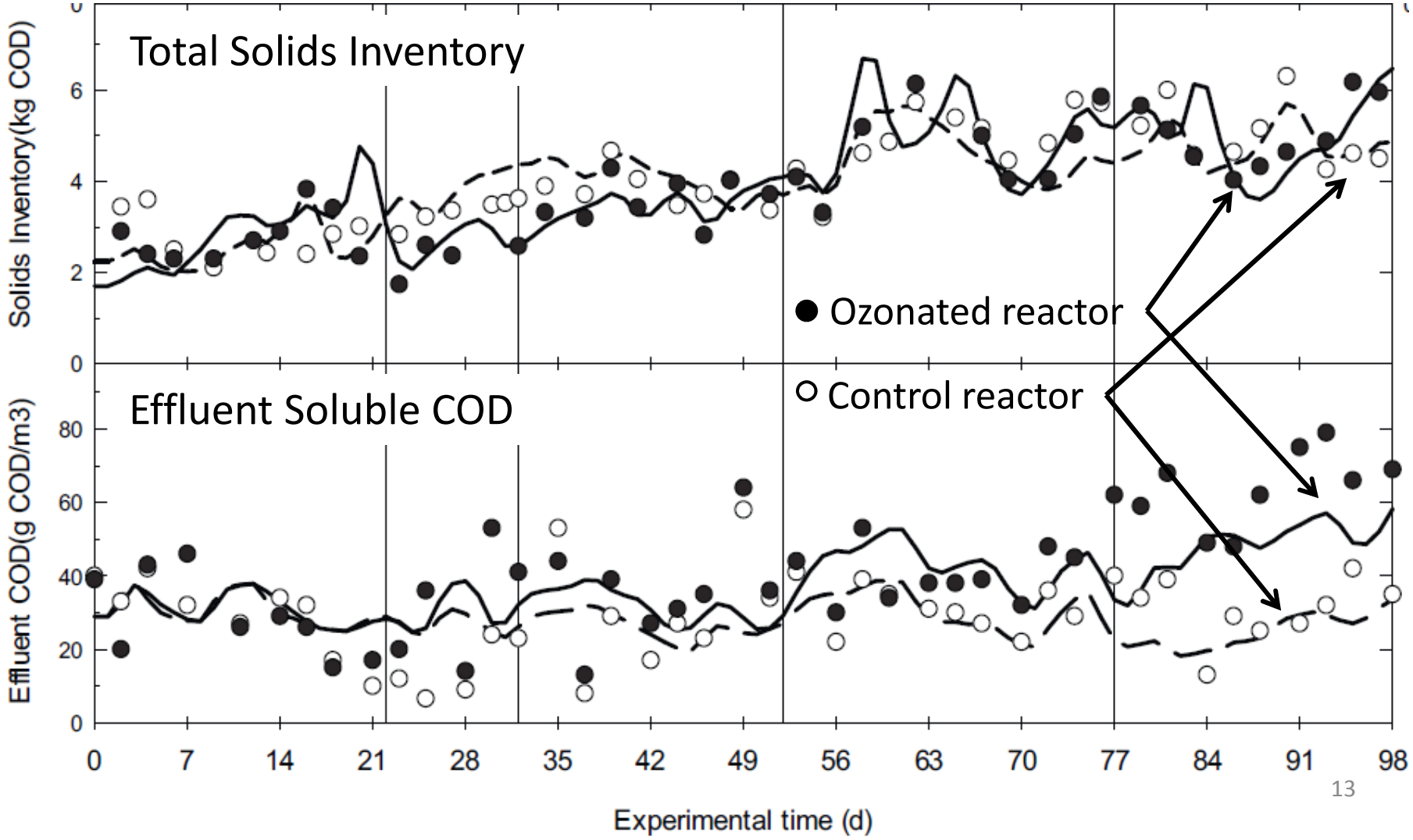
Ozonator Scale/Solids source	COD solubilization (mg-COD/mg-O_3)
Pilot-scale on RAS	
Control reactor	2.29 ± 0.27
Ozonated reactor	2.04 ± 0.25
Laboratory-scale on RAS	
Fresh RAS	2.47 ± 0.03
Sonicated RAS	3.34 ± 0.40
Laboratory-scale on Pure culture	
Average of four pure cultures[a]	1.48 ± 0.37

3 Pilot-Scale Experiments (3-5 months each)

	Aeration +Ozonated Reactor Control Rule	SRT (day)	Ozone Dose $\frac{g\text{-}O_3}{kg\text{-}VSS\ Inventory \cdot day}$	Biosolids Reduction
Year 1	Aerobic +Constant MLVSS	6	0 to 6.5	0 to 46%
Year 2	Aerobic +Constant SRT	6	10.3	53%
Year 3 Phase 1 Phase 2 Phase 3	 • Anoxic/Aerobic • Aerobic • Aerobic +Constant MLVSS	 • 12 • 12 • 6	 • 7.3 • 8.9 • 11.4 (lower COD solubilization)	 • 22% • 19% • 18%

Year 1 – Calibration of Model

- Independent calibration of inactivation parameters
- Fitting of inventory with transformation parameters.
- Good fit of the observed state variable.



