Application of sequencing batch reactor in seawater aquaculture denitrification

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Introduction: background

Total ammonia nitrogen (TAN) → Nitrate (NO_3^-) → 5-10% water renewal / Denitrification √

Recirculating aquaculture system (RAS) → more sustainable

Two functions of denitrification in RAS

- lower the nitrate level allowing less water exchange
- reduce the environmental impacts of the effluent

Introduction: problem statement

The problems of seawater aquaculture denitrification:

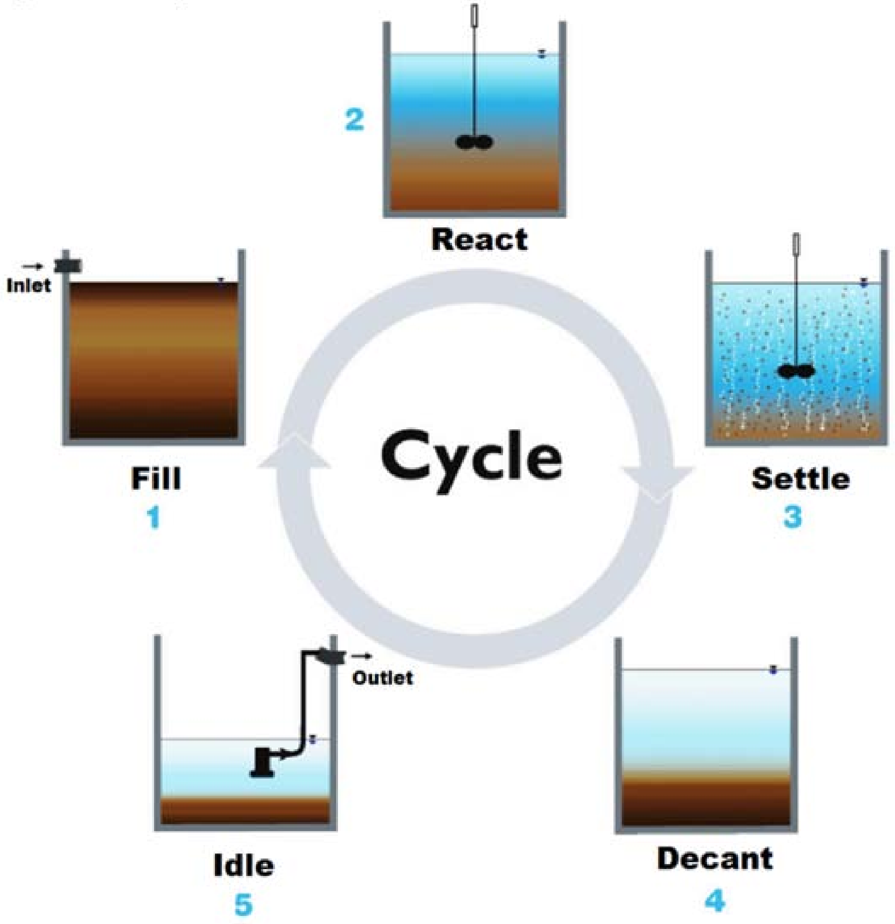
- Traditional media-based denitrification reactors
  - clogging
  - filter channeling
  - sulfide production
- The application of carbon sources
  - Poor denitrification performance of internal carbon
  - external carbon is costly

Candidate from activated sludge systems: **sequencing batch reactor (SBR)**

- Activated sludge normally can avoid the problems of media-based reactors.
- SBR has anaerobic reaction stage theoretically can facilitate the application of internal carbon.

Introduction: sequencing batch reactor (SBR)

Five simple stages



SBR has even more advantages:

(1) Less footprint and simple setup

(2) Reliable operation

(3) Multiple functions

(4) Better settling characteristics

(5) Stable condition and homogeneous distribution

Introduction: operational cycle time (OCT)

Operational cycle time (OCT) of pioneer study differed a lot from days to hours.

