Effective granular sludge reactors for managing high ammonia wastewater

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Date: 22/10/2025

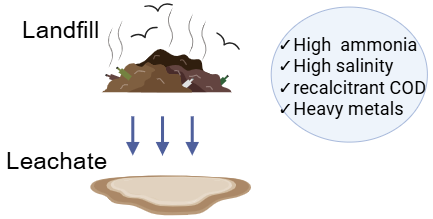
High-ammonia Wastewater Management

Landfill leachate

Leachate from decomposing waste.

High ammonia (**400–3,500 mg/L**),

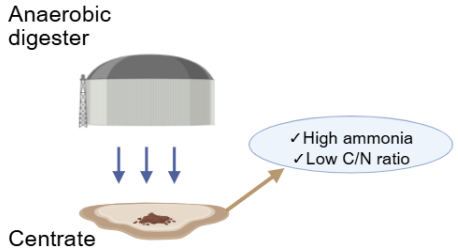
recalcitrant organic matter, heavy metals



Centrate

By-product of sludge dewatering / anaerobic digestion.

High ammonia (**400–2,000 mg/L**), low C/N ratio



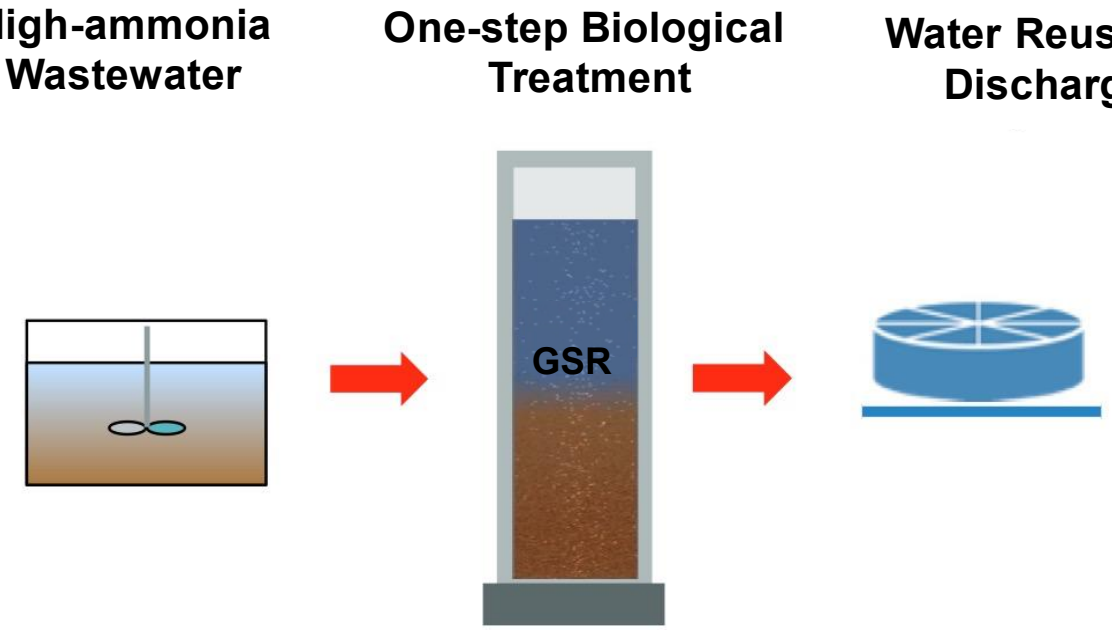
Excess nitrogen loading in treatment plants.

Risk of process **inhibition** and **instability**.

Potential effluent **non-compliance** and **ecosystem impacts**.

