LIFE DeNTreat

Decentralized innovative treatment of ammonium-rich urban wastewater

Keynote on anammox processes applied to industrial wastewater: success stories and critical issues

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DICEA DIPARTIMENTO DI INGEGNERIA CIVILE E AMBIENTALE

LIFE DeNTreat FINAL EVENT – web meeting

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Overview PN/Amx full-scale applications

1. Municipal WWTP

- Conventional biosolids reject liquors (*centrate*)
- THP biosolids reject liquors
- Sludge drying condensates
- *Yet to come: Mainstream treatment*

2. Industrial effluents

- Food (gelatin, potato, fish, MSG, …) / Beverage industry / Manure
- (THP) Biosolids co-digestion reject liquors
- Fermentation industry
- Rendering (*slaughterhouse/meat processing*)

3. Others

- Leachate
- OFMSW (co-)digesters reject liquors

Industrial applications: critical issues

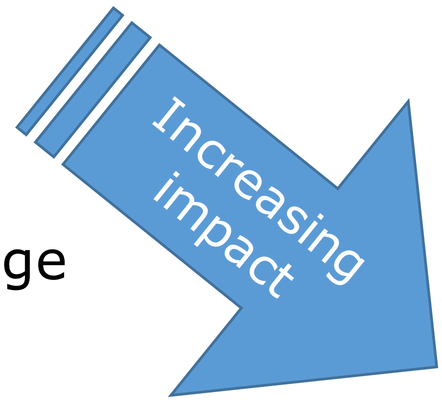
- Inhibiting/toxic compounds
- Solids/COD excessive load
- Overdosing dewatering polymers
- Foaming
- Scaling of biomass/piping
- Limiting alkalinity
- Limiting Inorganic Carbon, IC
- Conductivity

Industrial applications: critical issues

- Inhibiting/toxic compounds

→ Partly technology-dependent criticality extent

- Granular sludge
- MBBR/IFAS
- Flocculent sludge



- Antibiotics (manure), biocidal substances (anti-fouling agents, disinfectants)

→improved solid/liquid separation, dilution, larger reactor volume

- Inhibiting/toxic dewatering polymer

→ Change/optimization of polymer dosage

- H_2S

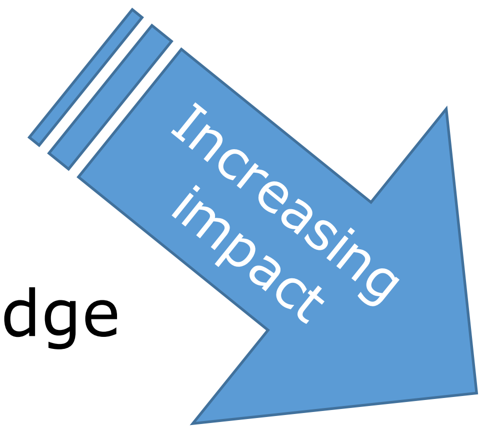
→Flash aeration before PN/A

Industrial applications: critical issues

- Solids/COD excessive load

→ Technology-dependent criticality extent

- Granular sludge
  - MBBR/IFAS
    - Flocculent sludge



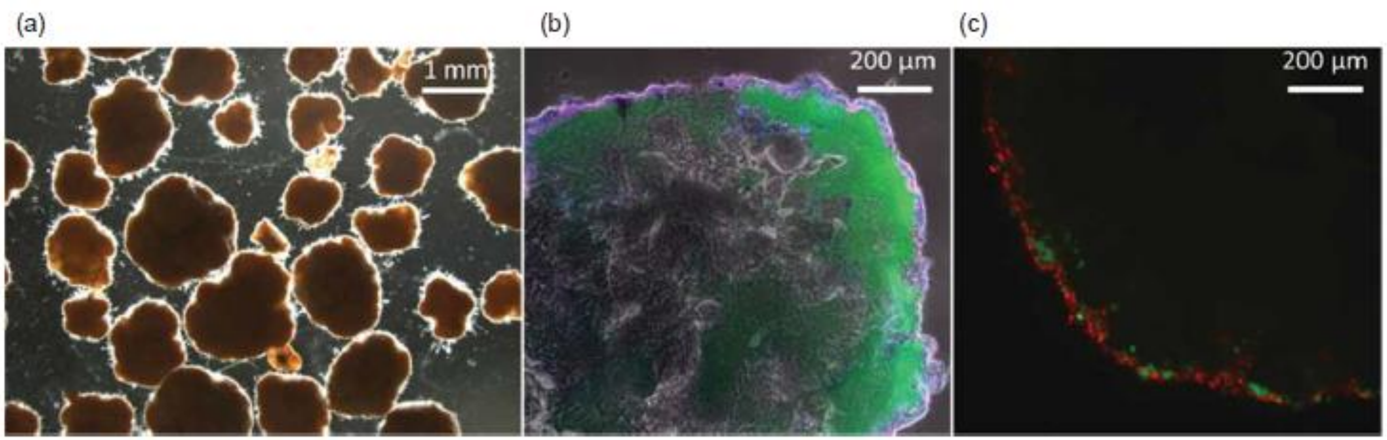
Industrial applications: critical issues

- Solids/COD excessive load

→ Granular sludge

- Risk for inefficient oxygen removal in external layer due to AOB growth on flocs formed by OHO growth: Anammox O_2 inhibition
- SOLUTION: efficient microbial clades segregation:

→easy to maintain low SRT for flocs while retaining AOB/Anammox in granules



Lotti et al., 2014

Figure 6. Microscopic images of granules (a) as well as FISH image of sliced granules (b and c). FISH was conducted on sliced granules and hybridization was accomplished with Cy3-red (AOB + NOB), Cy5-blue (Eubacteria), and Fluos-green (anammox)-labelled probes (b) and with Cy3-red (AOB) and Fluos-green (NOB)-labelled probes (c).

Industrial applications: critical issues

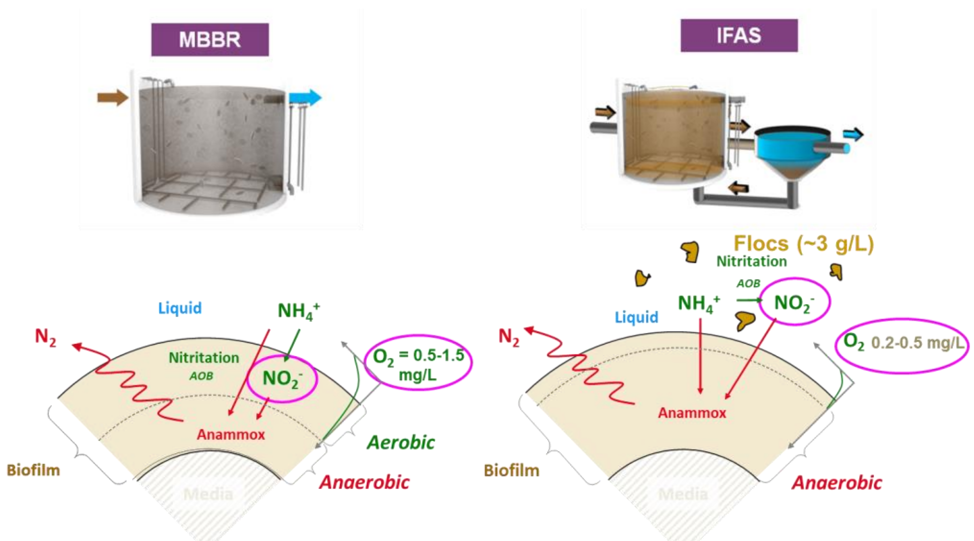
- Solids/COD excessive load

→ MBBR/IFAS

- Risk for inefficient oxygen removal in external layer due to AOB growth on flocs formed by OHO growth: Anammox O_2 inhibition

- Risk for AOB washout

SOLUTION: lower DO, lower AOB/Amx concentration (→lower NRR); higher flocs SRT (→ higher energy consumption)



Reactor	AnAOB		AOB	
	Liquid	Biofilm	Liquid	Biofilm
R1 (MBBR)	1%	99%	1%	99%
R2 (IFAS)	4%	96%	93%	7%

Industrial applications: critical issues

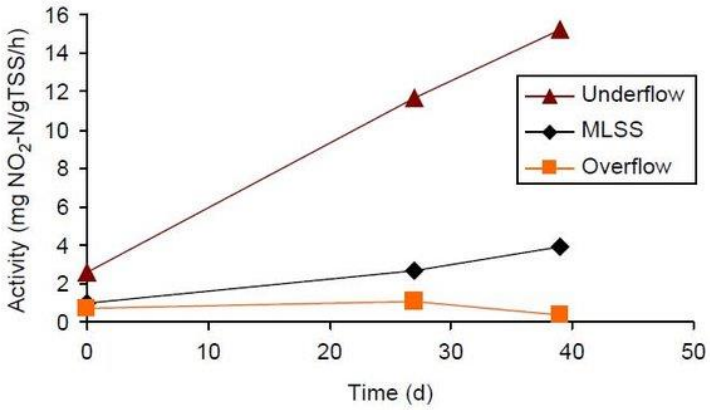
- Solids/COD excessive load

→ Flocculent sludge

- Risk for inefficient oxygen removal in external layer due to AOB growth on flocs formed by OHO growth: Anammox O_2 inhibition

- Risk for AOB/Anammox washout

SOLUTION: lower DO, lower AOB/Amx concentration (→even lower NRR); hydrocyclone (→ higher energy consumption)



Industrial applications: critical issues

- Overdosing dewatering polymers

Formation of slimy layer over biomass causing mass transfer limitation

- Lower oxygen (nutrients, NH_4^+) flux to biomass → lower NRR
- Lower N_2 flux from biomass → sludge floatation/washout

SOLUTION: optimizition of dewatering polymer dosage

Industrial applications: critical issues

- Foaming

→ often related to high influx of solids and dewatering polymer

Mass transfer limitation

- Lower oxygen transfer to bulk → higher energy consumption
- Biomass washout → process instability/failure

SOLUTION: antifoam dosage; optimization of dewatering process

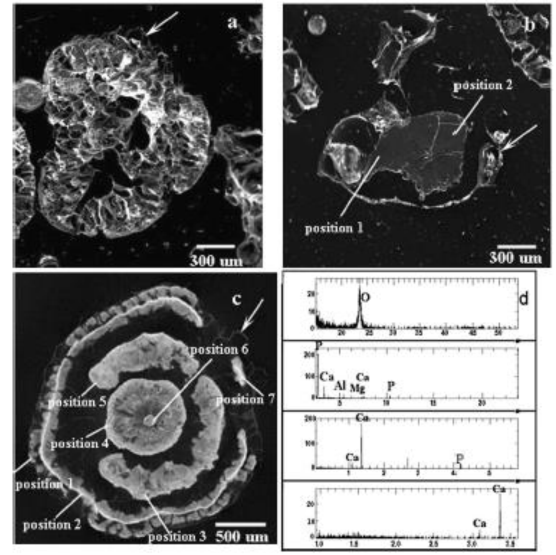
Industrial applications: critical issues