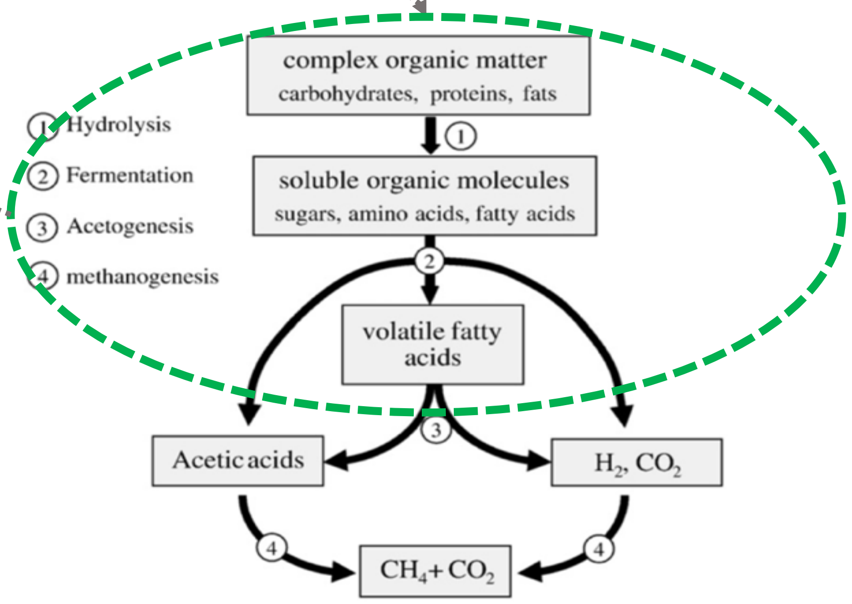
It connected to handling capacity and system dimension.

The sophisticated part of SBR was usually the setup of OCT.

Introduction: carbon sources

- external carbon: readily biodegradable
- internal carbon: Fish organic wastes (FOW)

Fermented fish organic wastes (FFOW)



- Anaerobic reaction stage theoretically can initiate fermentation.
- The comparison of different carbon sources is important for designing SBR.

Introduction: research objectives

Aiming to assess the potential of applying SBR in seawater aquaculture denitrification.

- Investigate the effects of operational cycle time and carbon sources on denitrification performance in seawater SBR.
    - Denitrification rate
    - Total ammonia nitrogen
    - Total sulfide
    - Carbon consumption

Materials and Methods

Setup and operation of SBR

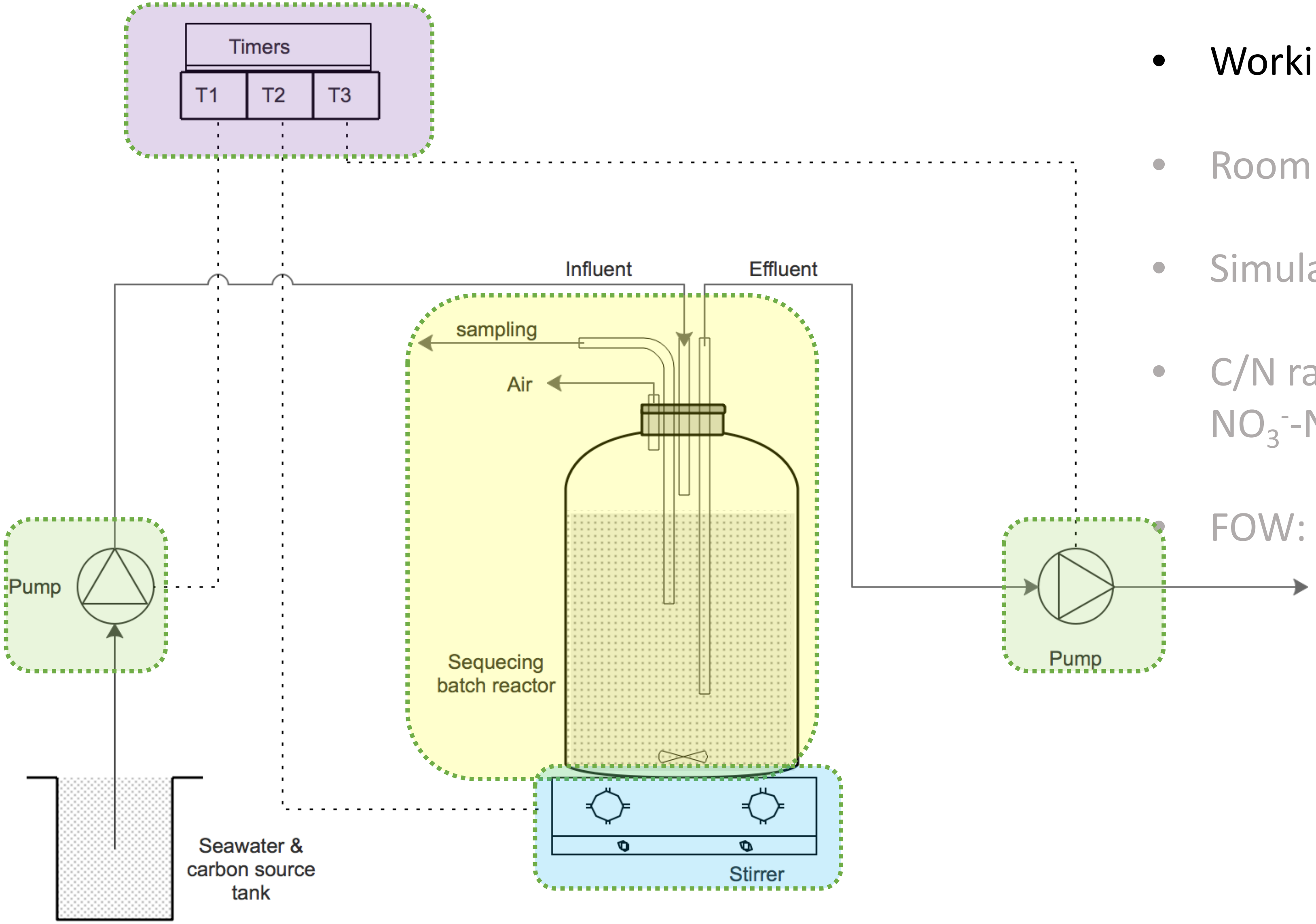
Tests of operational cycle time (OCT)