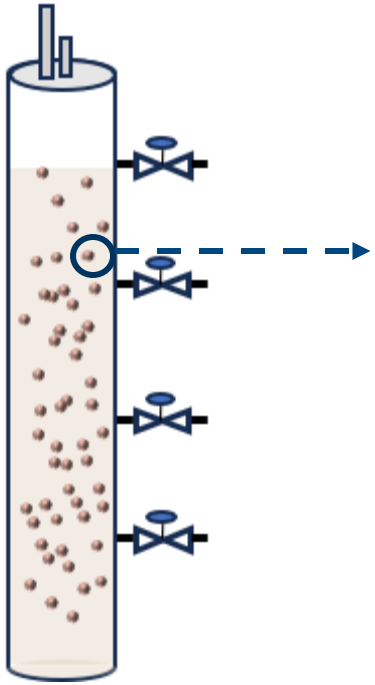
Project Aim

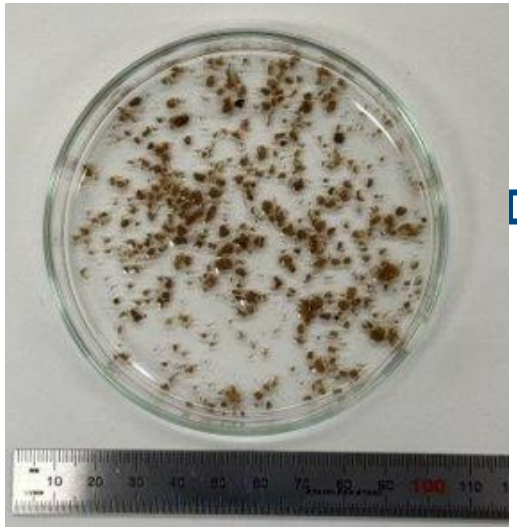
- The project aims to develop and optimise the Granular Sludge Reactor (GSR) process for the effective treatment of high-ammonia wastewaters, specifically anaerobically digested centrate and landfill leachate.

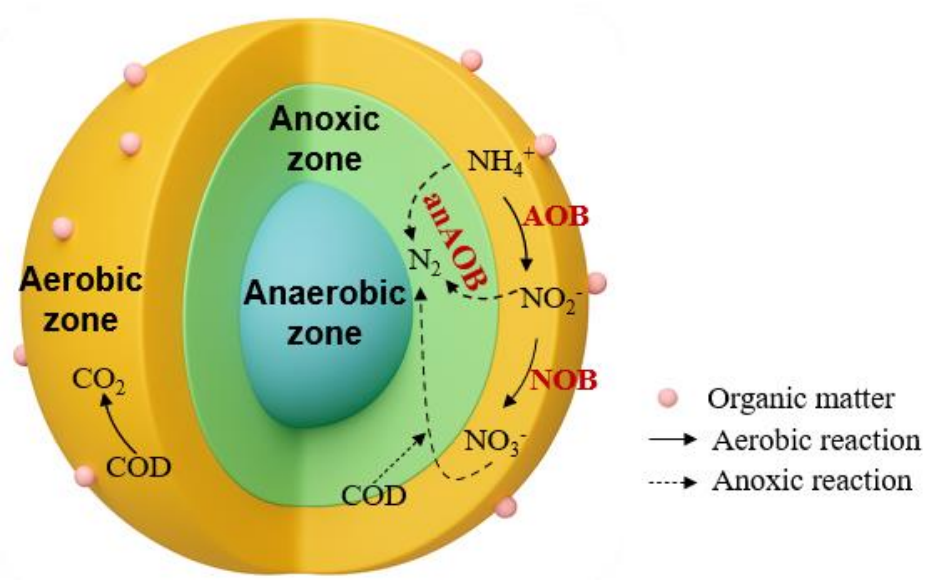


One-Stage Granular Sludge Treatment

- High biomass density
- Diverse microbial community
- Resistance to shock
- Small footprint

