Mainstream anammox: Promise and challenges for sustainable nitrogen removal in saline wastewater treatment

主流厭氧氨氧化技術用於含鹽污水可持續脫氮的前景與挑戰

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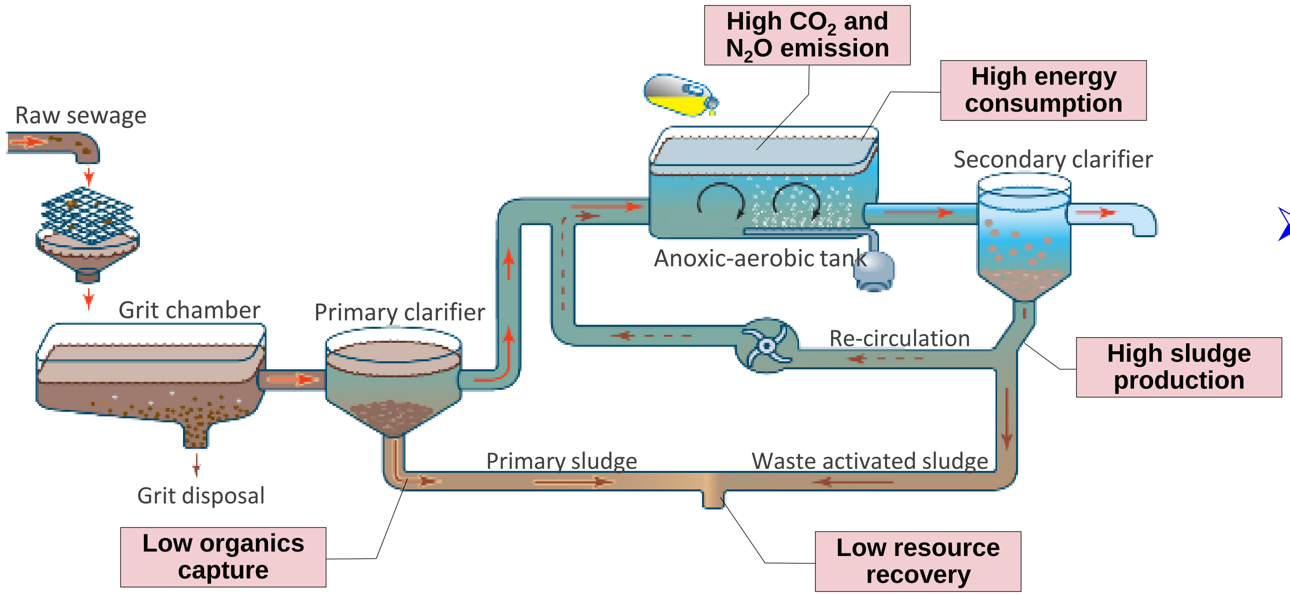
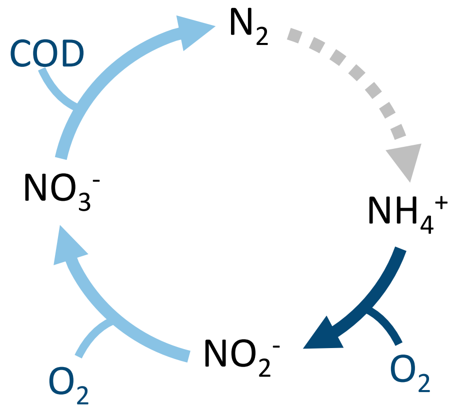
Conventional STWs: low-efficient and energy-intensive

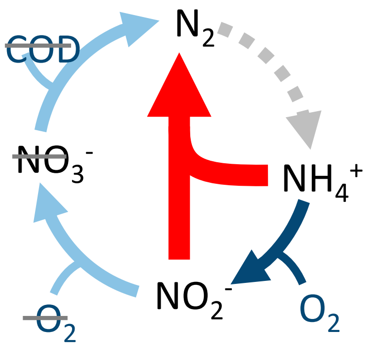


➢ **N removal is particularly difficult and costly!**



- Organic matters: oxidation of the organic carbon into CO_2
- Phosphorus: storage in PAO for removal with WAS
- **Nitrogen: nitrification & denitrification**

Autotrophic nitrogen removal – Anammox



Partial nitritation-anammox (PNA)

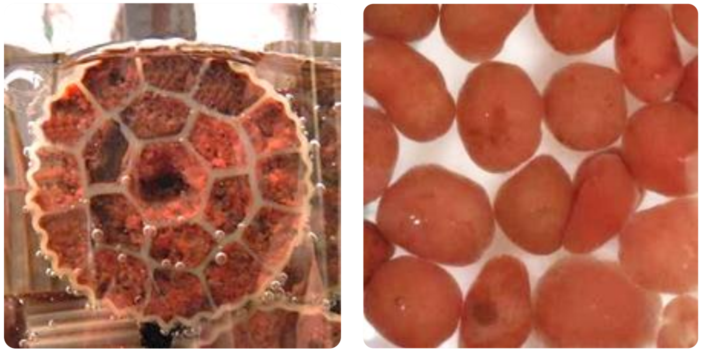
Attractive cost-saving N removal process