Tests of carbon sources

Sample analysis

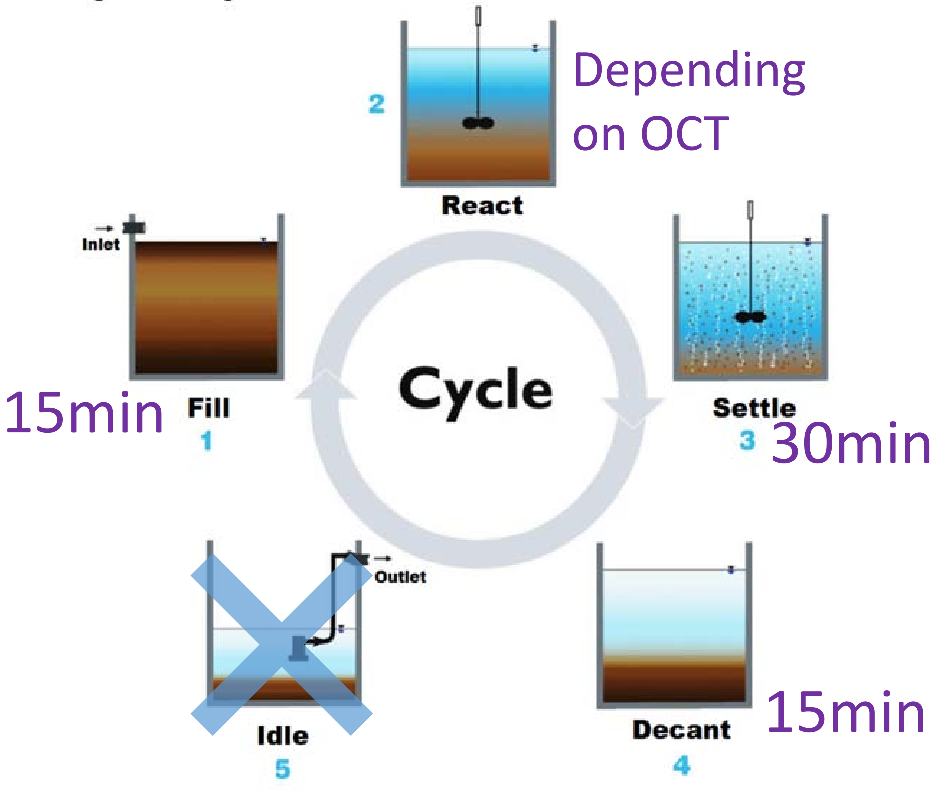
Data analysis

Materials and Methods: setup and operation of SBR



- Working/deposition volume= 8L/2L
- Room temperature: 15±2 °C
- Simulated seawater with 50 mg NO_3^--N/L
- C/N ratios ≈ 6 (300 mg COD/L for 50 mg NO_3^--N /L)
- FOW: rainbow trout RAS

Materials and Methods: tests of OCT



- SBR only has 4 steps
- OCT of 6h, 4h and 2h were tested.
- Acetate, FOW and FFOW: present three main categories of carbon sources in aquaculture denitrification
- 2 weeks to grow activated sludge and 1 week to acclimate.

