Proceso ANAMMOX: experiencia presente y perspectivas de futuro

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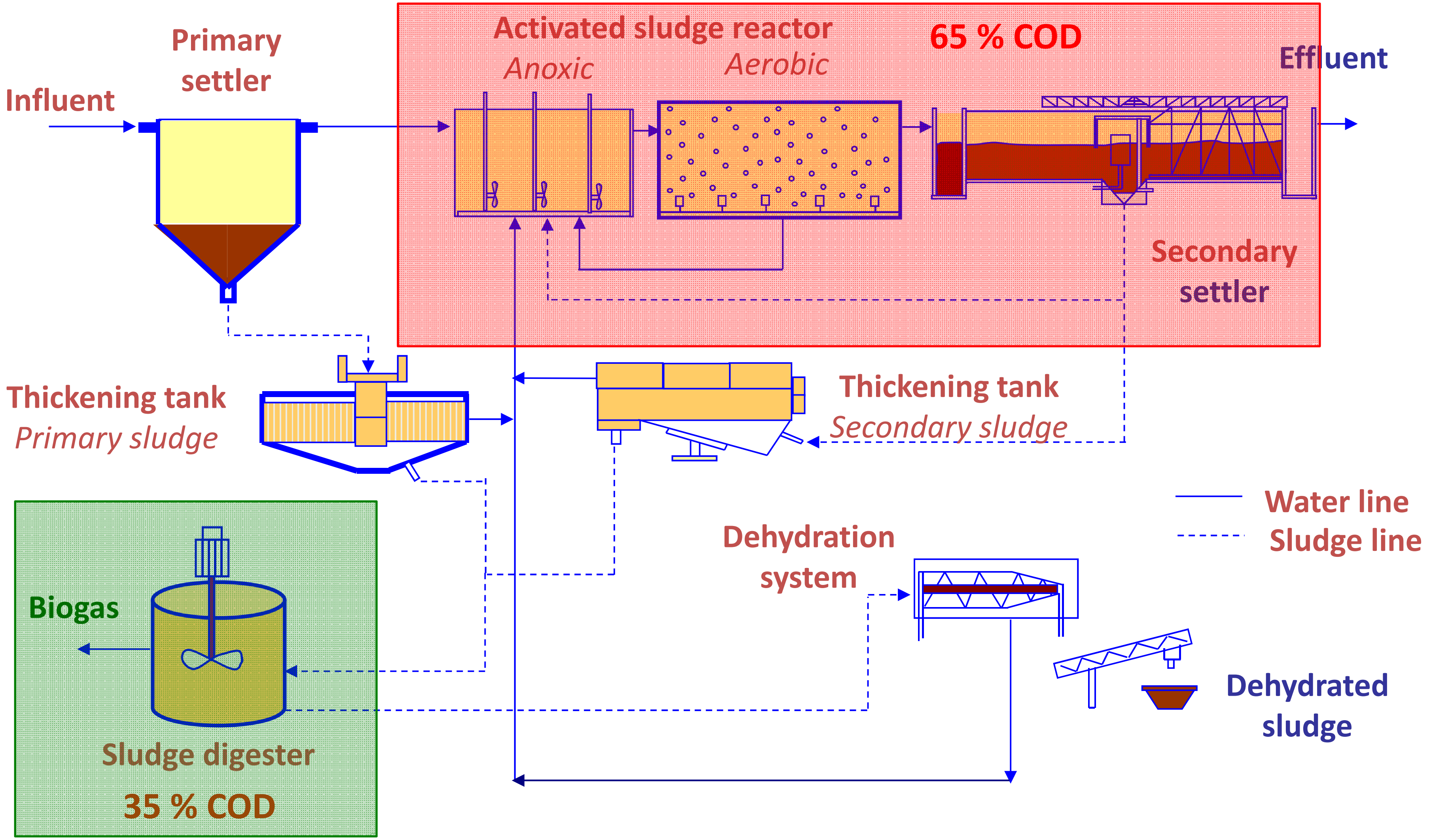
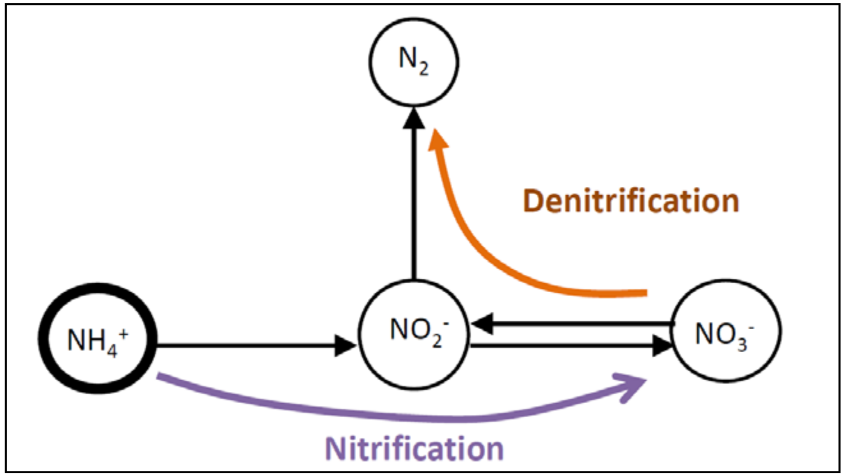
Cátedra UPV FACSA-FOVASA

The wastewater contains energy which can be recovered

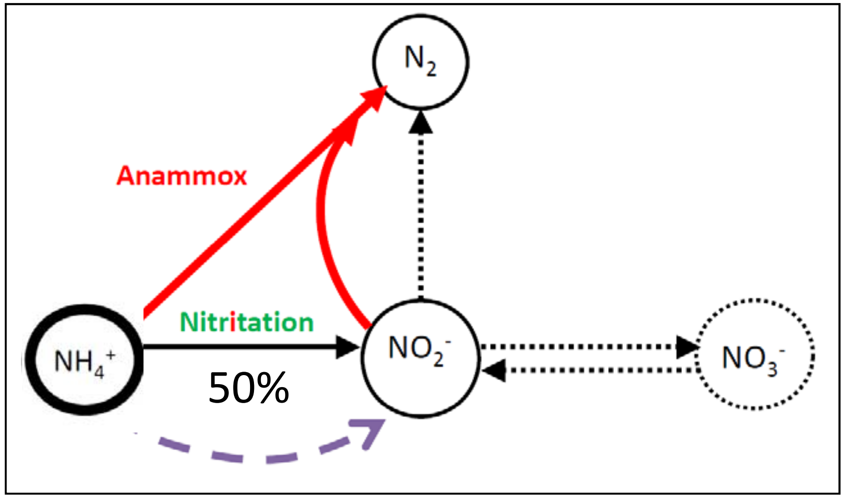


Nitrogen is removed from wastewater by biological processes

Conventional nitrification-denitrification



Partial nitritation-Anammox process

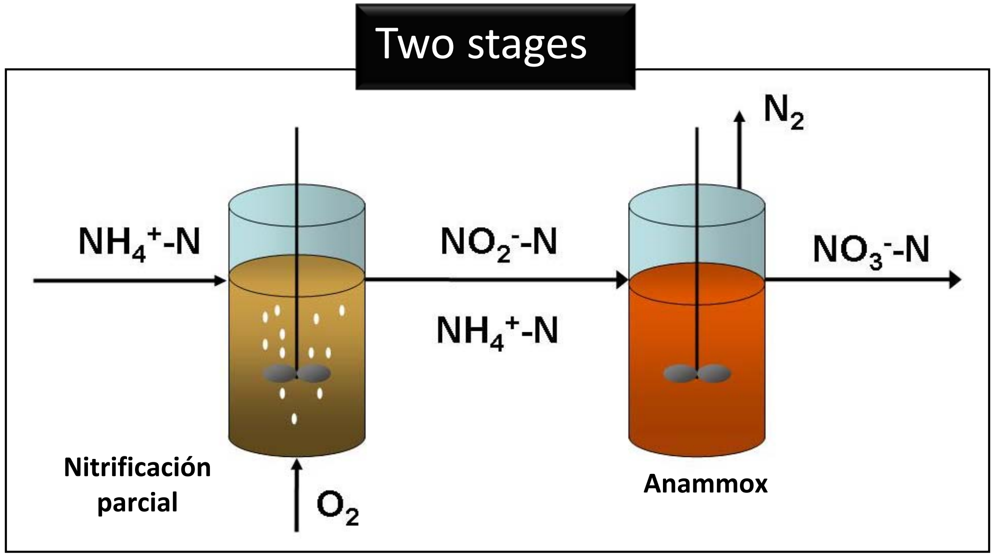


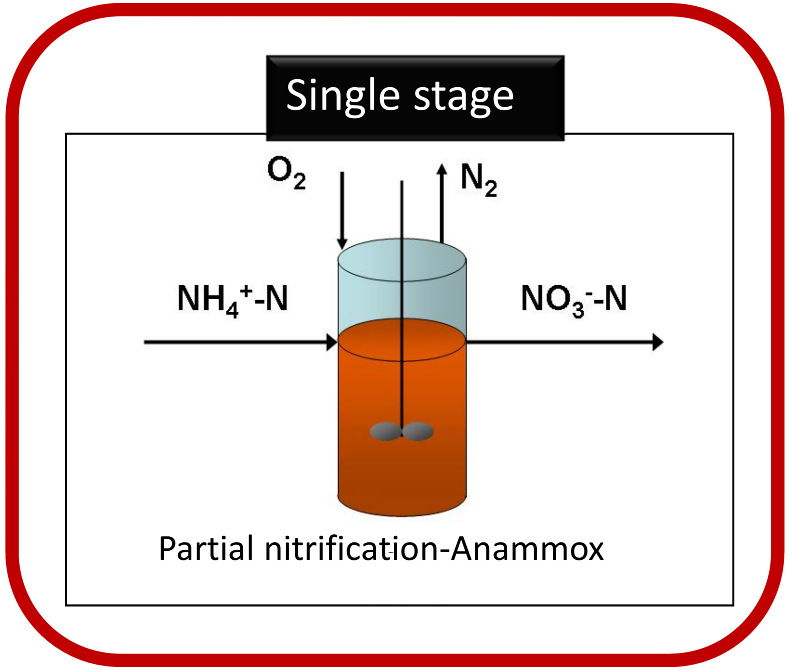
Anammox: Anaerobic AMMonium OXidation

$$\mathbf{NH_4^+ + 1{,}32\ NO_2^- + 0{,}066\ HCO_3^- + 0{,}13\ H^+}$$

$$\mathbf{\rightarrow 1{,}02\ N_2 + 0{,}26\ NO_3^- + 0{,}066\ CH_2O_{0{,}5}N_{0{,}15} + 2{,}03\ H_2O}$$

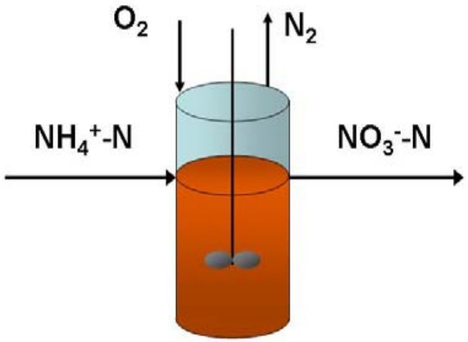
Two alternatives are feasible to carry out the partial nitritation-anammox (PN-AMX) processes