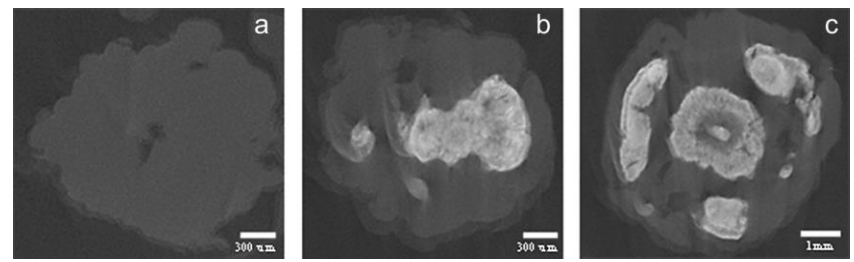
- Scaling of biomass/piping

→ Technology-dependent criticality extent

- Flocculent sludge
  - Granular sludge
    - MBBR-IFAS
      - MBBR

Increasing impact





Lin et al., 2013

SOLUTION:

- GENERAL: P-recovery; anti-scaling agents dosage
  - Granular: SRT controll based on heavy biomass removal (low part of sludge bed)
  - MBBR/IFAS: SRT control of carriers

Industrial applications: critical issues

- Limiting alkalinity

→ PN/Anammox process produces about 1,1 mol H+ per mol NH_4^+

Corresponding to about 3.7 gCaCO3/gN-NH4

- Risk for low process pH limiting microbial activity
- $FeCl_3$ in anaerobic digestion lower alkalinity

SOLUTIONS:

- Alkalinity dosage (e.g. NaOH)
- Cope with lower Nitrogen removal efficiency

Industrial applications: critical issues

- Limiting Inorganic Carbon, IC

→ AOB and Anammox are both obligate autotrophic microorganisms

→ Anammox are more affected by IC limitation than AOB….but!

  - Risk for limiting conditions for microbial activity
  - Risk for excessive N_2O production/emission

  SOLUTIONS:

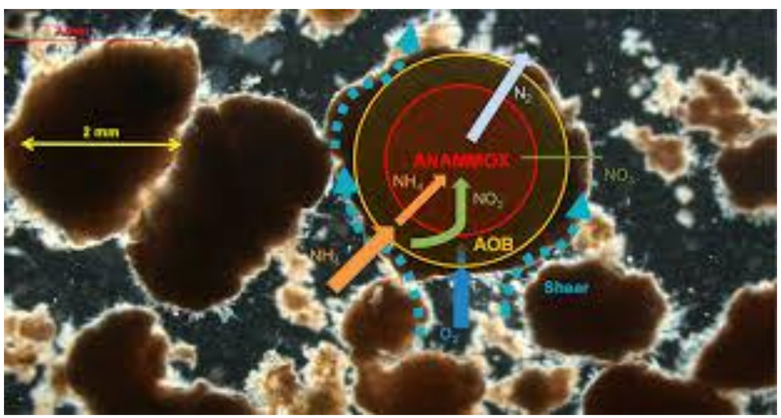
  - IC dosage

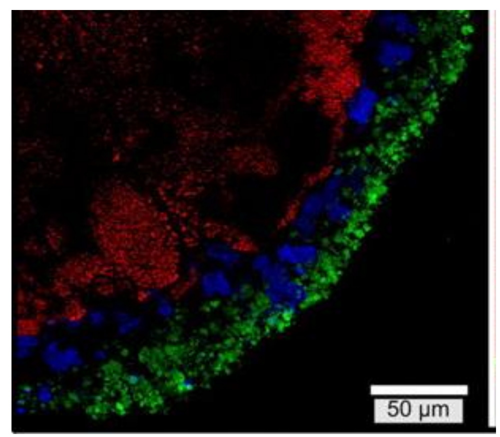
Industrial applications: critical issues

• Limiting Inorganic Carbon, IC

→ Anammox are more affected by IC limitation than AOB….**but!**

- It is documented that both AOB and select NOB can up-regulate their CO2 fixation as well as their HCO3/CO2 machinery in response to IC limitation (Kim et al., 2012; Wei et al., 2006), while anammox do not have this metabolic capability (Strous et al., 2006).
- In addition to the fundamental metabolic differences between AMX, AOB and NOB, mass transfer limitation to the inner layers of biofilm also contribute to the reduced availability of IC to AMX relative to surface-associated AOB and NOB





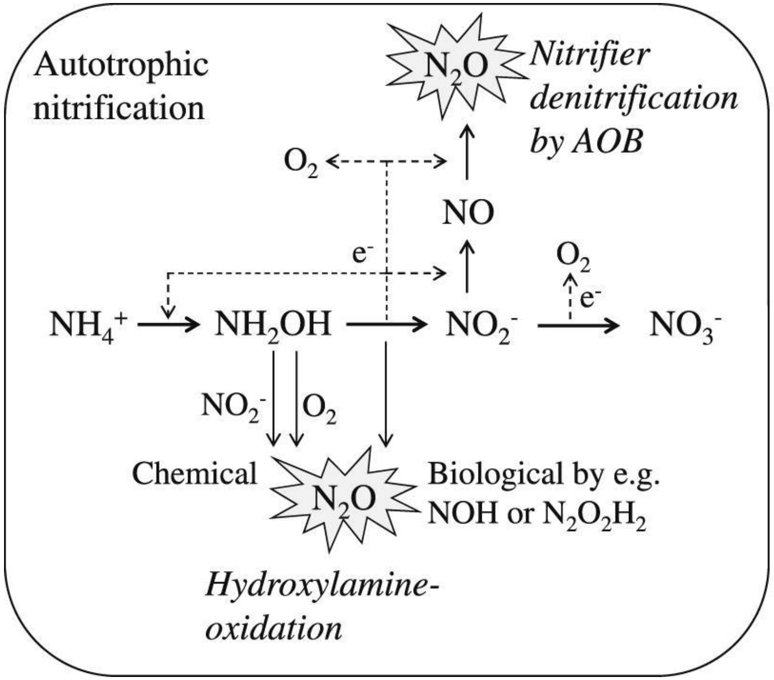
AOB
NOB
AMX

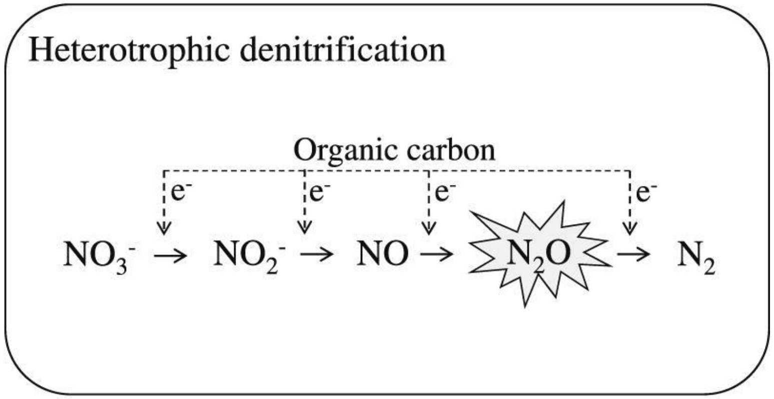
Industrial applications: critical issues

• Limiting Inorganic Carbon, IC

→ Anammox are more affected by IC limitation than AOB….**but!**

→Risk for excessive N_2O production/emission



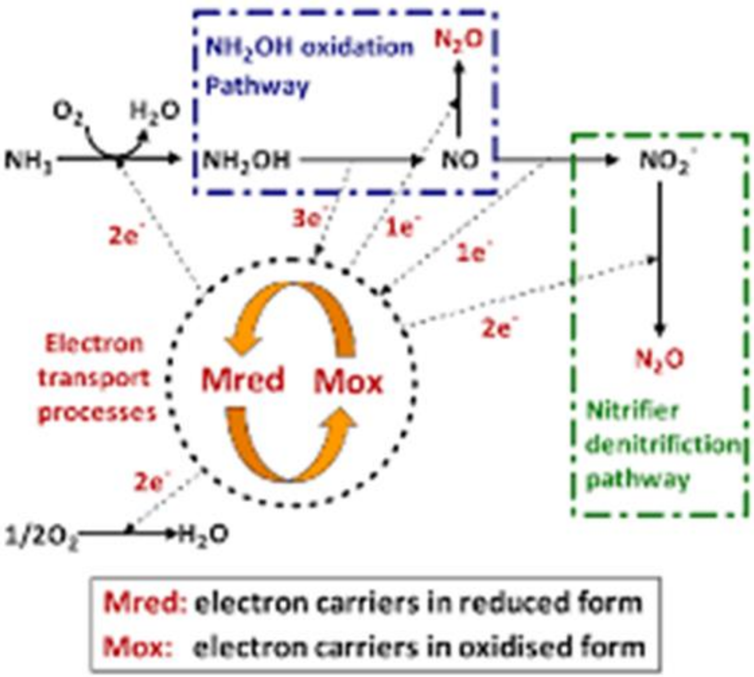


Industrial applications: critical issues

• Limiting Inorganic Carbon, IC

→ Anammox are more affected by IC limitation than AOB….**but!**

→Risk for excessive N_2O production/emission

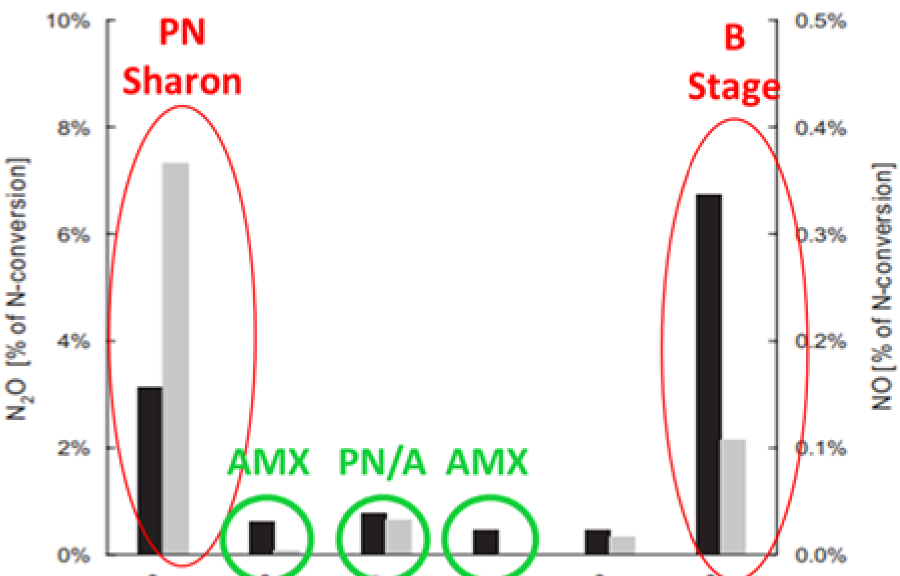


N_2O production by AOB is associated to the imbalance between the supply and availability of electrons or reducing equivalents (Chandran et al., 2011; Yu et al., 2010).
IC limitation may cause similar imbalance in AOB and feedback inhibition for NH4 oxidation for both AOB and AMX, resulting in NH2OH/NO accumulation and thus chemical N2O production (Ma et al., 2016).