Materials and Methods: tests of carbon sources

- After OCT tests, a suitable cycle was chosen for the further trials.
- Two more external carbon sources (propionate and ethanol) were introduced.

Materials and Methods: sample analysis

NO_3^-

NO_2^--

Total ammonia nitrogen (TAN)

Total sulfide production

Volatile fatty acid (VFA)/ethanol

Biomass of activated sludge (COD sample)

Dissolved oxygen (DO)

pH

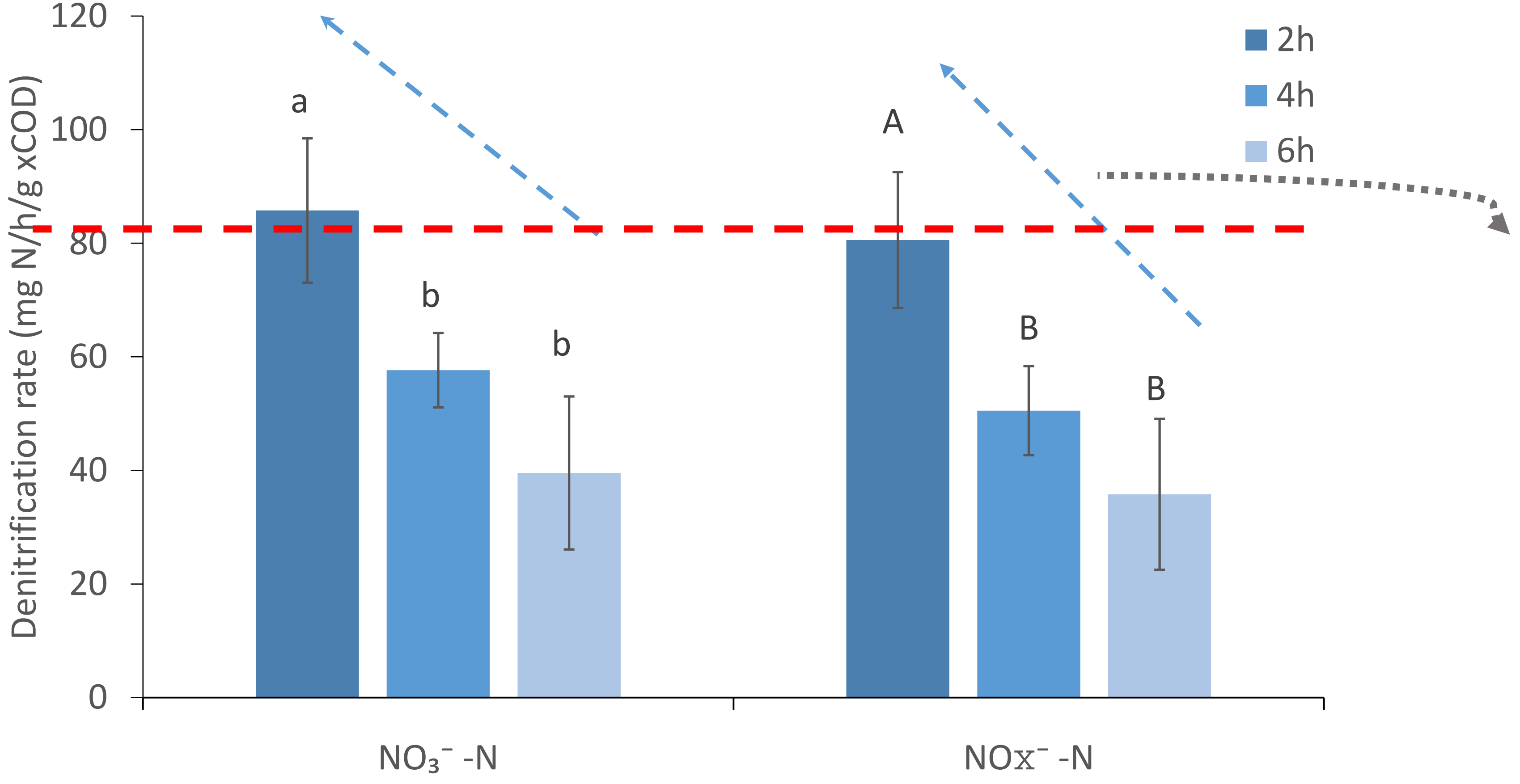
Materials and Methods: data analysis

- Denitrification: NO_3^- and NO_x^- (NO_3^- + NO_2^-) reduction
