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Systematic design of optimal control systems for WWTPs: case study of the SHARON-Anammox process

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1. INTRODUCTION

Challenges faced when developing control structures for WWTPs:

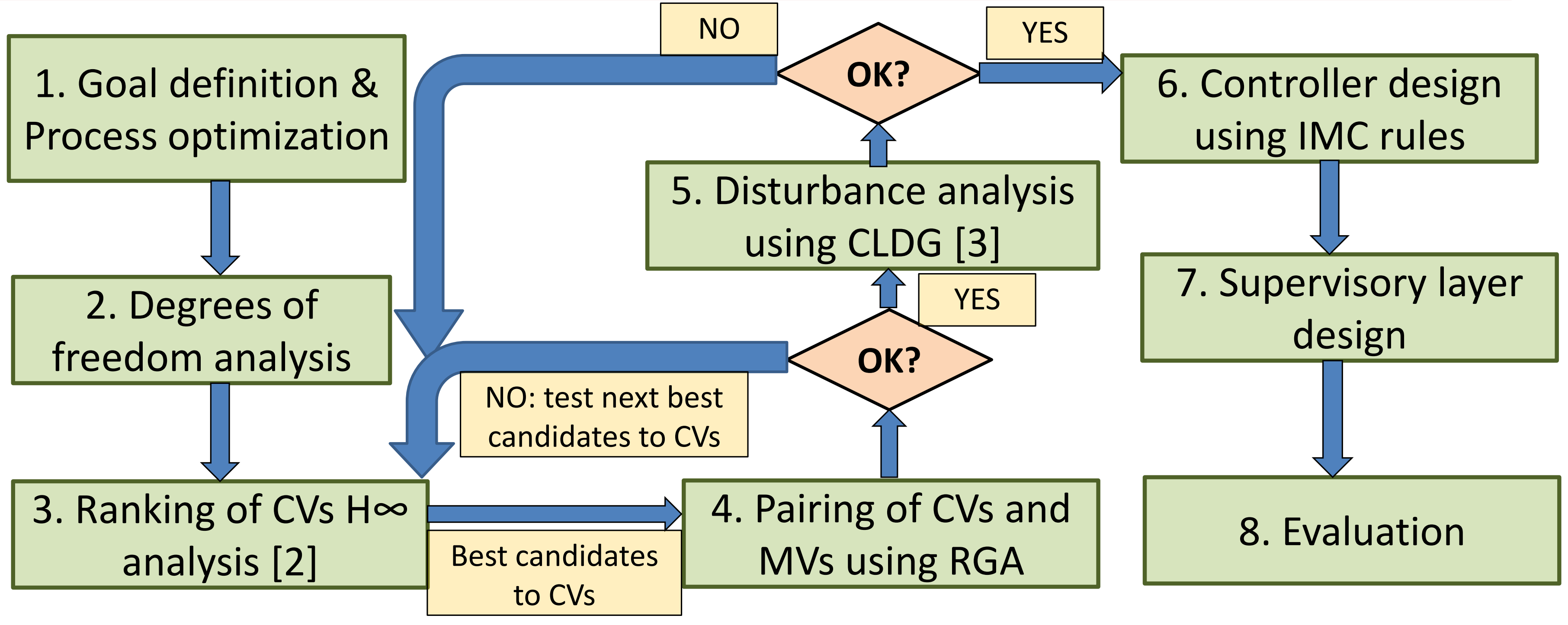
- Scarcity of actuators
- Control variables linked to the objectives of the plant

How can we design a control system using a model-based systematic approach?

Objectives:

1) To develop a **methodology** to design **optimal control structures** for WWTPs. The methodology should be suited for systematic design of **regulatory control** layers when **high number of controlled variables** and **few actuators** are available.
2) To apply the novel methodology to the SHARON-Anammox process

2. CONTROL DESIGN PROCEDURE [1]



1. Goal definition & Process optimization

2. Degrees of freedom analysis

3. Ranking of CVs H∞ analysis [2]

Best candidates to CVs

4. Pairing of CVs and MVs using RGA

OK?

NO: test next best candidates to CVs

YES

5. Disturbance analysis using CLDG [3]

OK?