N_2O emissions: general considerations

N_2O production/emission is an environmental issue related to any biological process (e.g. WWTP bu also agriculture soil, estuaries, river/marine sediments, etc..)

- N_2O emissions in mainstream activated sludge varies between 0-14 % of N-load (Kampschreur et al., 2009)
- N_2O emissions are caused by imbalance/variation of N-COD loading/aeration
- N_2O emission in PN/A process is much lower compared to other biological processes in WWTP (see graph below, Kampschreur et al., 2008)



→ Buffer tanks and continuous operation systems mitigate inbalances/rapid variations and thus reduce N_2O emissions

Industrial applications: critical issues

- Conductivity

→ AOB and especially Anammox are inhibited at high conductivity

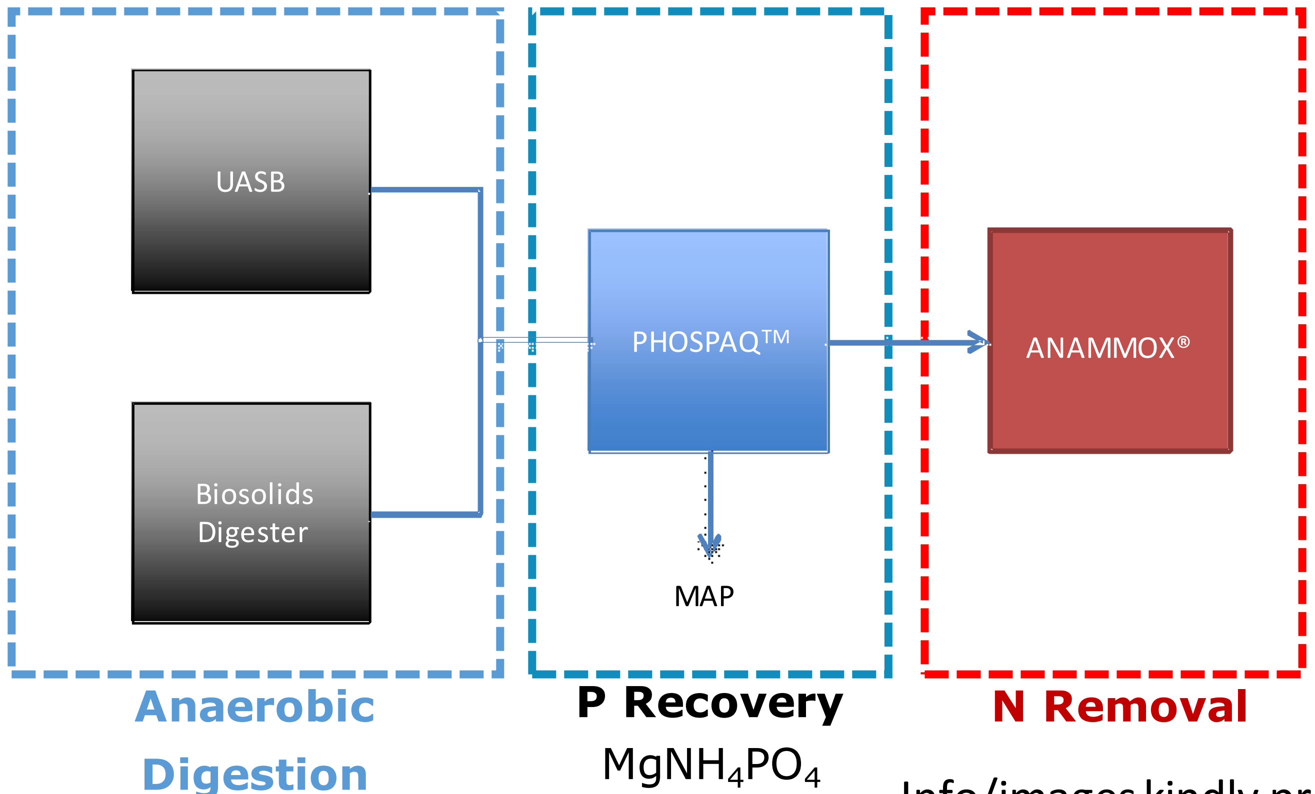
SOLUTIONS:

- Adaptation (shown in several case studies)
- Enrichment in salinity tolerant genera (e.g. Candidatus Scalindua)
- Dilution

Industrial applications: success stories

Municipal Reject water + Potato processing plant

- Maximising **Energy recovery** by methane from COD
- Recovery of **phosphorus** on biosolids reject
- Anammox® removal of remaining **ammoniacal nitrogen**



Info/images kindly provided by Paques

Industrial applications: success stories

Waterstromen Olburgen (WwTP)

Side stream treatment by Anammox®

(Abma et al, 2012)