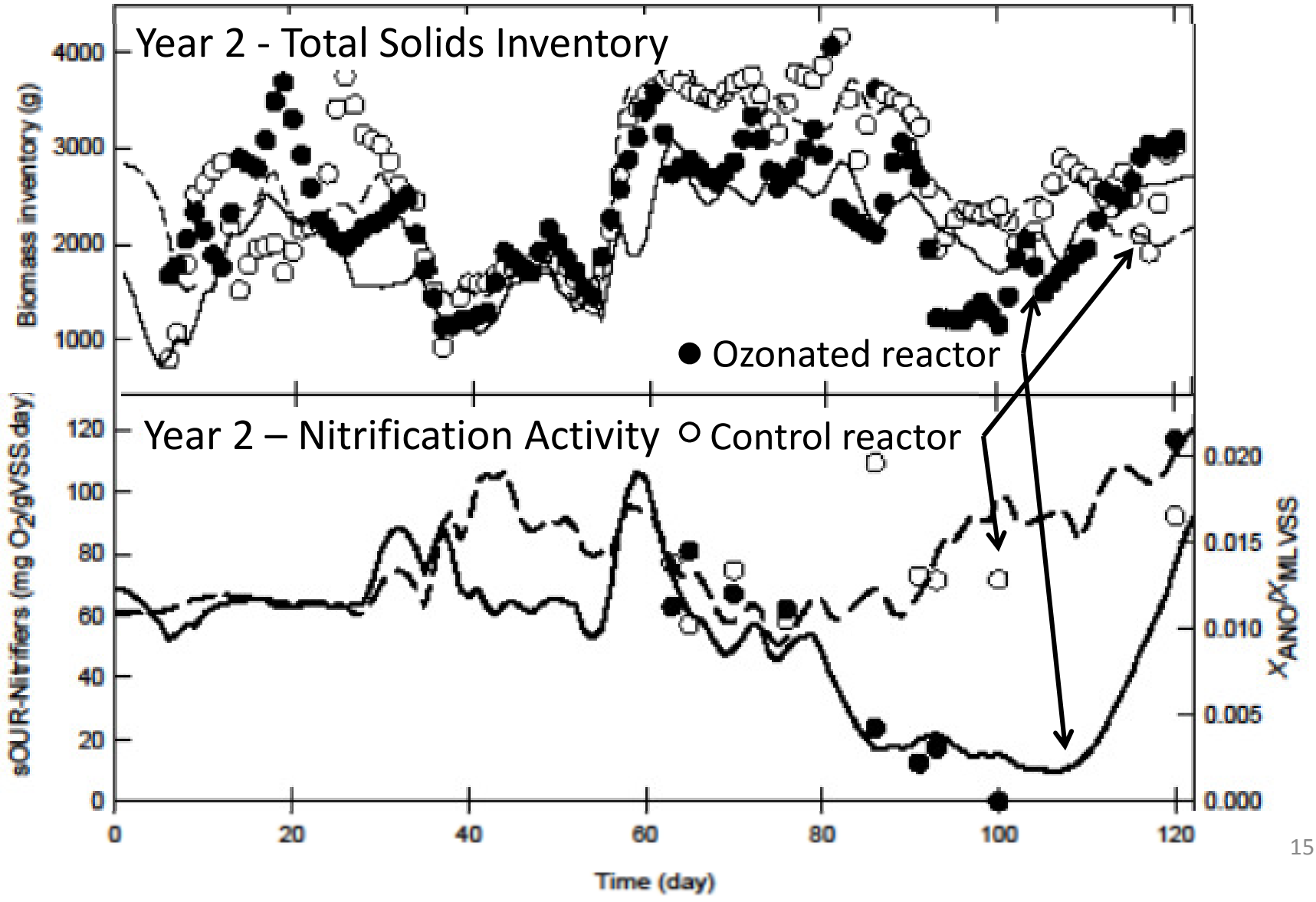
Improvements in State-Variables' Predictions for Different Descriptions of Inactivation

Inactivation	Linear	Exponential	Exponential
Fractions: Inactivation vs. Transformation	Same	Same	Independent
Predicted State-Variables Relative Squared Errors			
Biosolids inventory [a] [%]	23.3	22.0	21.8
Soluble undegradable (S_U)[b] [%]	19.5	14.0	12.0
Soluble biodegradable (S_B)[b] [%]	27.9	25.9	20.5
Nitrate (S_{NO_3}) [%]	23.8	21.8	20.1