- Activated sludge biomass: xCOD = TCOD – sCOD
- Denitrification rates: NO_3^- and NO_x^- reduction rate (the linear part of the curve versus time), standardized by the biomass of activated sludge (xCOD).

Result and Discussion

- The effect of OCT on denitrification
- The effect of carbon sources on denitrification
- Total ammonia nitrogen (TAN) in SBR
- Total sulfide production in SBR
- Foam formation
- Decision of OCT setup
- Assessment of carbon sources
- A case study

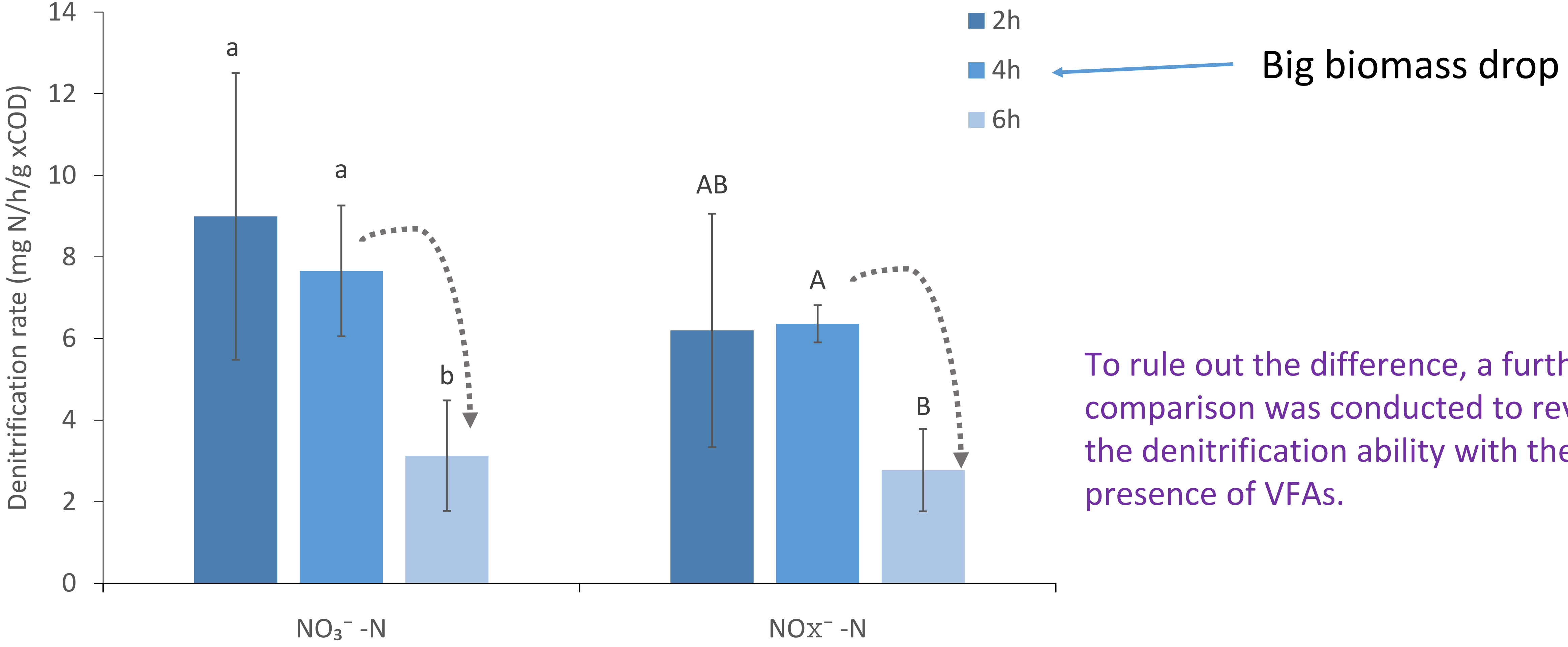
Result and Discussion: the effect of OCT on denitrification with **acetate**