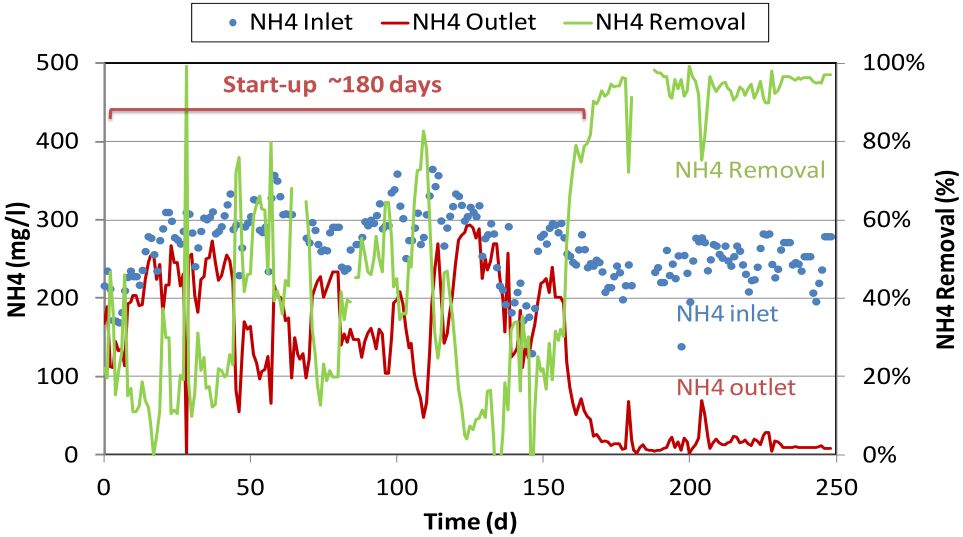
Savings on aeration

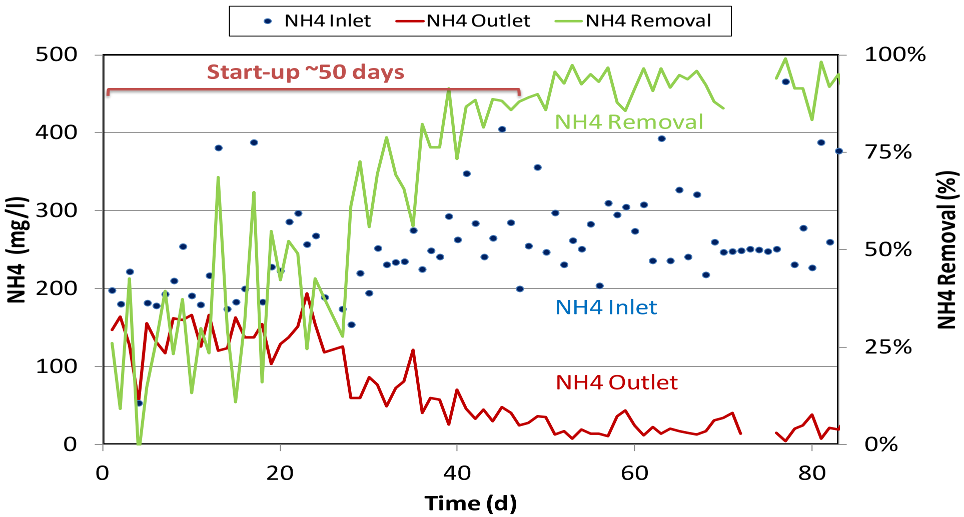
Savings on footprint

Increasing Capacity WWTP

Info/images kindly provided by Paques

Start-Up Period





Reducing start-up period

- 2002: 1000 days (1st)
- 2006: 180 days
- 2010: 50 days

Start-up period depends on

- Amount of Anammox GranularCatalyst
- Size of project
- Type of effluent

Info/images kindly provided by Paques

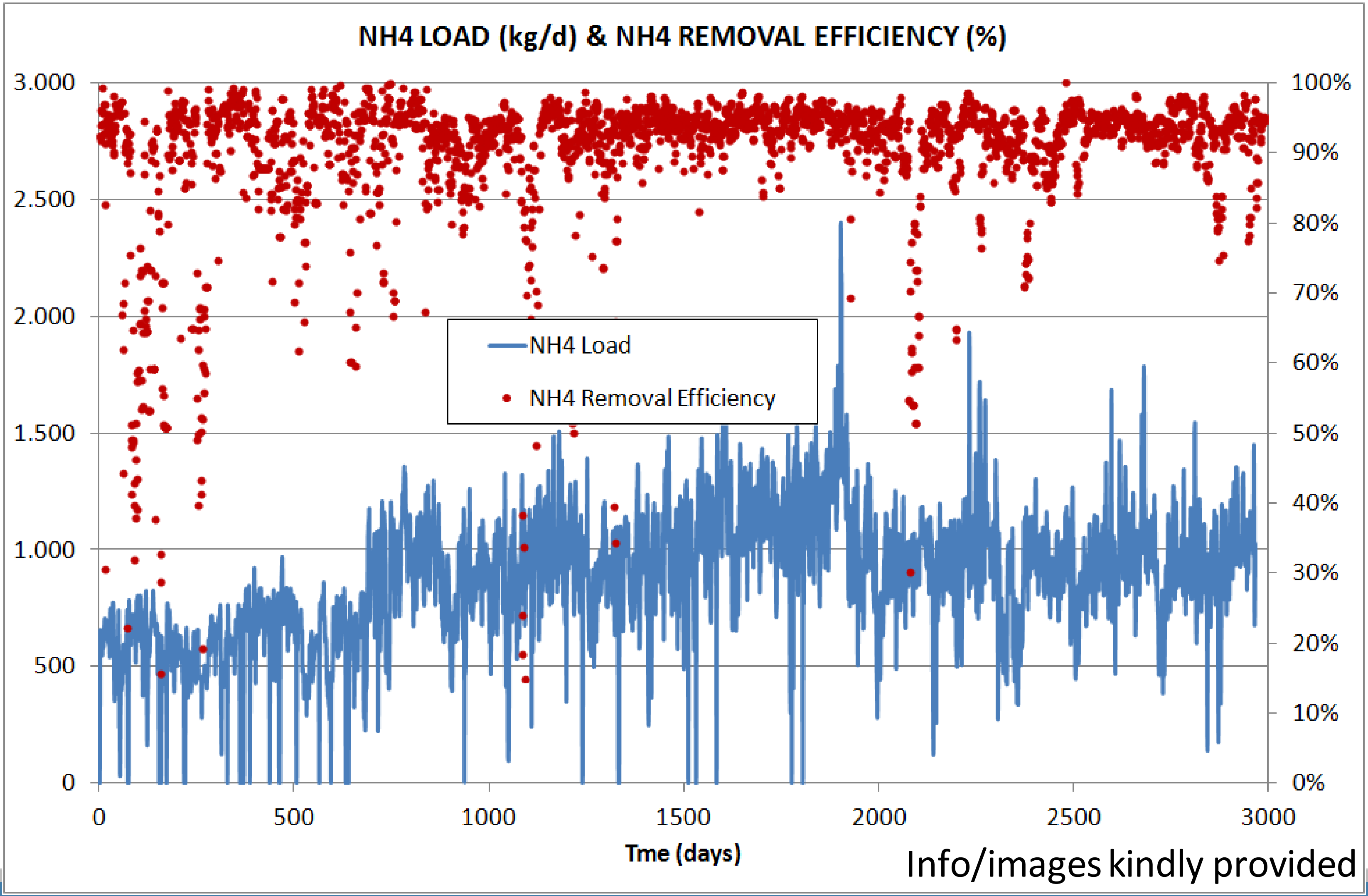
Operational issues you can encounter:

- Accidental failure blower
  - High amounts of sulphides eneter into PN/A reactor
  - Activity can be regained quickly **after → resolving blower failure**.
- Accidental failure pH chemical dosing
  - pH out of the optimal range (7-8) can cause some loss of activity in PN/A reactor
  - Activity can be regained in time by itself **after → correcting pH dosing**
- Acidental high loading of COD and solids
  - It can cause some loss of activity in PN/A reactor
  - Activity can be regained in time by itself **after → Improved operation of upstream UASB and digestate solid/liquid separation**

Info/images kindly provided by Paques

Waterstromen Olburgen (WwTP)

Side stream treatment by Anammox®



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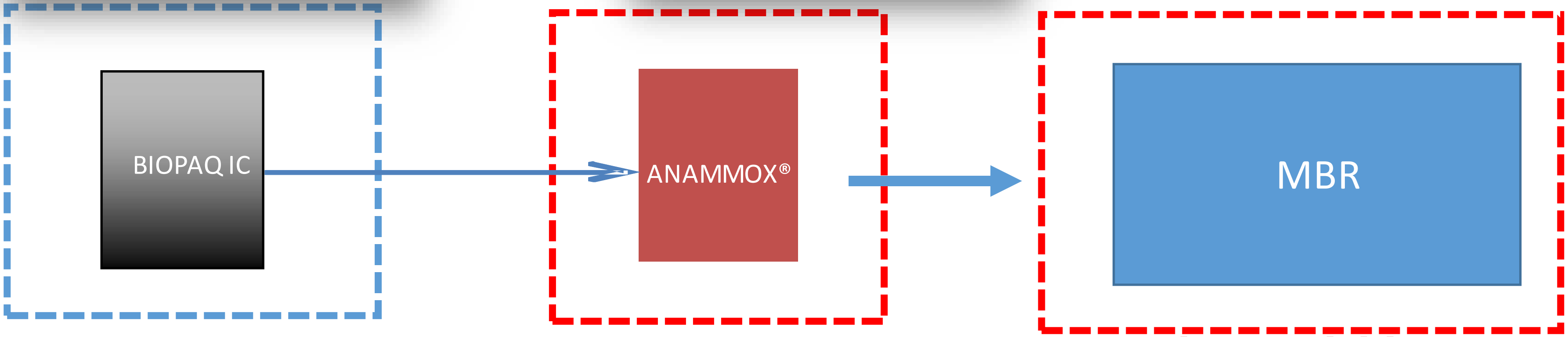
Rendering plant

Industrial Effluents + Manure & Food waste digestate

As compared to former complete aerobic treatment:

- Maximising **Energy recovery** by methane from COD
- **Energy savings** by using Anammox for ammoniacal N-removal



COD Removal

Anaerobic Digestion

N Removal

Final polishing

Info/images kindly provided by Paques

Requirements new treatment facility

- Accommodate **higher (additional) loadings**
- Meet **stringent discharge standards**
- Minimize **excess sludge** production
- Minimize **operational costs** (OPEX)
- Small **footprint (limited area)**

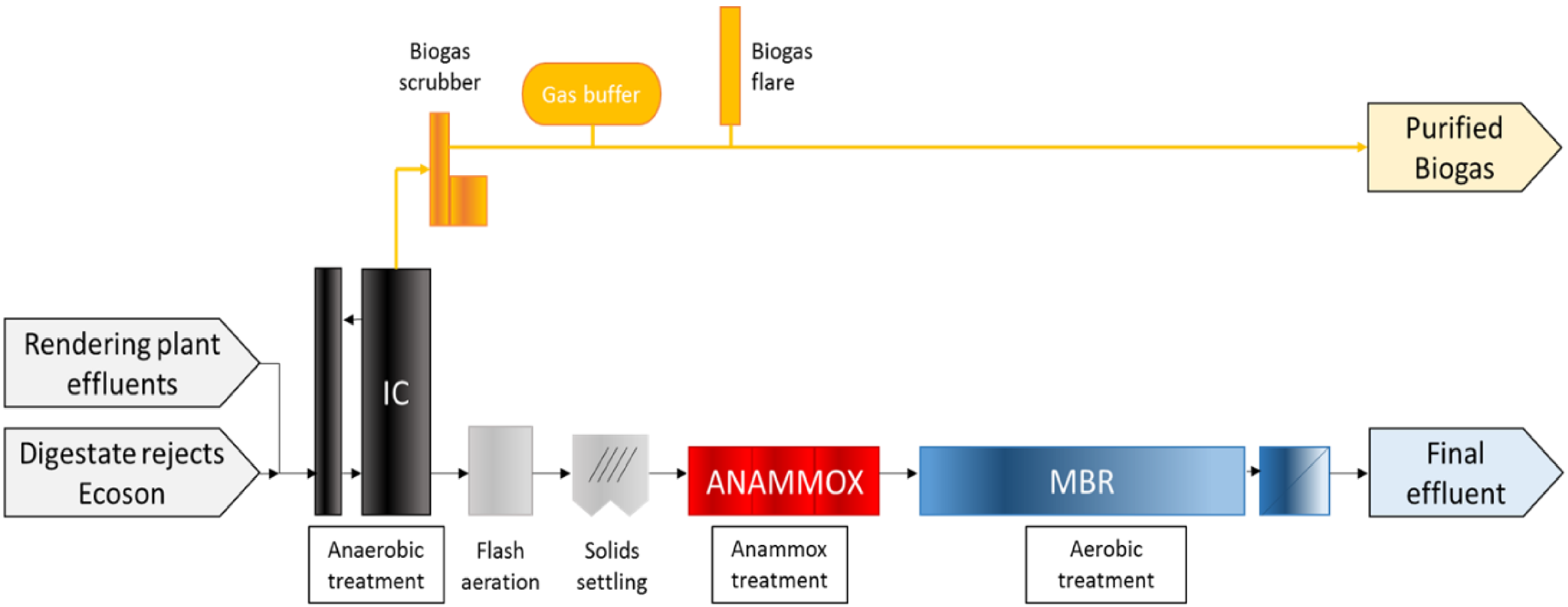
Info/images kindly provided by Paques

Wastewater Characteristics

Flow	2,800 m^3/d
Total-COD	22,500 kg/d
NH4-N	5,700 kg/d
Temperature (after cooling)	30-35 ˚C
pH	~ 7.5 - 8

