MARC RUSSENBERGER

HYDROGEN-DRIVEN AUTOTROPHIC DENITRIFICATION OF WASTEWATER USING A MEMBRANE BIOFILM PROCESS

THE UNIVERSITY OF AUCKLAND

water NEW ZEALAND
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water NEW ZEALAND CONFERENCE & EXPO
17–19 OCTOBER 2023
Tākina, Te Whanganui-a-Tara Wellington

ABOUT ME

MARC RUSSENBERGER

The University of Auckland

2nd year PhD Student

Education and achievements

- **Bachelor of Engineering (Hons)**

Chemical and Materials Engineering (2018 –2021), 1st class Hons, Dean's Honours List

- **Doctor of Philosophy (PhD)**

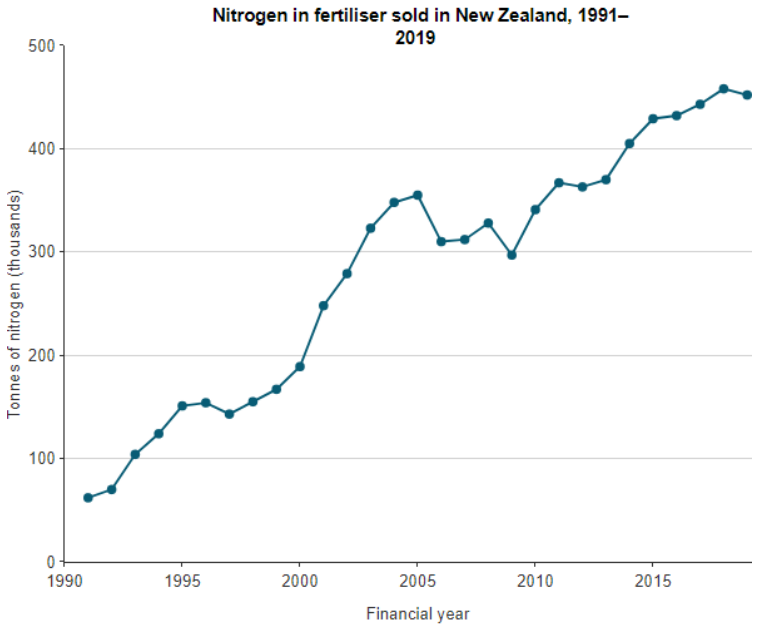
Civil and Environmental Engineering (2022 – present)

HOBBIES

- Running
- Hiking
- Traveling
- Gym

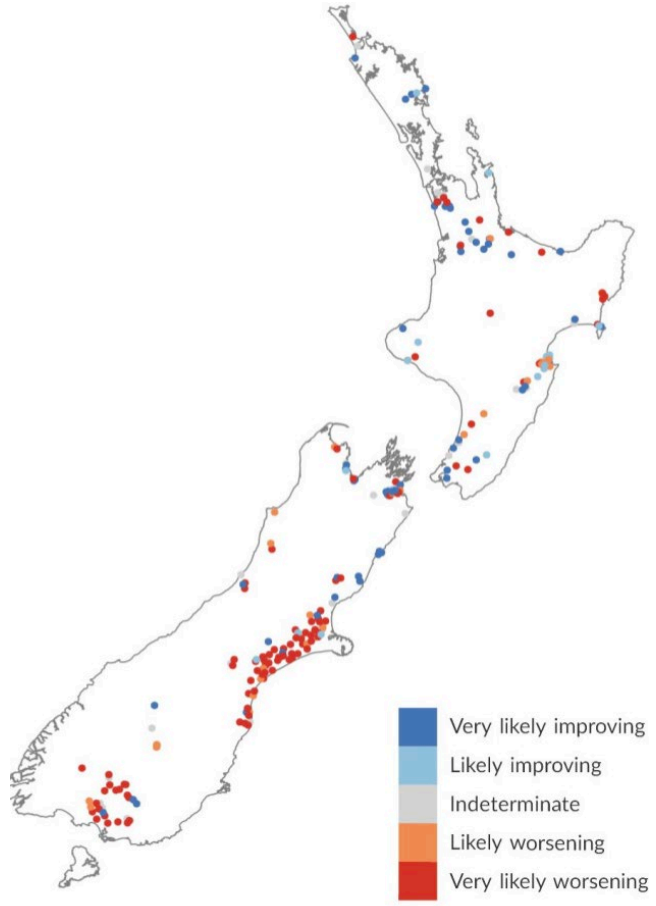
PRESENTATION PROCEEDINGS

NITRATE POLLUTION IN NEW ZEALAND



629% increase in nitrogenous fertilizer use (1991-2019) [1]

Secondary domestic wastewater effluent can be in excess of 40 mg N/L [2]



Worsening groundwater quality [3]

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IMPACTS OF NITRATE POLLUTION

Environmental

- Eutrophication [4]

Health

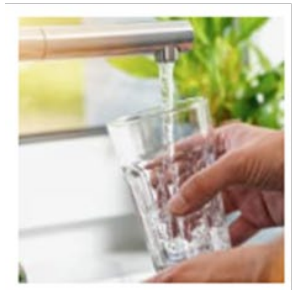
- toxicity to humans (cancer) [5]
- blue baby syndrome [5]

NEW ZEALAND

Dead zones: how our oceans are losing their breath

They're called "dead zones" - patches of our ocean where oxygen plummets to levels so low that many animals passing through them ...

11 Jan 2018



Up to 800,000 Nzers may have increased bowel cancer risk due to

News **New Zealand** / **Health** 22 Feb 2021

Between 300,000 and 800,000 New Zealanders may be exposed to potentially harmful levels of nitrates in their drinking water, which may increase their chances of developing bowel cancer. (AUDIO)

Concerns raised over nitrates' effects on babies

News **New Zealand** / **Country** 17 Oct 2017

Increased irrigation in Canterbury is putting newborn babies at increased risk from water contamination, a medical officer of health says