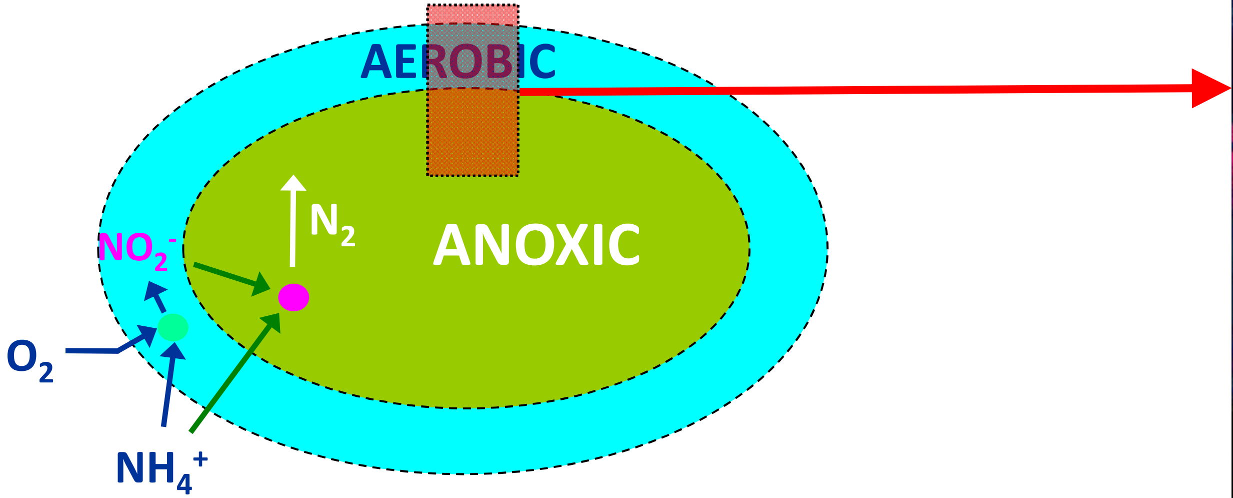


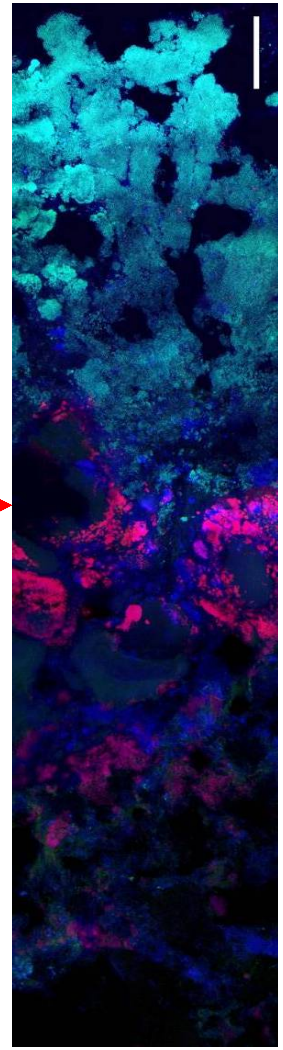


A. Mosquera-Corral, F. González, J.L. Campos, R. Méndez. (2005). Process Biochemistry, 40, 3109–3118.

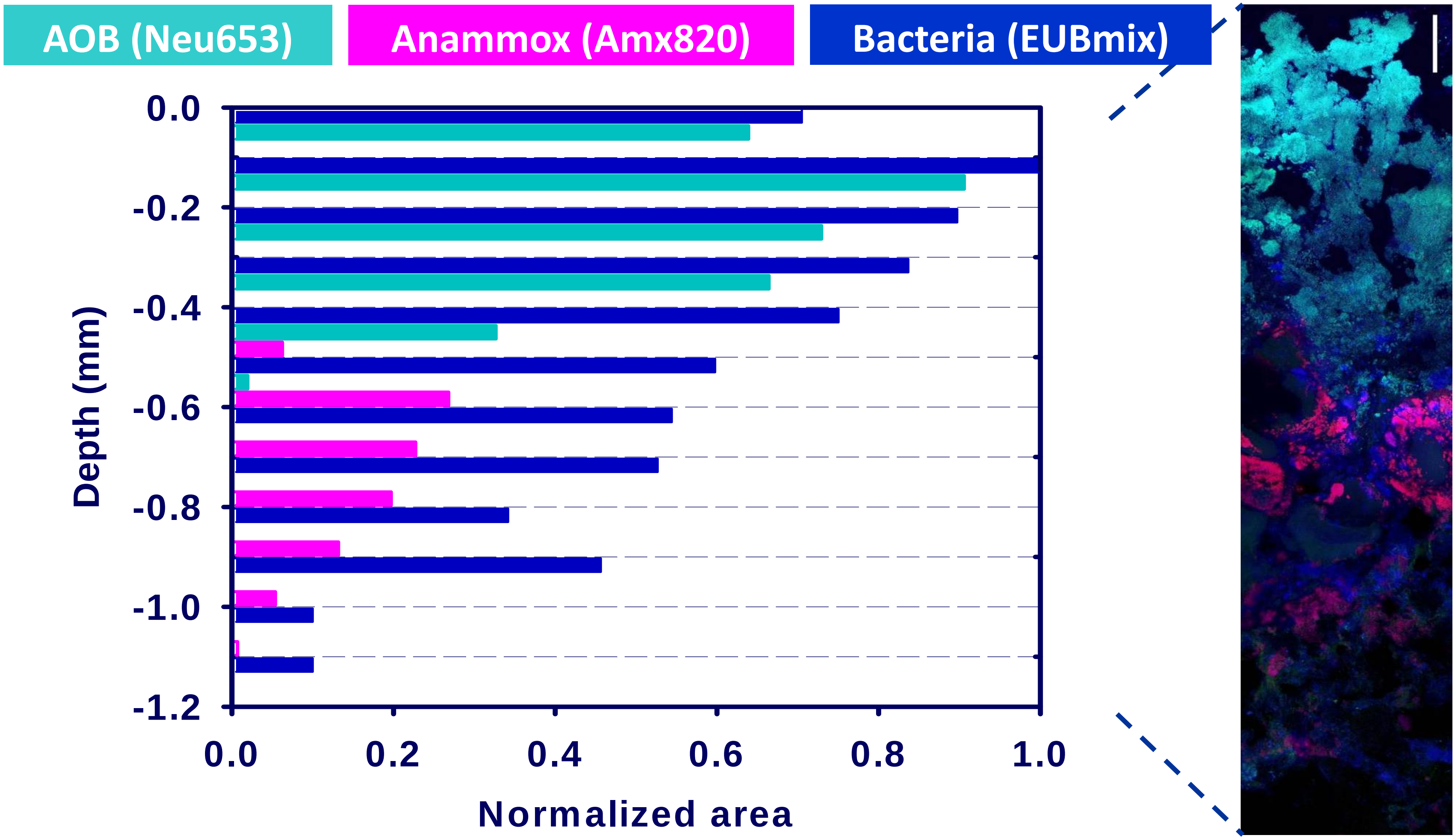
PN-AMX processes take place in single stage in granular biomass systems







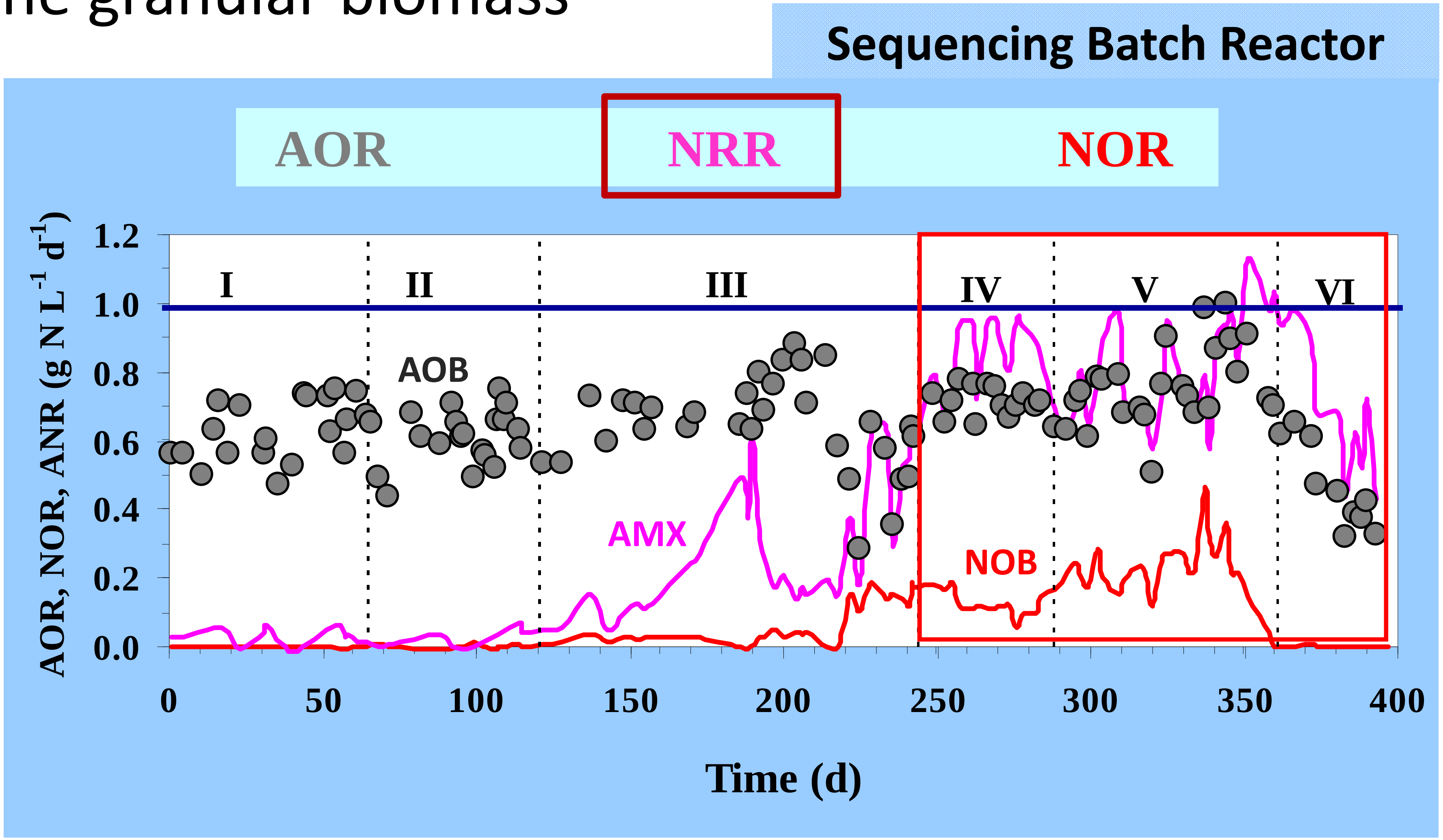
The structure of the granules allows for an external aerobic and an internal anoxic layer



AOB: Ammonium Oxidizing Bacteria

Vázquez-Padín J.R. et al. (2010). Water Research, 44, 4359-4370.

PN-AMX processes take place simultaneously inside the granular biomass



Dissolved oxygen (DO): 2.2 – 4.6 mg O_2/L

AOR: Ammonium oxidation rate

NRR: Nitrogen removal rate

NOR: Nitrite oxidation rate

Research at pilot scale was performed to validate the process (2010-2013)

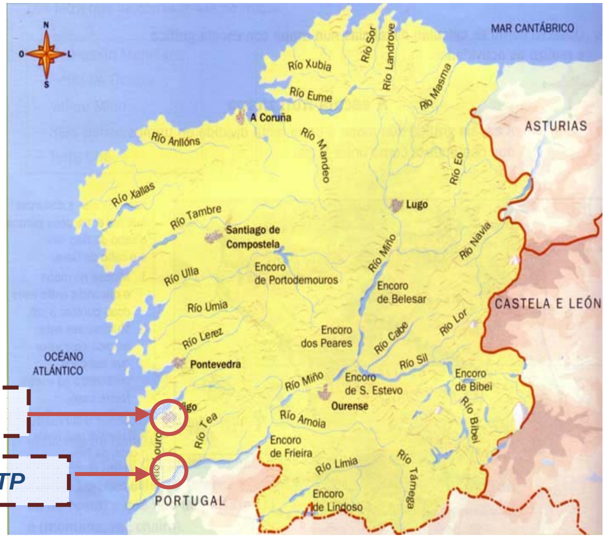
1.5 L

200 L

1200 L

***ELAN® process (ELiminación Autótrofa de Nitrógeno): combination of partial nitrification and Anammox in a single reactor.**