Info/images kindly provided by Paques

Process flow schematic



Info/images kindly provided by Paques

Final Design of the new WWTP

Info/images kindly provided by Paques

Overview Anaerobic-Anammox-MBR

Anaerobic treatment + aeration

Modular Anammox plant + MBR

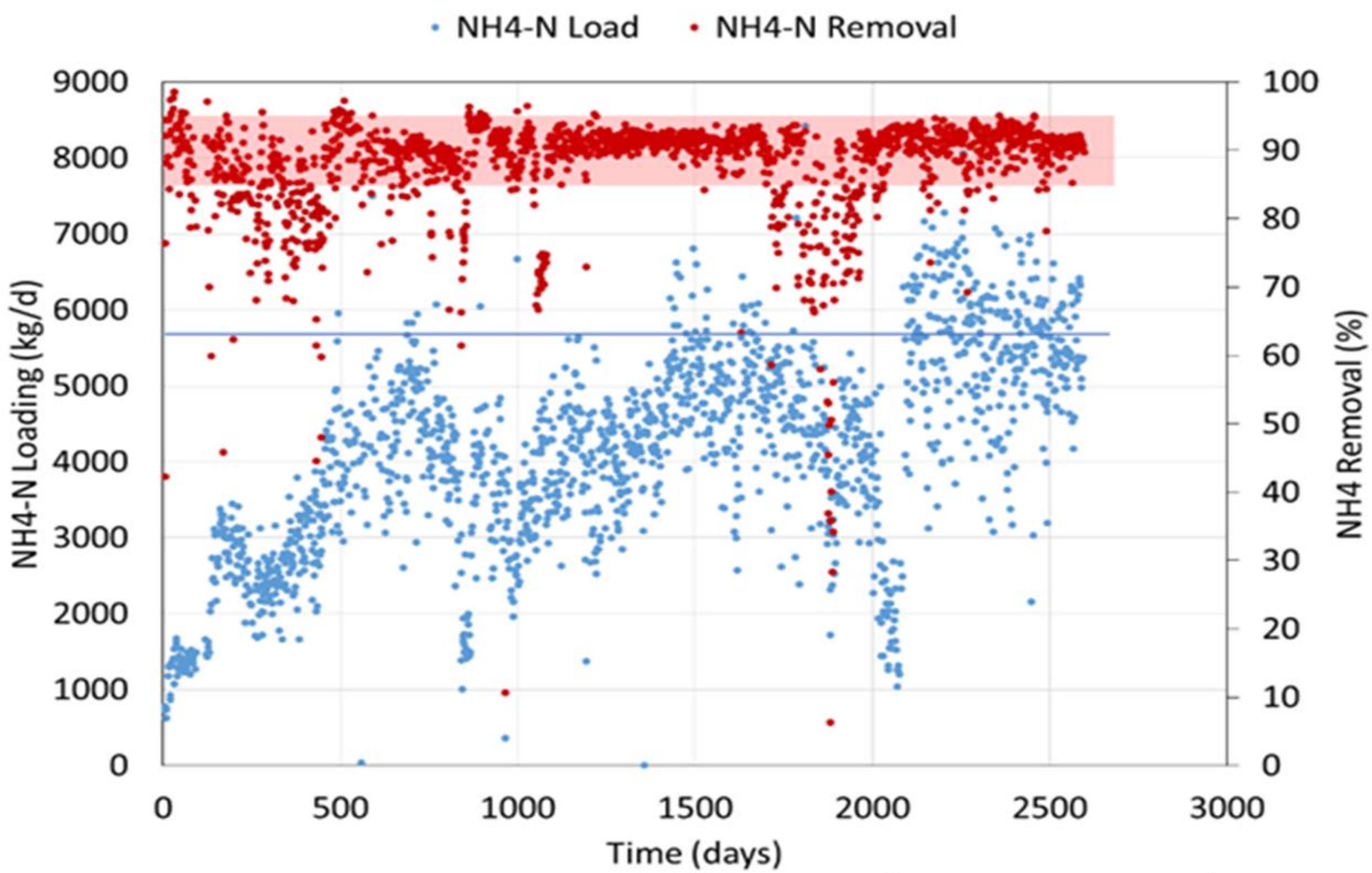
Info/images kindly provided by Paques

Benefits of the combined processes

Anaerobic Treatment	Anammox	Aerobic
Smallest footprint	Small footprint	Excellent effluent quality
Bulk COD removal	Bulk N removal	COD & N removal
Low energy consumption	Minimal energy required	
Net energy production (biogas)	No COD required	
No excess sludge production	Minimal excess sludge	

Info/images kindly provided by Paques

Results: NH4 Loading

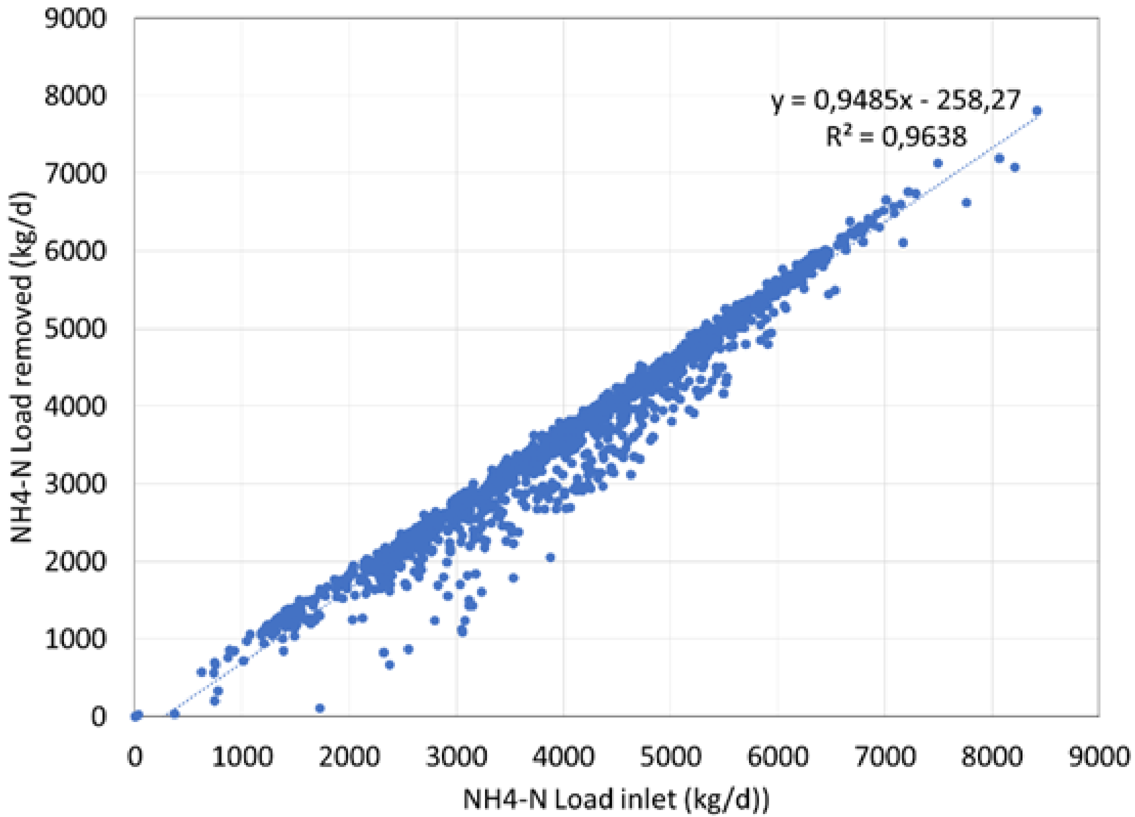


(Driesen *et al*, 2020)

Info/images kindly provided by Paques

Results: NH4 Removal

- NH4 removal (7year): 90-95 %
- ANAMMOX treated up to 2.7 kgNH4-N/(m^3.d)
- NH4 removal not impacted at high loadings



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Operational issues you can encounter:

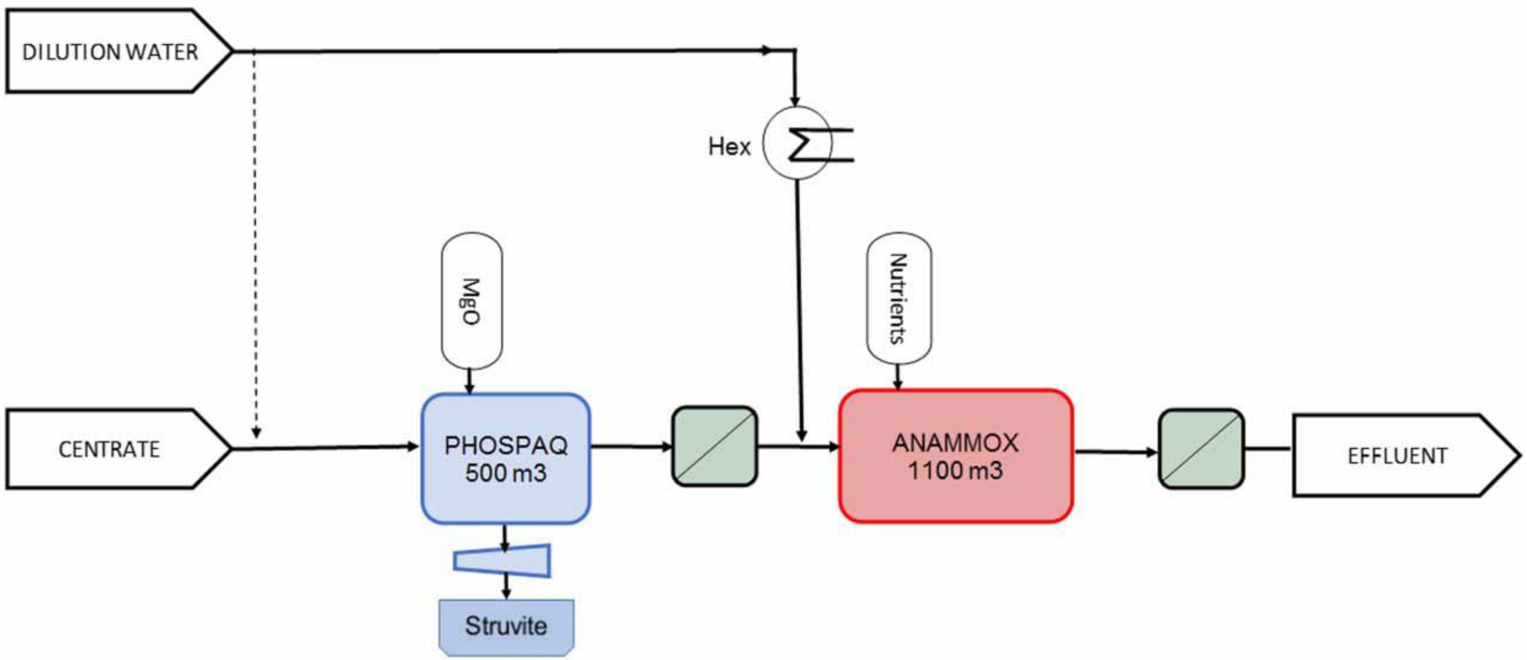
- Temperature rise over 42 °C
  - Some loss of activity in Anammox
  - Activity can be regained in time by itself
  - **Solution → Enlarge the heat-exhanger capacity and addition of cooling water**

- Failure aeration control in flash aeration tank
  - High amounts of sulphides enetering into PN/A reactor
  - Activity can be regained quickly **after → resolving aeration control error**.

Info/images kindly provided by Paques

Industrial applications: success stories

Treatment of sidestream dewatering liquors from thermally hydrolised (THP) and anaerobically digested biosolids

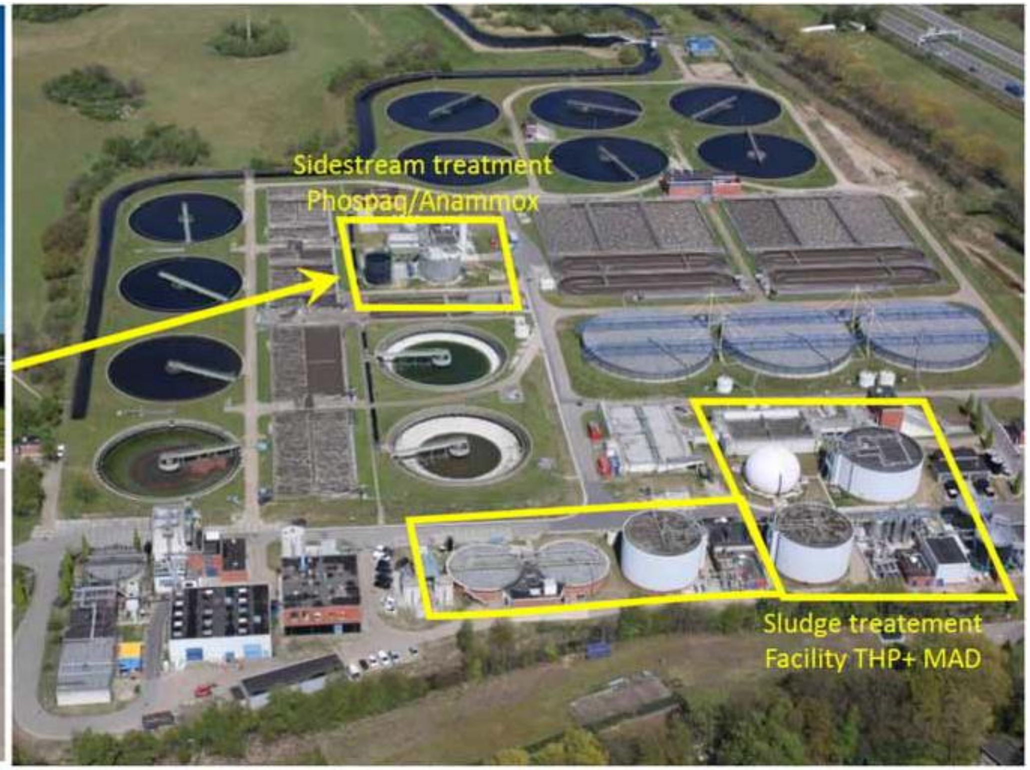


Although micronutrients are generally sufficiently available in digested sewage sludge reject liquors, fulvic and humic-like organic substances generated by the THP process are known for binding metal-ions, possibly reducing the bioavailability of essential trace elements.