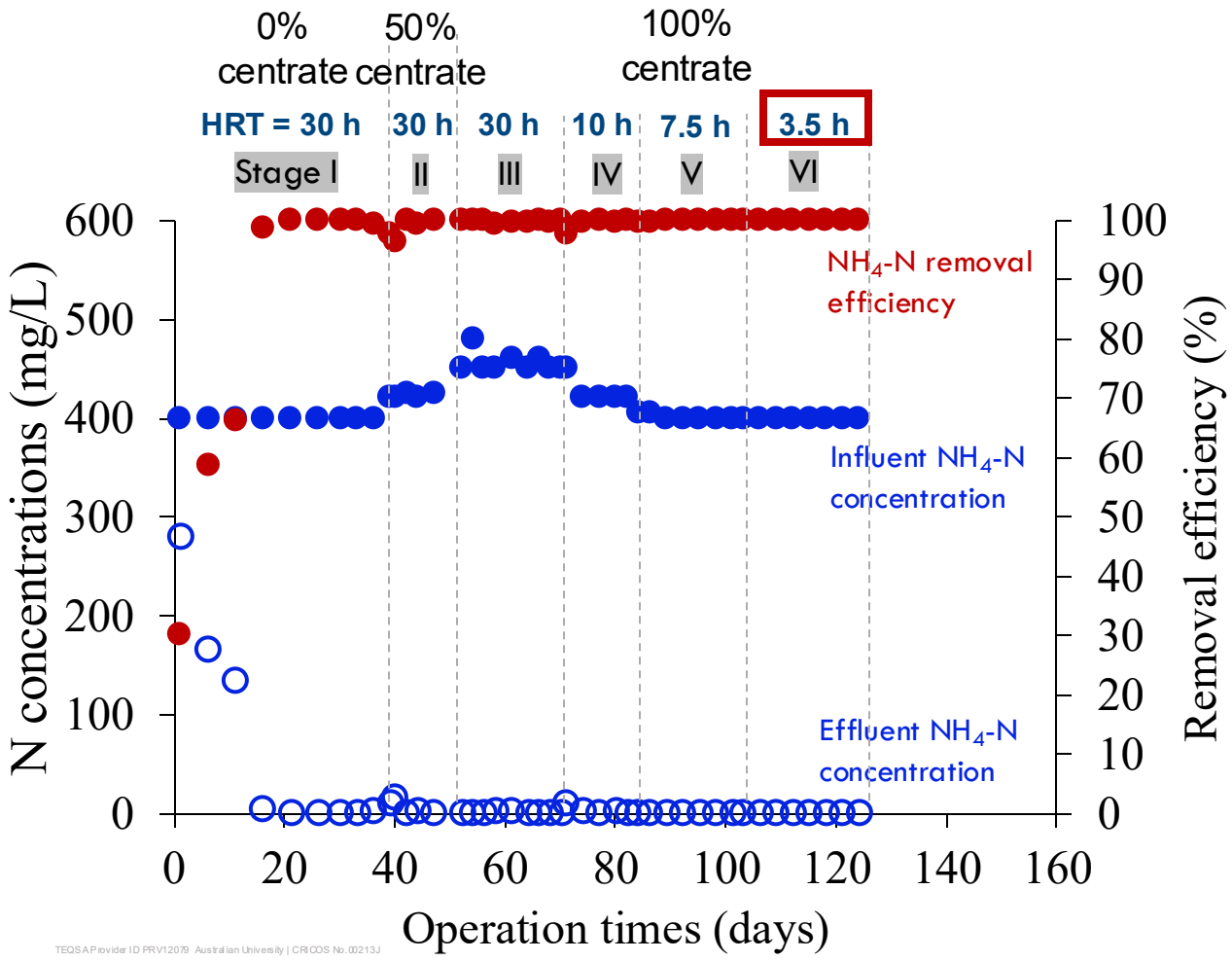






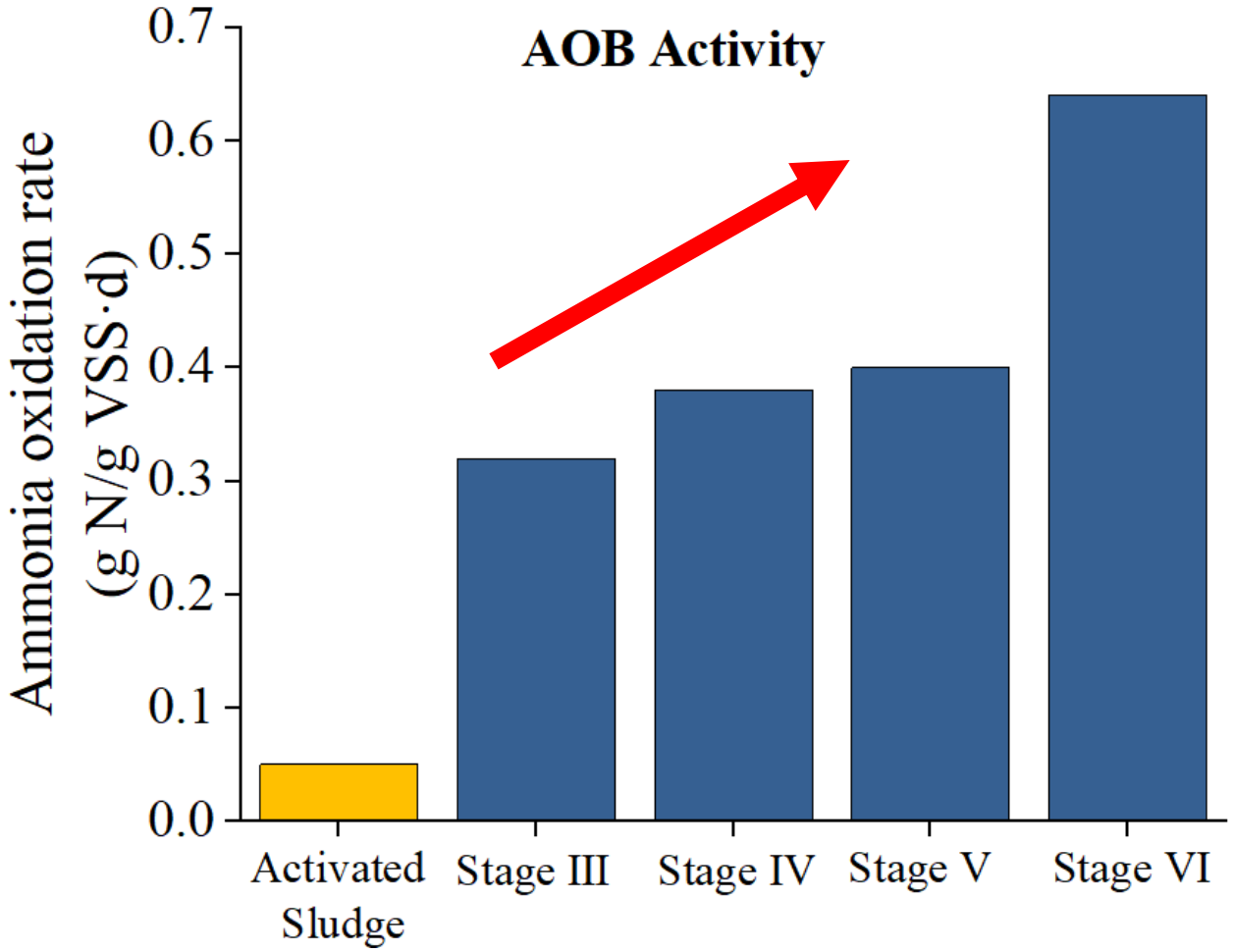
Stage 1: Implementing Granular-Sludge Based Biological Treatment for Efficient Centrate Treatment

Centrate Performance



At a remarkably **low HRT of 3.5 h**, the optimised GSR reduced 400–500 mg/L influent NH_4^+-N to **below 1 mg/L** .

Centrate – Microbial Activity



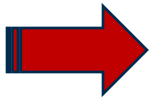
After operational strategies optimisation, AOB activity rose to **0.64 g N/g VSS·d**, more than **ten times higher** than in the original activated sludge.

Project 2: Implementing Granular-Sludge Based Biological Treatment for Efficient and Cost-Effective Landfill Leachate Treatment

From Centrate Success to Leachate Challenge

Higher concentrations, Greater challenges

Parameters	Unit	Centrate
sCOD	mg/L	170-327
NH_4-N	mg/L	405-490
NO_2-N	mg/L	3-7
NO_3-N	mg/L	<1
TN	mg/L	475-500
PO_4-P	mg/L	55-77
Alkalinity	mg/L as $CaCO_3$	1,600-1,900



Parameters	Unit	Leachate
sCOD	mg/L	11,071-16,290
NH_4-N	mg/L	2,121-3,068
NO_2-N	mg/L	<1
NO_3-N	mg/L	39.7-46.7
TN	mg/L	2,810-3,196
PO_4-P	mg/L	11.8-14.7
Alkalinity	mg/L as $CaCO_3$	7,053-10,561