Conclusions

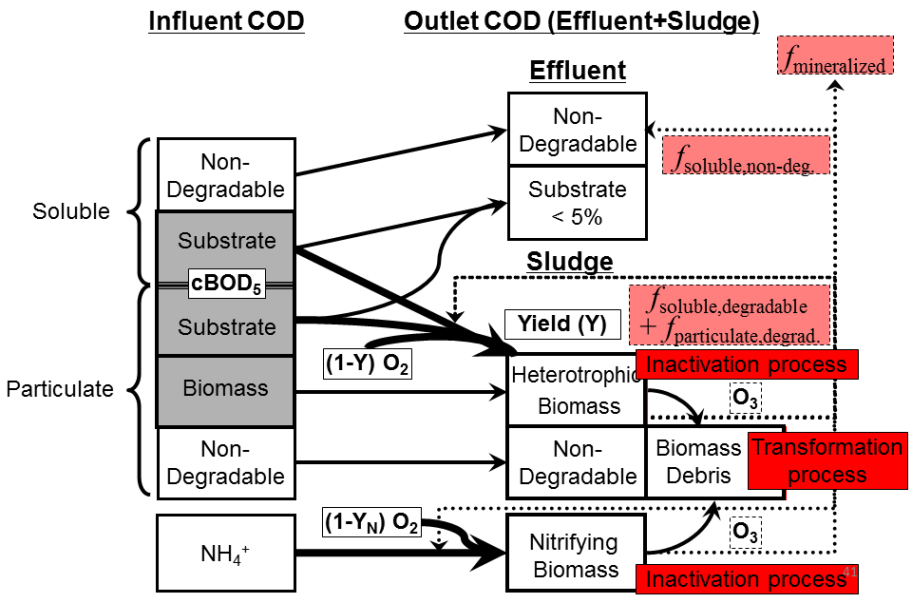
- Exponential inactivation works better
- Inactivation solubilizes <10% of cellular COD

Calibrated Parameters of Year 1 Satisfactorily Predicted Year 2 and Year 3 Observations