Info/images kindly provided by Paques

Industrial applications: success stories

Treatment of sidestream dewatering liquors from thermally hydrolised (THP) and anaerobically digested biosolids



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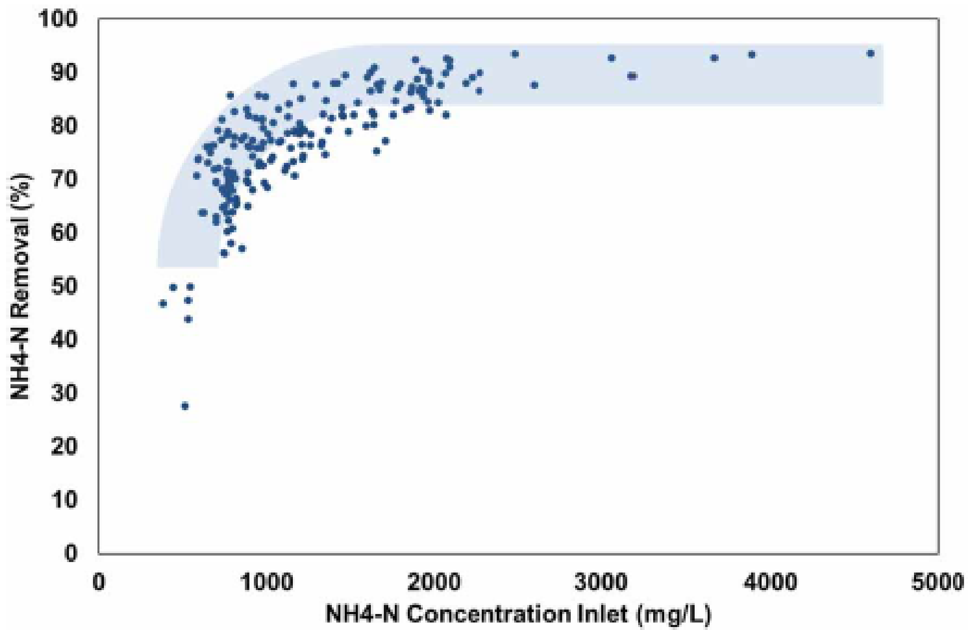
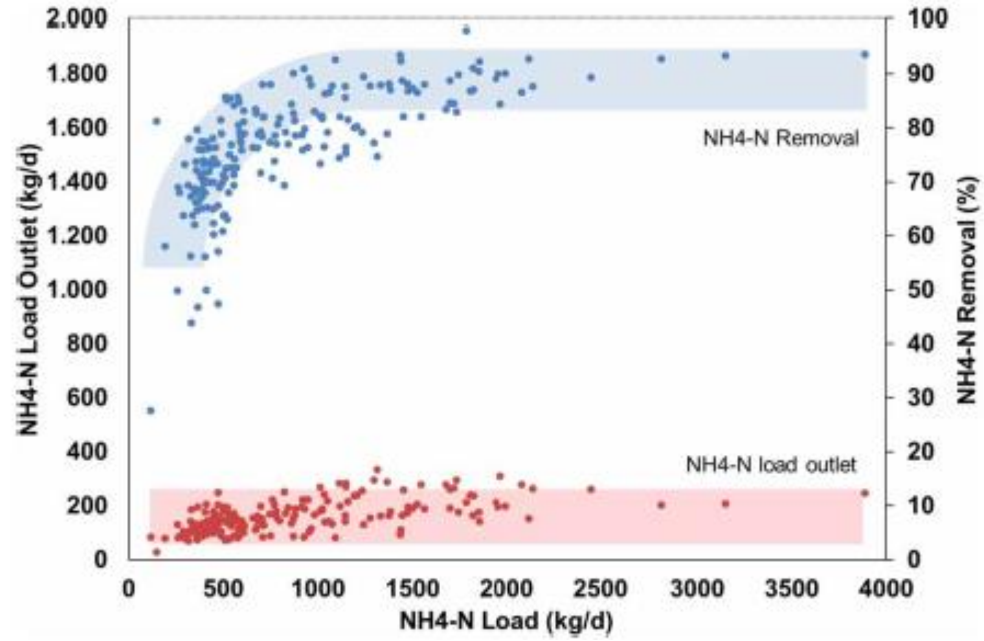
Industrial applications: success stories



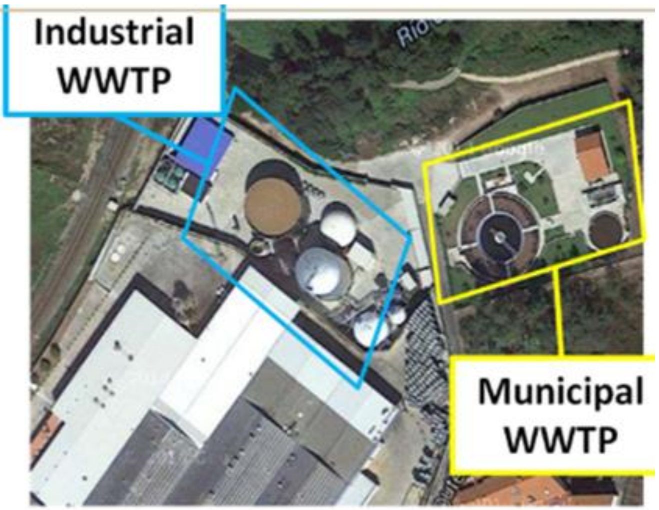


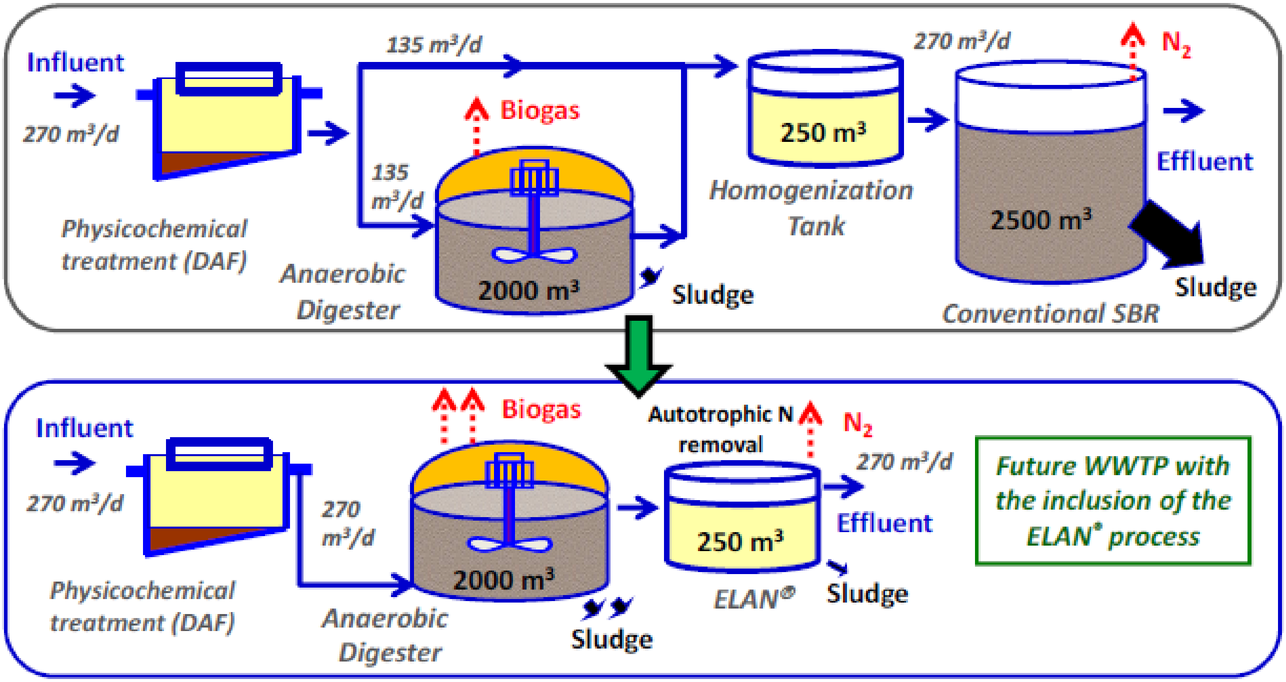
- No inhibition of the PN/Anammox process was observed, after applying methods intended to mitigate possible inhibition from the THP-MAD reject liquor like adding dilution water, removal of BOD and addition of micro-nutrients,
- Stable performance of up to 90% removal efficiency at volumetric nitrogen loadings rates exceeding 2.5 kgNH4-N/m3.day.
- High percentage ammonia removal efficiency was typically related to high ammonia influent concentrations and sufficient alkalinity present in the dewatering reject liquors.