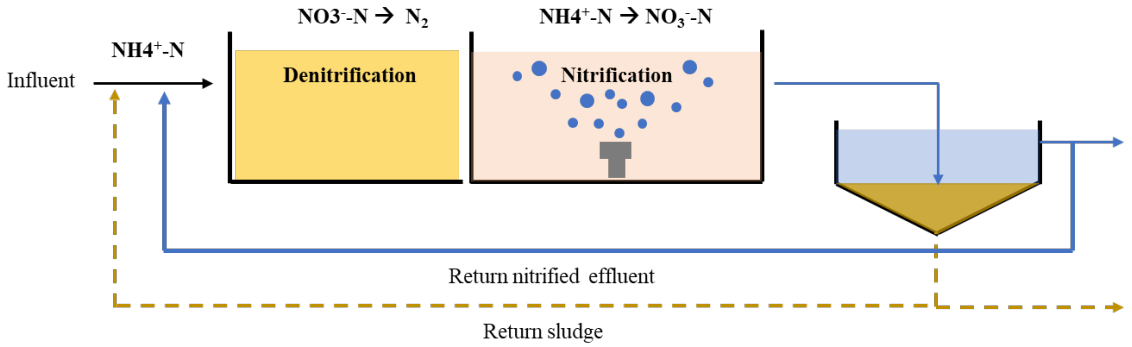
TRADITIONAL WASTEWATER DENITRIFACTION

Pre-anoxic approach

- Influent organic carbon drives denitrification

Disadvantages

- Energy intensive recycle
- Incomplete nitrate removal and nitrous oxide production

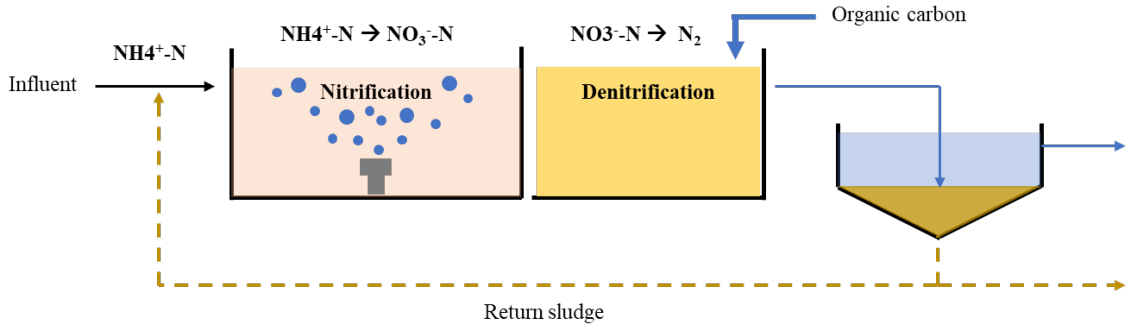


Post-anoxic (polishing process)

- External organic carbon drives denitrification

Disadvantages

- Overdosing cause carbon carryover
- Underdosing results in nitrous oxide production
- Organic carbon oxidation produces carbon dioxide



GREENHOUSE GAS EMISSION

Denitrification in wastewater treatment results nitrous oxide and carbon dioxide production [6]

Nitrous oxide is **300 times more potent** at warming the atmosphere than carbon dioxide [7]

Wastewater plants highest contributor of **greenhouse gas emissions** ...

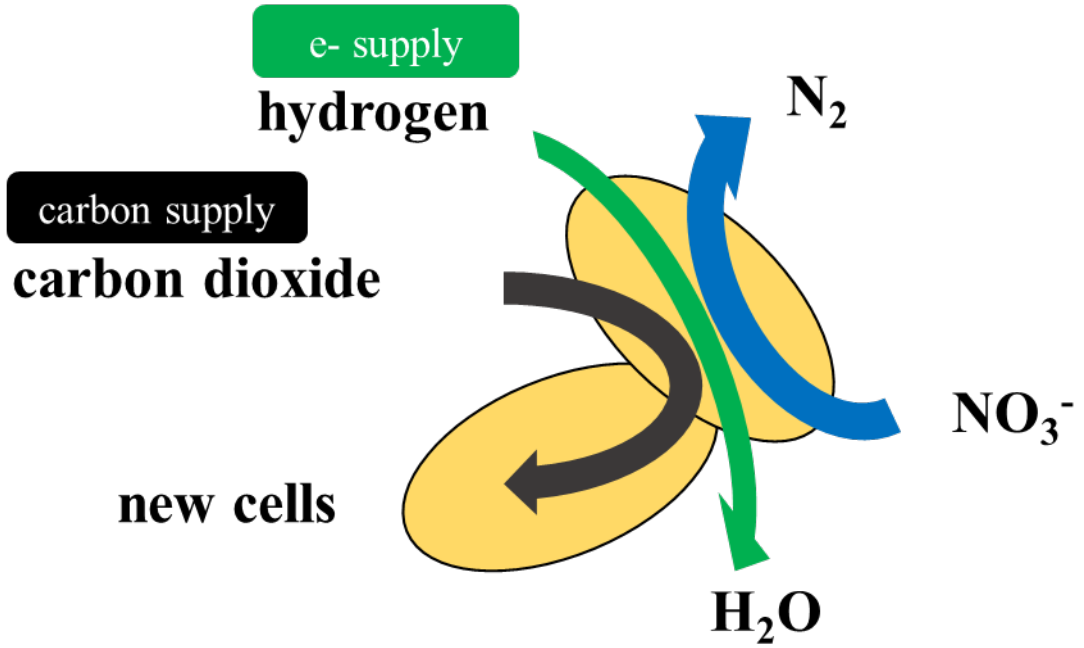
Stuff › environment › wastewater-plants-highest-contributor-of-...

14/04/2021 **...** The most common **greenhouse gases** emitted from wastewater treatment schemes were **carbon** dioxide, methane and nitrous oxide. Council reviewed

HYDROGEN DRIVEN DENITRIFICATION

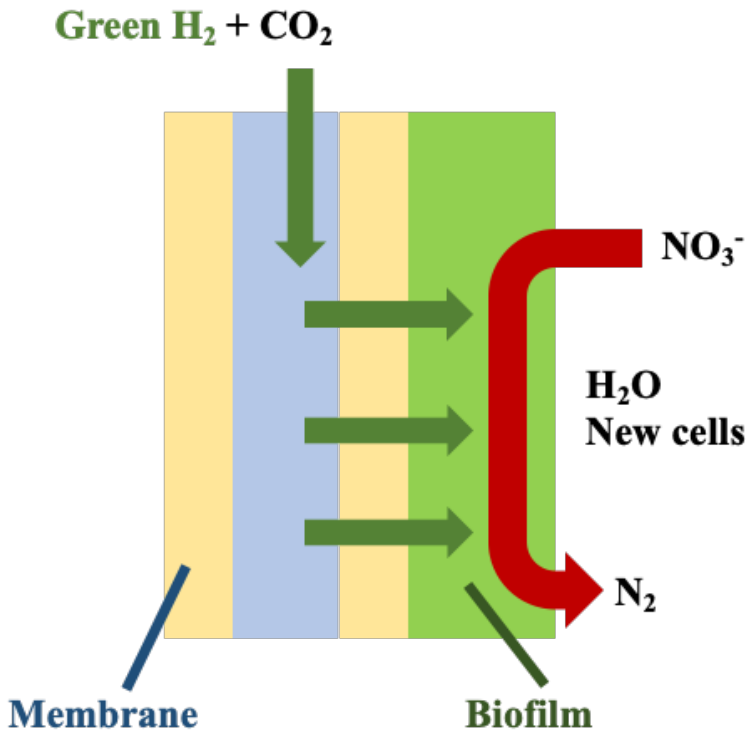
- bacteria **consume carbon dioxide** for growth
- bacteria consume hydrogen gas for energy generation
- works well in organic carbon deficient zones (post-anoxic)
- **Reduces nitrous oxide emissions** [8]
- **Lower growth rates** [9]