From **high** to **extremely high** ammonia concentrations

Free ammonia toxicity in high-ammonia wastewater

Disrupts metabolism → intracellular pH imbalance and key enzyme (*AMO*/*HAO*) inhibition

Inhibits nitrogen-removal microbes → NOB, AOB and denitrifiers inhibition

Destabilises system → sludge integrity loss and community shifts

Conventional biological treatment **fails to**

manage extremely high-ammonia wastewater

GSRs for Leachate Treatment

Challenge: Most existing biological processes depend on dilution instead of directly handling wastewater with ammonia concentrations >2,000 mg/L.

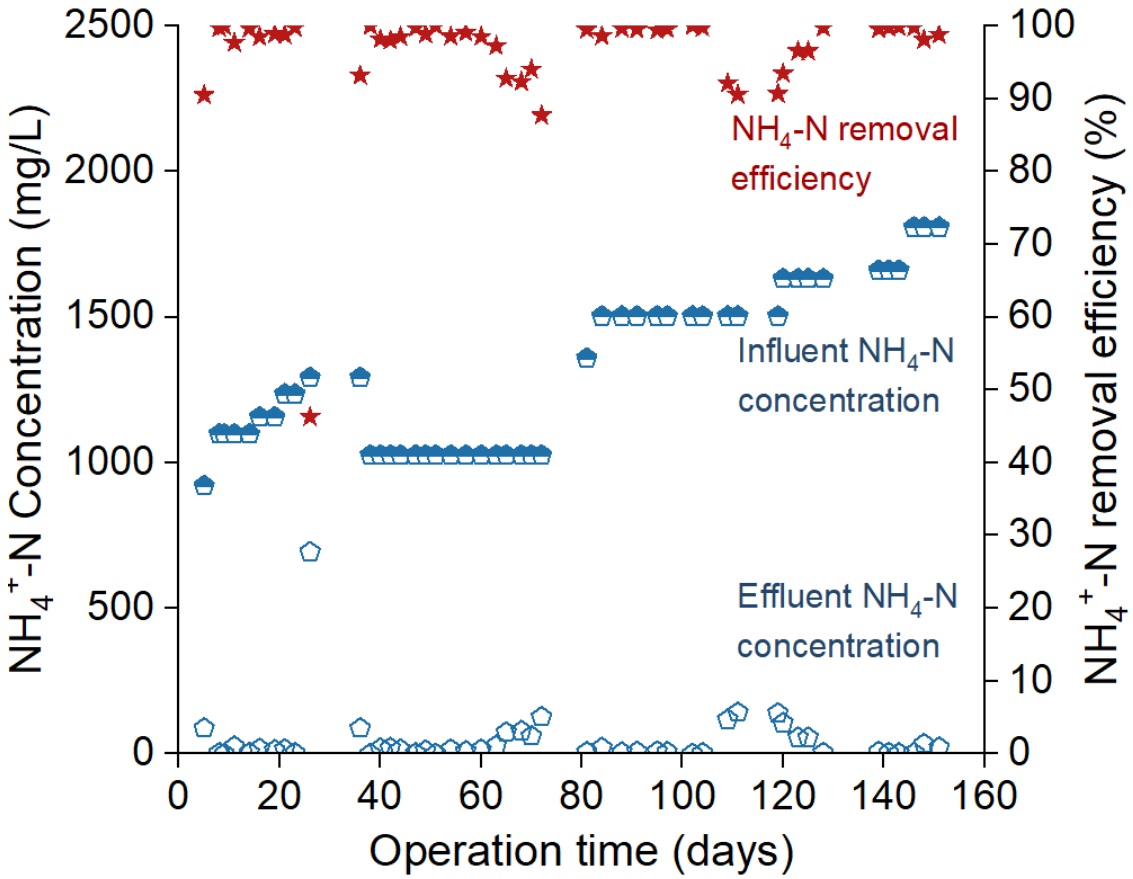
Previous work : GSR already proven at >1,200 mg/L.