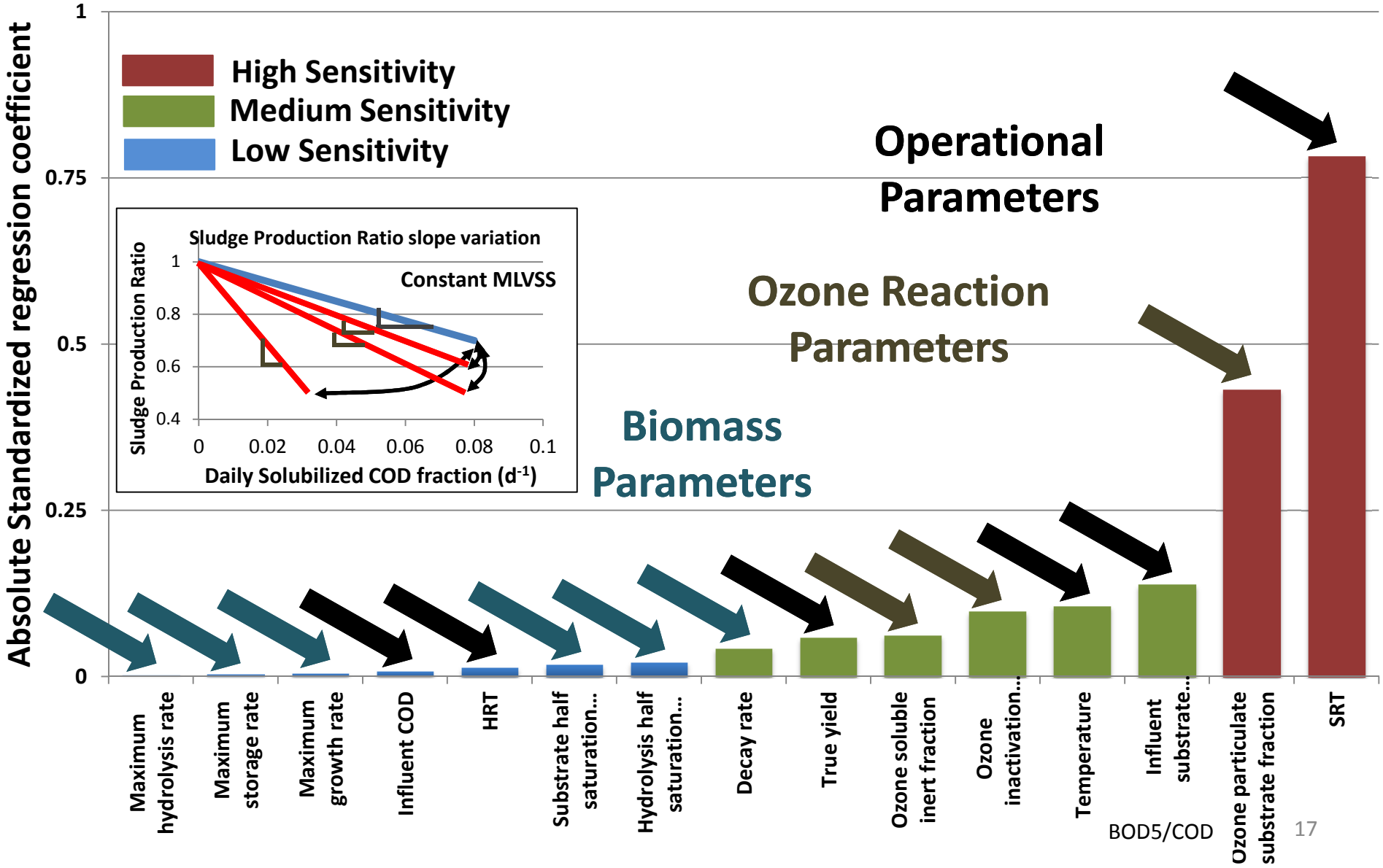


Model Global Sensitivity Analysis

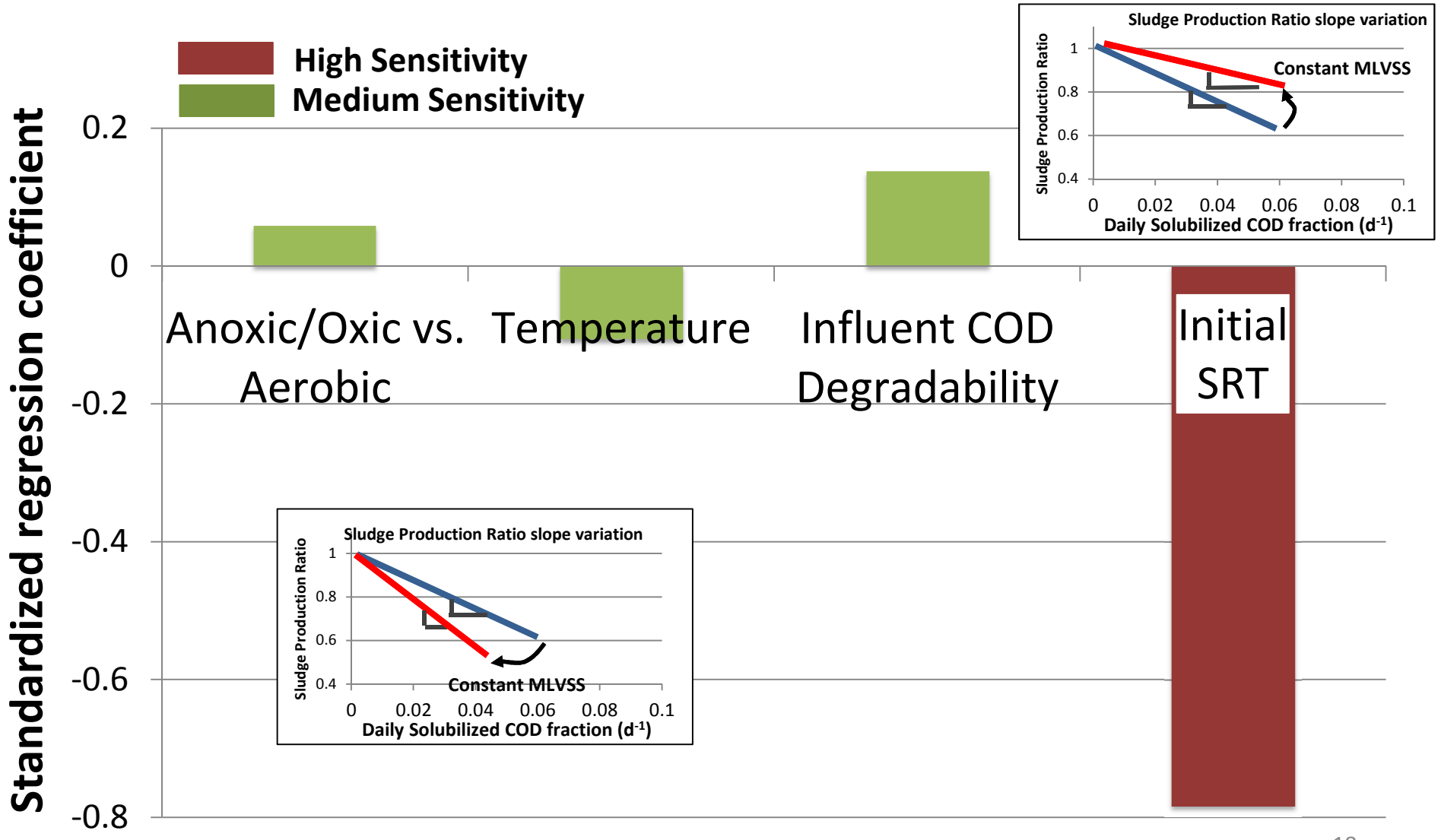
- Trends in biosolids reduction performance
- Generate implementation guideline



Sensitivity of Biosolids Reduction to Model and Operation Parameters

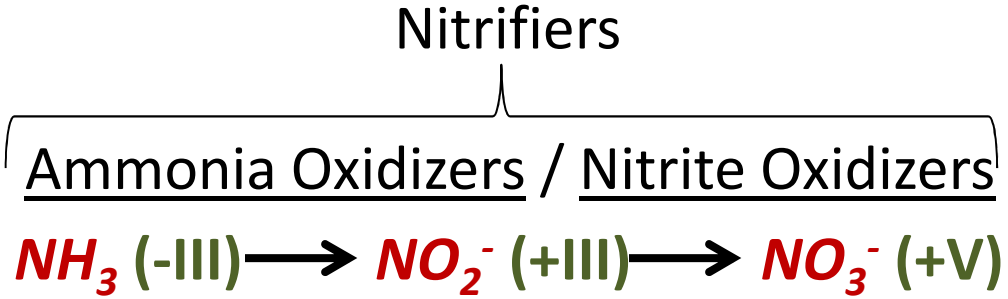


Operation Parameters Most Influential of Biosolids Reduction



Nitrification Scenario Analysis

- Explaining “inconsistent” data on nitrification rates
- Identification of operation conditions threatening nitrification
- Developing strategies to protect nitrification