NO

YES

6. Controller design using IMC rules

7. Supervisory layer design

8. Evaluation

3. CASE STUDY: SHARON-ANAMMOX PROCESS

1. Goal definition and process optimization

Goal: maximize the nitrogen removal

Optimal conditions for maximum N-removal (based on scenario analysis)**:**

- Nitrite to ammonia ratio of 1.3 in the influent to the Anammox reactor
- Oxygen level of 0.2 mg/L
- pH of 7.3

2. Degrees of freedom analysis (SHARON)

Manipulated variables	Controlled variables
Air supply	Dissolved oxygen (DO)
	pH
Acid/base addition	Ammonia (TAN)
	Nitrite (TNN)
	Nitrite to ammonia ratio

3. Ranking of CVs H∞ analysis

$$S=\frac{I}{I+G(s)C(s)}$$

bounded for performance

$$T=\frac{G(s)C(s)}{I+G(s)C(s)}$$

bounded for robustness and to avoid sensitivity to noise

$$CS=\frac{C(s)}{I+G(s)C(s)}$$

bounded to penalize large input variations

$$\min_{C}\|N(C)\|_\infty \quad N \triangleq \begin{pmatrix} W_U CS \\ W_T T \\ W_P S \end{pmatrix} \Rightarrow \begin{aligned} \bar{\sigma}(S(j\omega)) &\le \gamma\,\underline{\sigma}(W_P^{-1}(j\omega)) \\ \bar{\sigma}(T(j\omega)) &\le \gamma\,\underline{\sigma}(W_T^{-1}(j\omega)) \\ \bar{\sigma}(CS(j\omega)) &\le \gamma\,\underline{\sigma}(W_u^{-1}(j\omega)) \end{aligned}$$