The effects of cycle operational time on denitrification rate with acetate. n=4

- Starvation theory
- Selection pressure

Result and Discussion: the effect of OCT on denitrification with **FOW**



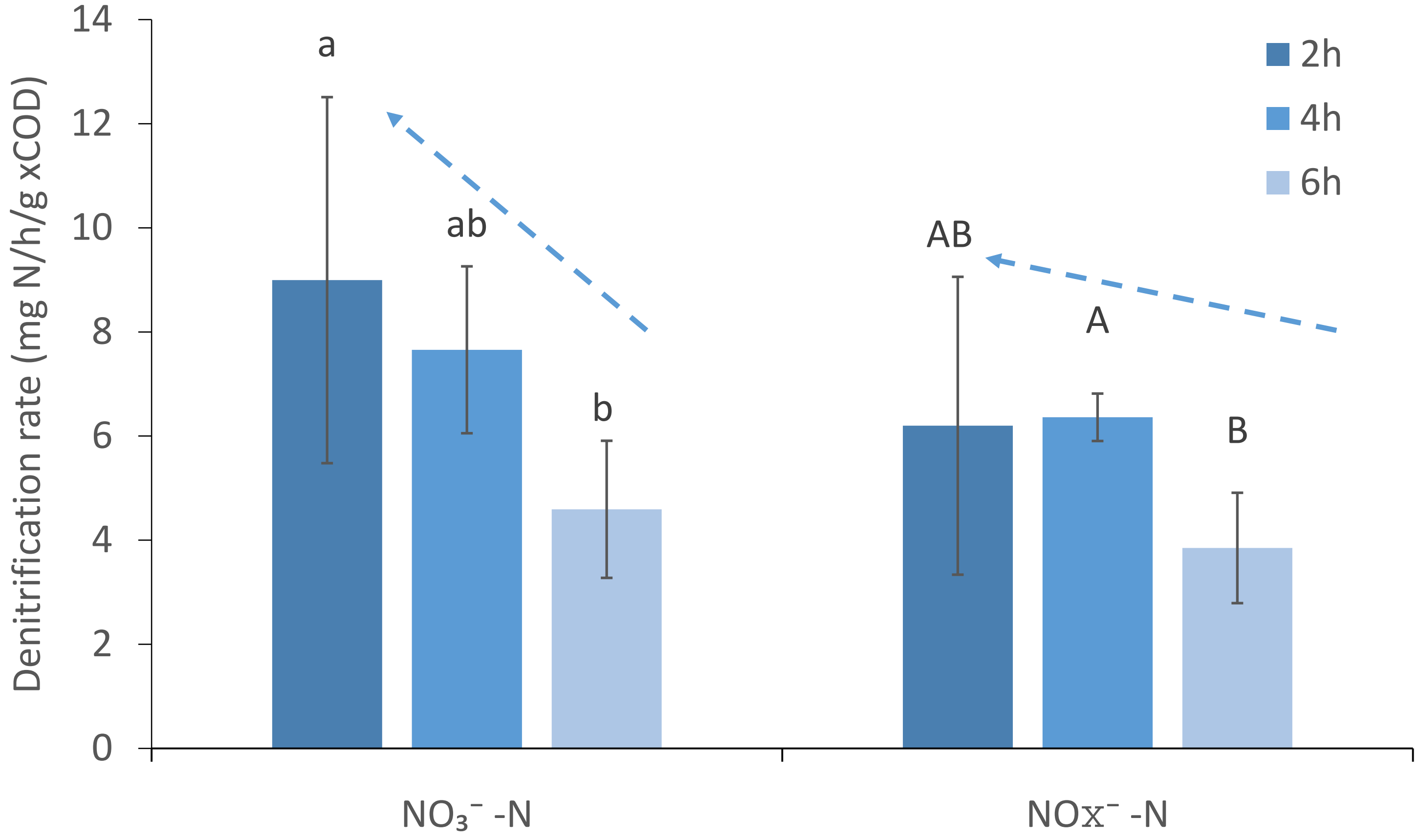
The effects of cycle operational time on denitrification rate with FOW from RAS. n=4

To rule out the difference, a further comparison was conducted to reveal the denitrification ability with the presence of VFAs.