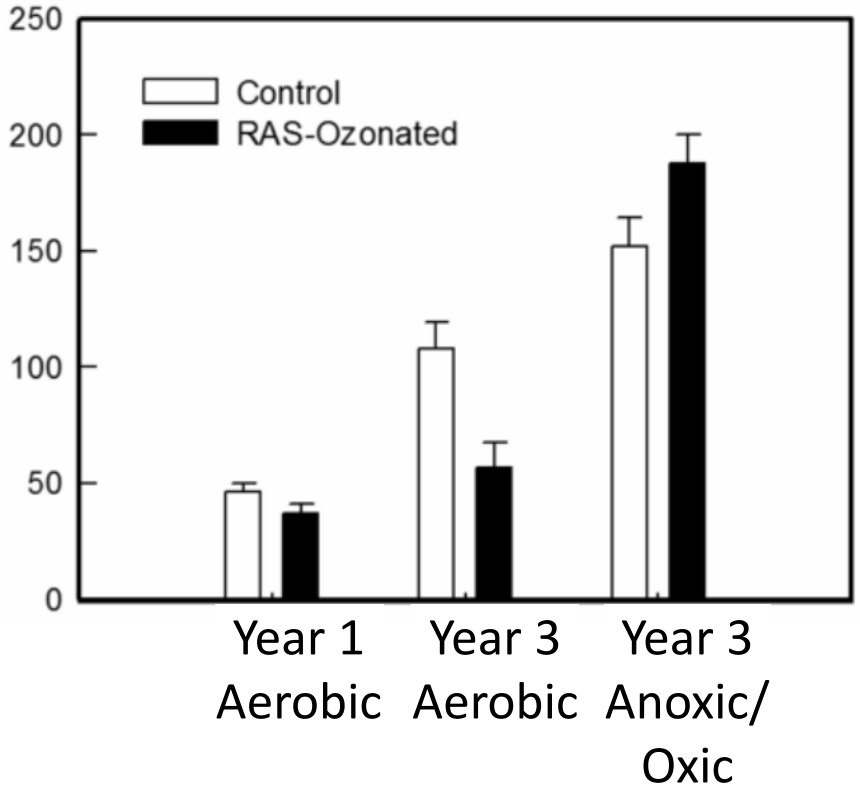


Change in Specific Nitrification Rates

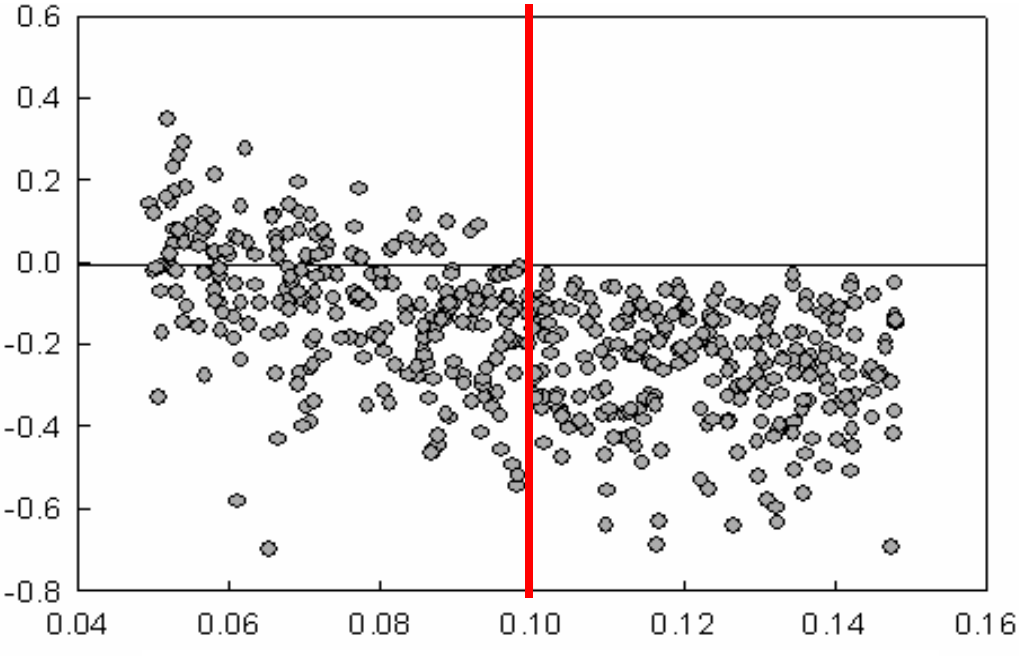
- Anoxic/Oxic conditions less detrimental than fully aerobic
- Specific nitrifcation rates can increase in some cases:

influent TKN/COD < 0.1 g-N/g-COD

Specific Nitrification Rate
(mg-N/(mg-VSS·day)