Info/images kindly provided by Paques

Industrial applications: success stories

FISH-canning industrial wastewater (Galizia, Spain)
<< very high salinity >>





Info/images kindly provided by Aqualia

Industrial applications: success stories

FISH-canning industry (Galizia, Spain)

Influent:
270 m³/day
150-400 mg/L TN
(mostly NH4-N)
4-20 g/L NaCl

→ **ELAN**
V: 250 m3
NLR: ≈ 0.3 kgN/m3/d →

Effluent results
<115 mg/L TN

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

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

N removal	SBR (N-DN)	ELAN®
Volume (m³)	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/(m³ 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

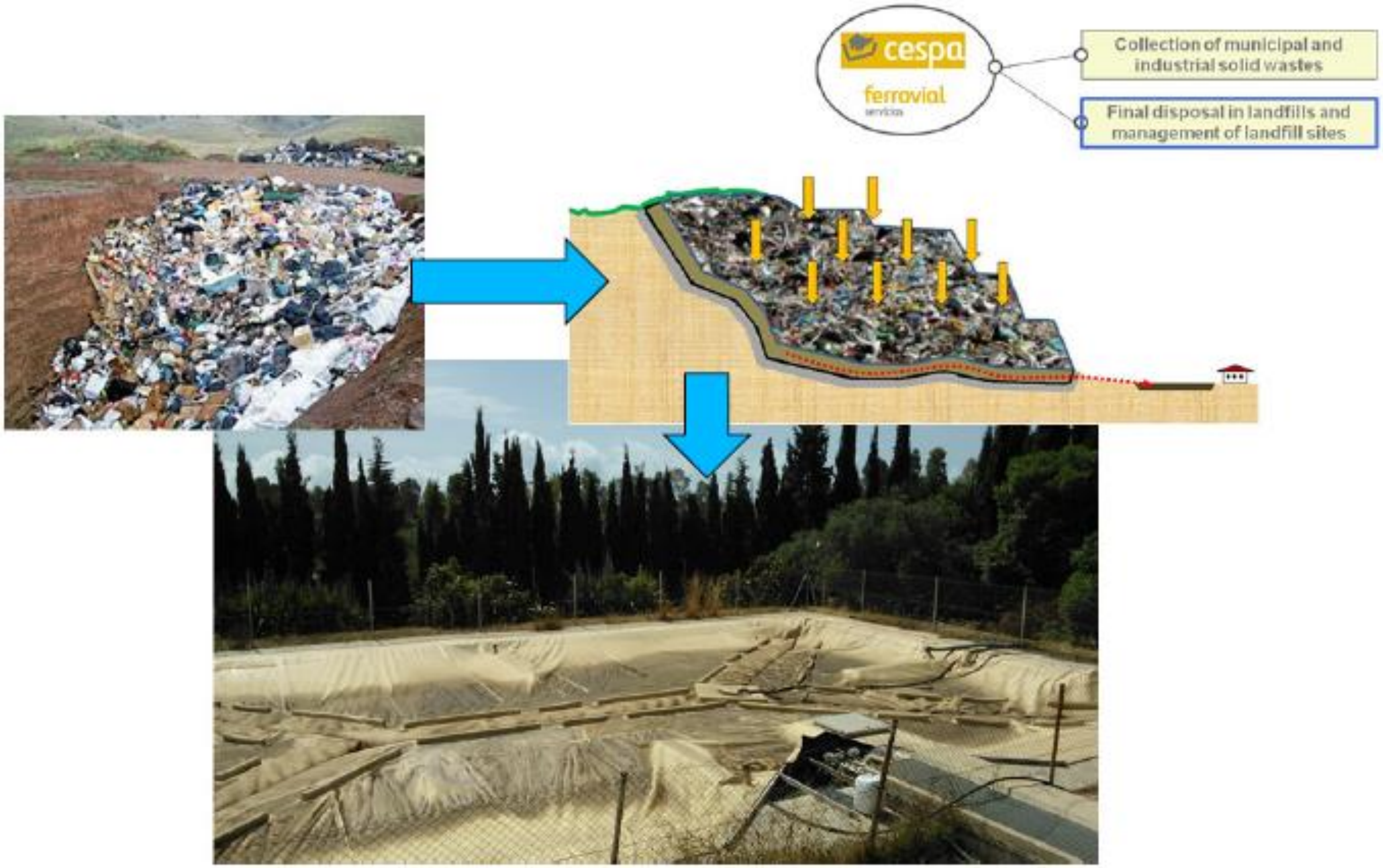
OPEX of ELAN® system expected to be 20% lower than conventional N-DN

- Sudden increase of salinity (industrial production) may result in salinity peak (up to 20 g NaCl/L): anammox inhibited, but quickly recovered in few days
- Adaptation is feasible in a matter of months: N removal values (80%, 0.2 gN/L·d) at 7–9 g NaCl/L
- Nitrite oxidizing activity suppressed for NaCl concentrations higher than 4–5 g/L

Info/images kindly provided by Aqualia

Treatment of mature landfill leachate

<<high salinity and inhibiting/toxic compounds>>

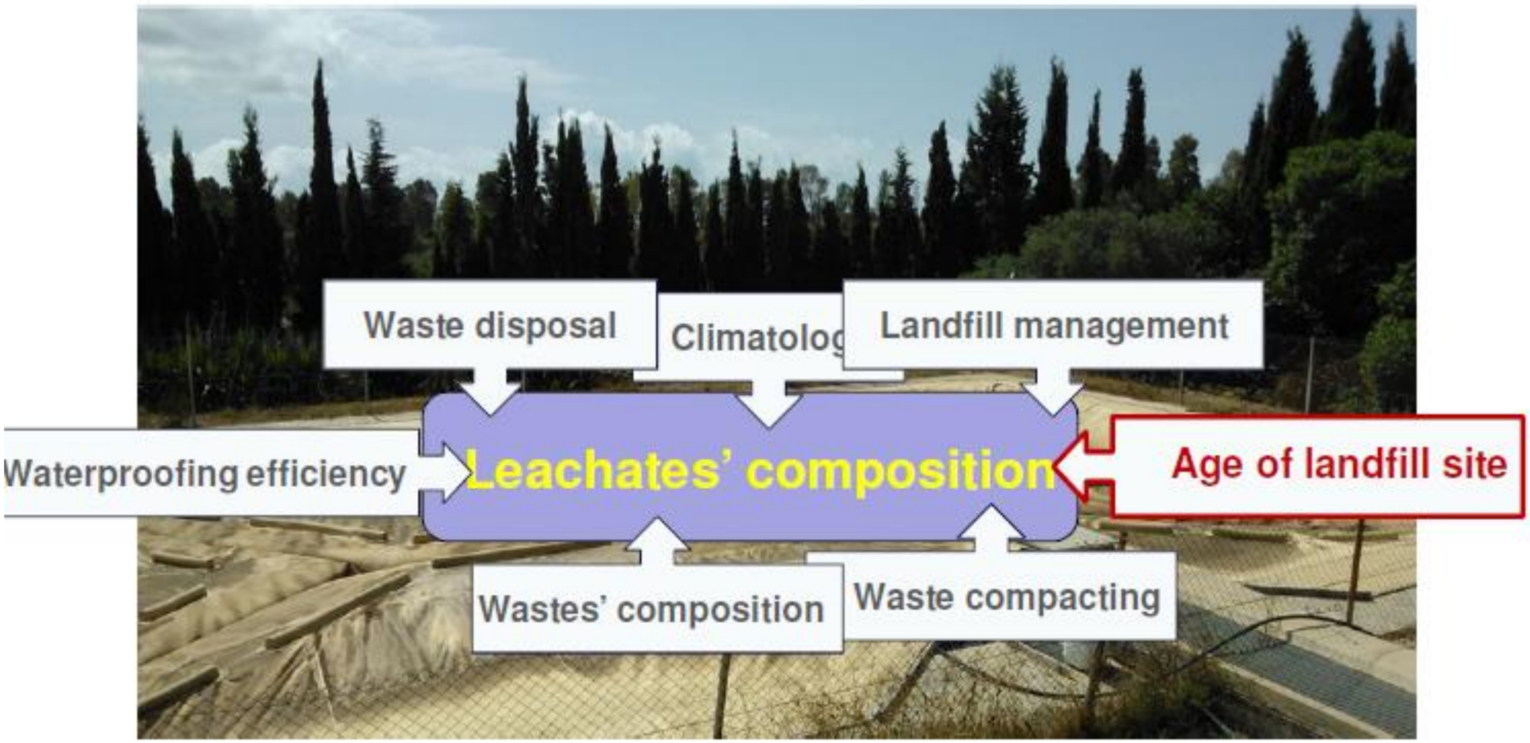


Info/images kindly provided by Panammox developers (Lequia/Cespa)

Industrial applications: success stories

Treatment of mature landfill leachate

→ Highly variable characteristics of leachate depending on multiple factors



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Treatment of mature landfill leachate

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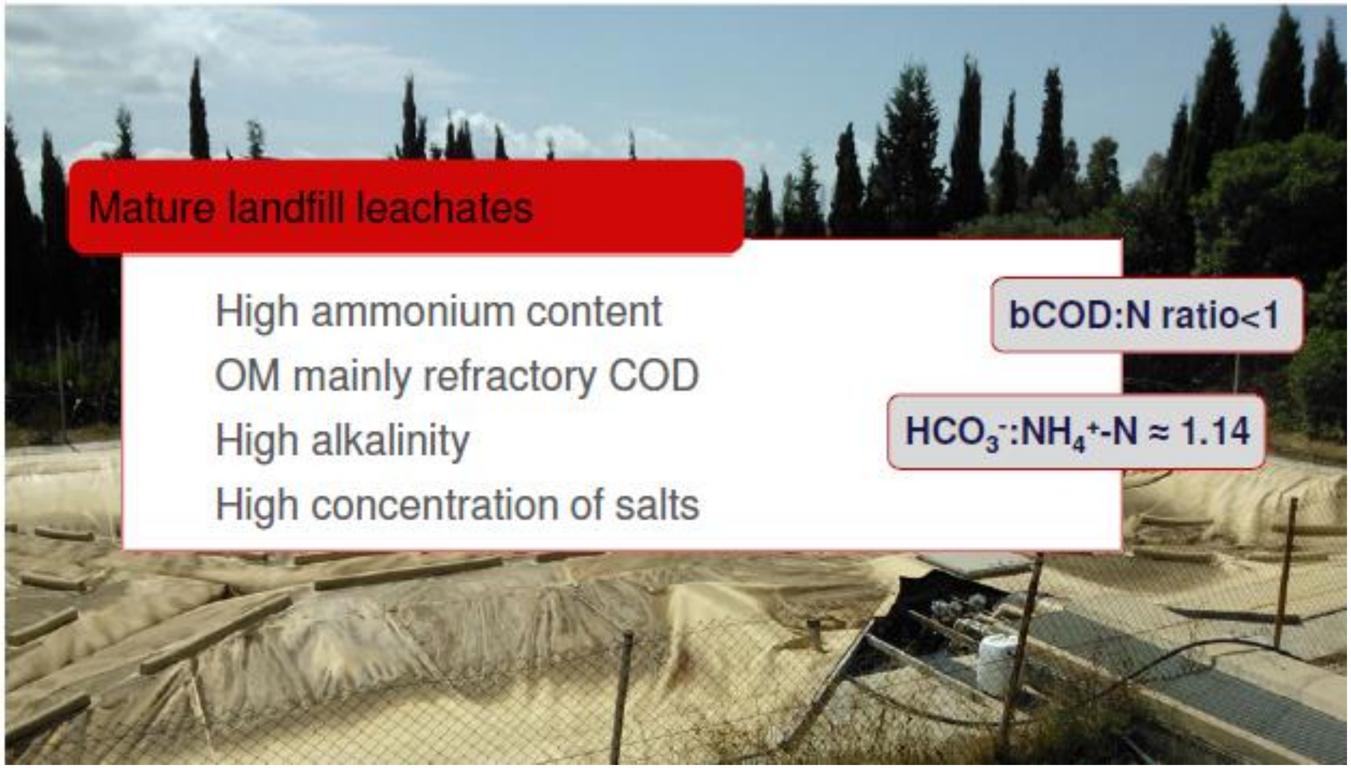