AUTOTROPHIC PROCESS



HYDROGEN WASTEWATER TREATMENT PROCESS

Solubility of Hydrogen in water is **1.6 mg H_2/L** [10]



Efficient and safe hydrogen delivery

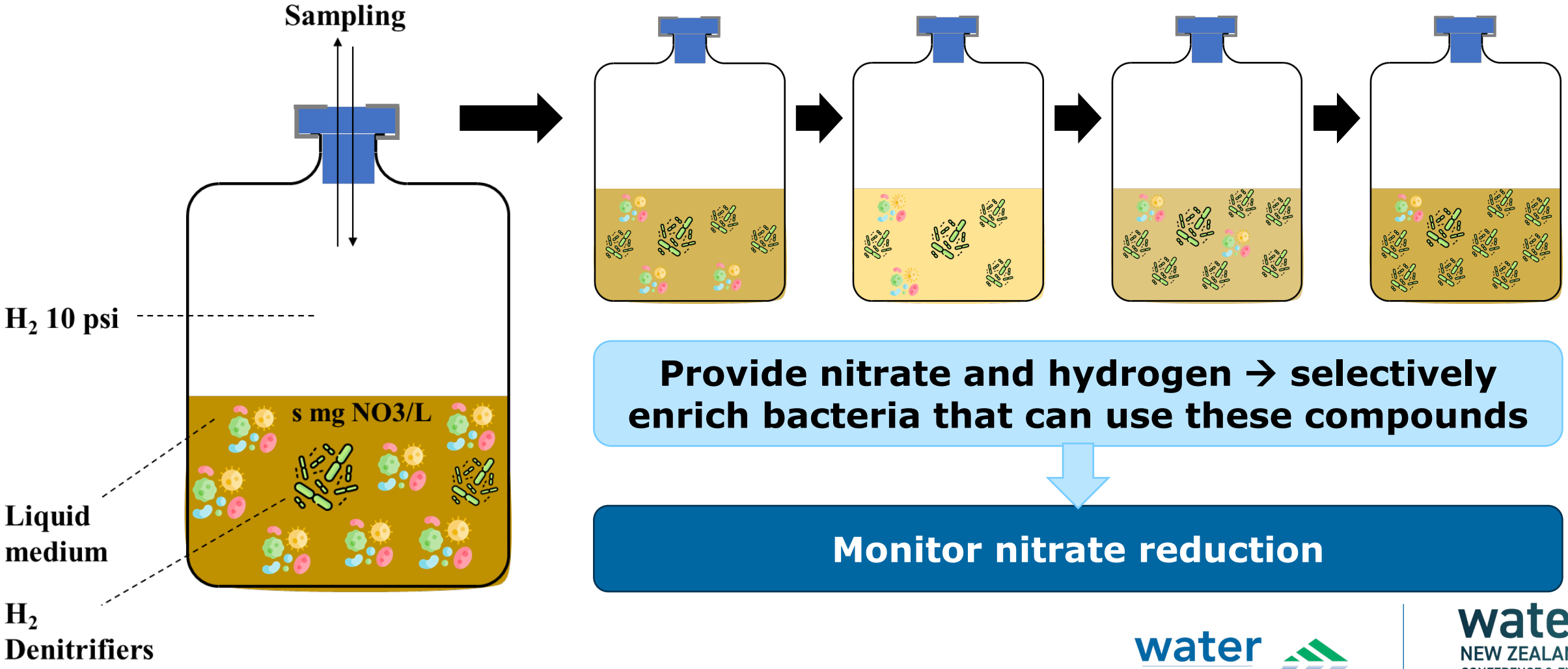
- *Attached growth process* → H_2 permeates through membrane into biofilm
- Improves H_2 efficiency and utilization rate
- Reduces H_2 accumulation in head space → limits explosive hazards

RESEARCH OBJECTIVES

Investigate the presence of indigenous hydrogenotrophic denitrifying bacteria in New Zealand wastewater treatment plants

Enrich these indigenous New Zealand bacteria in a novel continuous process suitable for wastewater treatment