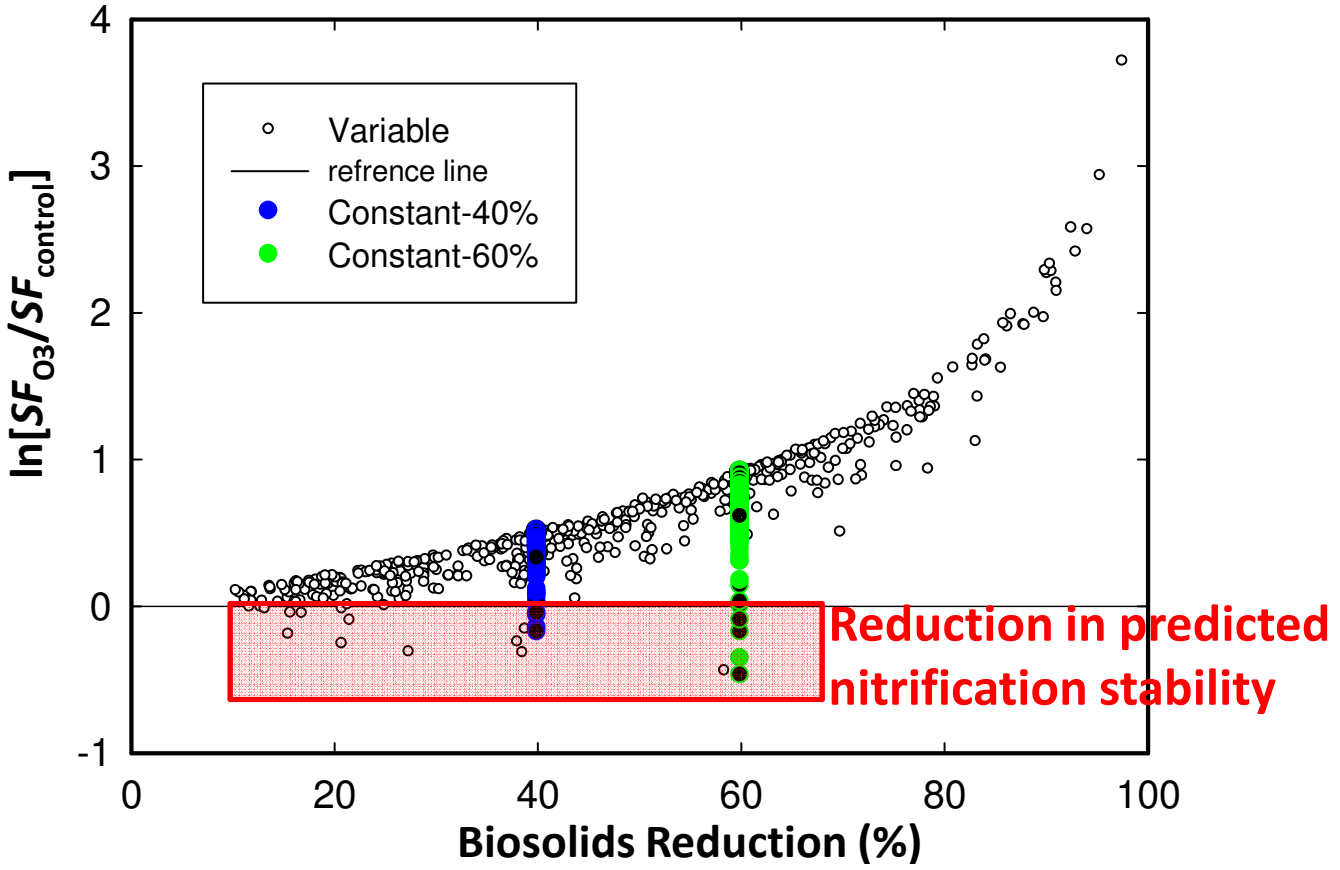


Change in Specific Nitrification Rates
(ln[Ozonated/Control])