Breakthrough: GSR achieved >2,000 mg/L at room temperature

Free ammonia management

Aeration strategy management

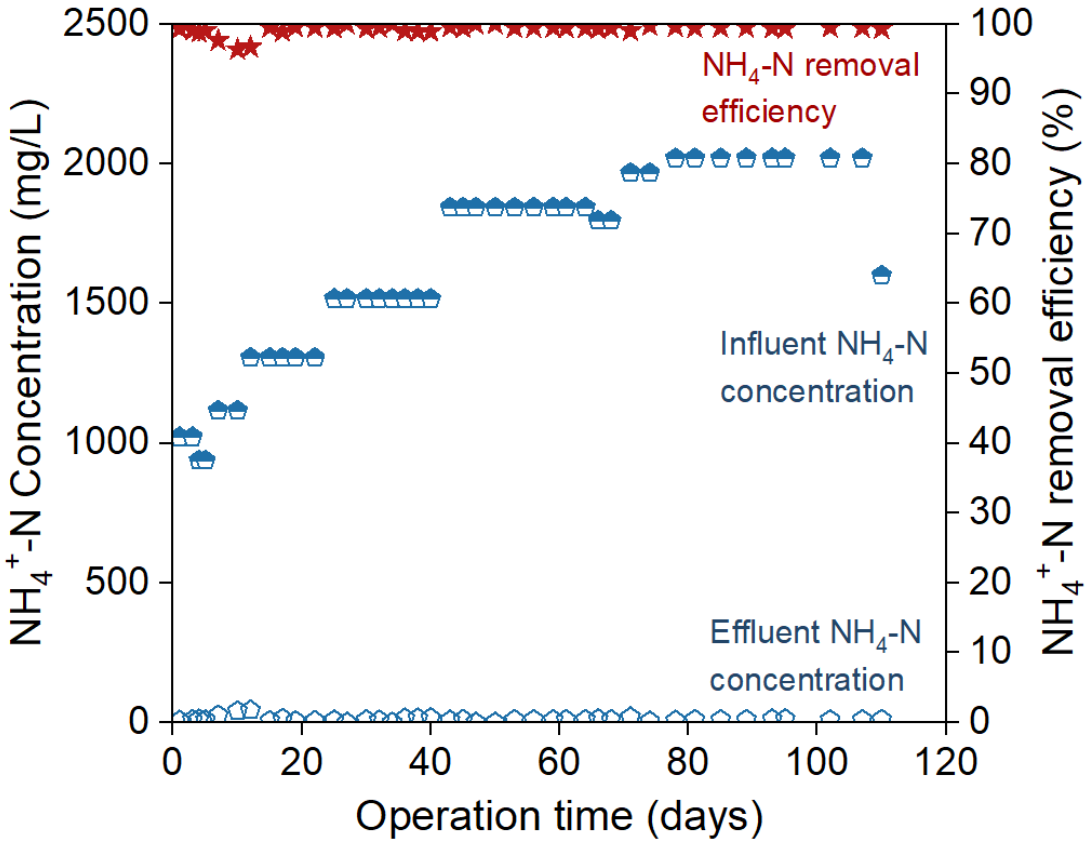
Leachate Performance- Free ammonia Synthetic wastewater



The reactor consistently maintained >90% NH_4^+-N removal efficiency under influent concentrations up to **1,800 mg/L**.