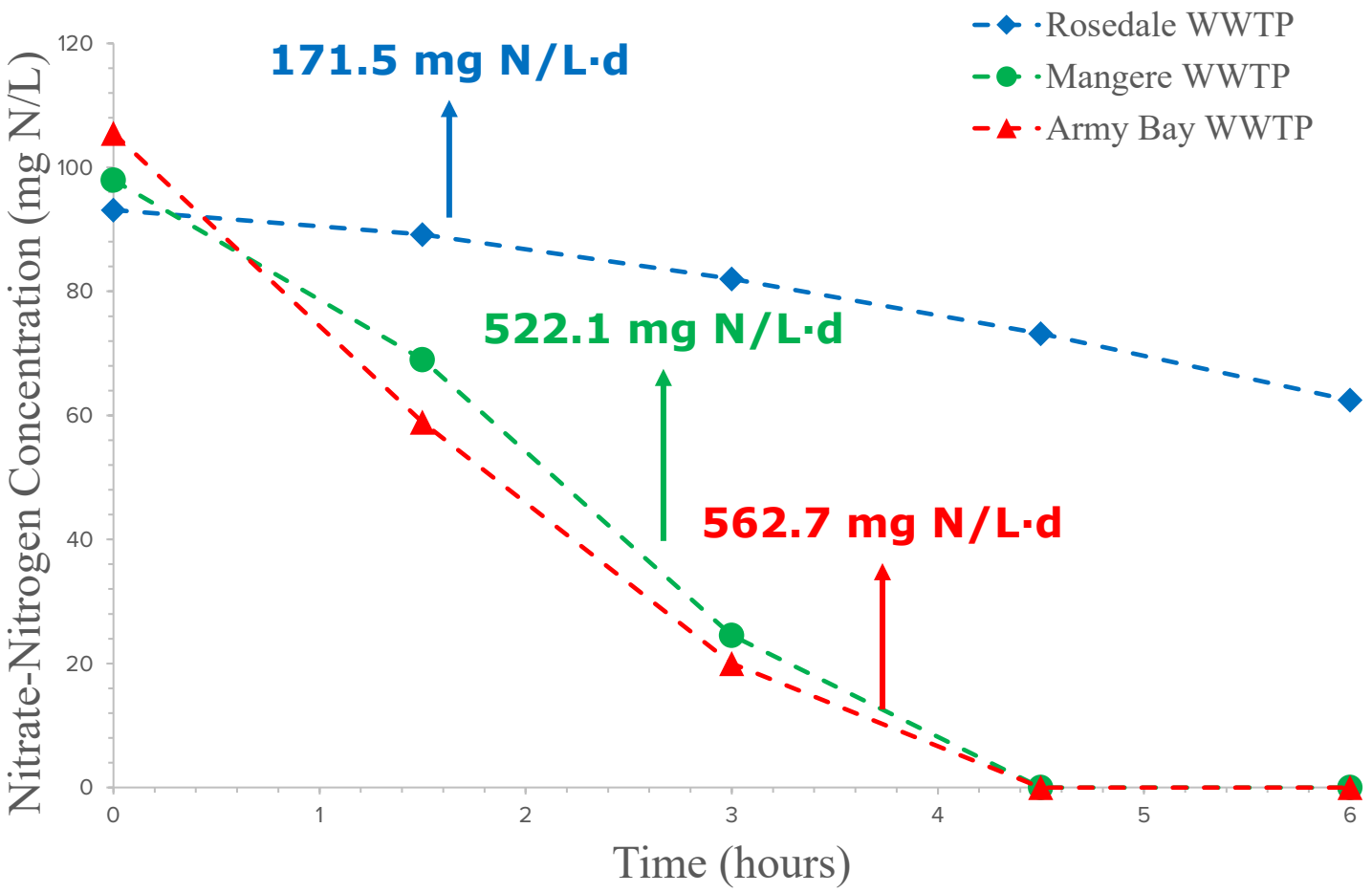
METHODOLOGY: Presence of h_2 oxidizing bacteria



Provide nitrate and hydrogen → selectively enrich bacteria that can use these compounds

Monitor nitrate reduction

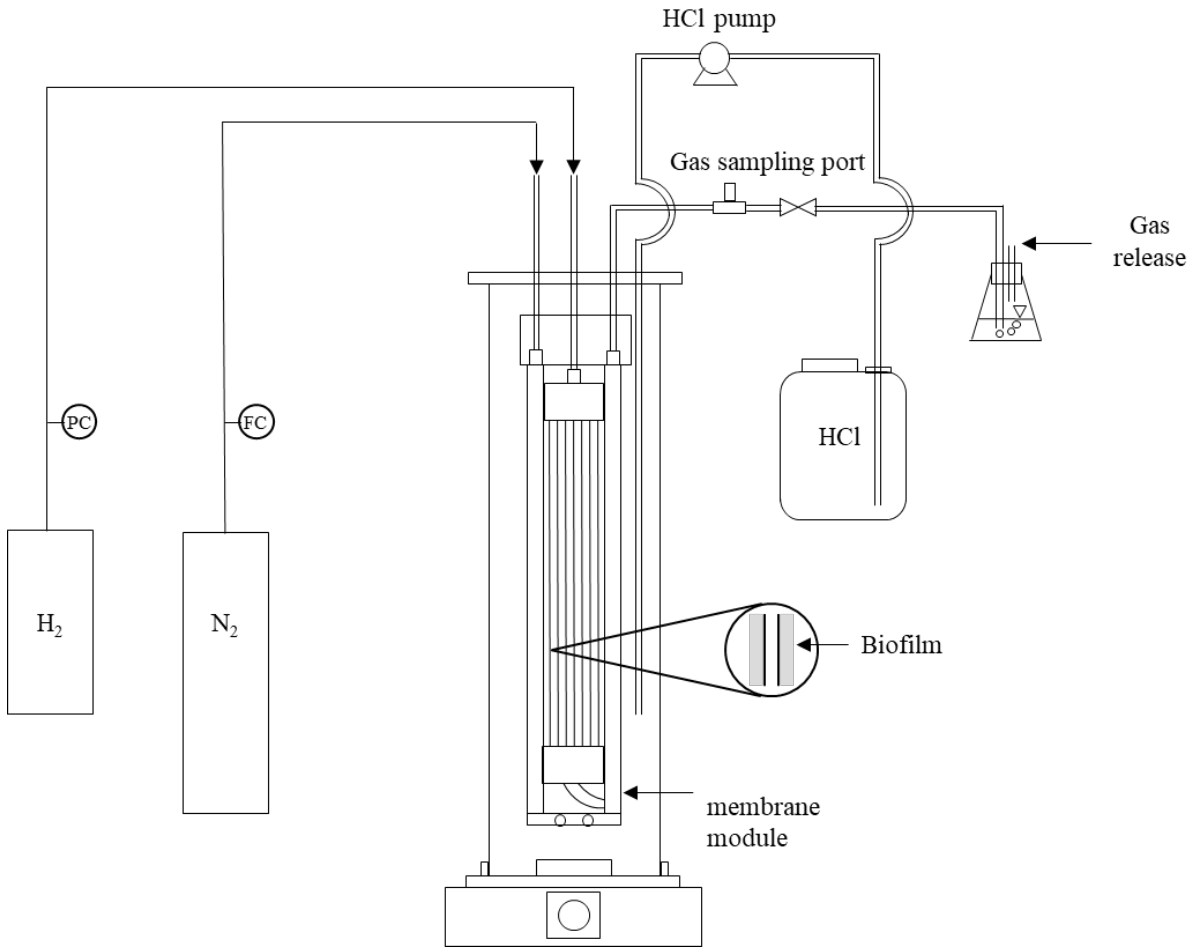
Results: Presence of h_2 oxidizing bacteria



- Hydrogenotrophic bacteria are **present at all three tested WWTPS**
- **Indigenous hydrogenotrophic** can be used to perform **efficient denitrification**