SBR granular reactors were evaluated by FCC Aqualia



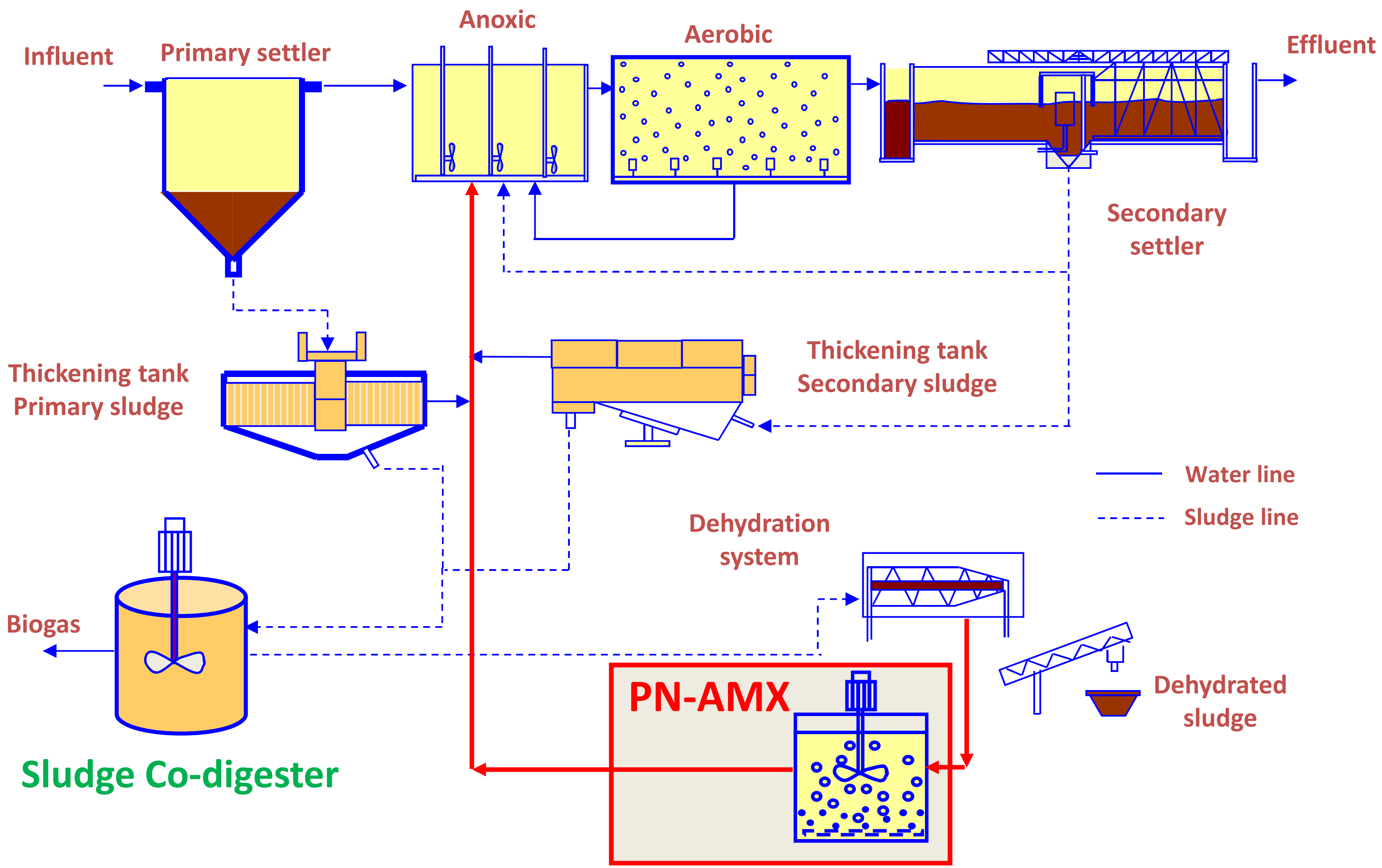
Vigo WWTP

Guillarei WWTP

Vigo WWTP ELAN® reactor

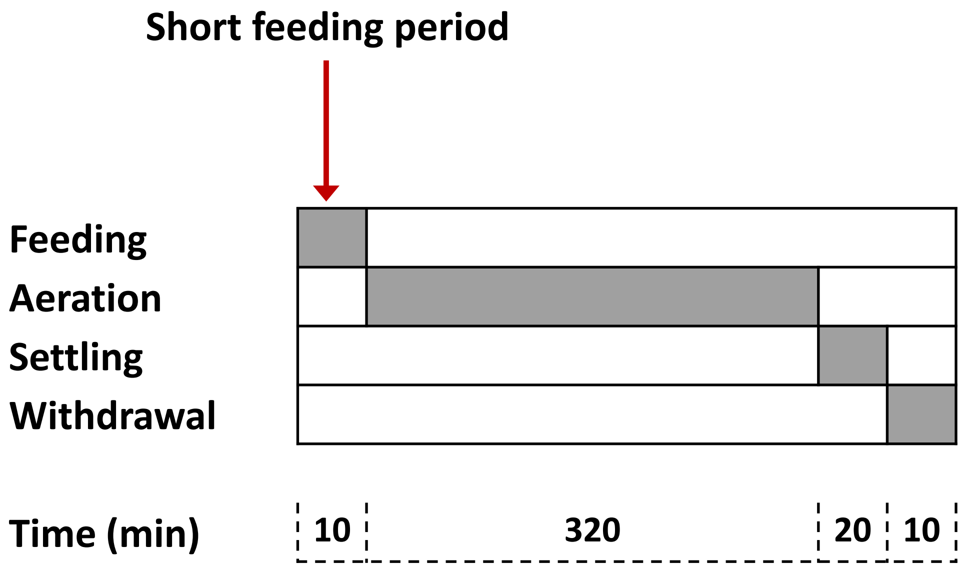
Guillarei WWTP: ELAN® reactor

The PN-AMX reactor is placed in the reject line in the WWTP

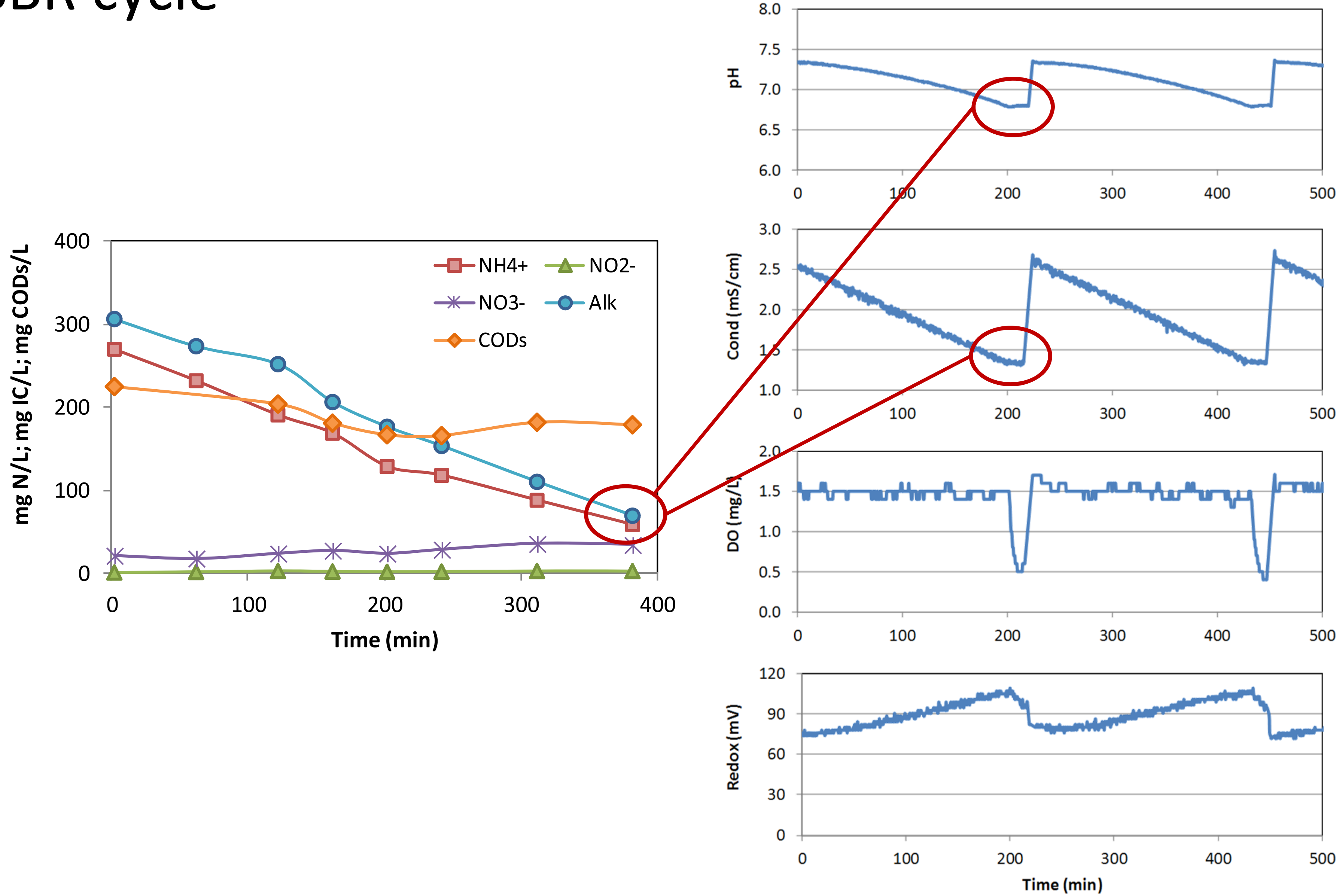


SBR granular reactors were evaluated in Guillarei

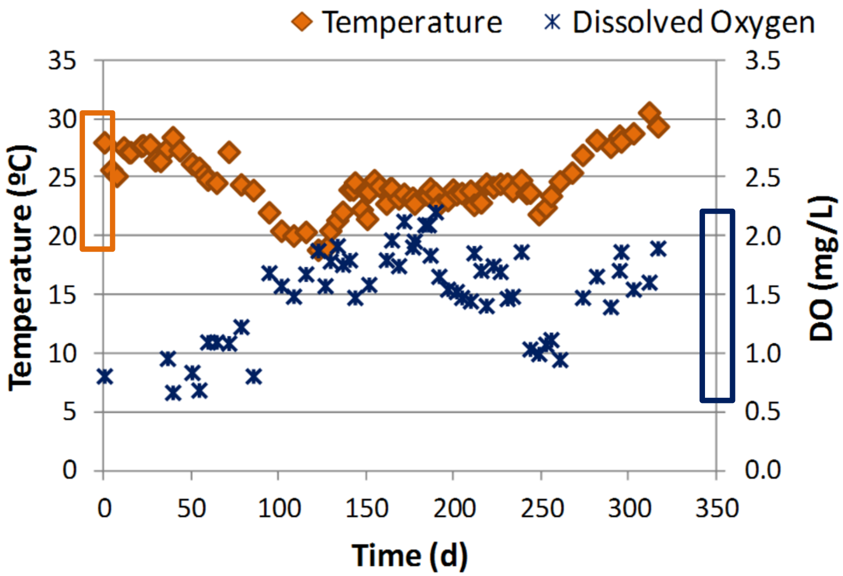
SBR: Sequencing Batch Reactor

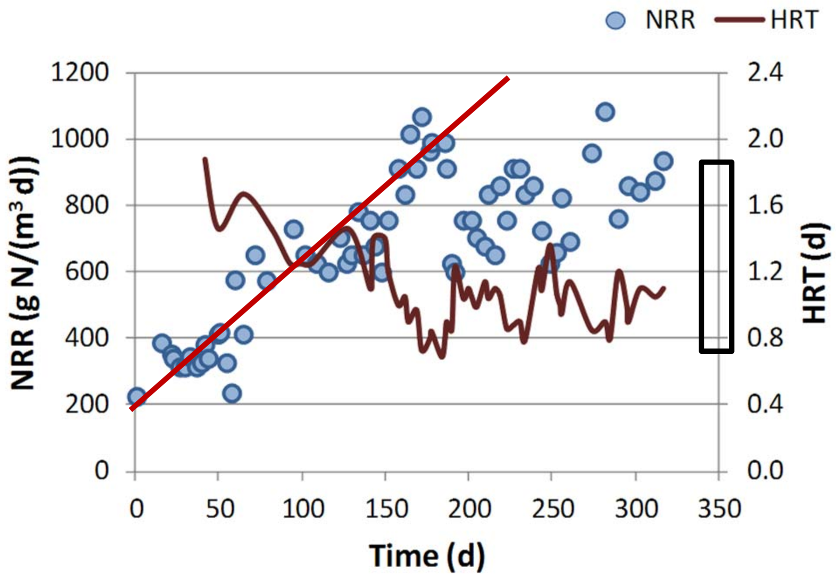


Conductivity set-point determines the length of the SBR cycle



SBR granular reactors were evaluated in Guillarei WWTP

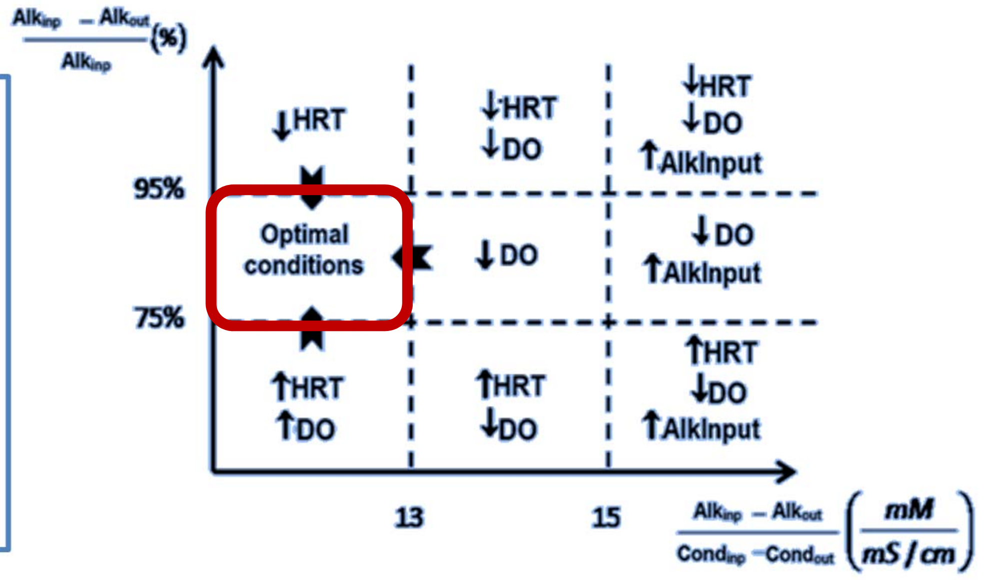




Nitrogen Compounds		
NH_4 influent	*mg N/L*	850 – 1500
NH_4 effluent	*mg N/L*	63 – 250
NO_2 effluent	*mg N/L*	1 – 5
NO_3 effluent	*mg N/L*	23 – 102
Average Nitrogen Removal		**82%**
Biomass		
TSS	*g/L*	12.9
VSS	*g/L*	11.8
SVI	*mL/g TSS*	36

The control of the ELAN® process is based on conductivity measurements

- Simple and robust control strategy
- HRT and Dissolved Oxygen concentration in the bulk liquid
- Following the "conductivity vs time slope" as method for reactor surveillance. (European Patent: EP2740713)



Parameter	Nitrification-Denitrification	ELAN®	Saves (%)
O_2 consumption (kg O_2/kg N)	3.18	**1.83**	**-42**
COD consumption (kg COD/kg N)	4.9	**0**	**-100**
Biomass yield (kg VSS/kg N)	2.11	**0.12**	**-94**

(Vázquez-Padín et al., 2014 Water Science and Technology)

The ELAN® process is scaled up at full scale

In operation/start up

Design/under construction

2015

Sidestream municipal WWTP

Mainstream industrial WWTP

Comparison: Secondary treatment vs. ELAN® design

	Biological R. (water line)	ELAN® (sludge line)
Reactor Volume (m^3)	9562	115
N denitrified (kg N/d)	226	67
Ammonium oxidized (kg N/d)	630 (to NO_3^-)	43 (to NO_2^-)
O_2 consumption for nitrification (kg O_2/d)	2879	148
N removal rate (kg N/(m^3 d))	0.02	0.60
N oxidation rate (kg N/(m^3 d))	0.06	0.37

Water line 83 times bigger than sludge line unit

Water line treates 3.4 times the load of the sludge line

Current ELAN® process operation to treat the effluent from an anaerobic sludge co-digester in a WWTP

25 m^3 activated sludge (3.5 g TSS/L) + 1.4 m^3 of anammox enriched sludge (10 g VSS/L)