γ must be small for controllability

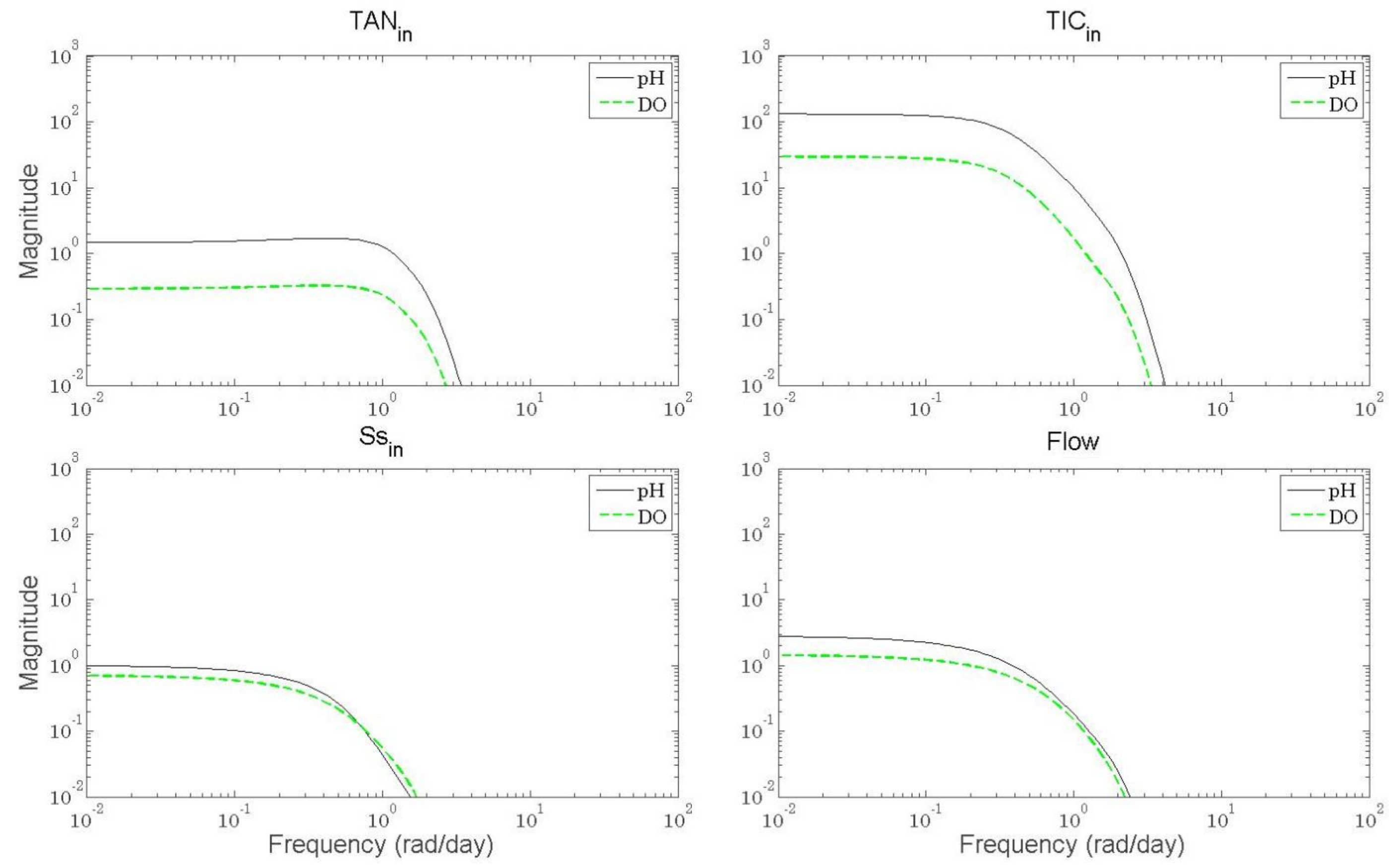
Ranking of CVs

CVs		γ
DO	pH	7.0
DO	TAN	13.3
TAN	TNN/TAN	19.5
pH	TNN/TAN	20.3
DO	TNN/TAN	24.7
pH	TAN	32.0
TAN	TNN	41.6
pH	TNN	48.9
DO	TNN	53.6
TNN	TNN/TAN	92.6

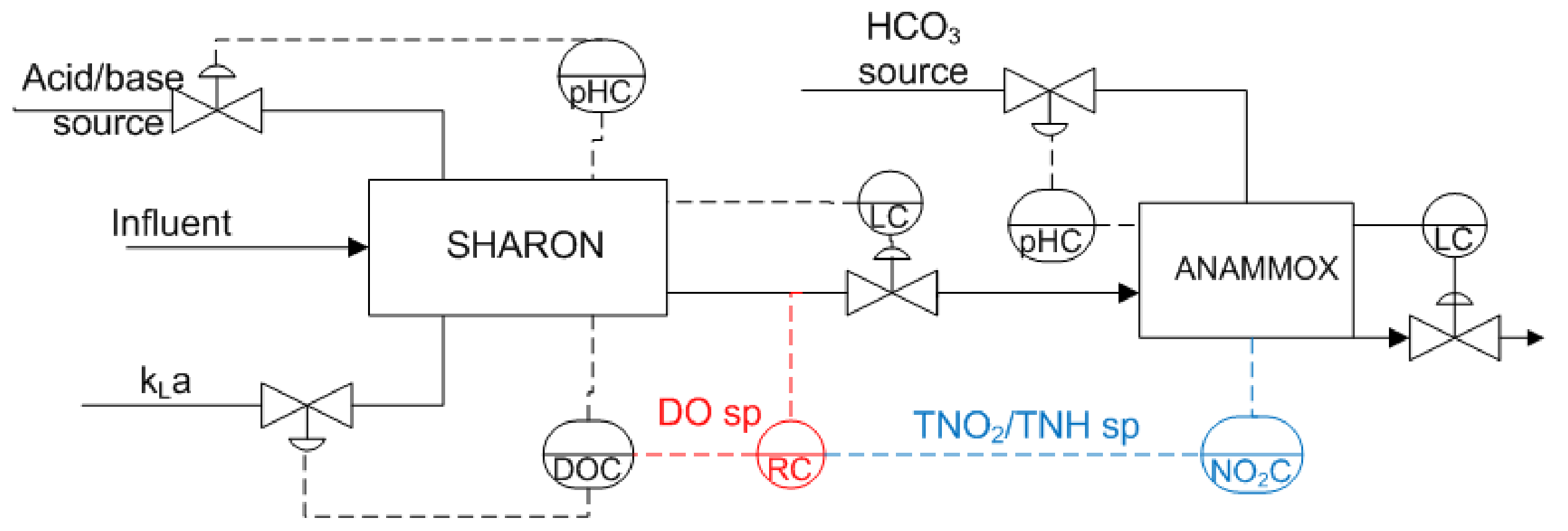
4. Pairing using the Relative Gain Array

CVs	MVs	
	Fbase	k_La
DO	-0.233	1.233
pH	1.233	-0.233

5. Disturbance analysis using the Closed Loop Disturbances Gain plots



6. 7. Regulatory and Supervisory control layers



8. Evaluation under dynamic conditions

Structure	Nitrogen removal		DO SHARON	pH SHARON
Regulatory	**89%**	IAE	5.97 d	22.67 d
		TV	744.5 d^{-1}	7.22·10-4 m^3d^{-1}
Cascade	**92%**	IAE	85.26 d	53.03 d
		TV	1060 d^{-1}	5.07·10-4 m^3 d^{-1}
Nested cascade	**95%**	IAE	87.9 d	61.49 d
		TV	1070 d^{-1}	4.5·10-4 m3 d^{-1}