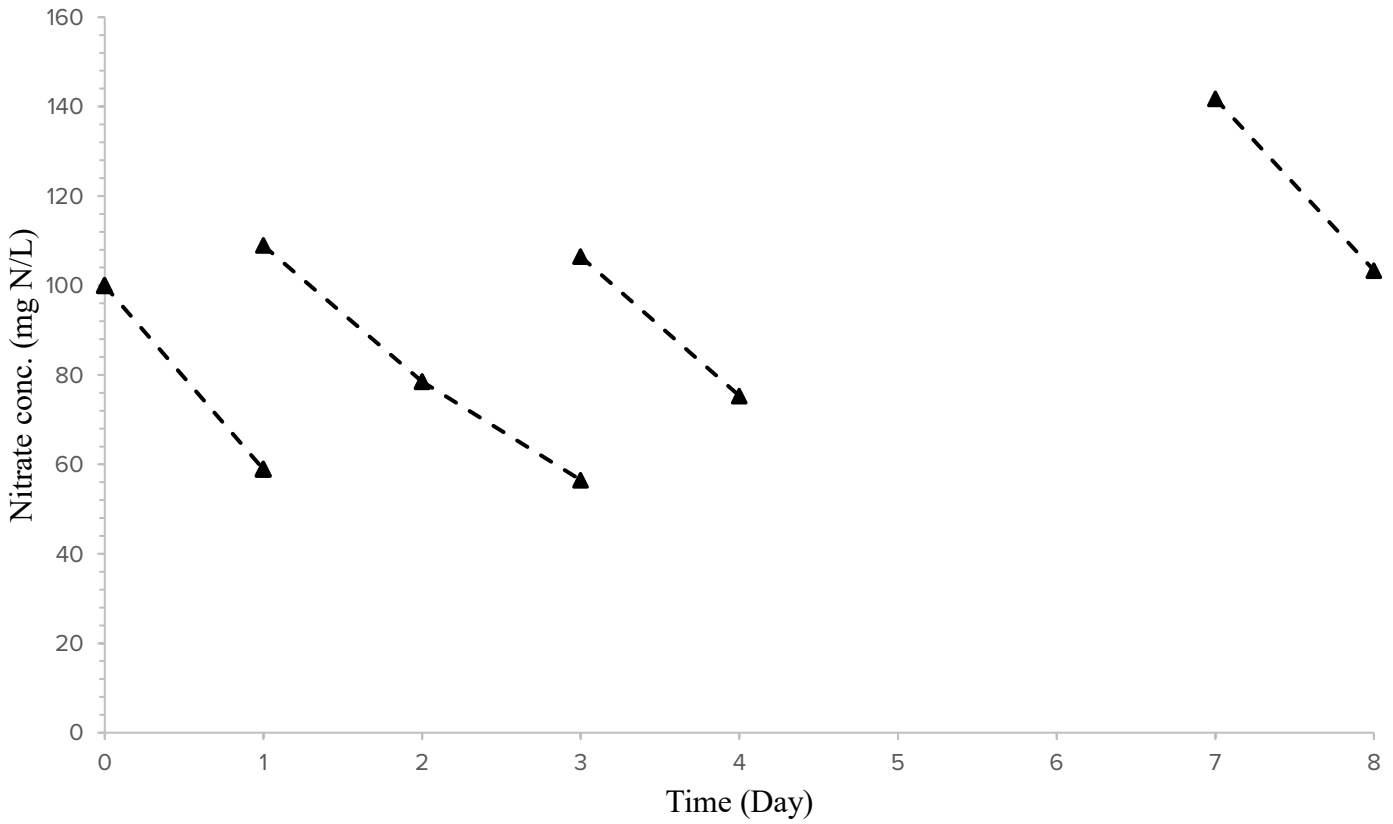
METHODOLOGY: Bioreactor start-up

BATCH PROCESS



- Enable growth and accumulation bacteria
- Hydrogen provided through direct diffusion into biofilm
- Nitrate concentrations maintained between 50 - 150 mg N/L

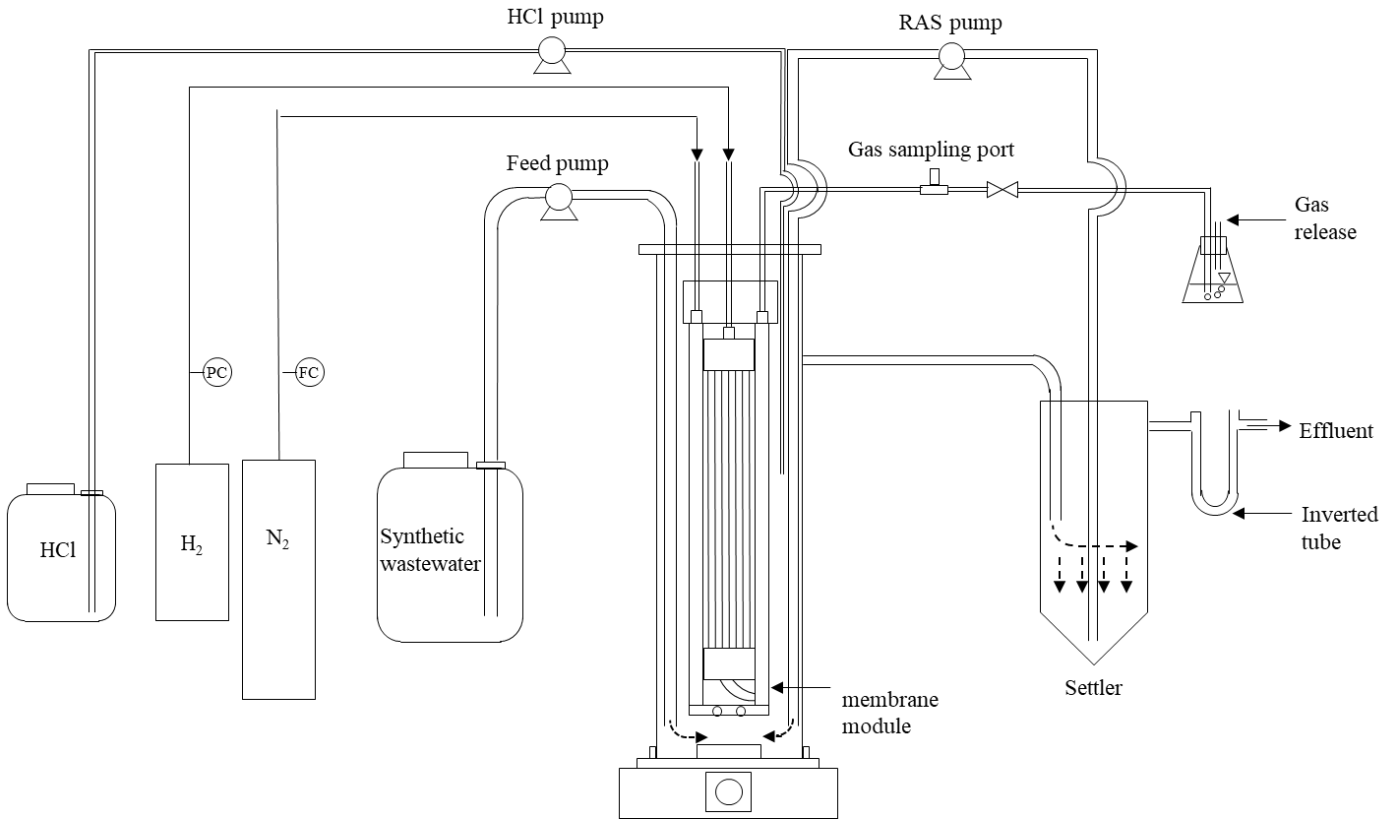
Results: Bioreactor start-up



- The reactor was **successfully started-up** could perform nitrate removal from day one
- The membrane could **effectively provide hydrogen** through bubbleless permeation into a biofilm