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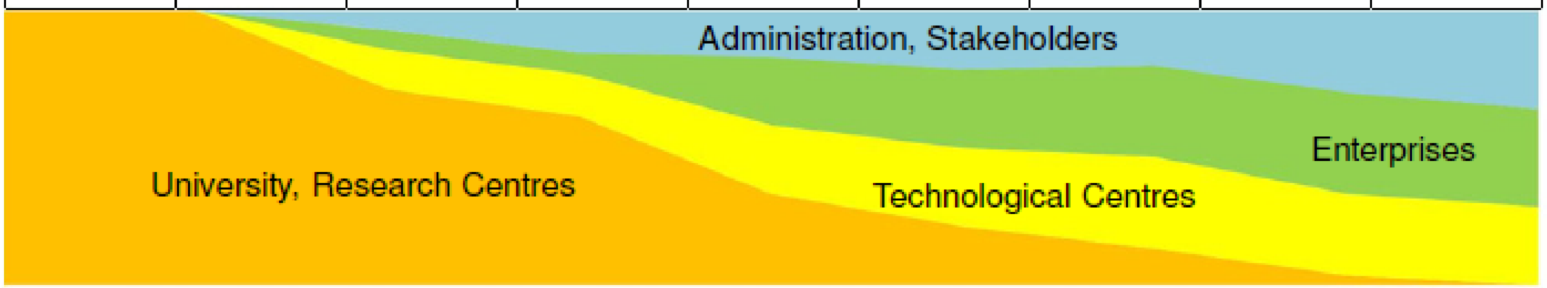
Industrial applications: success stories

Treatment of mature landfill leachate

Technology Readiness Level (TRL): 1-9

Technology Readiness Levels (TRL)								
1	2	3	4	5	6	7	8	9
Basic principles observed	technology **concept** formulated	experimental **proof of concept**	technology **validated in lab**	Technology **validated in relevant environment**	technology **demonstrated** in relevant environment	**system prototype** demonstrated in environmental environment	**system complete and qualified**	**Actual system proven in operational environment**



Conception/Discovery (TRL: 1-3)
3-4 years
Motivation: science/ society challenges
Key role: University, Research centres

Validation (TRL:4-6)
2-4 years
Motivation: economics/breakthough
Key role: Technological Centres

Demonstration/market (TRL:7-9)
1-2 years
Motivation: business
Key role: Enterprises

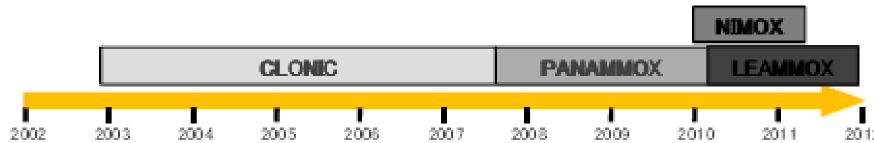
Global process: 6-10 years

- Technology transfer: 3-6 years
- Time to market 2 years: TRL 8-9

Info/images kindly provided by Panammox developers (Lequia/Cespa)

Treatment of mature landfill leachate

Development and implementation PANAMMOX® technology



Lab-scale (10-20 L)

Pilot-scale (20-250 L)

Semi-Industrial (400 L)

CLONIC
- Study of biological processes: PN+Anammox
- Anammox biomass enrichment and process control

PANAMMOX
- Adaptation to raw landfill (anammox)
- Extreme conditions

LEAMMOX
- Pre-industrial scale treating real leachate.

NIMOX
- Pre-industrial scale application to sludge digestion returns in WWTP.

Info/images kindly provided by Panammox developers (Lequia/Cespa)

Industrial applications: success stories

Treatment of mature landfill leachate

Location selected: CORSA landfill site (Catalonia, Spain)

Leachate characteristics:

Parameter	Units	Mean	δ	Min.	Max
Conductivity	mS/cm	30.72	8.54	9.28	44.00
Ammonium nitrogen	mgN/L	2251	816	635	3856
COD	mgO_2/L	3609	1277	868	5915
Clorurs	$mgCl^-/L$	4979	1608	1073	7532
pH	-	8.4	0.4	7.4	9.4

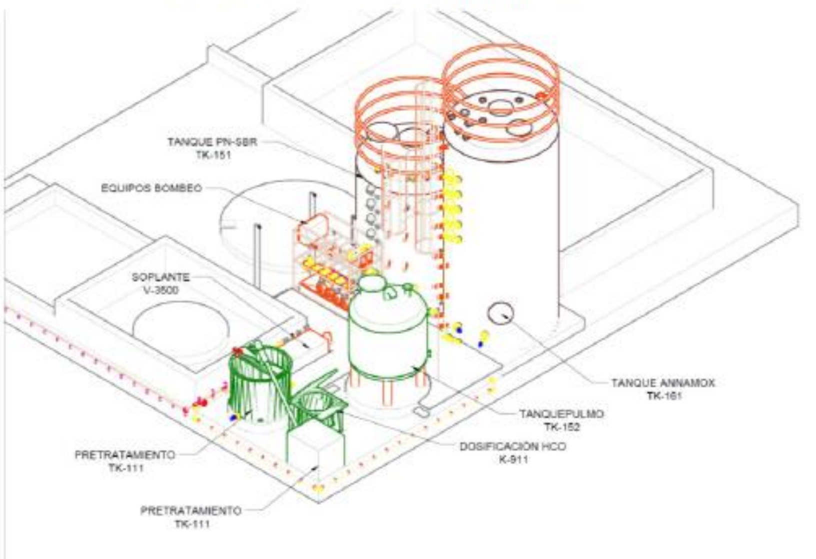
Daily flow to treat: 19 m^3

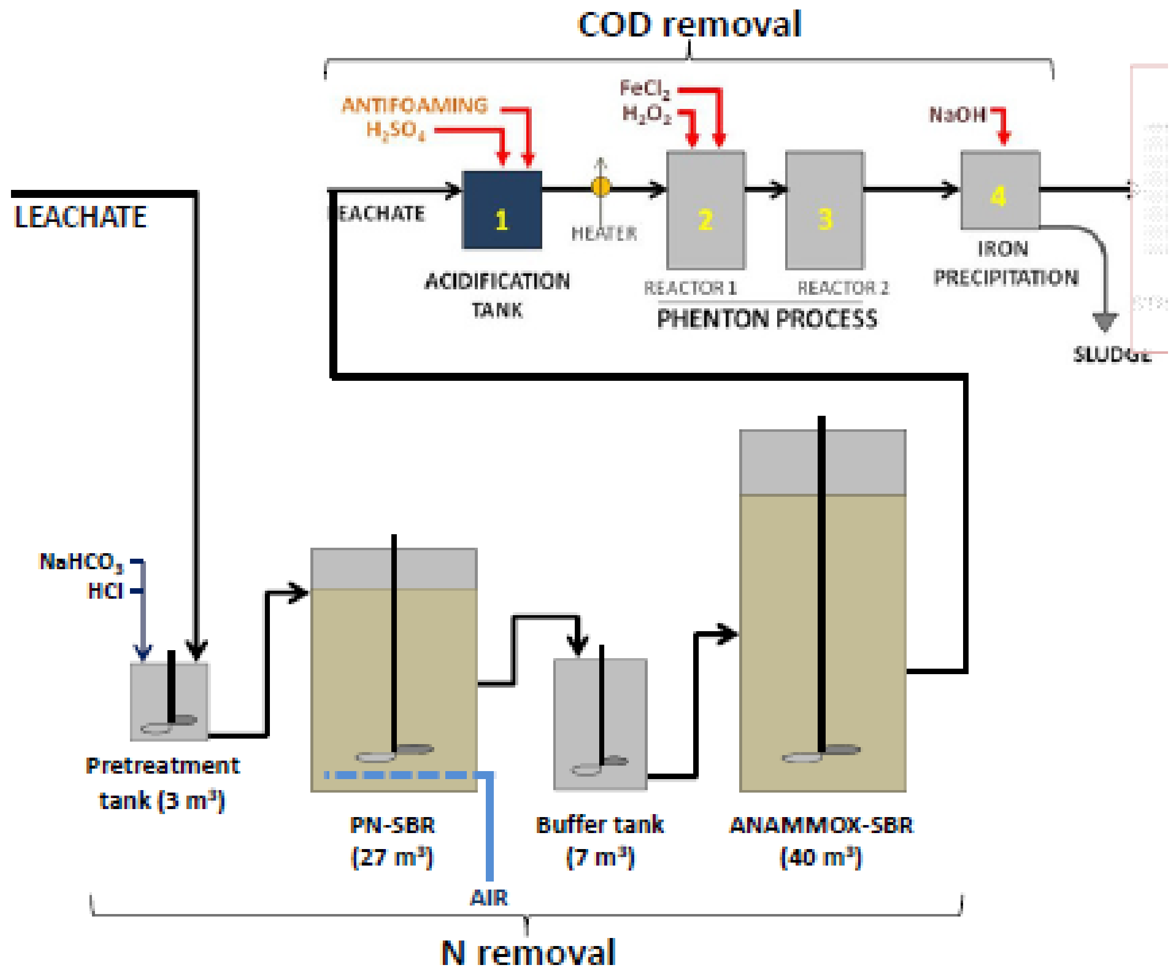
Info/images kindly provided by Panammox developers (Lequia/Cespa)

Industrial applications: success stories

Treatment of mature landfill leachate
Full-scale implementation

Designed to treat 19 m³ day⁻¹ of landfill leachate





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Treatment of mature landfill leachate
Full-scale implementation

Designed to treat 19 m^3 day^{-1} of landfill leachate

PN inoculation (April 2014)

- Activated sludge from a municipal WWTP

Operational conditions

- DO set-point at 2.0 mg O_2 L^{-1}; Temperature control <20° C; pH_{max}=7.9

Inoculation Anammox (July 2014)

- 90% of the mixed liquor from anammox pilot plant
- Initial VSS of only 0.07 gVSS L^{-1}

Info/images kindly provided by Panammox developers (Lequia/Cespa)

Treatment of mature landfill leachate

- PN-SBR full operational
- Anammox-SBR is at the enrichment phase of the start-up:
  - Treatment capacity from 0.025 kg N d^{-1} to 1.00 kg N d^{-1}
  - Biomass from 0.07 g VSS L^{-1} to 0.28 g VSS L^{-1}

- PN-SBR is treating up to 25 m^3 d^{-1} of leachate,
- The PN effluent is partially by-passed directly to the AOP

Info/images kindly provided by Panammox developers (Lequia/Cespa)

Thank you

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