Nitritation: Ammonia-oxidizing bacteria (AOB) Low aeration demand

$$NH_4^+ + 1.38O_2 + 1.98HCO_3^- \rightarrow 0.018C_5H_7O_2N + 0.98NO_2^- + 1.036H_2O + 1.89H_2CO_3$$

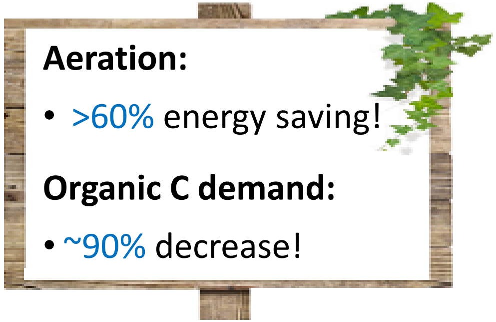
Anaerobic ammonium oxidation: Anammox (AMX) No organic C needed and low sludge yield

$$NH_4^+ + 1.32NO_2^- + 0.066HCO_3^- + 0.13H^+ \rightarrow 1.02N_2 + 0.26NO_3^- + 0.066CH_2O_{0.5}N_{0.15} + 2.03H_2O$$

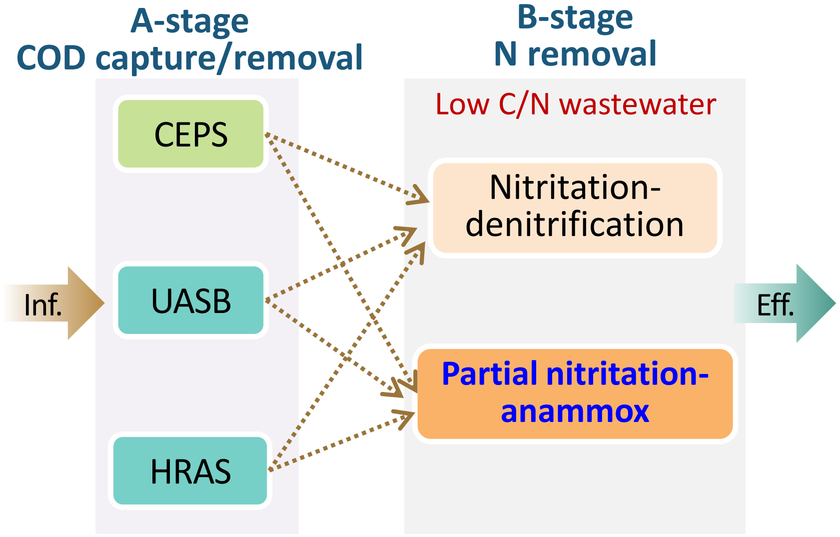


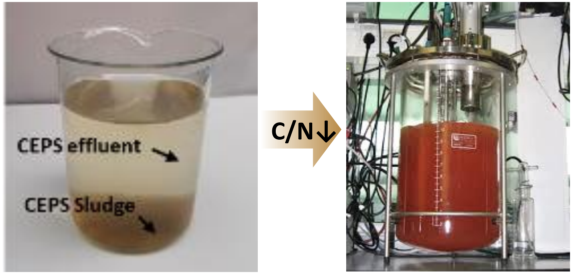
Anammox sludge
(works generally well for high-strength wastewater)

Promise and expected benefits:

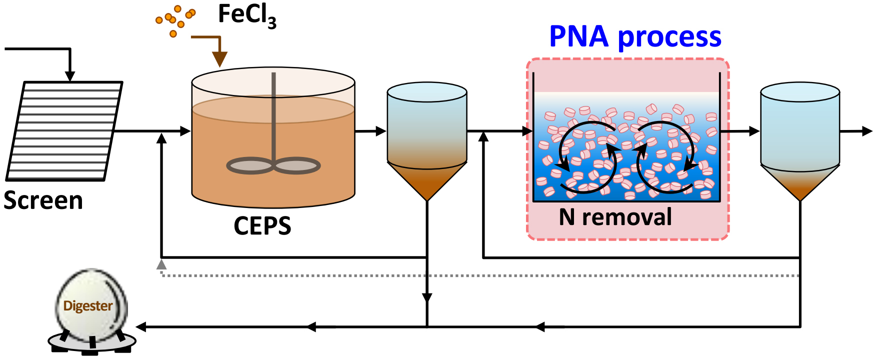


A-B two-stage process for municipal wastewater treatment



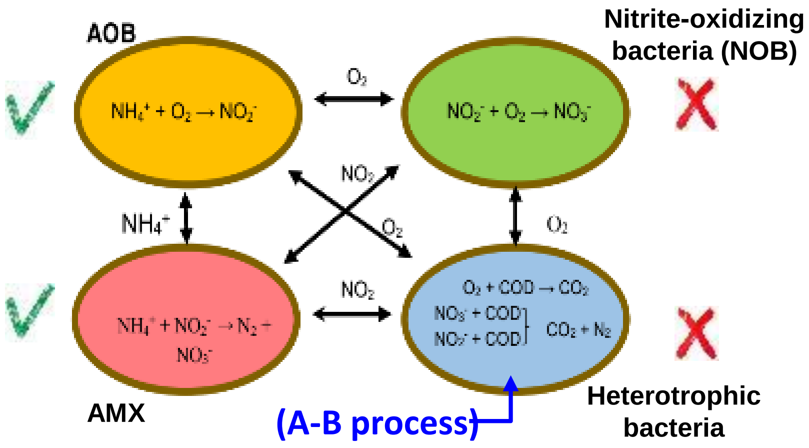


- ✓ Hong Kong has adopted CEPT that can act as the A-stage for COD capture/removal.
- ➢ **How to utilize anammox in B-stage to achieve autotrophic N removal?**