METHODOLOGY: Novel bioreactor schematic

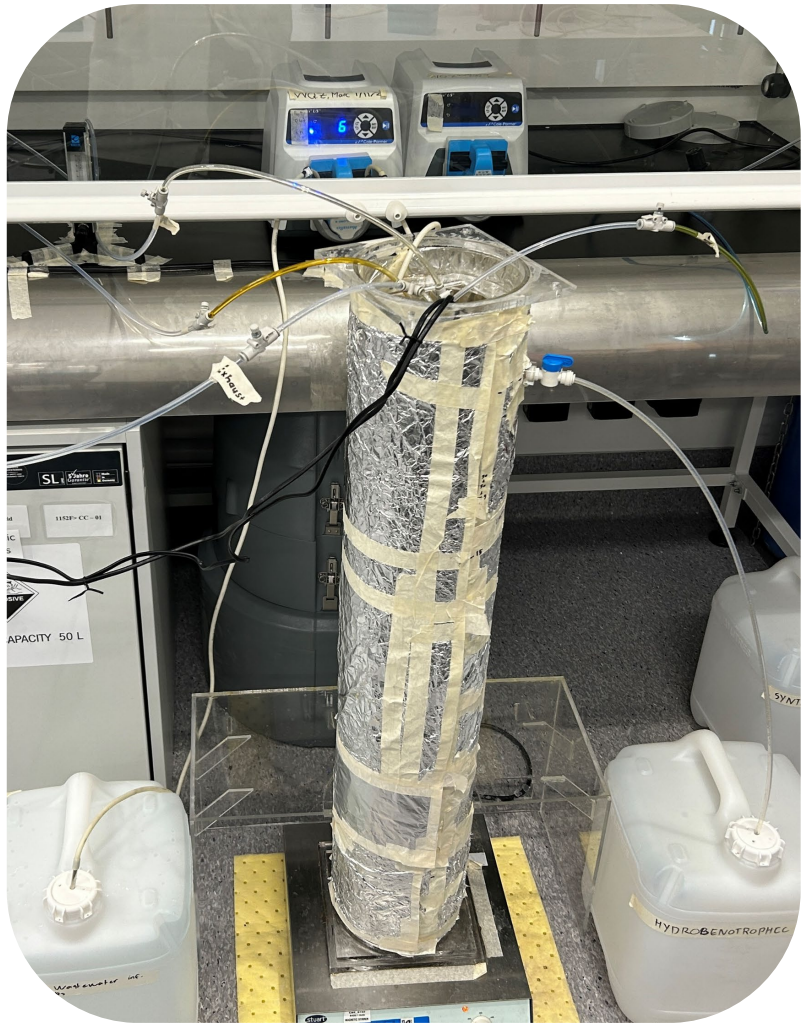
CONTINUOUS PROCESS



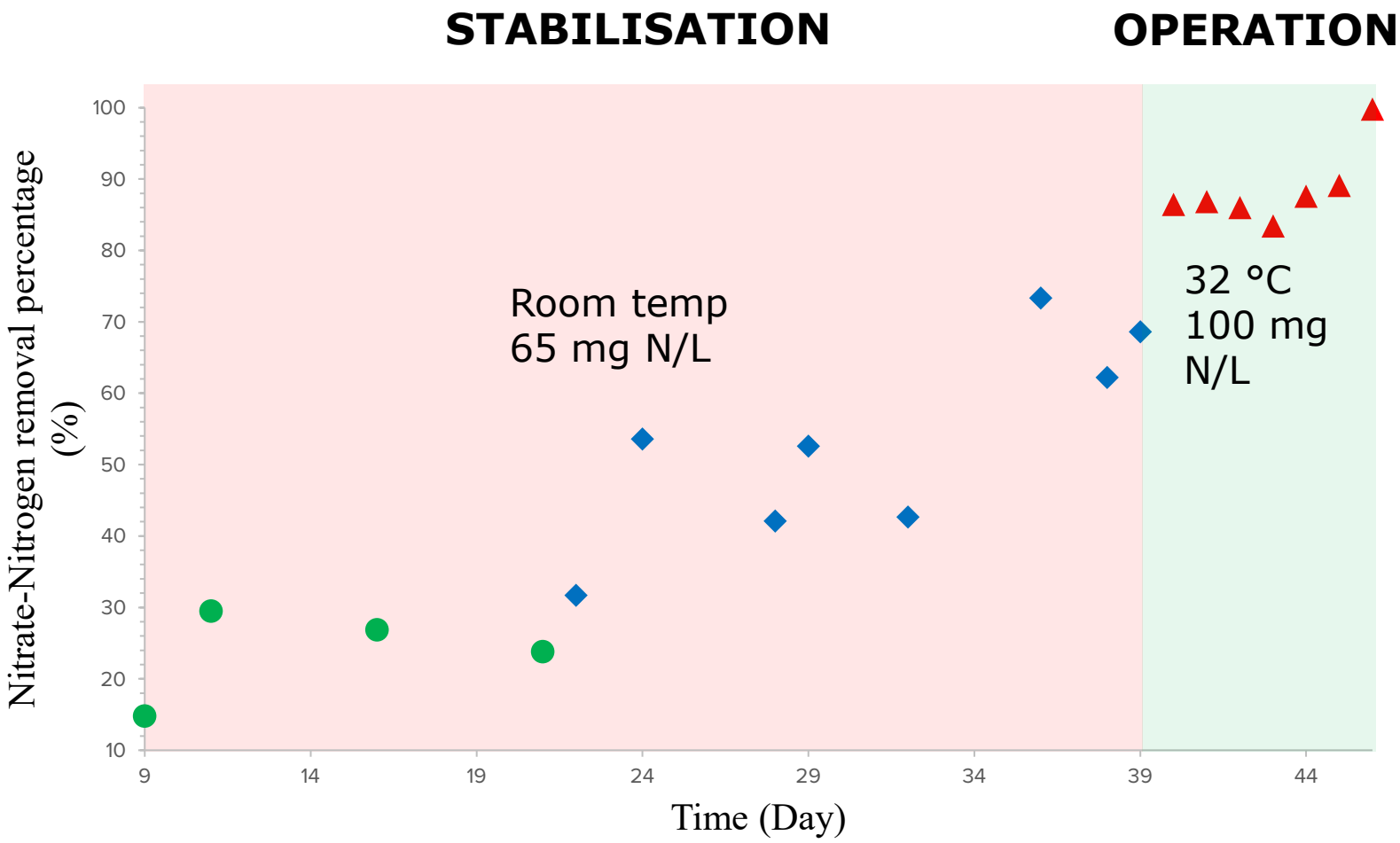
- Operated with a synthetic nitrate-amended wastewater
- Magnetic stirring and nitrogen sparging manage biofilm growth and accumulation
- HRT can be adjusted