5 g VSS/L

Oxygen limitation

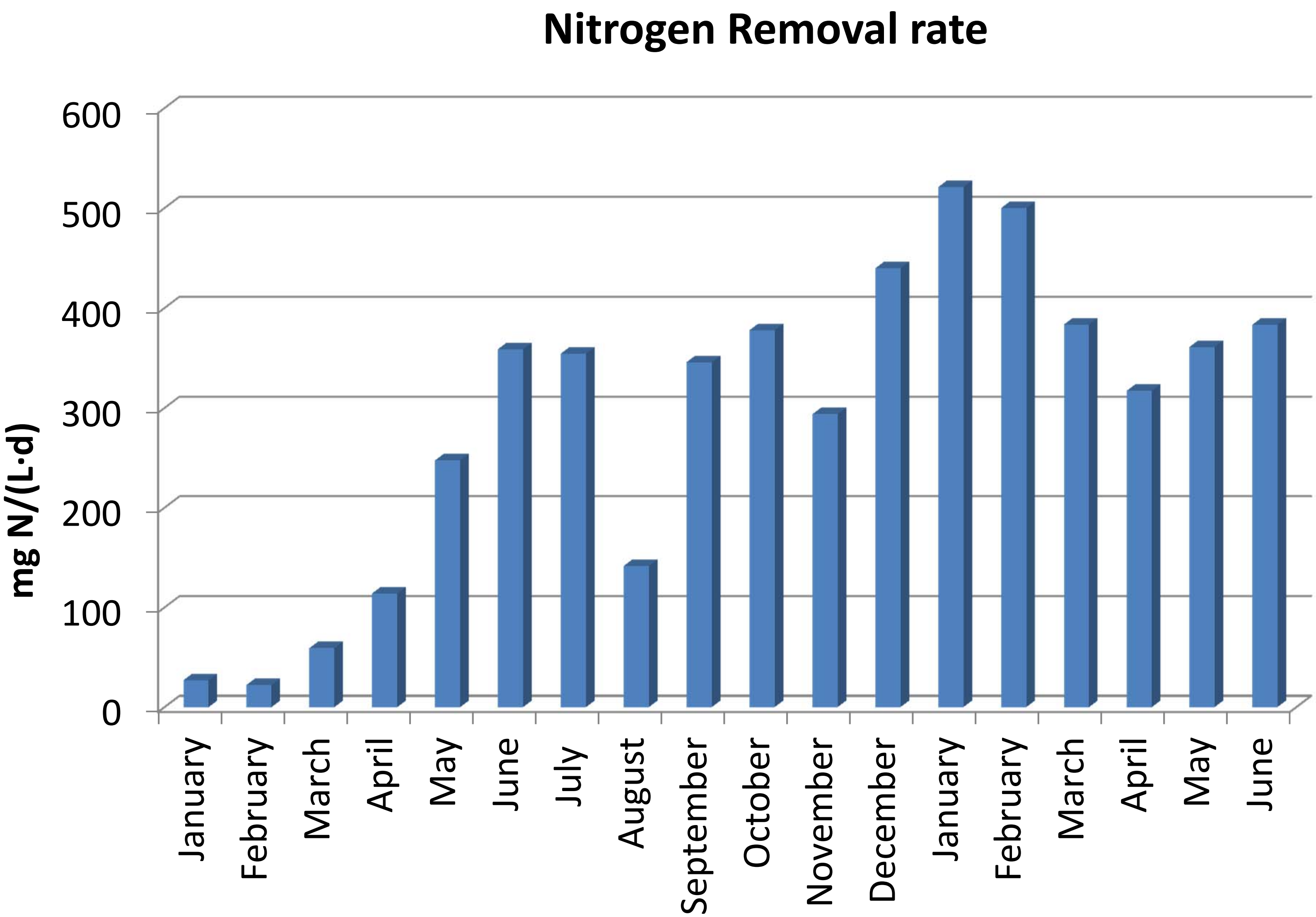
400 – 700 mg NH_4^+-N/L

Consorcio de Augas do Louro

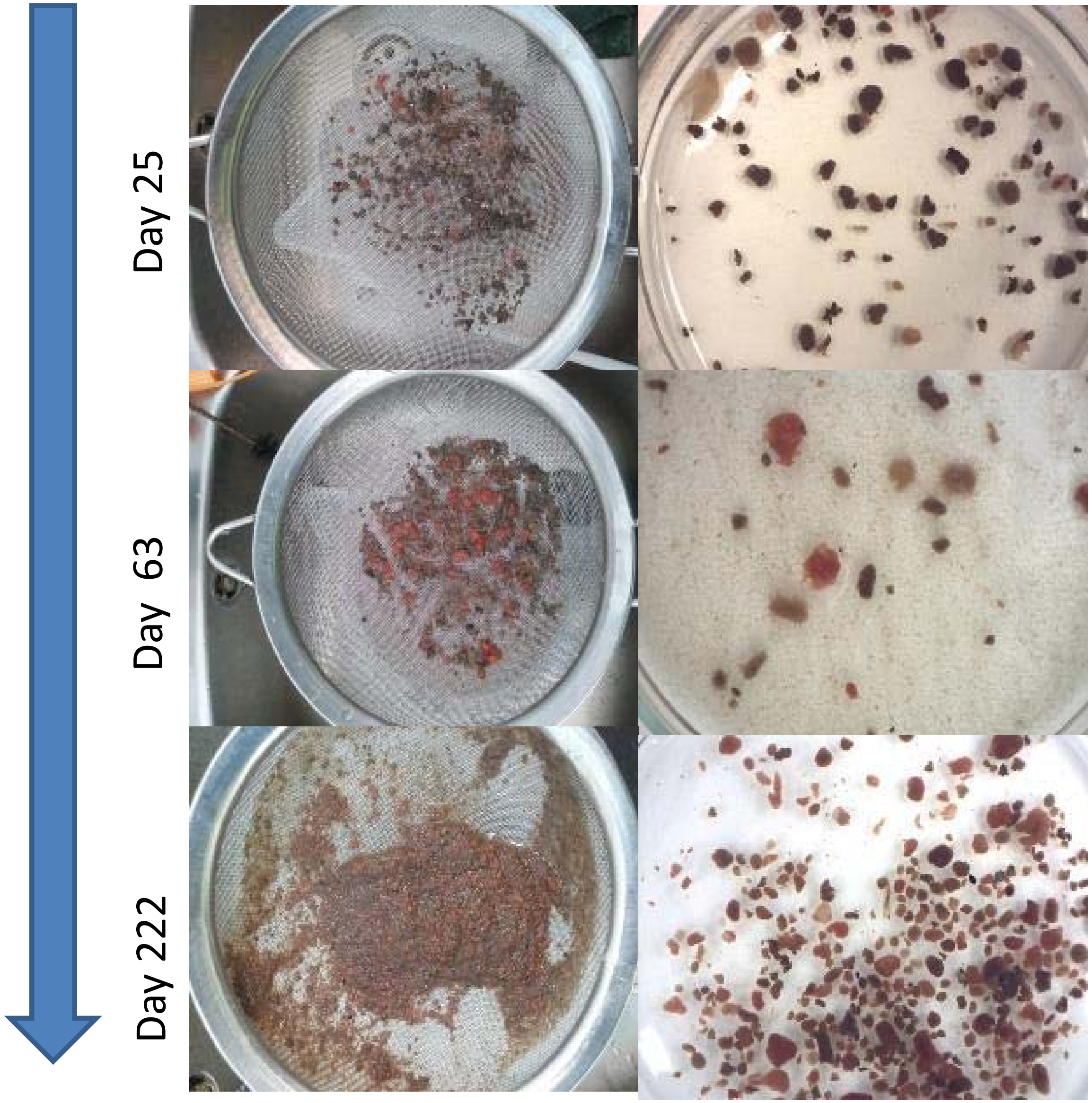
XUNTA DE GALICIA

MOS

Nitrogen removal rates over 350 mg N/(L·d) are achieved



Granular biomass is accumulated in the SBR



Biomass granulation

Biomass accumulation

The ELAN® process to treat the effluent from an anaerobic digester in a fish cannery

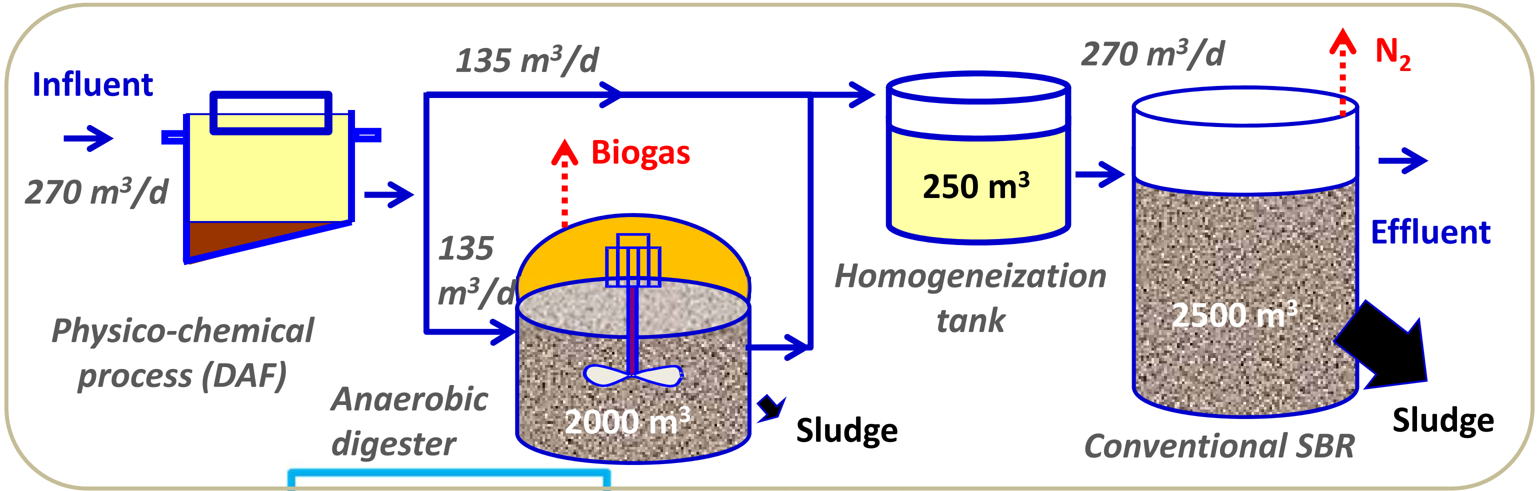
Galicia (northwest of Spain):

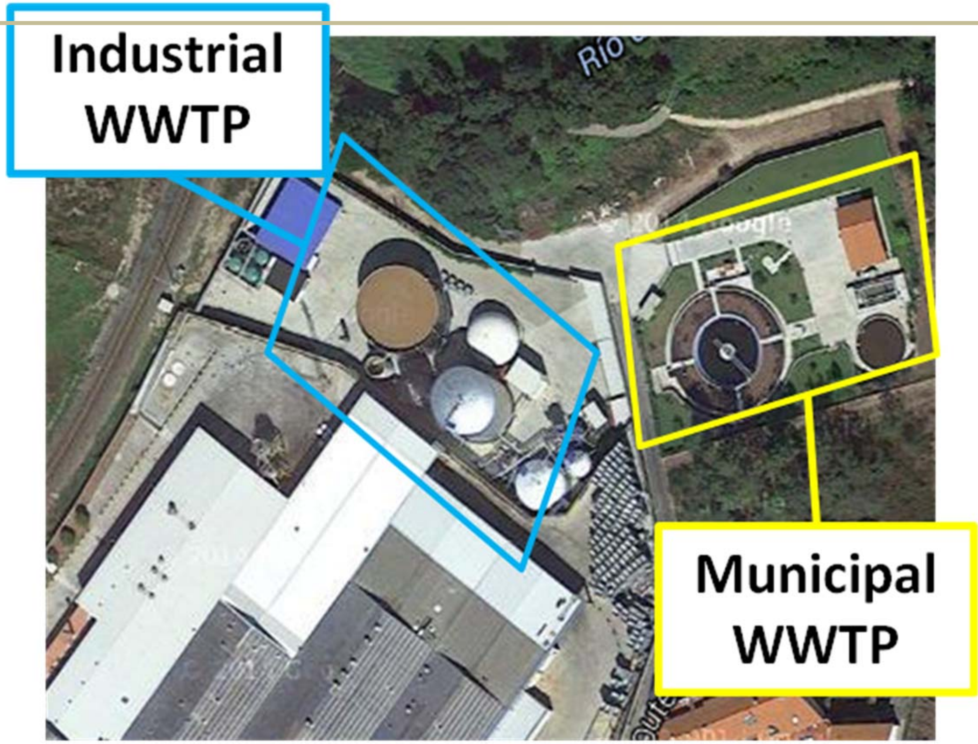
- Approximately 65 fish canning industries
- 86% of the total Spanish production
- 1st region of Europe
- 3th region in the world

Wastewaters from the fish canning industry:

- <u>High variable composition and salt content 10 g/L</u>
- <u>Surface limitation for the WWTP installation</u>

The ELAN® process will be used to upgrade the fish cannery



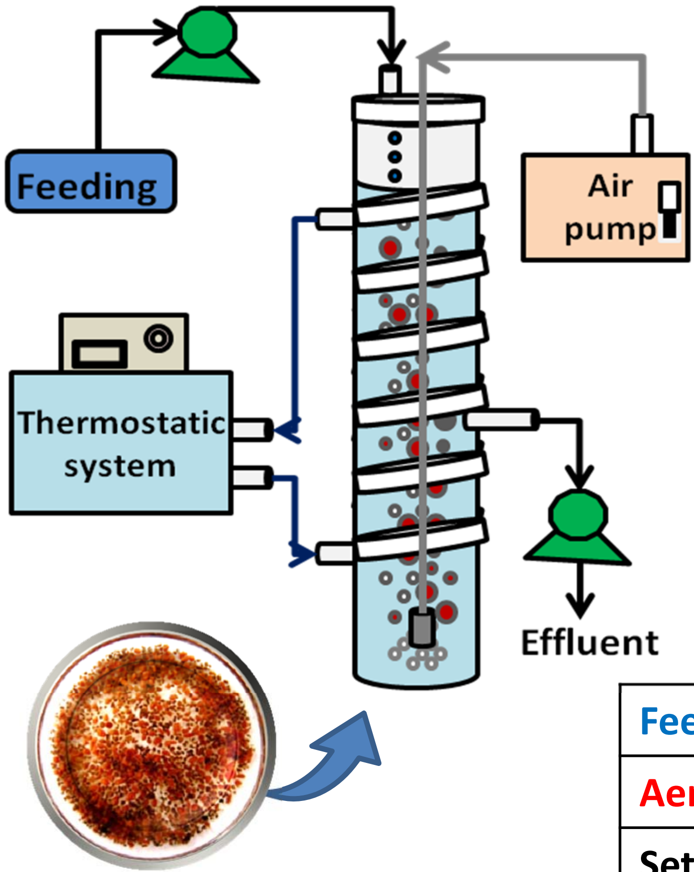


The feasibility of ELAN® to treat fish canning effluents was evaluated

- Variable composition
- Salt content

Moving from lab to Full Scale

The feasibility of ELAN® to treat fish canning effluents was evaluated



- **Volume = 1.5 L**
- **Temperature = 24 ± 1 °C**
- **DO = 2 - 3 mg O_2/L**
- **HRT = 1.0 - 1.5 days**

Feeding: effluent of an anaerobic reactor treating wastewater of the fish canning industry

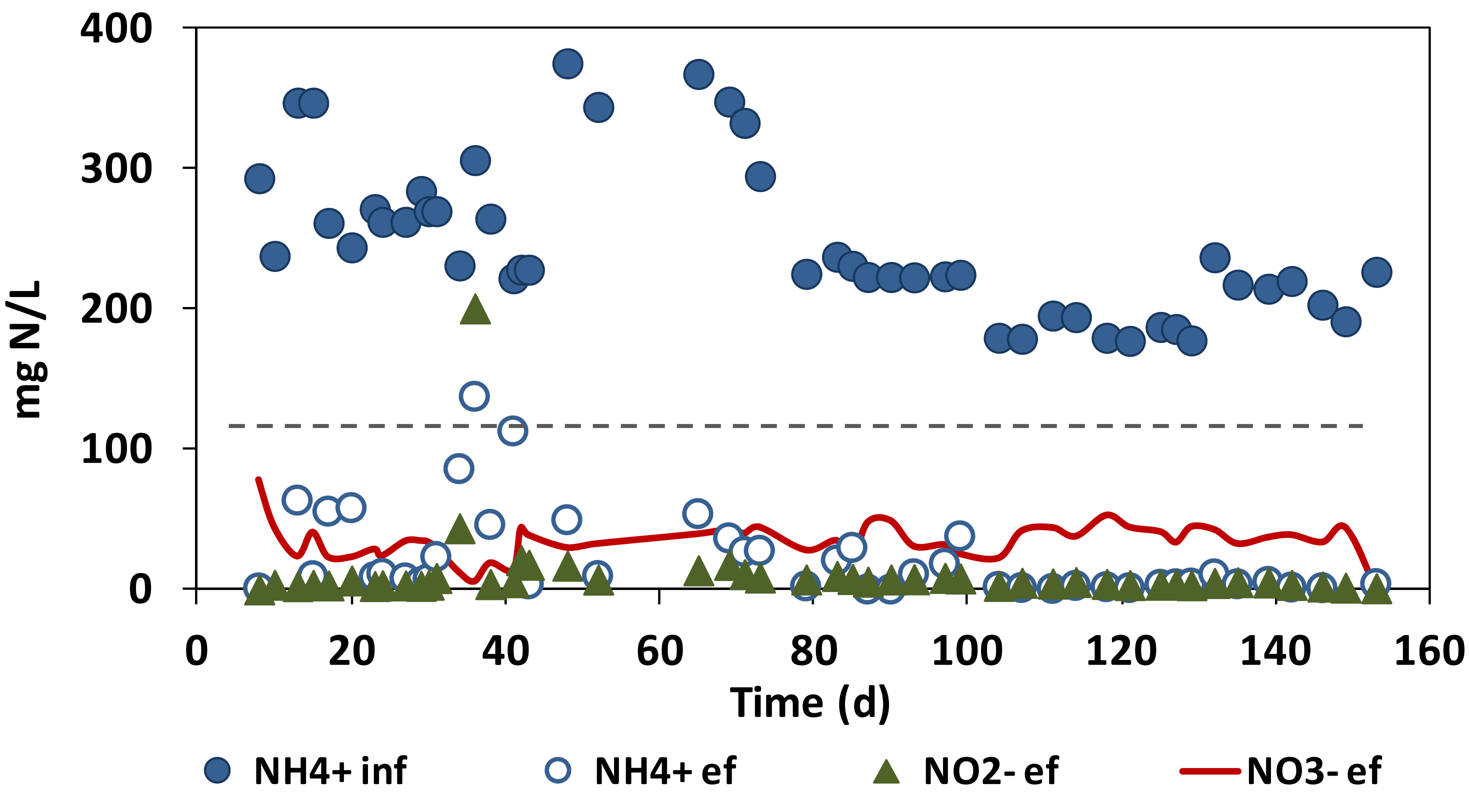
Inoculum: ELAN® granules from a pilot plant in an urban WWTP

Cycle of operation = 3 h (180 min)

Feeding	5
Aeration	160
Settling	10
Withdrawal	5

Val del Rio A. et al. (2018). Journal of Environmental Management, 208, 112-121. 10.1016/j.jenvman.2017.12.007