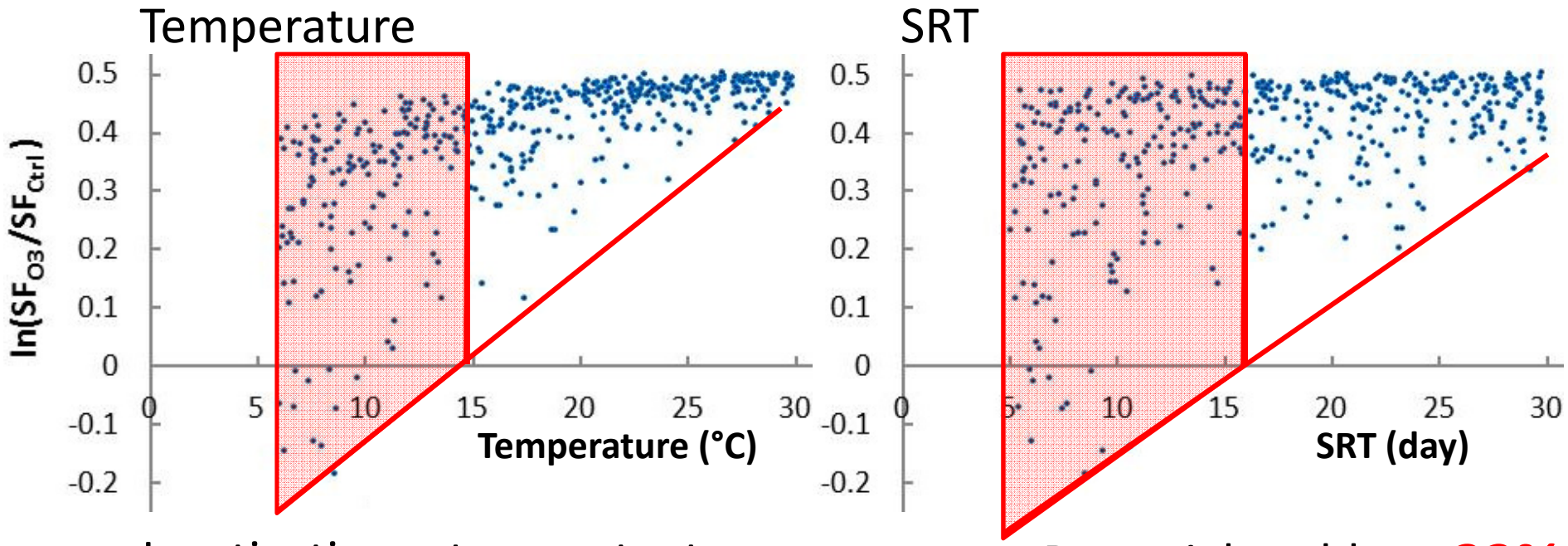


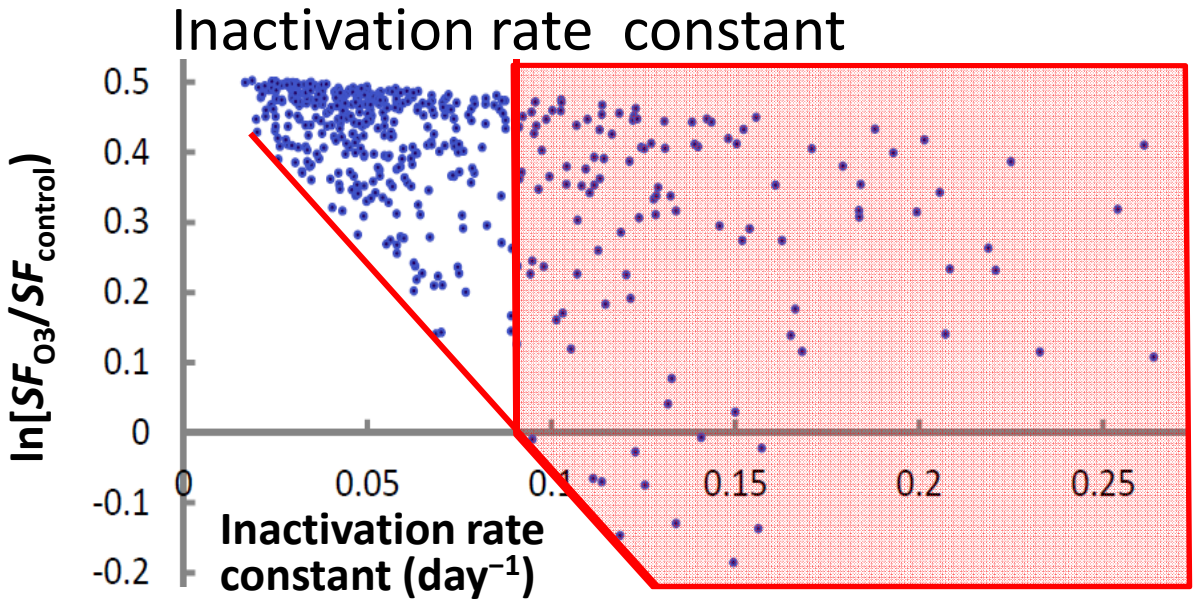
Operation Conditions Threatening Nitrification

- Safety Factor (SF) = $SRT_{operation}/SRT_{min}$
  $SRT_{min\ of\ nitrifiers} = (\mu_{ANO,max} - b_{ANO} - b_{ANO,O3})^{-1}$
- 3 simulation studies of 1,500 simulations: variable reductions, 40% and 60% reduction
- Lower sludge reduction shows higher risk



Operation Conditions Threatening Nitrification (Constant 40% Biosolids Reduction)

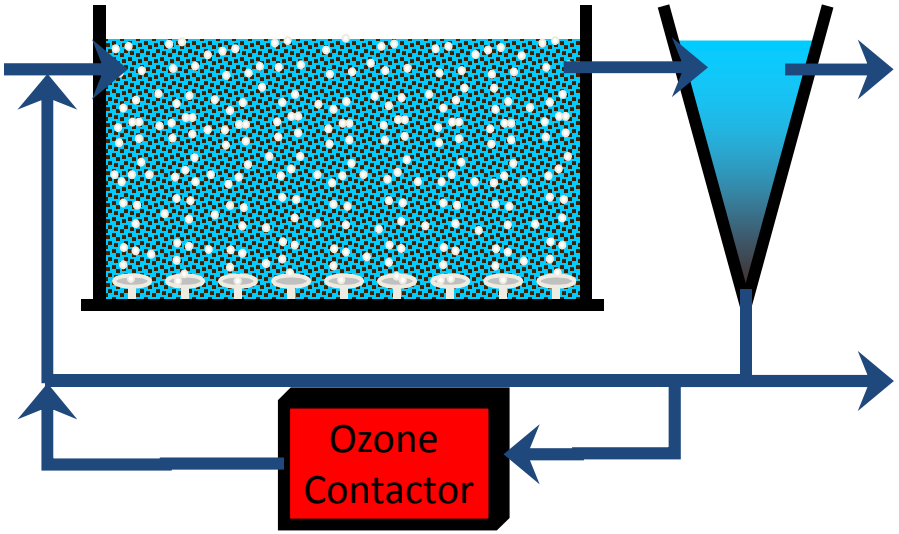




Potential problem: **32%**

- Temperature < 15°C and
- SRT < 16 days and
- Inactivation rate constant > 0.09 day^{-1}