METHODOLOGY: Novel bioreactor and biofilm

- 20-liter continuous reactor with two hollow fiber membrane modules
- Thick biofilm formation at the top of the membrane
- Biofilm was thicker closer to the top, and the hydrogen source



Results: Novel bioreactor stabilization and operation



- **Numerous changes** were made **during stabilization** (HRT, mixing, sparging)
- The **performance** of the seeded reactor **significantly improved** across a 30-day period
- The reactor stabilized above an **85% removal efficiency**

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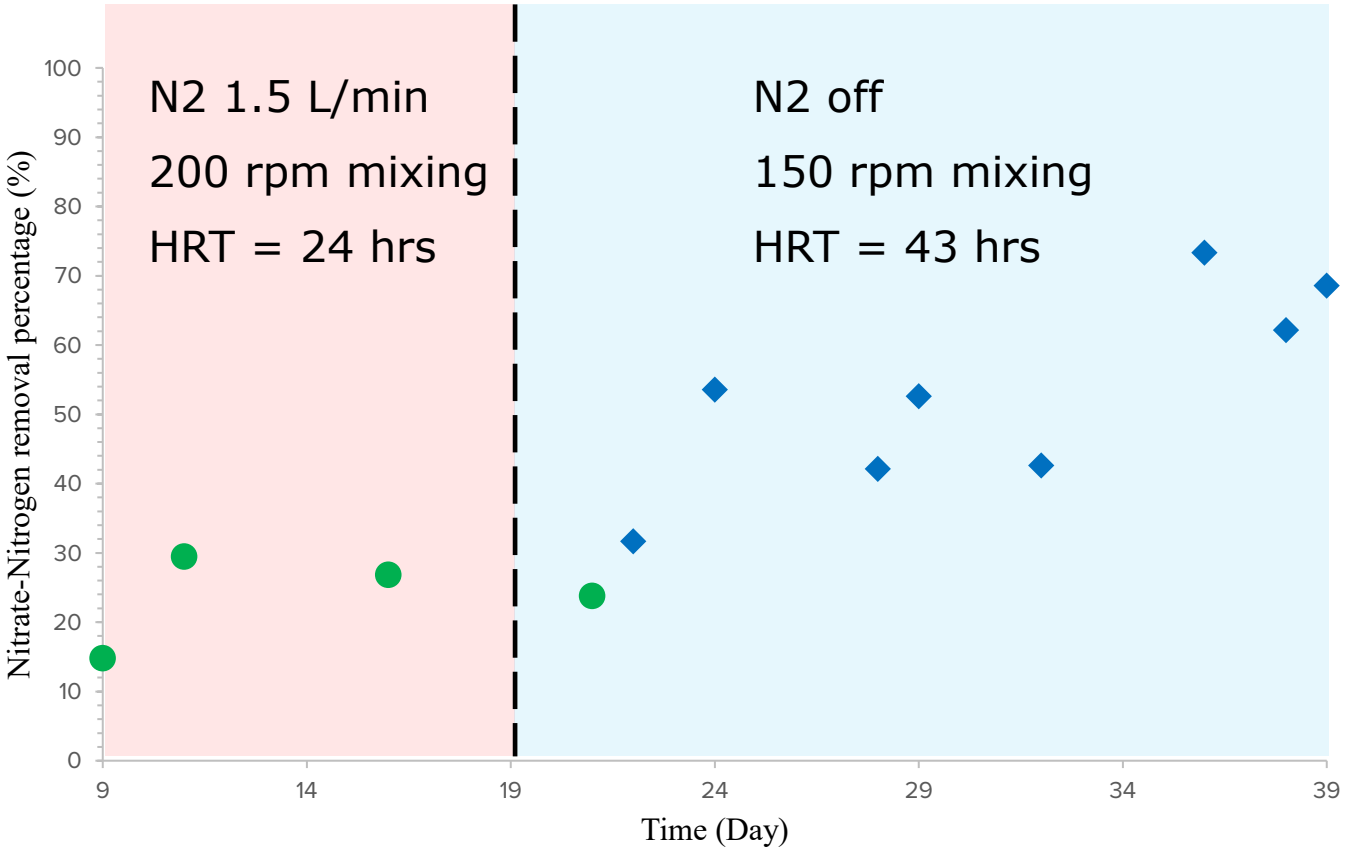
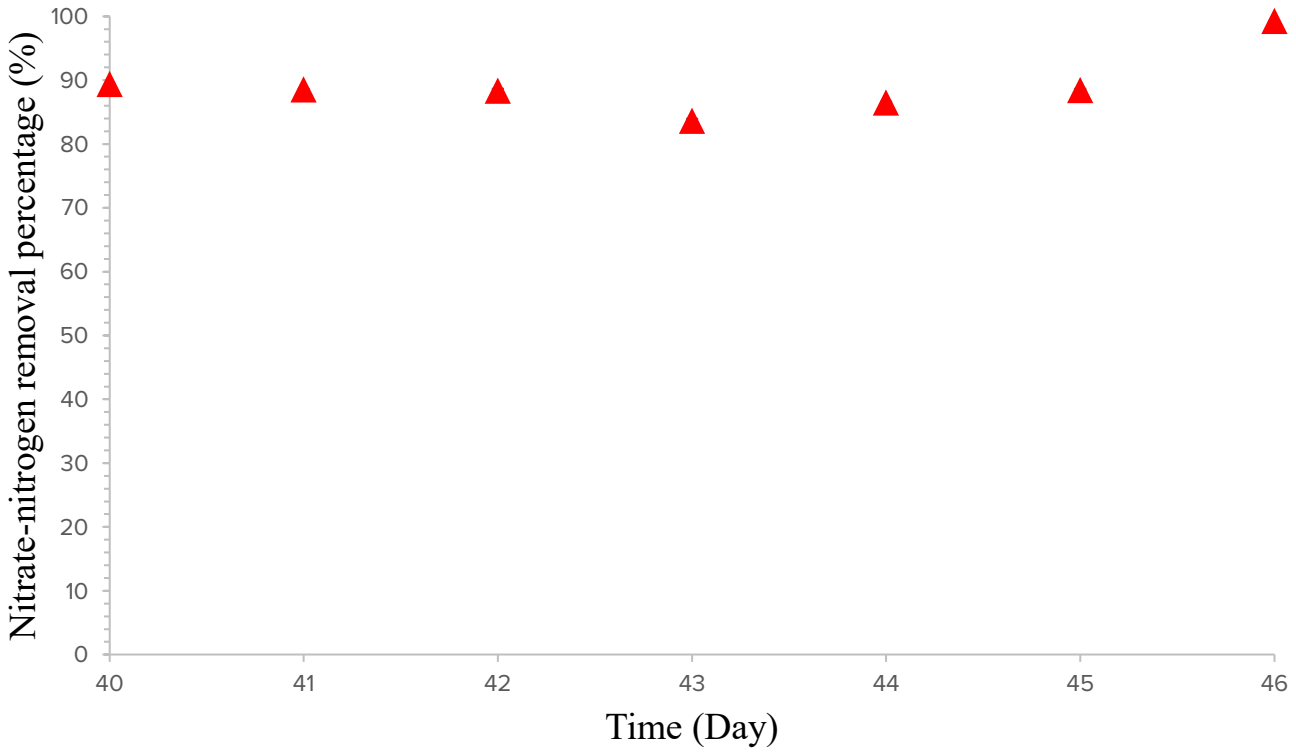
Results: Novel bioreactor stabilization