Nitrogen removal successfully achieved in the SBR



NO_2^- did not accumulate

↓

Good performance of the anammox process

NO_3^- due to anammox

↓

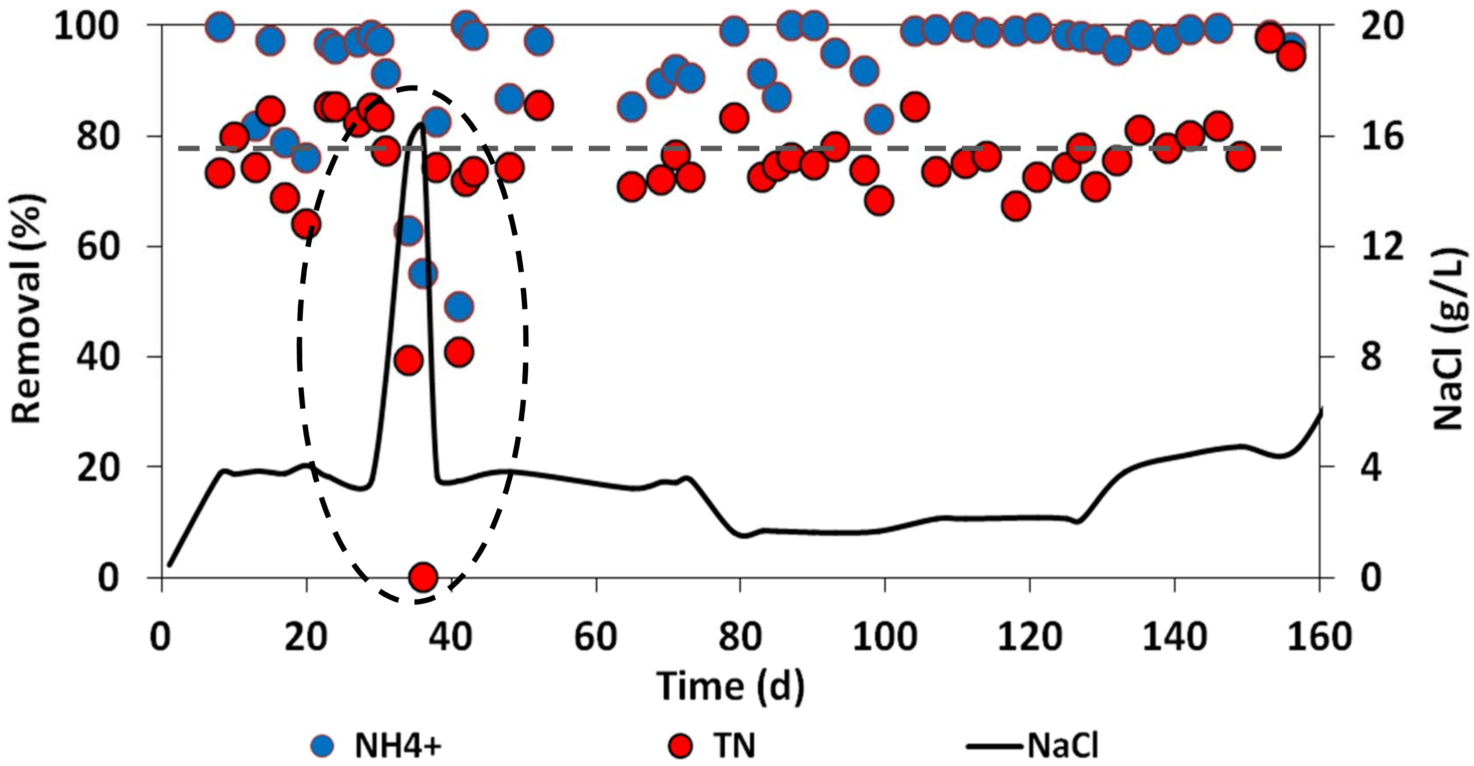
ELAN stoichiometry:

$NH_4^+ + 0.85\ O_2 + 1.11\ HCO_3^- \rightarrow$

$0.44\ N_2 + 0.11\ NO_3^- + 2.56\ H_2O + 1.11\ CO_2$

Fulfilled the industrial limit of N discharge < 115 mg N/L

Sudden increase of salt concentration reduced the N removal in the SBR



Sharp increase of salinity from 4 to 16 g NaCl/L:

✓ 40% AOB inhibition

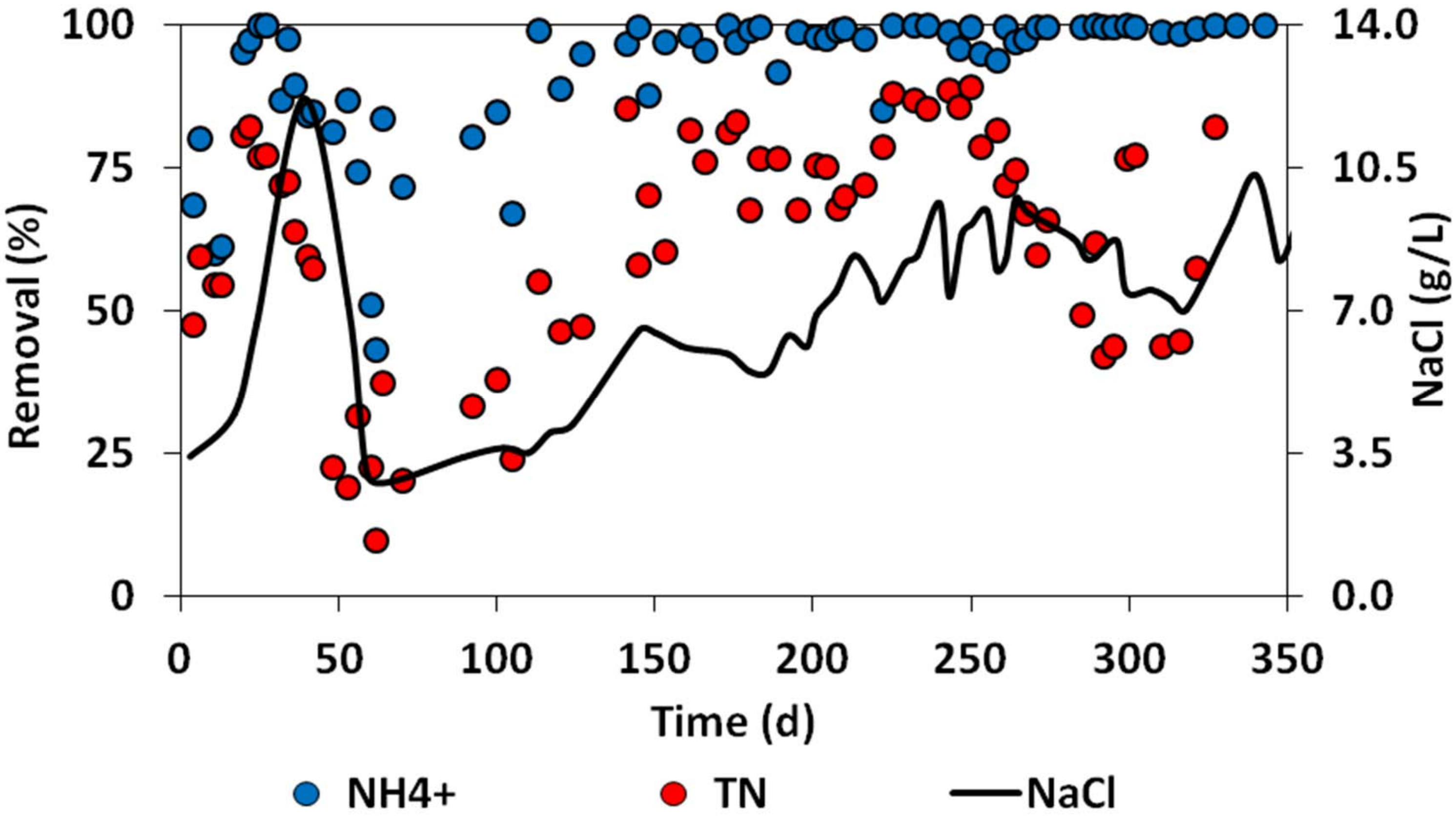
✓ 100% anammox inhibition

Reversible inhibition

≈ 100% NH_4^+ oxidation

≈ 80% total nitrogen removal

An strategy of salt progressive increase is evaluated



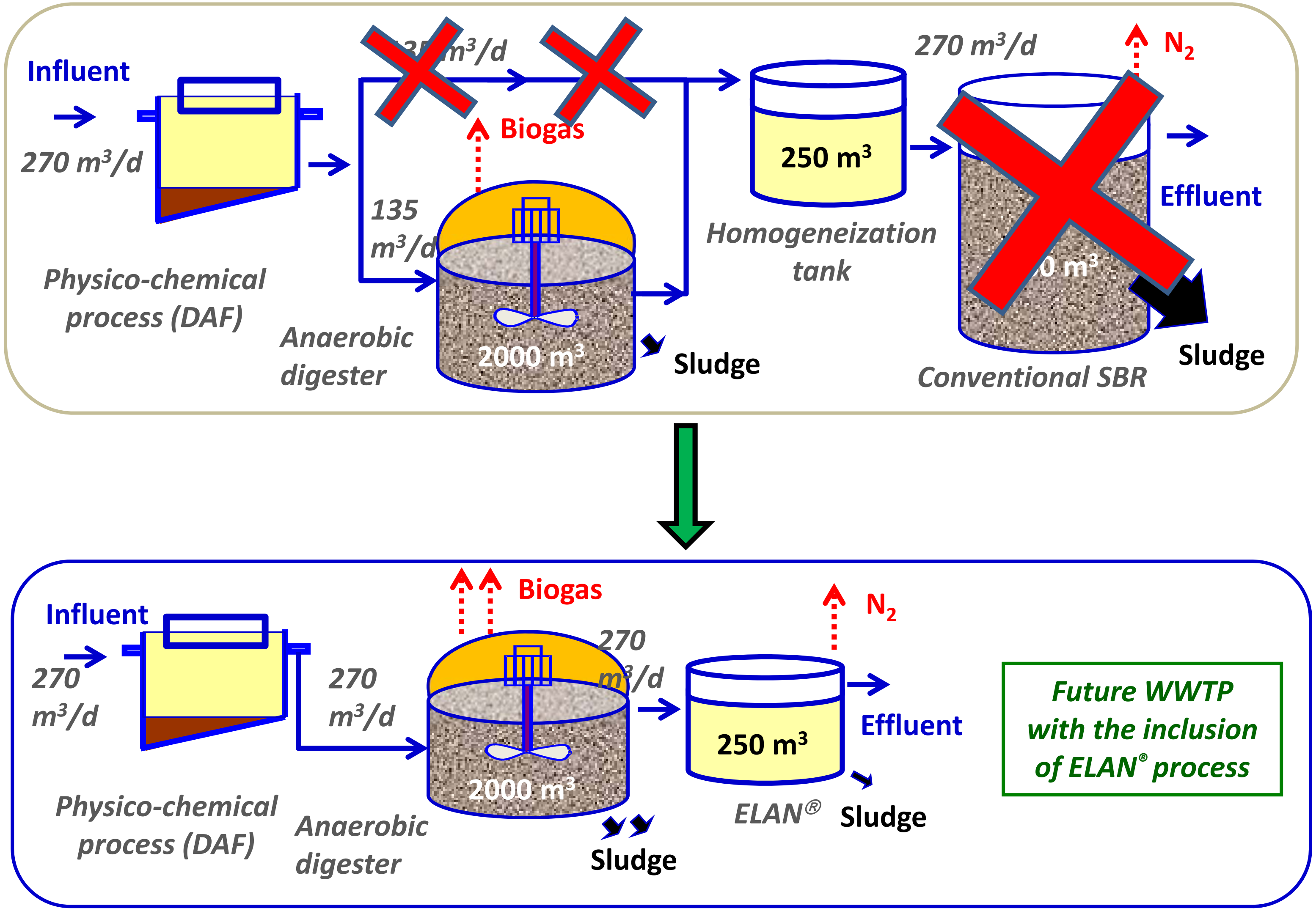
Biomass adaptation → TN Removal up to 70%

Operational conditions need to be defined to minimize salinity effects

- ✓ Reduce the nitrogen load applied to compensate for the inhibition.
- ✓ Use a homogenization tank, helping to mitigate the sharp salt increases.
- ✓ Promote biomass progressive adaptation to increasing salt concentrations.

9 g NaCl/L
100% NH_4^+ oxidation
70% total nitrogen removal

The implementation of the ELAN® process in the fish cannery involves several changes



Together with a number of advantages

	Influent		Effluent	
	g/m³	*kg/d*	*g/m³*	*kg/d*
COD	6700	1 818	250	67
TN	300	94	40	10

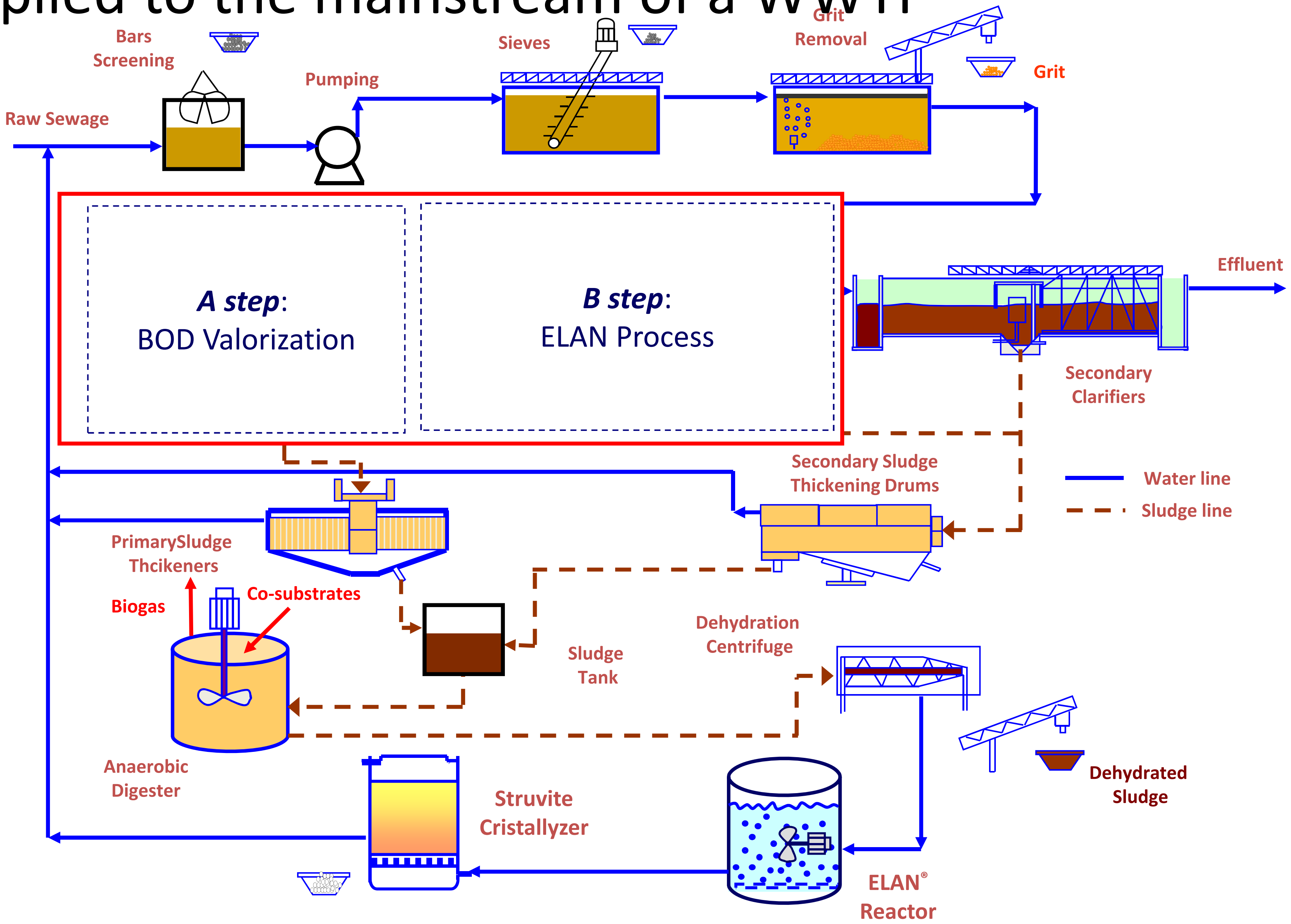
AD Effluent		Without ELAN®	**With ELAN®**
Water Flow	*m^3/d*	135	**270**
CH_4	*m^3/d*	245	**490**
	g/m³	*kg/d*	***kg/d***
COD	670	90	**181**
TN	312	42	**84**