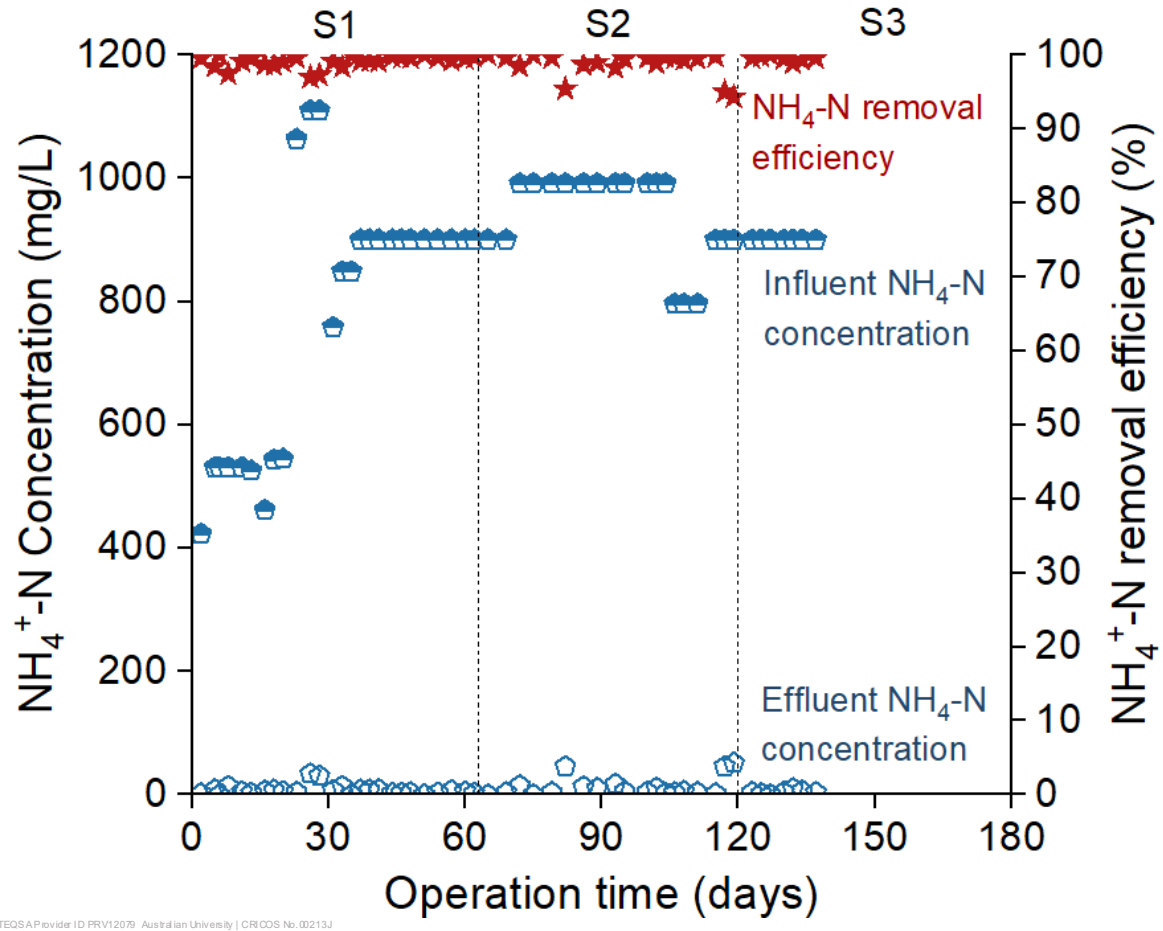
Even as influent concentrations increased stepwise, the system adapted without significant performance decline, confirming its **robustness under extreme nitrogen loads**.

Leachate Performance- Raw leachate



The GSR stably and efficiently removed **over 2,000 mg/L NH_4^+-N** from raw leachate at a required HRT of 17.5 h, consistently achieving removal efficiencies above 99%.

Leachate Performance- Aeration strategy



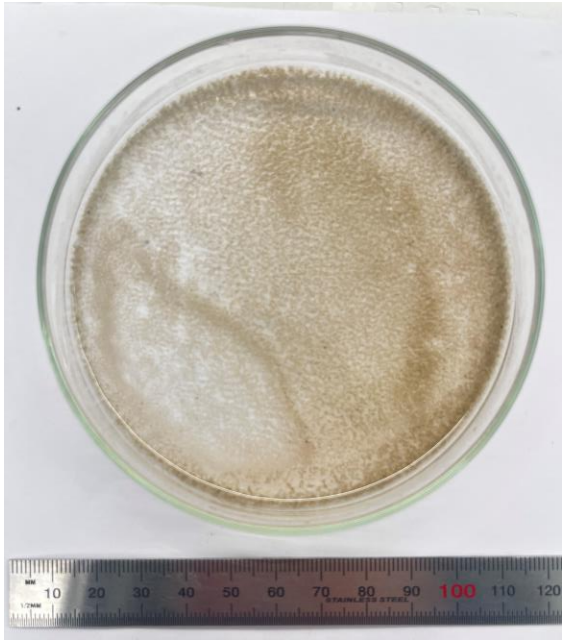
The system is designed to further improve **energy efficiency** and **environmental sustainability**, aligning treatment performance with long-term practical application goals.