- During stabilization, biofilm growth and the accumulation of hydrogenotrophic biomass was still in a key phase
- Excess **bubbling** and **mixing limited biofilm growth** and **accumulation**

After the stabilization period, the removal rate was in excess of 70%

Results: Novel bioreactor operation



- Peak removal percentage was 99.3%
- Peak specific removal rate was **55.2 mg N/L·d**
- Relative to the volume and surface area, the removal rate was **367.7 mg N/m2·d**

The novel process could meet nitrate wastewater discharge regulations

CONCLUSION

Indigenous strains of hydrogenotrophic denitrifiers are present in New Zealand Wastewater treatment plants

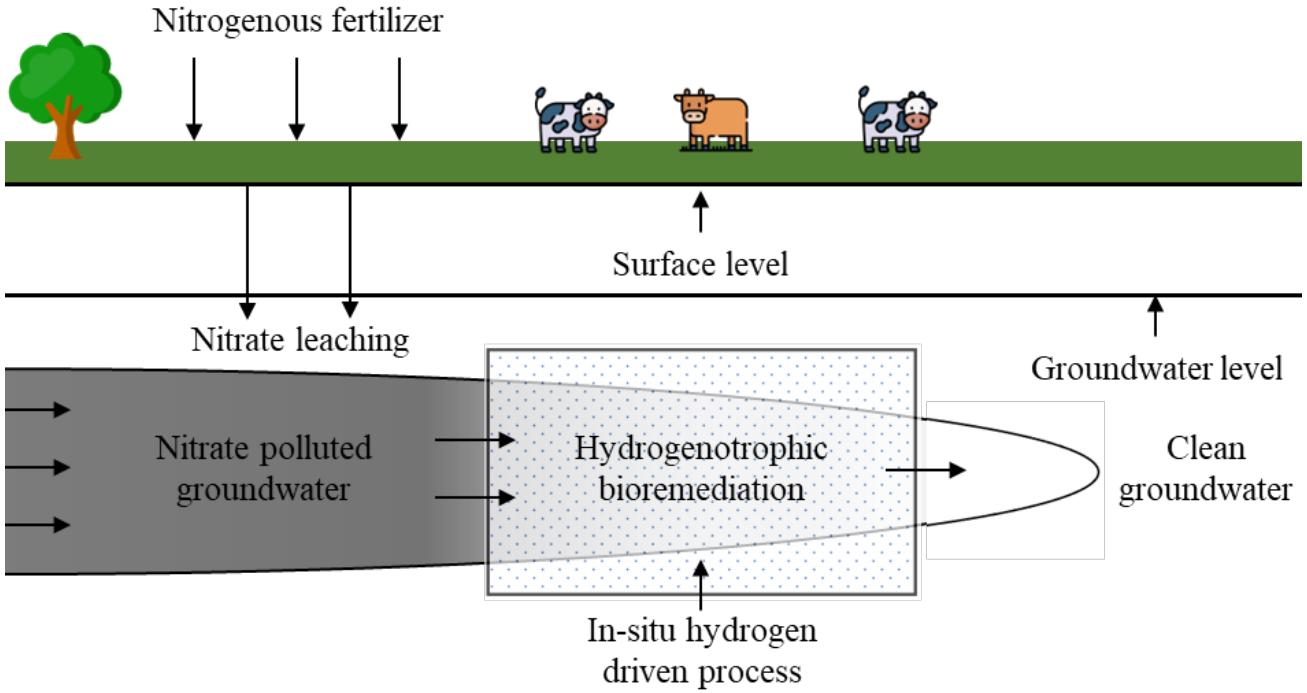
Hydrogenotrophic denitrifiers can be seeded in a novel bioreactor

Indigenous New Zealand hydrogenotrophic denitrifiers have the potential to meet wastewater discharge standards

FUTURE WORK

FUTURE DEVELOPMENTS

- reduce startup and stabilization time
- Optimise the denitrification process
- Use carbon dioxide to manage pH and as a carbon source



FUTURE APPLICATIONS

- carbon dioxide sequestration
- non-point source treatment system

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THANK YOU
ANY QUESTIONS?

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APPENDIX

HYDROGEN CONSUMPTION AND BIOMASS PRODUCTION

HYDROGENOTROPHIC DENITRIDICATION

$$NO_3^- + 3.03H_2 + H^+ + 0.229CO_2 \rightarrow 0.046C_5H_7O_2N + 0.477N_2 + 3.37H_2O$$

- 1 kg of nitrate removed
- 0.43 kg of hydrogen gas consumed
- 0.37 kg of biomass produced