N removal	SBR (N-DN)	**ELAN®**
Volume *(m^3)*	2 500	**250**
$Sludge_{waste}$ *(kg DS/d)*	264	**3**
N removal *(kg N/d)*	74.5	**74.5**
Energy *(kWh/d)*	1 340	**198**
N removal rate *kg N/(m^3 d)*	0.03	**0.30**

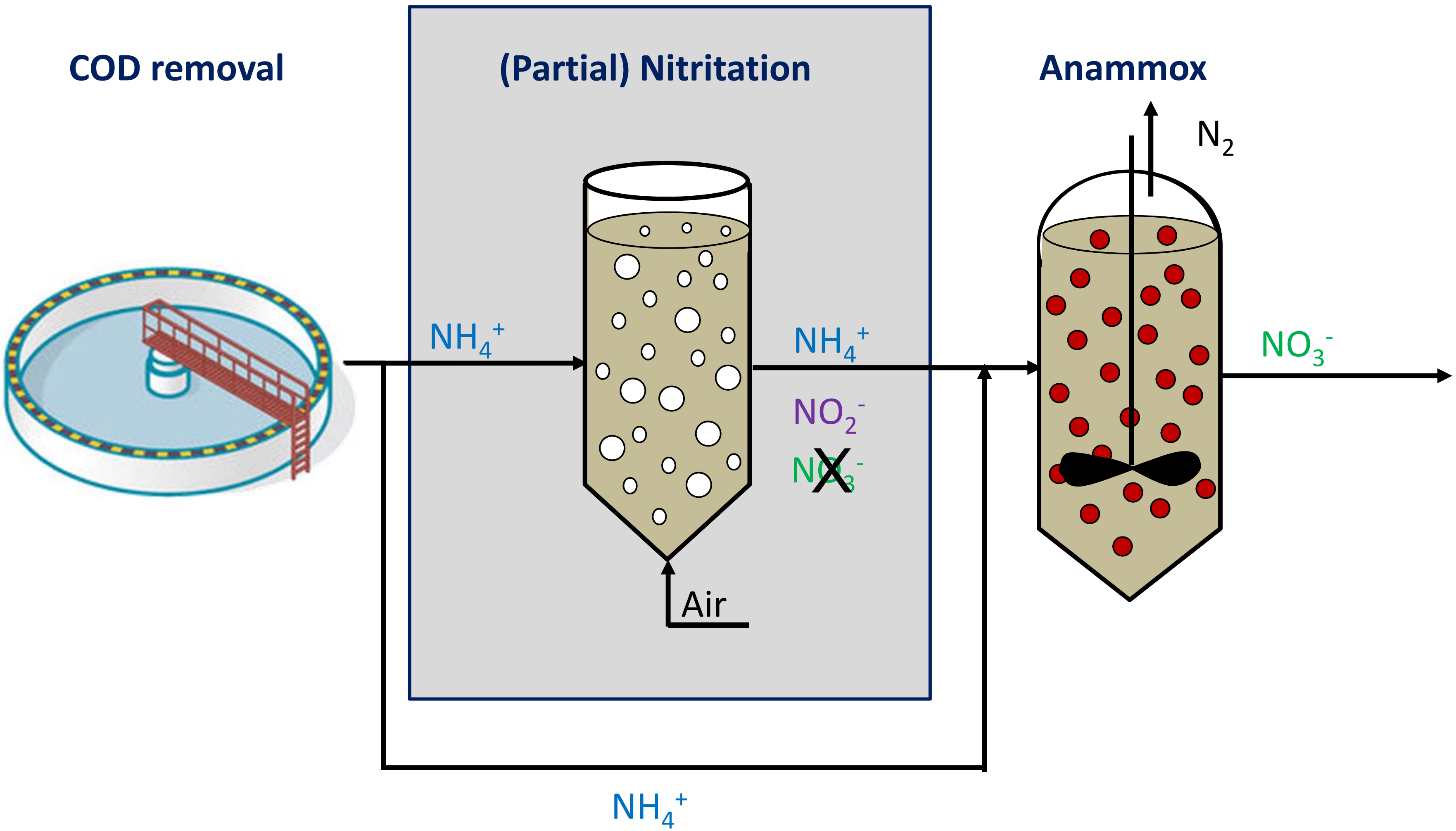
- ✓ **Achieving the same removal**
- ✓ **100 % of the flow anaerobically treated**
- ✓ **Double methane production**
- ✓ **Only 10 % of aerobic volume**
- ✓ **98 % sludge reduction**
- ✓ **85% Less Energy for aeration**
- ✓ **N removal rate increase by 10**
- ✓ **Positive Energy Balance: 4900 kWh ther vs 200 kWh elect**

OPEX of ELAN® system expected to be 20% lower than conventional N-DN

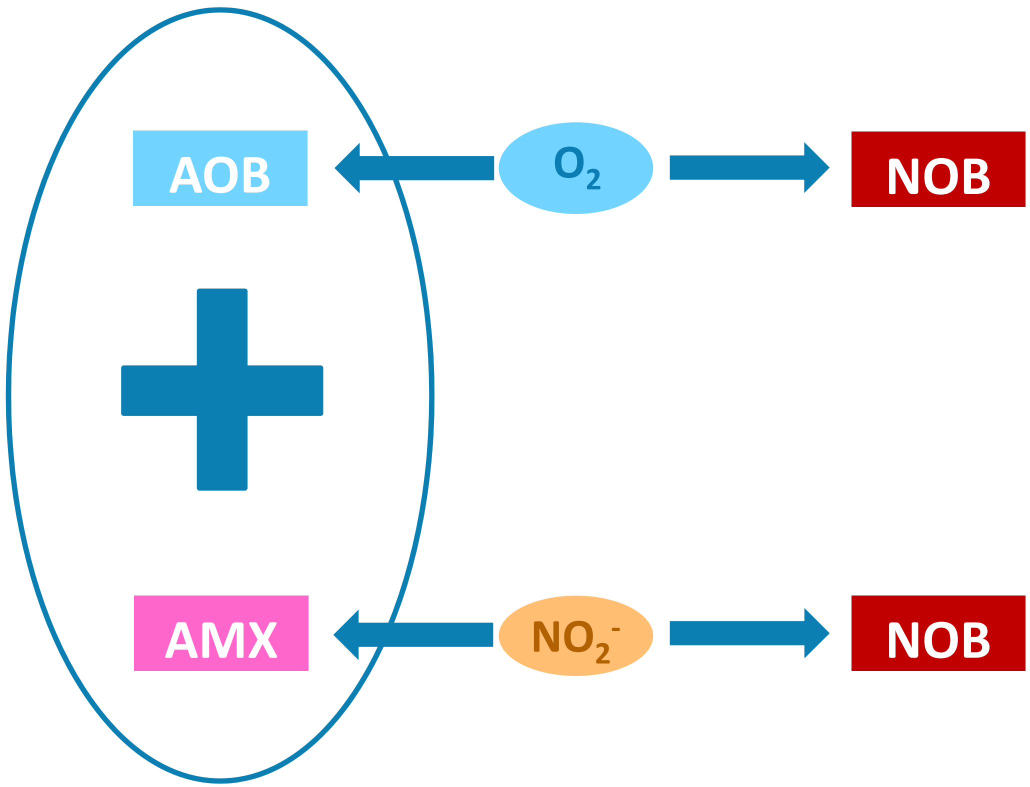
In the **future** ELAN® modified is expected to be applied to the mainstream of a WWTP



Two-stage configuration allows to optimize each process separately



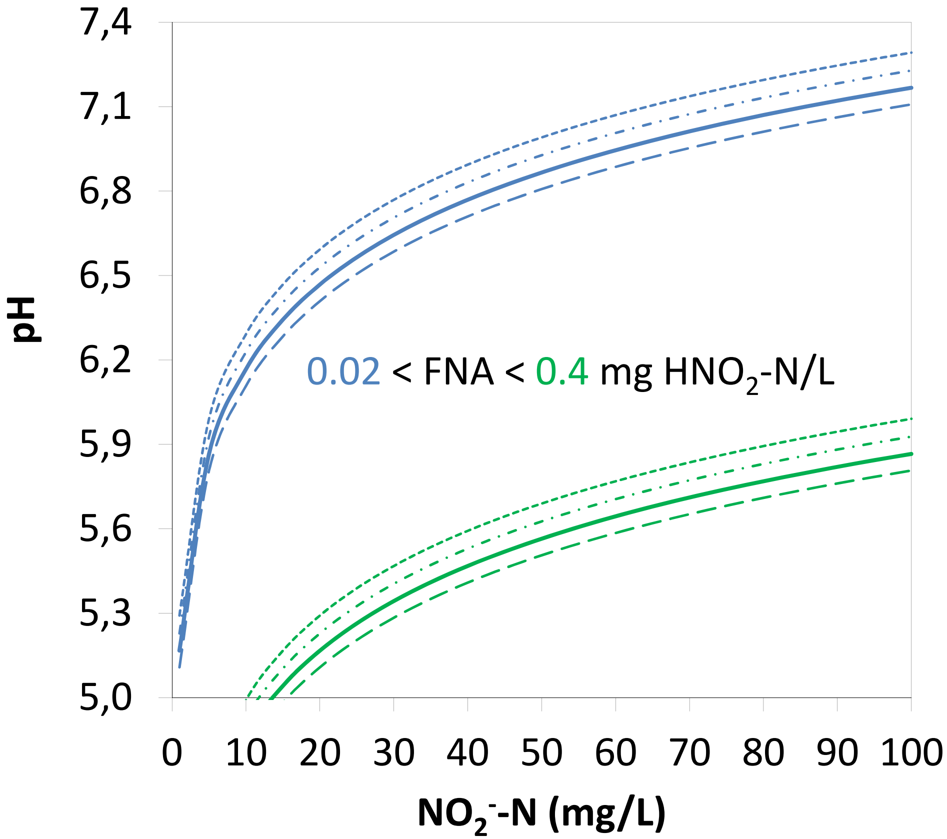
The process limited by NOB activity



AOB = Ammonium oxidizing bacteria
NOB = Nitrite oxidizing bacteria
AMX = Anammox bacteria

NOB are more sensitive to free nitrous acid (FNA) than AOB

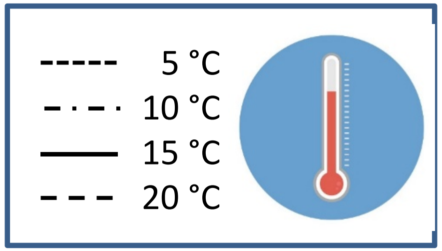
Nitritation: $NH_4^+ + \mathbf{2\ HCO_3^-} + 1.4\ O_2 \rightarrow NO_2^-$



$$FNA = \frac{NO_2^- - N}{10^{pH} e^{-2300/(T+273)}}$$

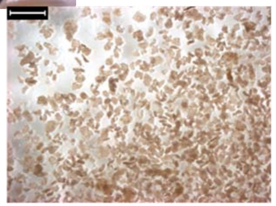
AOB 0.4 mg HNO_2-N/L

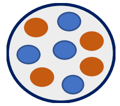
NOB 0.02 mg HNO_2-N/L



Anthonisen et al. (1976) Journal Water Pollution Control Federation ; 48, (5), 835-852.
Blackburne et al. (2008) Biodegradation; 19:303-312.

Two-stage configuration allows a better NOB suppression and promotes the anammox process



Inoculum: sludge with significant NOB activity 

Sequencing batch reactor (**SBR**): 2 L

T = 16 ± 1 °C

SBR cycle distribution

Feeding+aeration			
Settling			
Drawing			
Time (min)	158	20	2

✓ NOB suppression

Pedrouso et al. (2017) Separation and Purification Technology 186, 55-62.

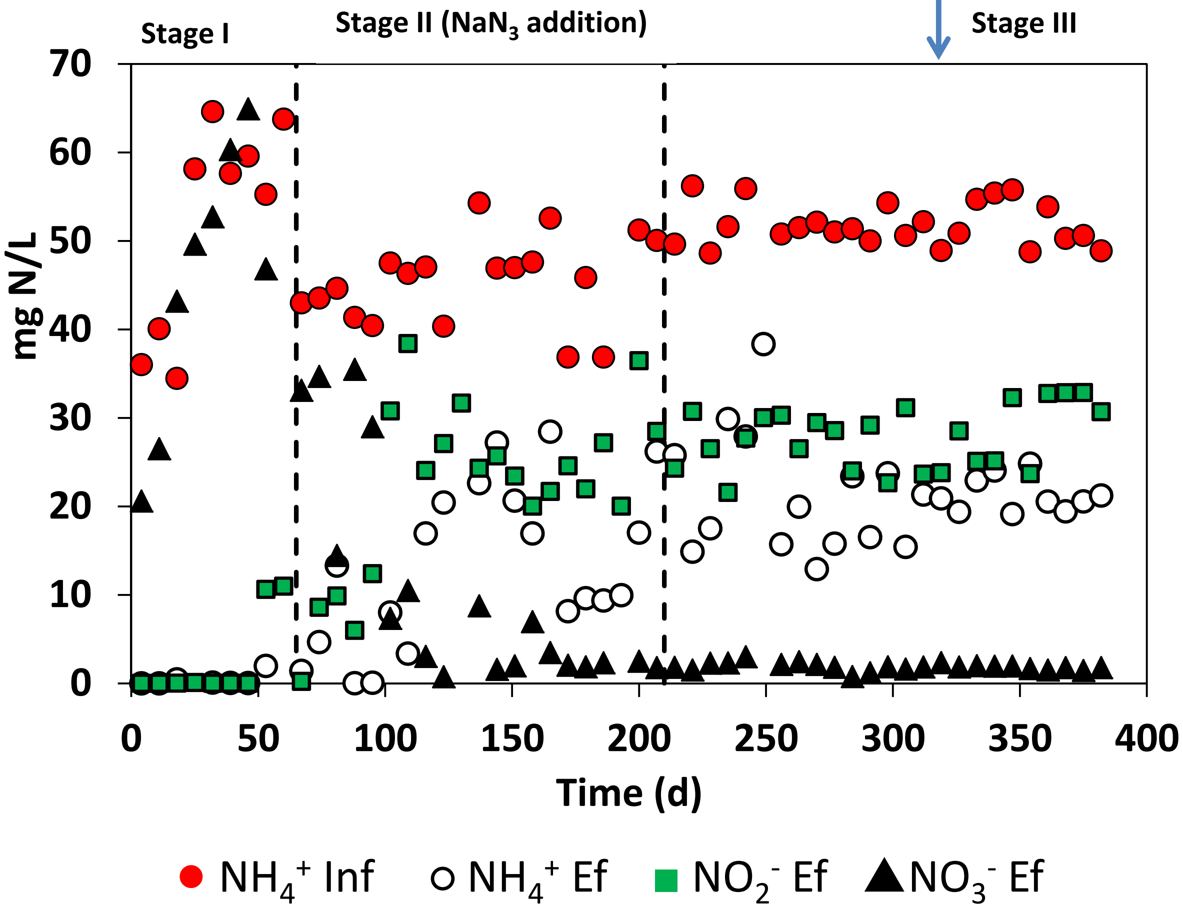
To succeed the main point is to avoid nitrite oxidizing bacteria (NOB) activity