PNA for N removal: A good idea, but difficult for low-strength wastewater

- **NO_2^- production, and its consumption by AMX**



Primary obstacles to PNA application:

- Anammox sludge retention

- Long-term NOB suppression

Sidestream wastewater (sludge liquor)
High N content & moderate temperature

- **Sidestream $[NH_4^+\text{-N}]$: ~300 mg N/L**

vs.

Mainstream wastewater
Low N content & low temperature

For mainstream treatment:

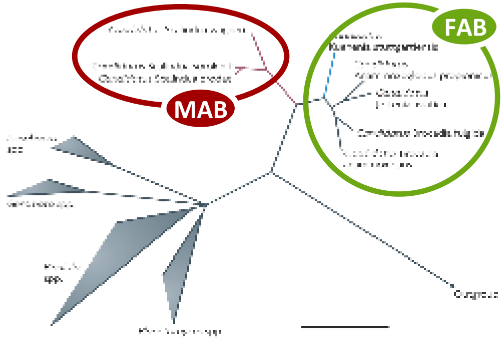
- **Mainstream $[NH_4^+\text{-N}]$: 20-40 mg N/L**
- Low biomass yield of AMX: 0.065 g/g N

→ New biomass growth **< 2 mg AMX biomass/L**

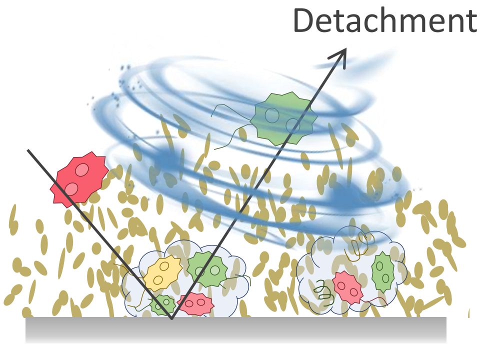
Challenges for saline mainstream PNA in Hong Kong

Key challenges:

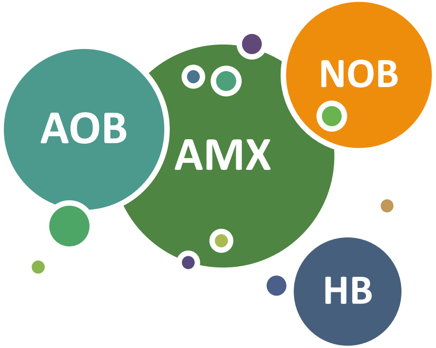
- **High salinity** in saline wastewater: Slow adaptation of the seed freshwater anammox bacteria (FAB) to saline conditions and a long start-up period of the anammox-based bioreactors.
- **Low N concentration** in wastewater influent: Slow AMX sludge growth, and difficulty in controlling nitrate build-up and inhibition of NOB in mainstream conditions.
- **High flow-rate** of mainstream wastewater treatment: Activity decrease of functional AMX bacteria under the low N loading condition, and the high sludge wash-out rate.



Lack of rapid adaptation strategy for FAB

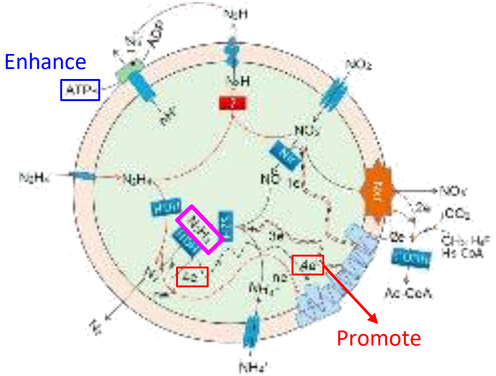


Turbulent condition hindering biofilm formation

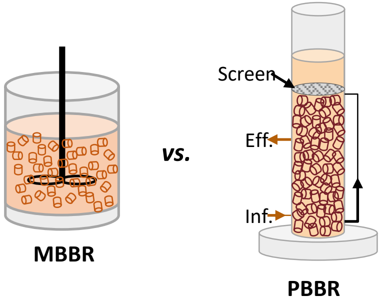


Low AMX activity & difficulty in NOB suppression

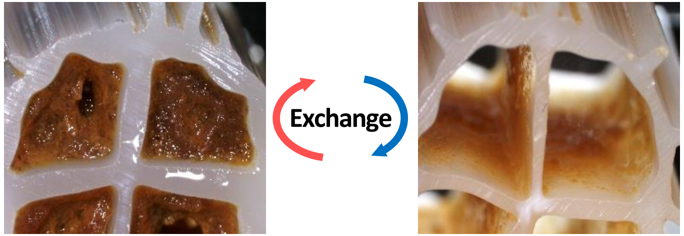
Saline mainstream PNA: How to make it work?