Previous experiments in our group:

DO < 0.6 mg/L did not compromise ammonia removal efficiency

Leachate – Sludge Characteristic

Inoculum



MLSS: ~3.0 g/L

SVI:570 mL/g

Initial GSR

MLSS: ~4.0 g/L

SVI:120.1 mL/g

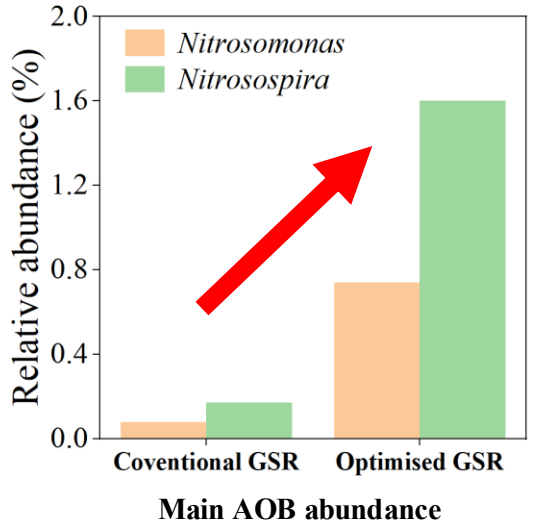
Denser and more compact

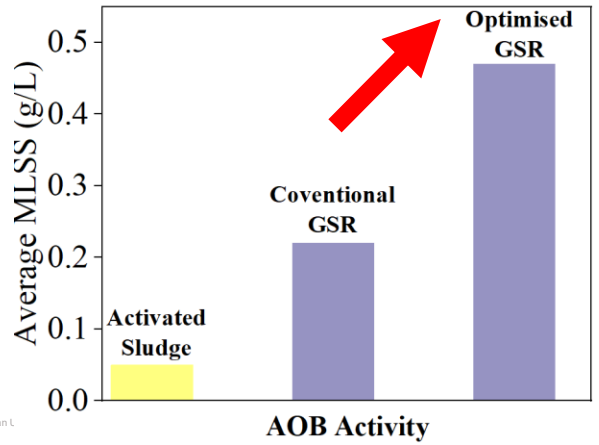
Optimised GSR

MLSS: ~12.0 g/L

SVI:25.8 mL/g

Leachate – Microbial Adaption





	Inoculum	Conventional GSR	Optimised GSR
Corynebacterium	18.2	19.9	28.0
Thauera	7.5	1.9	3.5
Rubinisphaera	4.0	3.3	1.4
Truepera	2.5	2.8	2.8
SM1A02	2.1	2.6	2.1
Flavobacterium	3.2	1.9	0.7
SWB02	2.0	2.4	1.5
Pirellula	1.8	2.1	2.2
Hydrogenophaga	1.0	0.8	0.2
Bdellovibrio	2.0	2.6	0.6

Future Outlook

Energy efficiency : Enhance energy efficiency through optimised aeration and process control.

Environmental Sustainability: Mitigate and manage N_2O emissions to minimise climate impacts.

Pilot Development: Advance pilot-scale experiments to demonstrate scalability and practical application.

Summary

- Effective strategy: GSR stably and effectively treated **high- and extreme-strength ammonia** wastewaters (centrate, raw leachate).
- High efficiency: >99% NH_4^+-N removal, lowering **>2,000 mg/L** to near-zero effluent.
- Microbial enhancement: **AOB activity increased >10×** vs activated sludge.
- Future focus: Improve **energy efficiency**, reduce N_2O emissions, and support sustainable nitrogen management.

Acknowledge

Acknowledge following funding support and colleagues from Professor Liu's research team.

CITY OF GOLDCOAST.

RACE for 2030
RELIABLE
AFFORDABLE
CLEAN
ENERGY

Thank you!

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