European Patent applied: *EP 16 38 2266*

Complete nitrification

Selective inhibition of NOB → PN

Long term PN without chemical addition

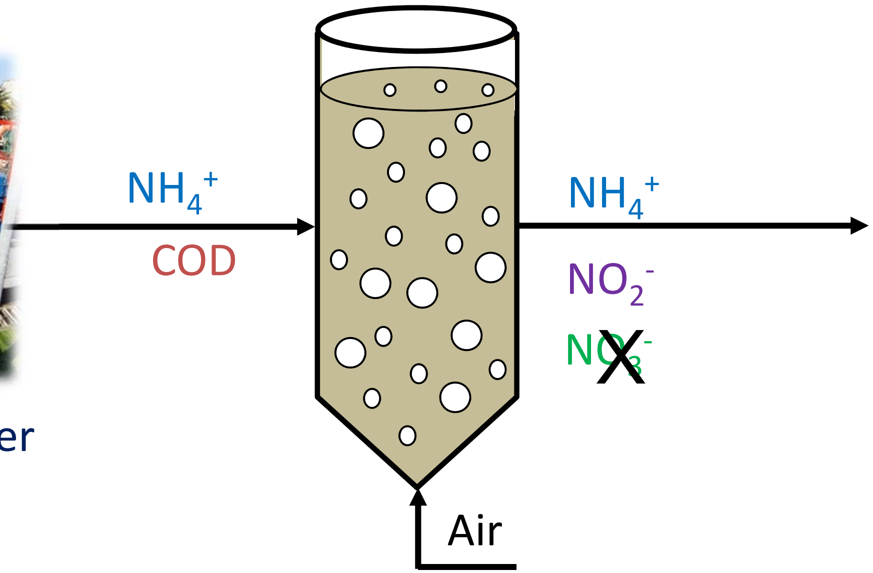


Stage (day)	Abundance Nitrospira (%)
SI (44)	27.4%
SIII (248)	3.4%
SIII (303)	3.4%
SIII (336)	0.0%

Partial nitritation by in-situ FNA accumulation tested with municipal wastewater

Mainstream OM removal	Mainstream N removal
Settling	Mod. ELAN

Primary settled wastewater



PN with primary settled WW adjusts to defined scenarios

Inoculum: sludge without significant NOB activity (Giustinianovich et al. (2018))

Sequencing batch reactor (**SBR**): 2 L

T = 15 ± 1 °C

HRT = 6 h

To maintain the AOB selection

NH_4^+-N/IC ratio < 0.6 (100% oxidation)

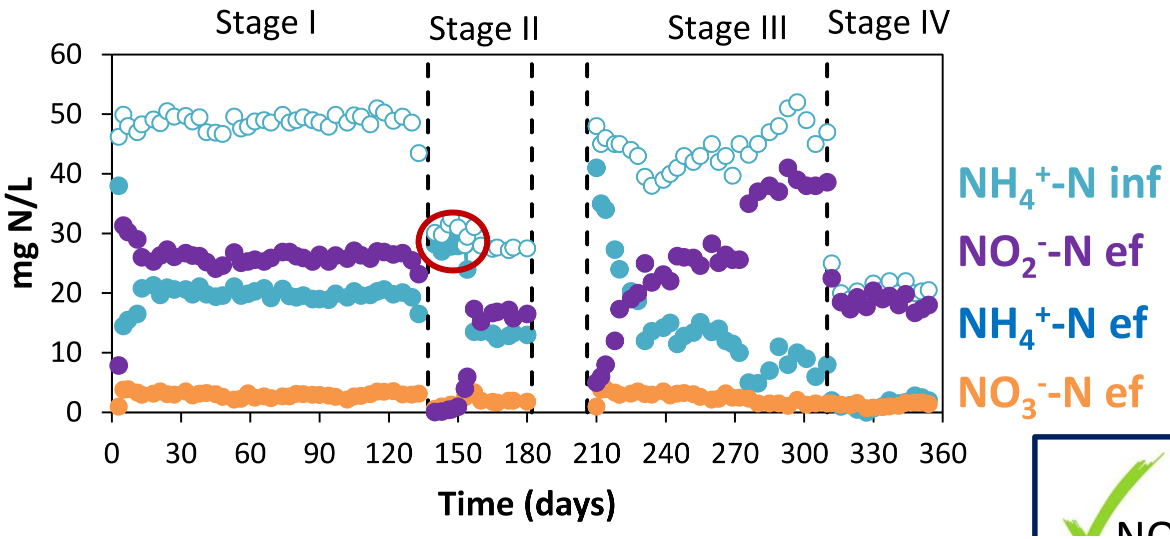
Biomass storage at 4 °C

Stage	Days	Feeding	NH_4^+-N (mg N/L)	pH	N/IC (g/g)	TOC (mg/L)
I	0 - 137	Synthetic*	50 ± 3	7.70 ± 0.10	0.89 ± 0.02	-
II	138 – 182	Sewage	29 ± 5	6.95 ± 0.15	0.80 ± 0.05	40 ± 7
III	207 - 310	Sewage	45 ± 10	7.20 ± 0.25	0.68 ± 0.08	45 ± 9
IV	311 - 354	Sewage	20 ± 1	7.01 ± 0.09	0.61 ± 0.02	22 ± 3

Giustinianovich et al. (2018) Chemosphere 194, 131-138.

*Pedrouso et al. (2017) Separation and Purification Technology 186, 55-62.

Partial nitritation established and succesfully maintaned by the in-situ FNA produced



✓ NOB suppression

Synthetic feeding

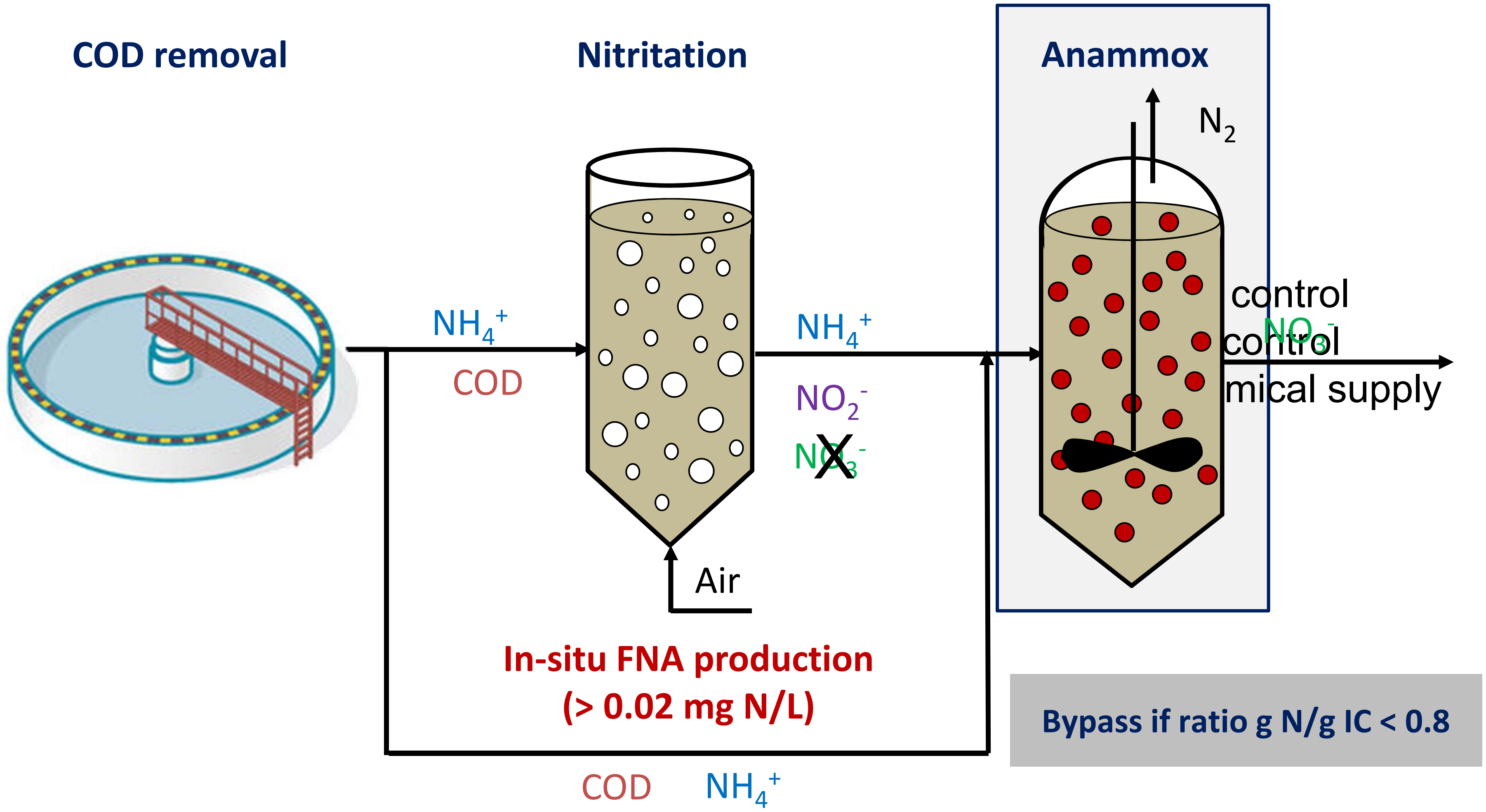
Feeding+aeration	■		
Settling		■	
Drawing			■
Time (min)	158	20	2

Municipal wastewater

Feeding	60			
Aeration	158			
Settling			20	
Withdrawal				2

Pedrouso et al. (2018) *"Simultaneous partial nitritation and organic matter removal in urban wastewater at low temperature"* 4th IWA Specialized International Conference, IWA, Ontario, Canada.

Succesful NOB inhibition by FNA in presence of organic matter



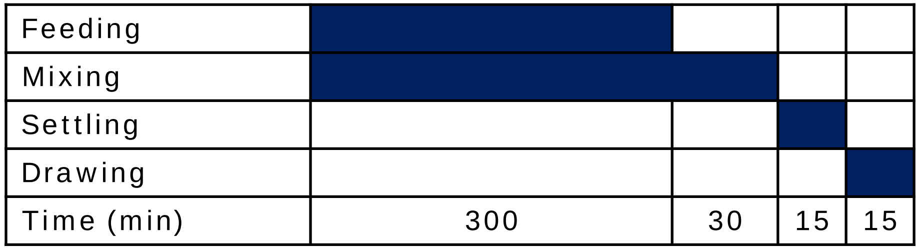
Mainstream anammox was operated at laboratory scale

Inoculum: ELAN® pilot plant treating reject water
Synthetic media
Sequencing batch reactor (**SBR**): 5 L

T = 15 ± 1 °C

HRT = 24 h

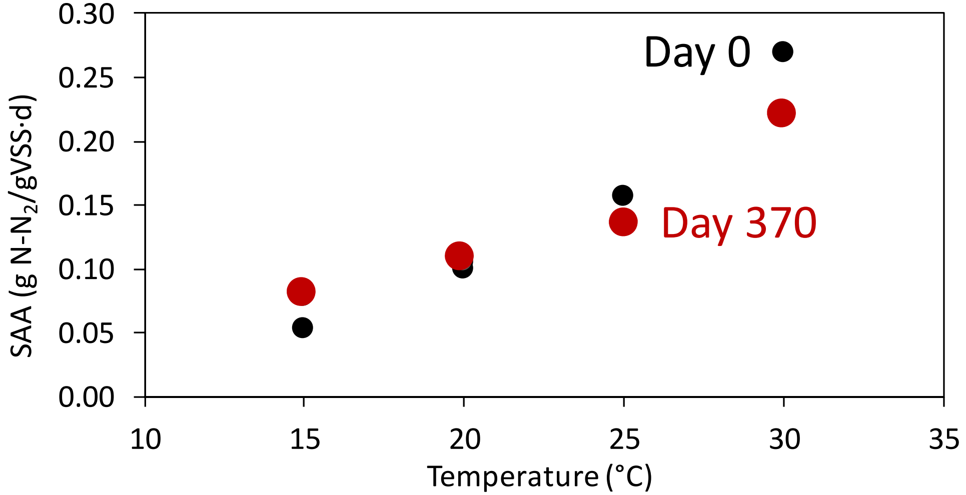
SBR cycle distribution



Stage	Days	Alk (mg IC/L)	g NH_4^+-N/g IC
I	0 - 197	130	0.20
II	198-248	65	0.38
III	249-338	30	0.83
IV	338-392	10	2.5

- ✓ Biomass retention
- ✓ Anammox activity
- ✓ Not affected by low alkalinity

Anammox activity is not affected by exposure time at low temperature



✓ Biomass retention

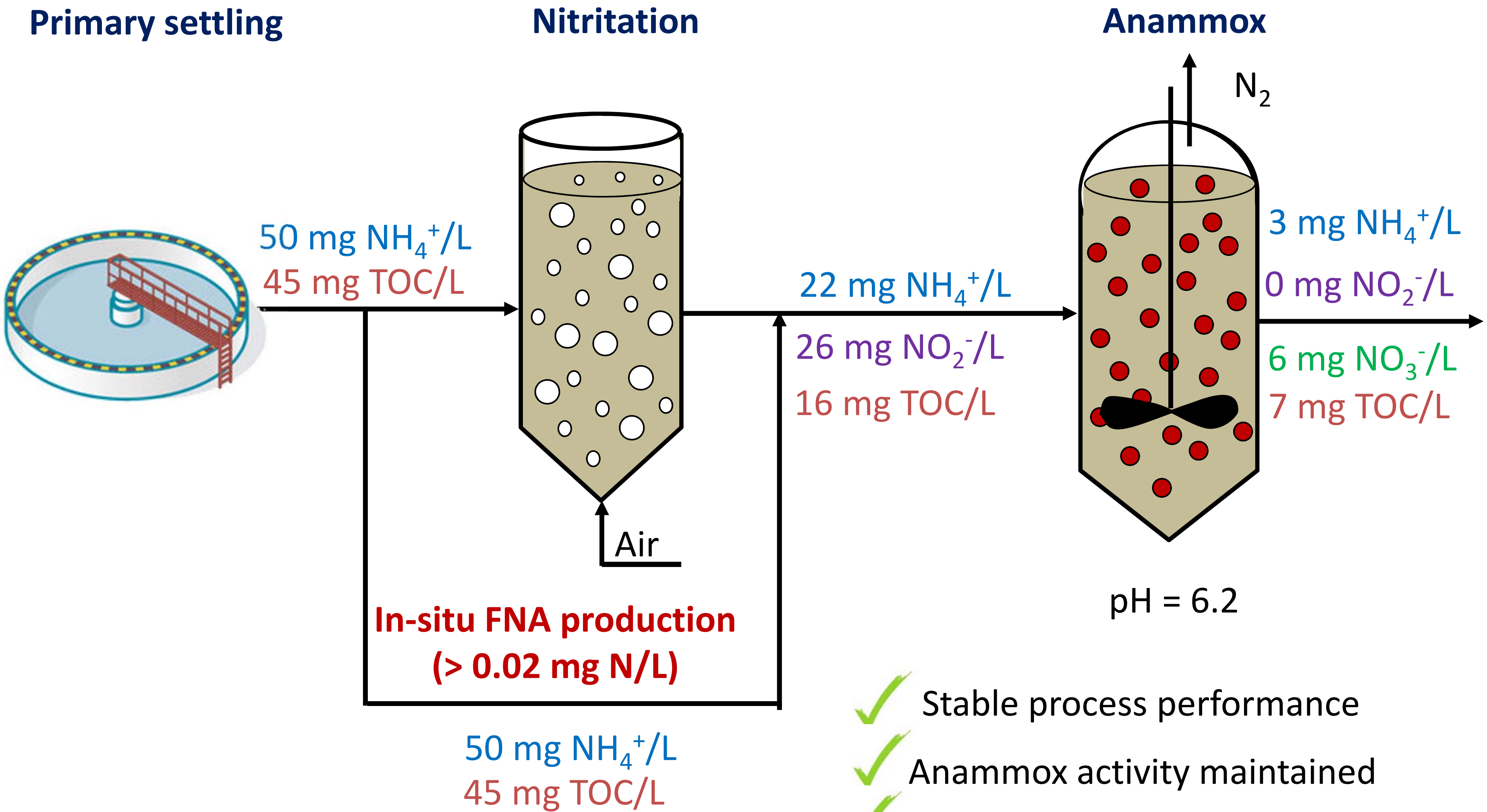
✓ Anammox activity

✓ Not affected by low alkalinity

Sampling day	SAA (30 °C) (mg N/(g VSS·d))	SAA (15 °C) (mg N/(g VSS·d))
0	270 ± 13	53 ± 11
370	200 ± 13	78 ± 8