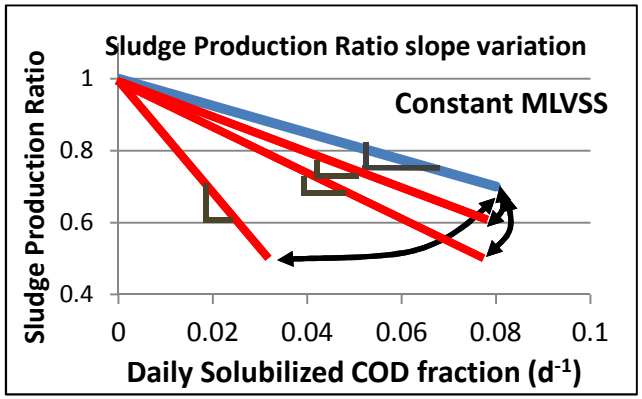
How to minimize inactivation rate?



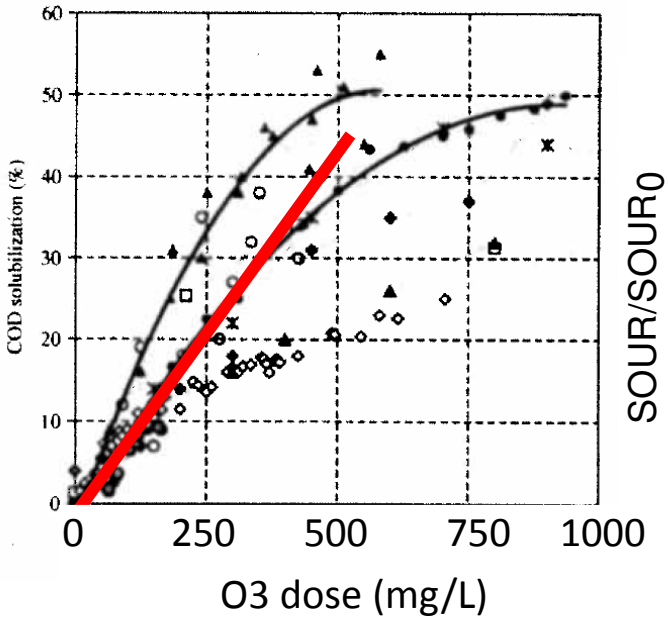
- Biosolids production is function of overall daily solubilization
- Overall daily solubilization:
  - Solubilization in contaction
  - Proportion of inventory treated
- Same factors for overall inactivation

➢ Minimize proportion of inventory

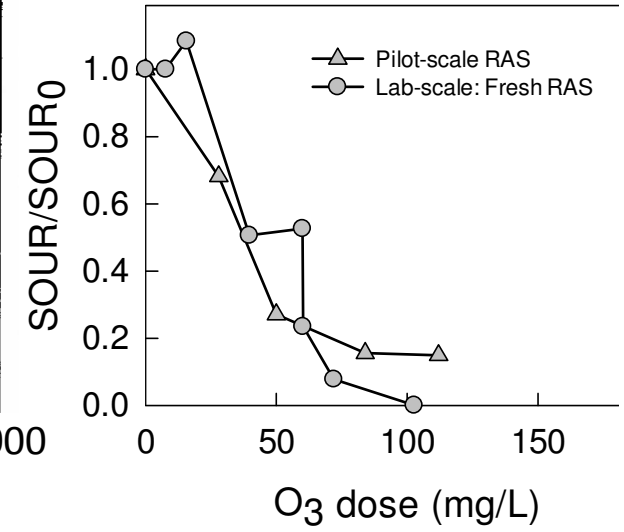
Biosolids Production vs. Overall Solubilization



Solubilization in Contactor



Inactivation in Contactor



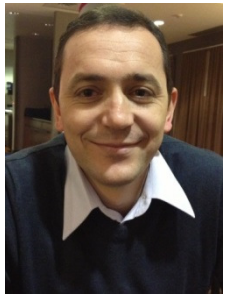
Conclusion

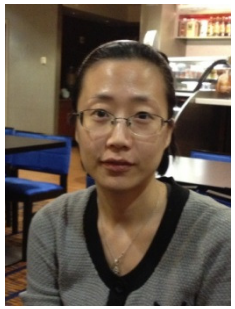
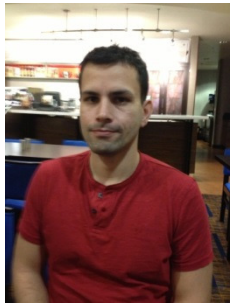
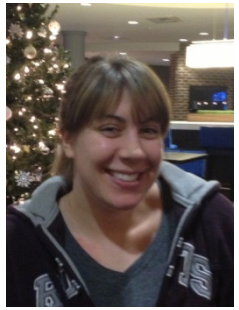
- Bioprocess conditions influence greatly performance of RAS-ozonation units for biosolids reduction.
- Developed a model capable of predicting performance based on inactivation and COD solubilization.
- Nitrification stability is generally enhanced.
- Nitrification can be negatively impacted at lower temperature, SRT and higher overall inactivation.
  - Contactor operation can be adjusted to alleviate problems.

Acknowledgements

- Students

Overall Operation | Inactivation | Sensitivity | Lab-scale reactors

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