N_2H_4 as an enhancer for FAB adaptation



PBBR for AMX biofilm growth



Technical solutions for application of PNA in N removal from saline mainstream wastewater:

- ✓ Short-term addition of N_2H_4 as an enhancer to facilitate the adaptation of FAB to the saline condition.
- ✓ Biocarriers in packed-bed biofilm reactor (PBBR) to achieve rapid formation of biofilms for AMX retention.
- ➢ Feasibility and performance of PNA in practical application of saline wastewater treatment : Pilot study.

Objectives

1. Adaptation of seed AMX to the saline condition: *Short-term addition of chemical enhancer (N_2H_4)*

- Assess the effectiveness of enhancers (e.g., N_2H_4) in the adaptation of FAB to salinity.
- Investigate the feasibility of PNA-IFAS (integrated fixed-film activated sludge) for treating saline wastewater.

2. Rapid growth of AMX biofilms for the start-up of PNA reactors: *Packed-bed biofilm reactor (PBBR)*

- Use PBBR as a simple and reliable technique for rapid biofilm formation to provide healthy anammox biofilms.
- Investigate the feasibility of PBBR for treating saline sidestream wastewater and salt-tolerant AMX enrichment.

Experimental Results and Findings

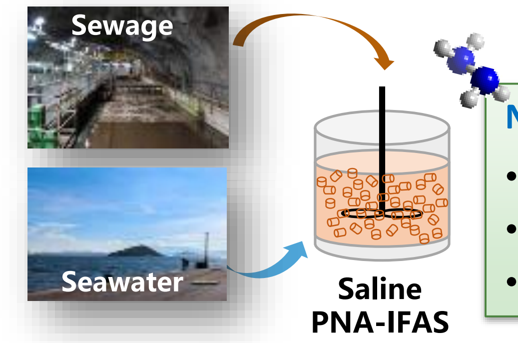
1. Hydrazine-assisted rapid salinity adaptation of anammox bacteria

2. PBBR for rapid biofilm formation and anammox retention

1. Hydrazine-assisted rapid salinity adaptation of AMX bacteria

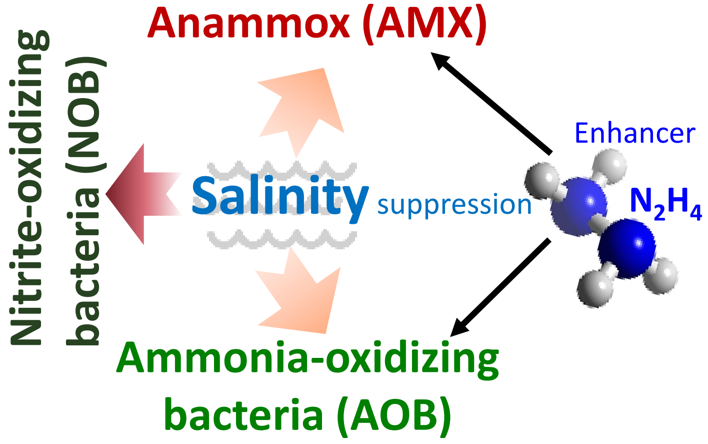
Adaptation of AMX to the saline condition: Chemically-enhanced adaptation (N_2H_4)

- Assess the effectiveness of enhancers (e.g., N_2H_4) in the adaptation of AMX bacteria to salinity.
- Investigate the feasibility of PNA-IFAS (integrated fixed-film activated sludge) for treating saline wastewater with 60 mg N/L.



N_2H_4 as an enhancer (5 mg/L):

- Promote ATP synthesis
- Enhance electron transfer chain
- Relieve nitrite poisoning