Nitrogen removal efficiency

Stable anammox process performance treating the effluent of the partial nitritation unit



- ✓ Stable process performance
- ✓ Anammox activity maintained
- ✓ 0.10 g NO_3^--N_{prod}/g NH_4^+-N cons

Partial nitritation and anammox process at pilot scale – Stay research

EDAR Valdebebas (Madrid)

- 260 000 hab-eq
- 52 000 m^3/d
- Eliminación de materia orgánica

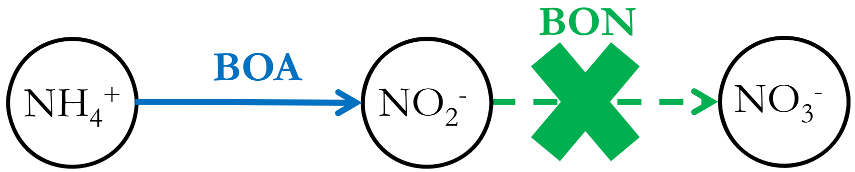
AquELAN®

NP

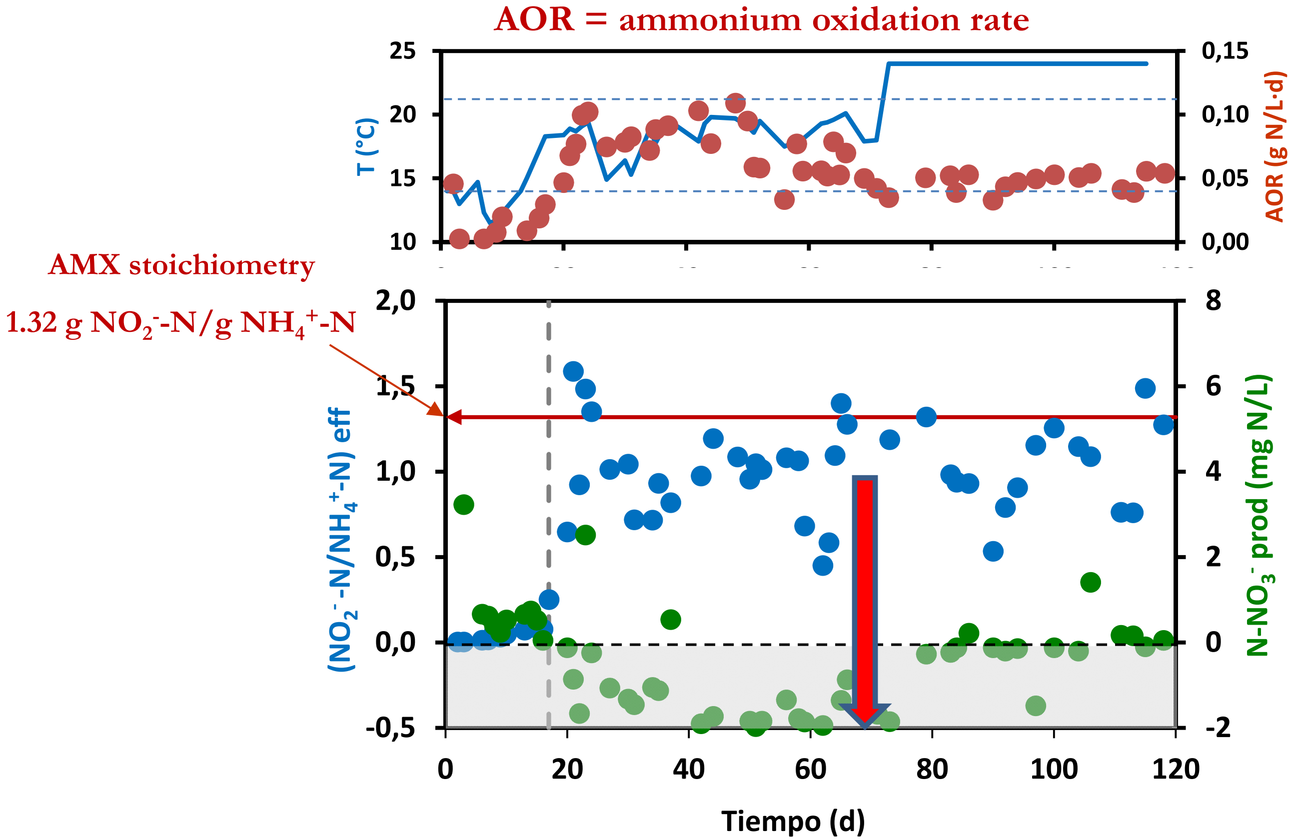
AMX

NOB successfully suppressed at pilot scale

Partial Nitritation

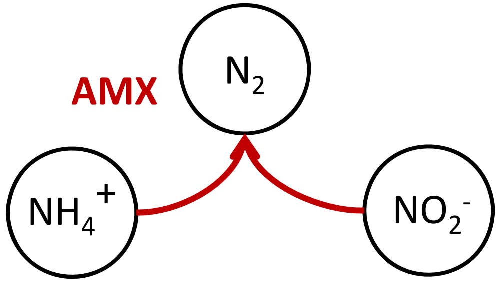


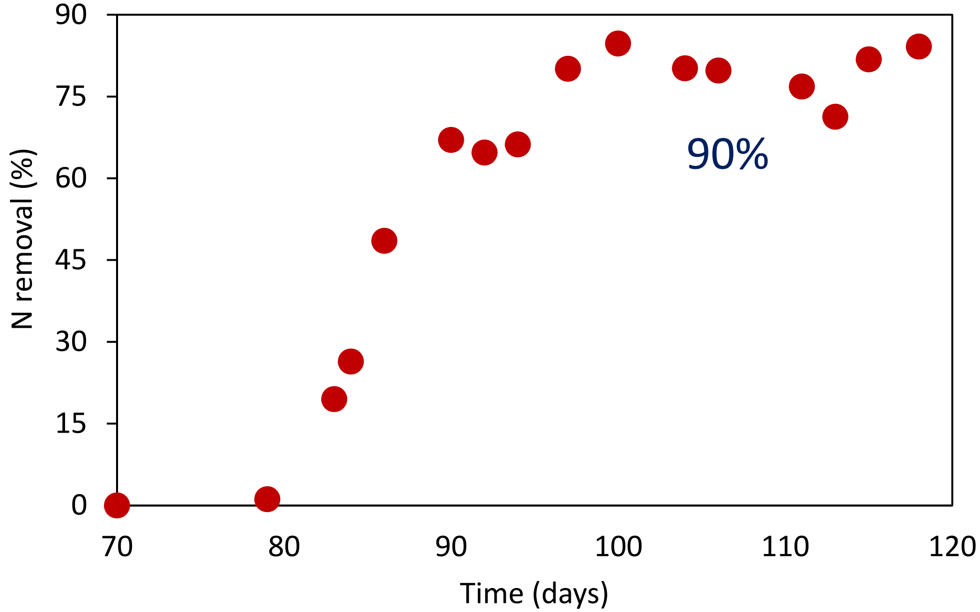
Influent: 50 mg N/L



Anammox process was quickly established

AMX



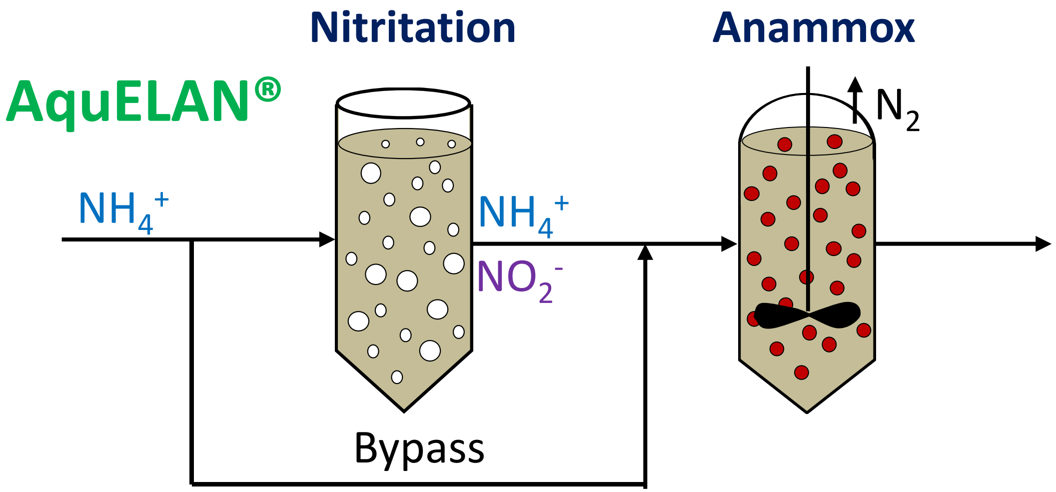


Summer time: average temperature 24 °C

Load treated (2 units): 100 g N/m³·d

Variable nitrite conversions are possible depending on the wastewater characteristics

NH_4^+-N/IC ratio → NH_4^+-N/NO_2^--N
pH control
PN bypass to anammox unit



Case	NH_4^+-N/IC ratio (g N/g C)	Stream to PN unit (%)	Ammonia oxidized to nitrite (%)	Action required
A	>1.0	100	50	Alkalinity supply
B	0.8-1.0	100	50	None
C	0.6-0.8	50-100	50-100	Bypass to anammox unit
D	<0.6	50	100	Bypass and pH control

Acknowledgements

- Improved control and application of nitrogen cycle bacteria for ammonia removal from wastewater (ICON). European Commission (EESD) (EVK1-CT-2000-00054). 01/02/2001 - 31/01/2004.
- Development of biological reactors for the ANaerobic AMMonium OXidation (OXANAMON). Ministery of Science and Technology (PPQ2002-00771). 01/11/2002 - 31/10/2005.
- Development of clean technologies for the optimization of the design and operation of WWTPs. Galician Government. 08/08/2010-30/09/2013.
- ITACA project funded by the Spanish Ministry of Economy through the CDTI INNPRONTA program (2011/CE25).
- Competitive reference group (GRC 2013-032) funded by FEDER.
- Pioneer_STP - The Potential of Innovative Technologies to Improve Sustainability of Sewage Treatment Plants (PCIN-2015-22 (MINECO) / ID199 (WaterJPI)). April 2016 - May 2019

The performance of PN-AMX processes needs to be assessed for each type of wastewater

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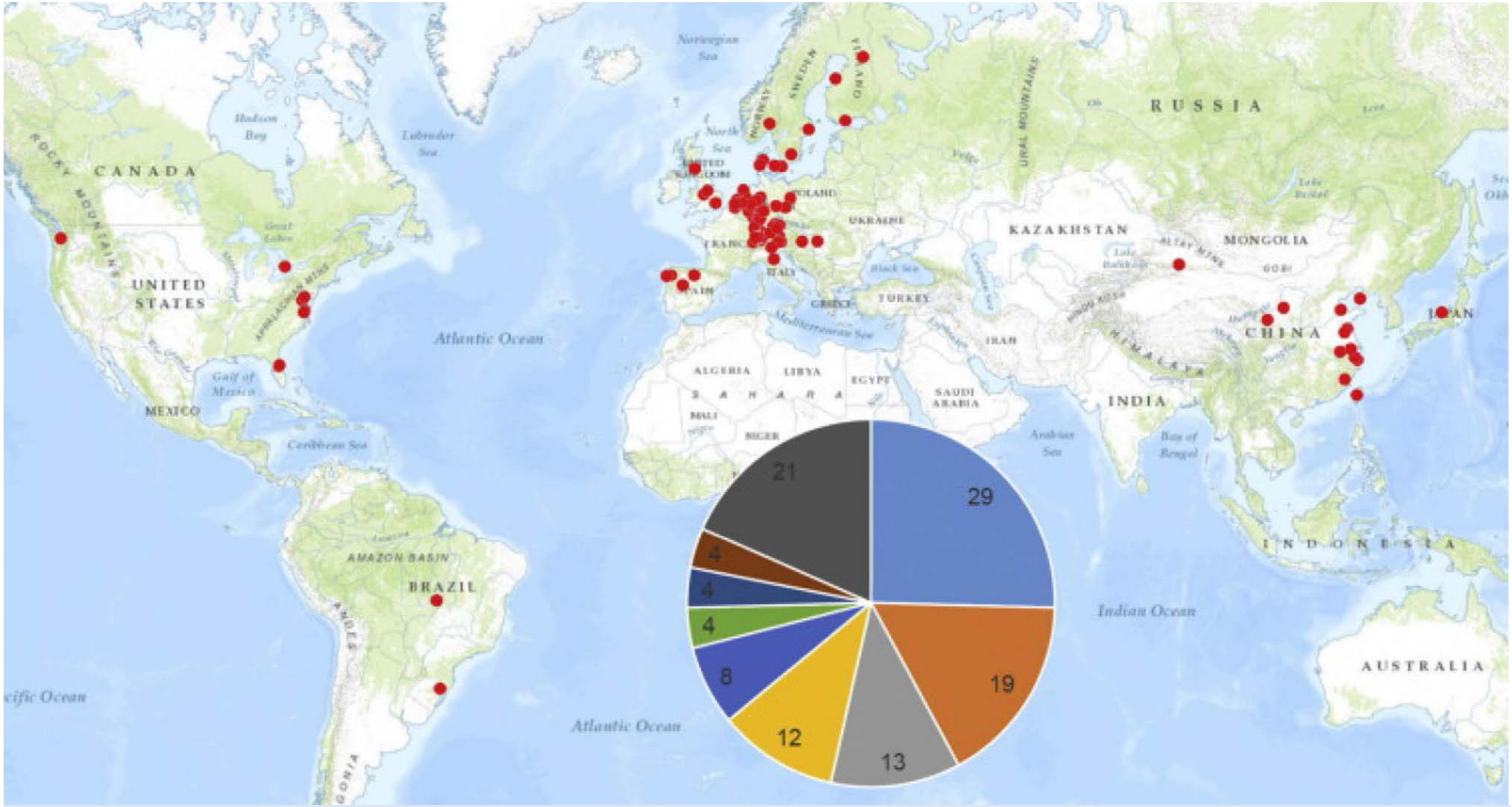

Over 100 full scale anammox based plants in the world

- Germany
- Netherlands
- China
- Switzerland
- USA
- Finland
- Spain
- UK
- Others

Mao N., Ren H., Gen J., Ding L., Xu K. (2017) World J Microbiol Biotechnol, 33:153.