4. CONCLUSIONS

- Methodology combining of ***H∞* analysis, RGA and CLDG plots** is successfully applied to design **optimal regulatory control structures** for WWTPs
- ***H∞* analysis** is used to screen the **candidates to CVs**
- **Nested cascade** structure performs **best** in terms of nitrogen removal

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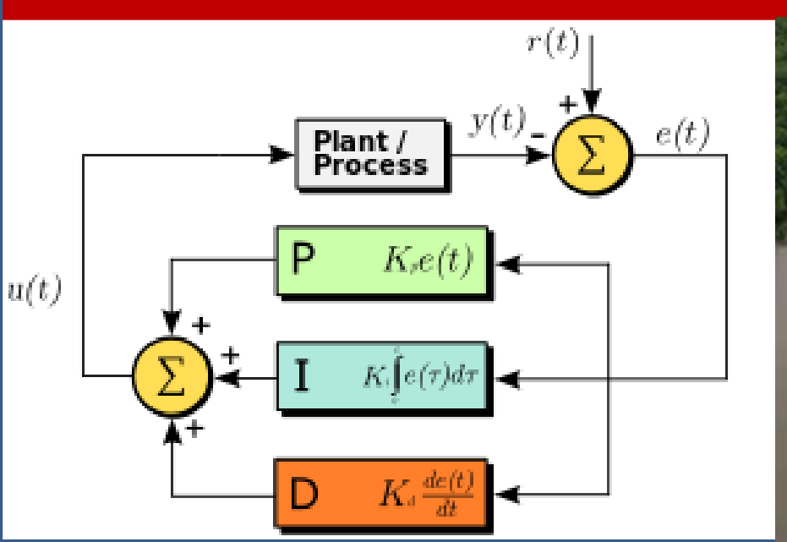

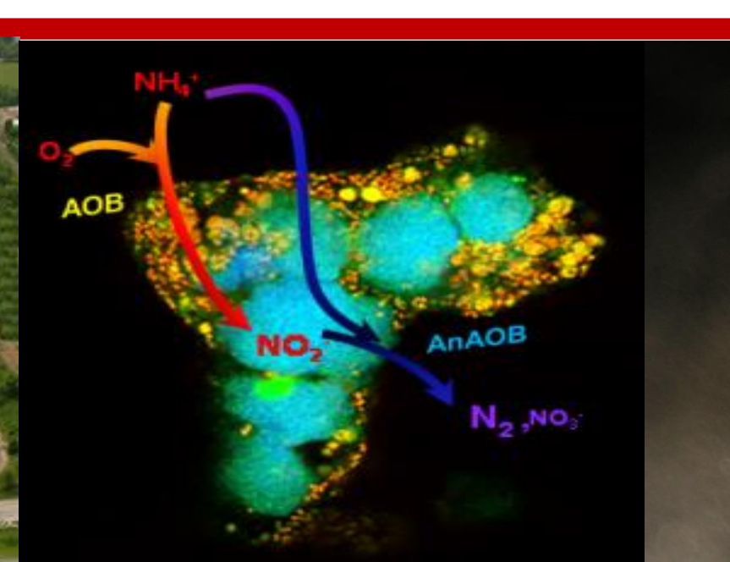

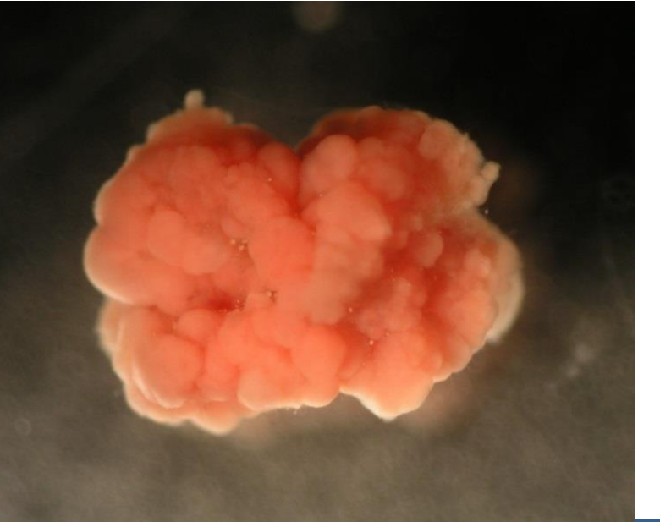

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