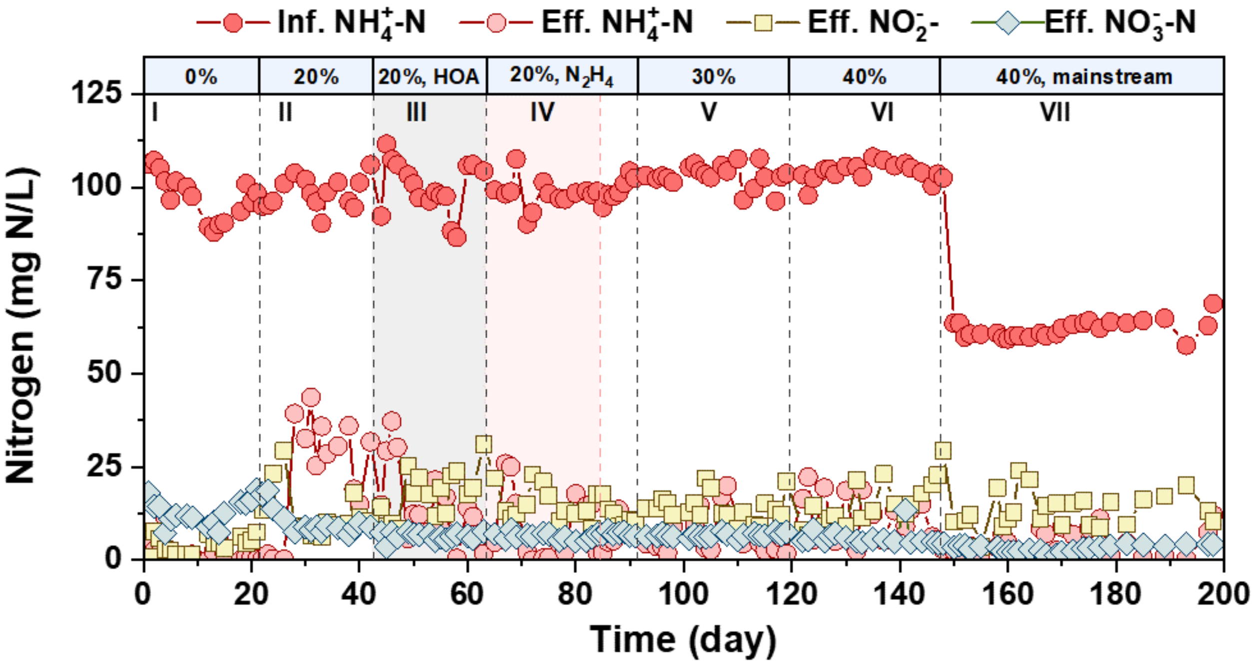


Reactor: Column-type SBR, V_{work} = 5 L, HRT = 12 h, PNA sludge from a livestock wastewater treatment plant as the seed sludge;

CEPS: As A-stage to remove organics, 25 mg Fe/L ;

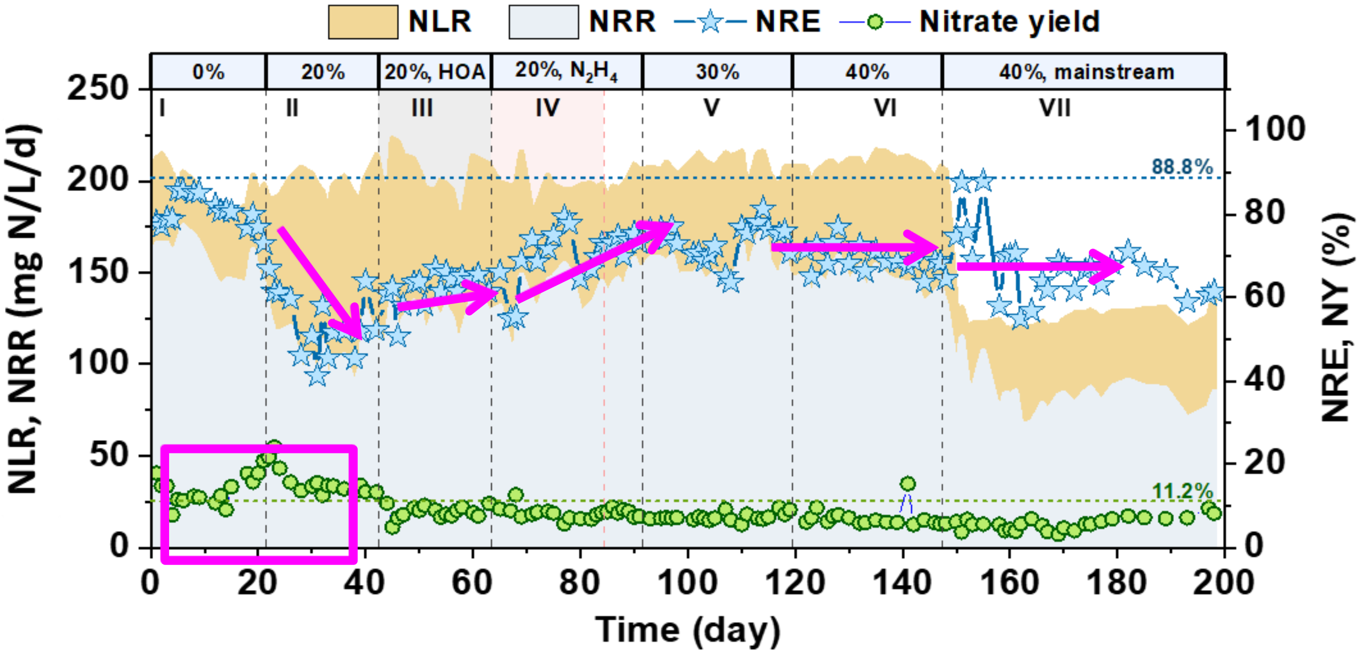
Influent: Adjusted NH_4^+-N concentration to 60-100 mg N/L; the seawater proportion increased stepwise to 40%.

1. Hydrazine-assisted rapid salinity adaptation: performance



- Salinity in the influent exerted a negative impact on the overall N removal performance of the PNA;
- Nitrate concentration in the effluent maintained at a low level during the experiment, indicating the much reduced risk of NOB bloom and nitrate build-up in the saline PNA system.

1. Hydrazine-assisted rapid salinity adaptation: performance



NLR: N loading rate

NRR: N removal rate

NRE: N removal efficiency

$$NRE = \frac{TIN_{Inf}}{TIN_{Eff}}$$

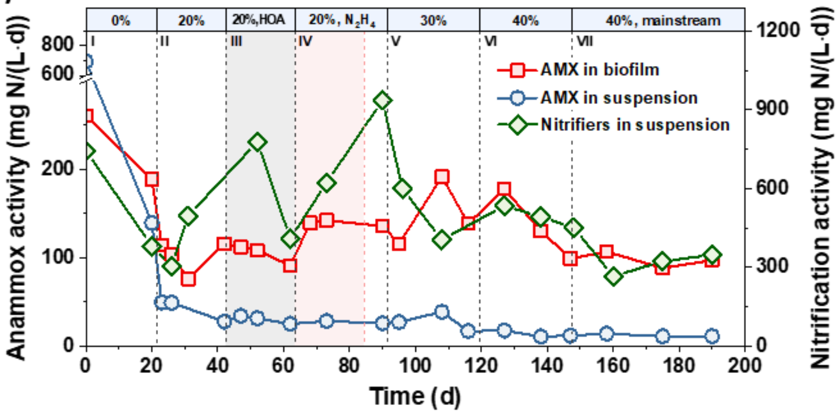
NY: Nitrate yield

$$NY = \frac{c(NO_3^-)}{TIN_{Inf} - TIN_{Eff}} \times 100\%$$

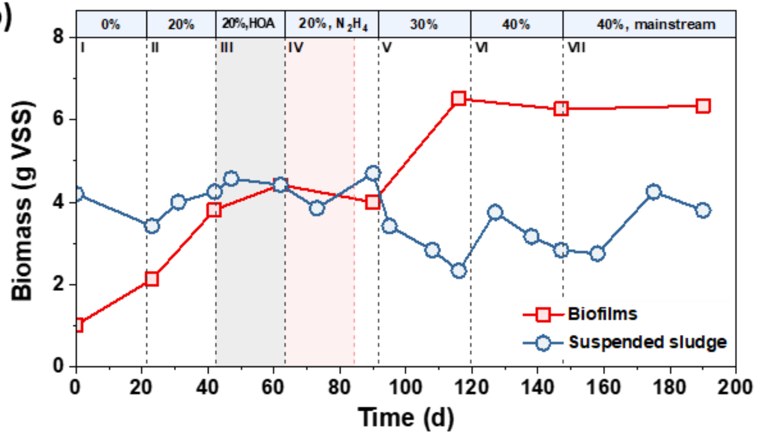
- Short-term dosing of **N_2H_4** (5 mg/L) had a long-term positive impact on PNA performance;
- **NRR** and **NRE** kept at **140.4–148.7 mg N/(L·d)** and **67.5%–70.8%** for the influent with 40% seawater;
- No NO_3^- build-up in the saline PNA-IFAS reactor, nitrate yield kept at **7.0%–7.9%** in Stage III–VII.

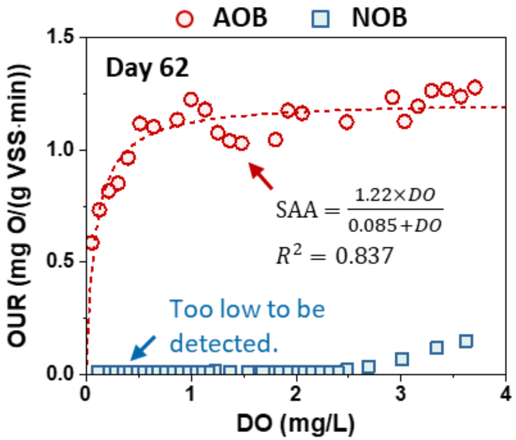
1. Hydrazine-assisted rapid salinity adaptation: biomass activities

(a)



(b)



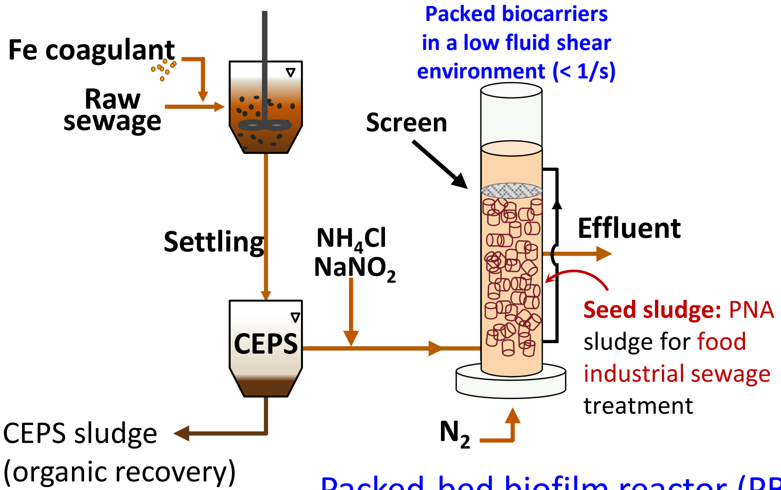


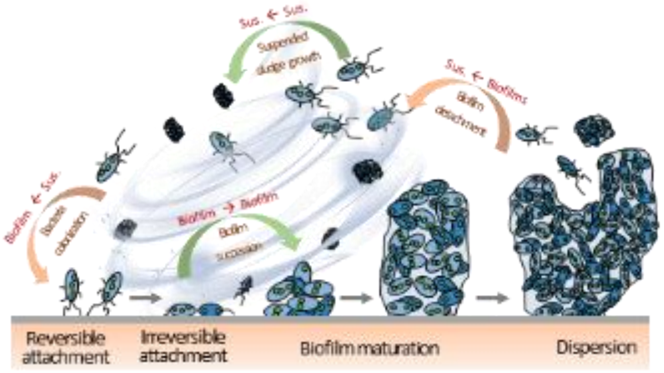
- AMX is more vulnerable than nitrifies in the saline environment.
- N_2H_4 can serve as an enhancer of both AMX and AOB, restoring the performance of PNA in saline wastewater treatment.
- AOB activity was 40–100 times higher than NOB.

2. PBBR for rapid formation of anammox biofilms

Rapid formation and growth of biofilms on K1 carriers under low-turbulent conditions:

- PBBR is a simple and reliable technique for rapid start-up of biofilm reactors, providing healthy anammox biofilms.
- Investigate the feasibility of PBBR for treating saline sidestream wastewater and salt-tolerant anammox enrichment.

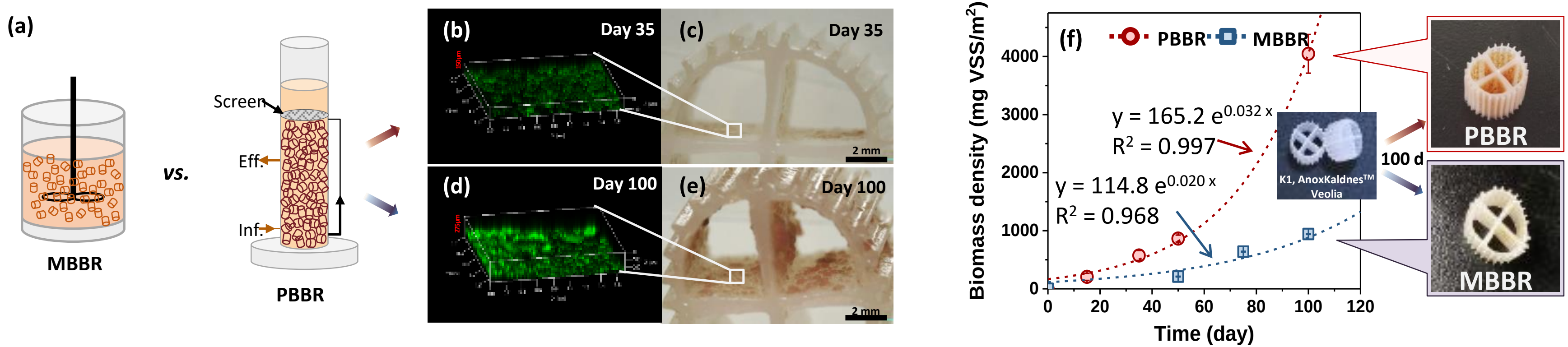


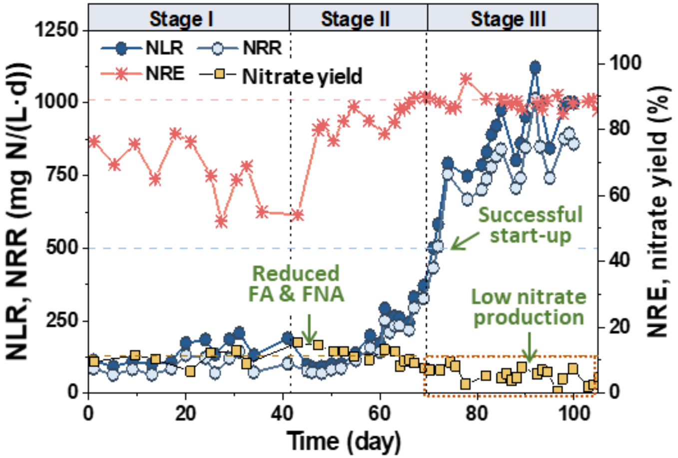


Hydraulic turbulence hinders initial bacterial colonization and biofilm formation

Packed-bed biofilm reactor (PBBR) (different from MBBR):
A submerged bio-filter with a mild fluid condition for the initial microbial attachment and colonization.

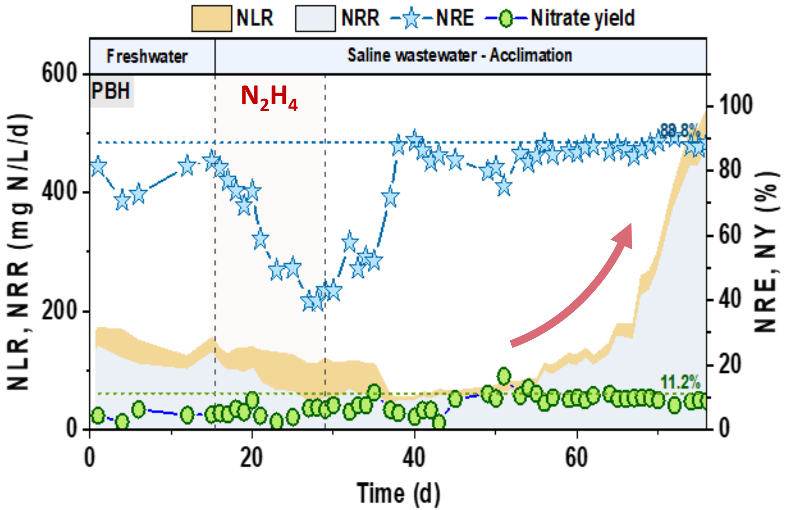
2. PBBR for rapid formation of anammox biofilms: performance

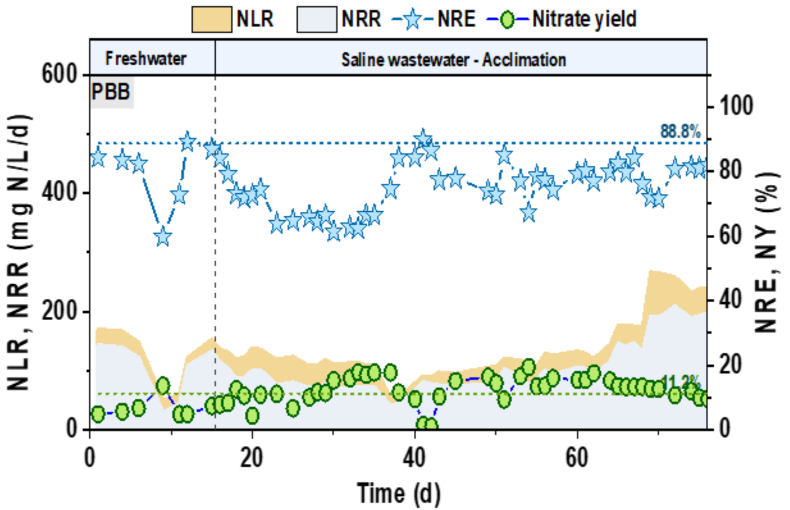




- PBBR is simple and efficient in biofilm formation for AMX retention and enrichment, which shortened the AMX reactor start-up period to <2 months.
- Low hydraulic turbulence, strict anaerobic conditions, and low levels of free ammonia (FA) and free nitrous acid (FNA) are the key for AMX enrichment.

2. PBBR for rapid formation of anammox biofilms: salinity



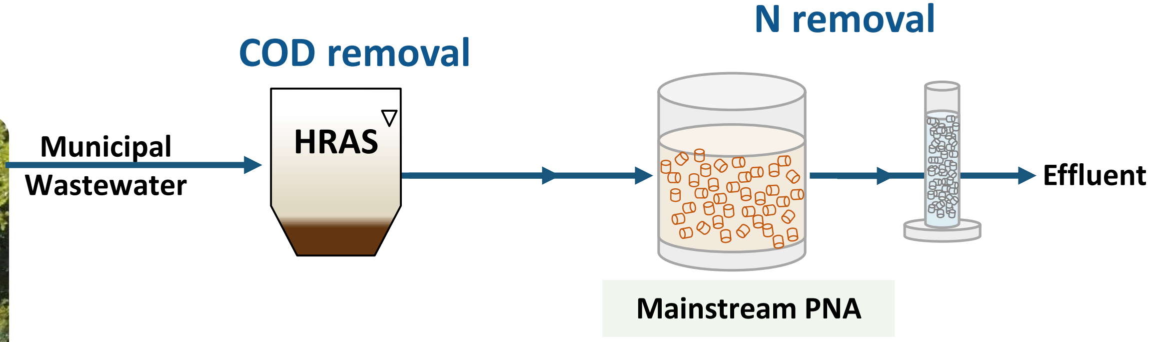


Week	1	2	3	4	5	6	7	8	8	10	11
PBBR-H	Freshwater		N_2H_4 dosing		Saline conditions						
PBBR	Freshwater		Saline conditions								

- Dosing N_2H_4 as an enhancer (5 mf/L) in the initial stage of PBBR for just 2 weeks can effectively facilitate the adaptation of freshwater AMX to the saline condition.
- Without the dosing of an enhancer, the nitrogen removal performance of PBBR remained low.

Pilot study at Shatin Sewage Treatment Works

Pilot study at Shatin STW
Treatment capacity: 5 m^3/d



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Summary

1. Partial nitritation-anammox (**PNA**) can be achieved in **saline** low-strength wastewater treatment with **long-term suppression** of **NOB**. Salinity in wastewater can be beneficial for **reducing the risk of nitrate build-up** and increasing the **robustness** of PNA for sustainable wastewater treatment.

2. As anammox bacteria are vulnerable to saline conditions, N_2H_4 can be dosed for a **short period** (2-3 weeks) to facilitate their **salinity adaptation**, benefiting the N removal performance in both mainstream and sidestream wastewater treatment for a long-term.

3. Packed-bed biofilm reactor (**PBBR**) is an innovative technical strategy to rapidly cultivate **anammox biofilms** for PNA bioreactors, serving as a "farm" for **AMX biofilm** enrichment and augmentation.

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Thank you!