Result and Discussion: the effect of OCT on denitrification with **FOW**

C/N ratio in FOW group with the presence of VFAs. n=4

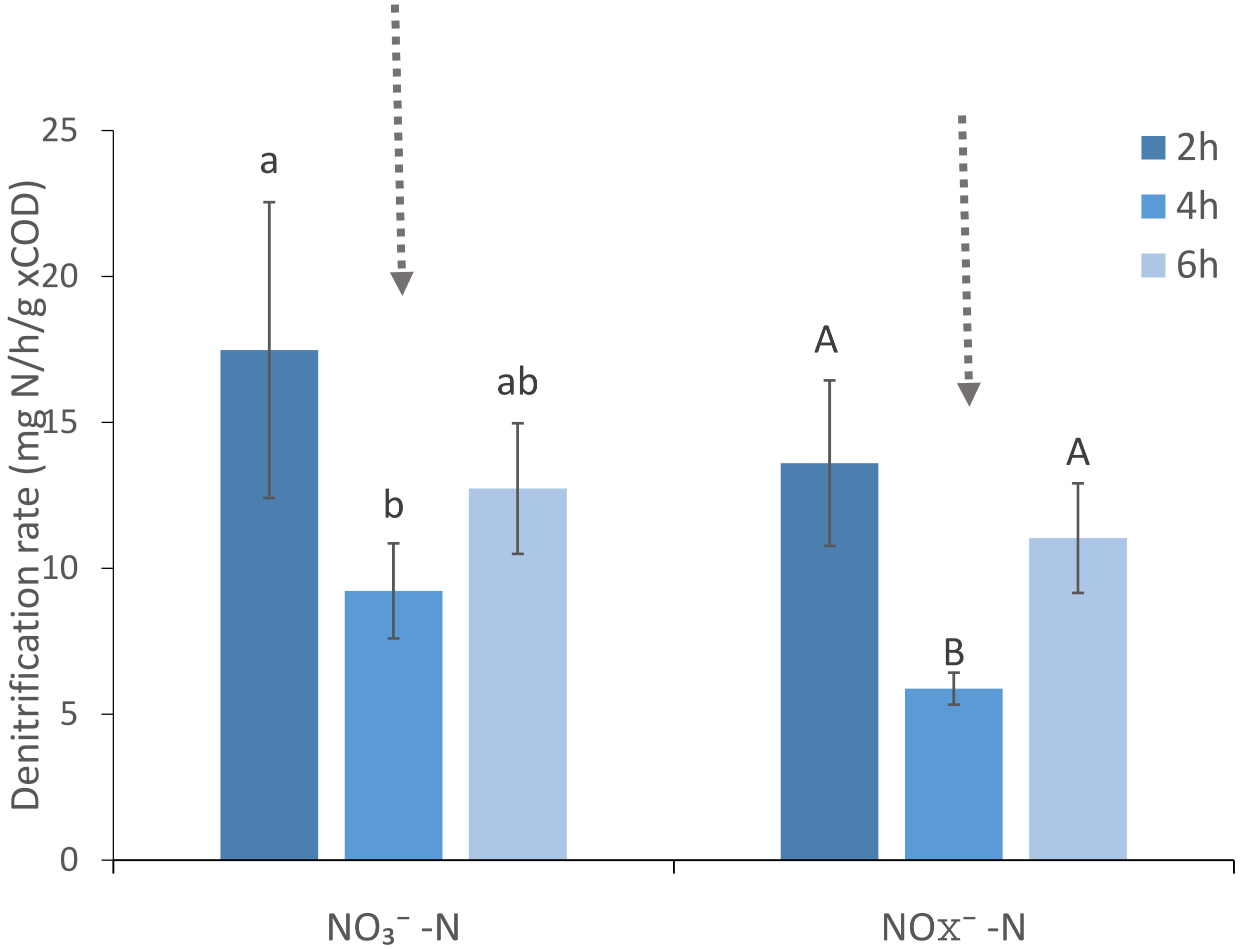
Cycle time	2h	4h	6h
C/N	1.25±0.68	0.83±0.53	1.73±1.26



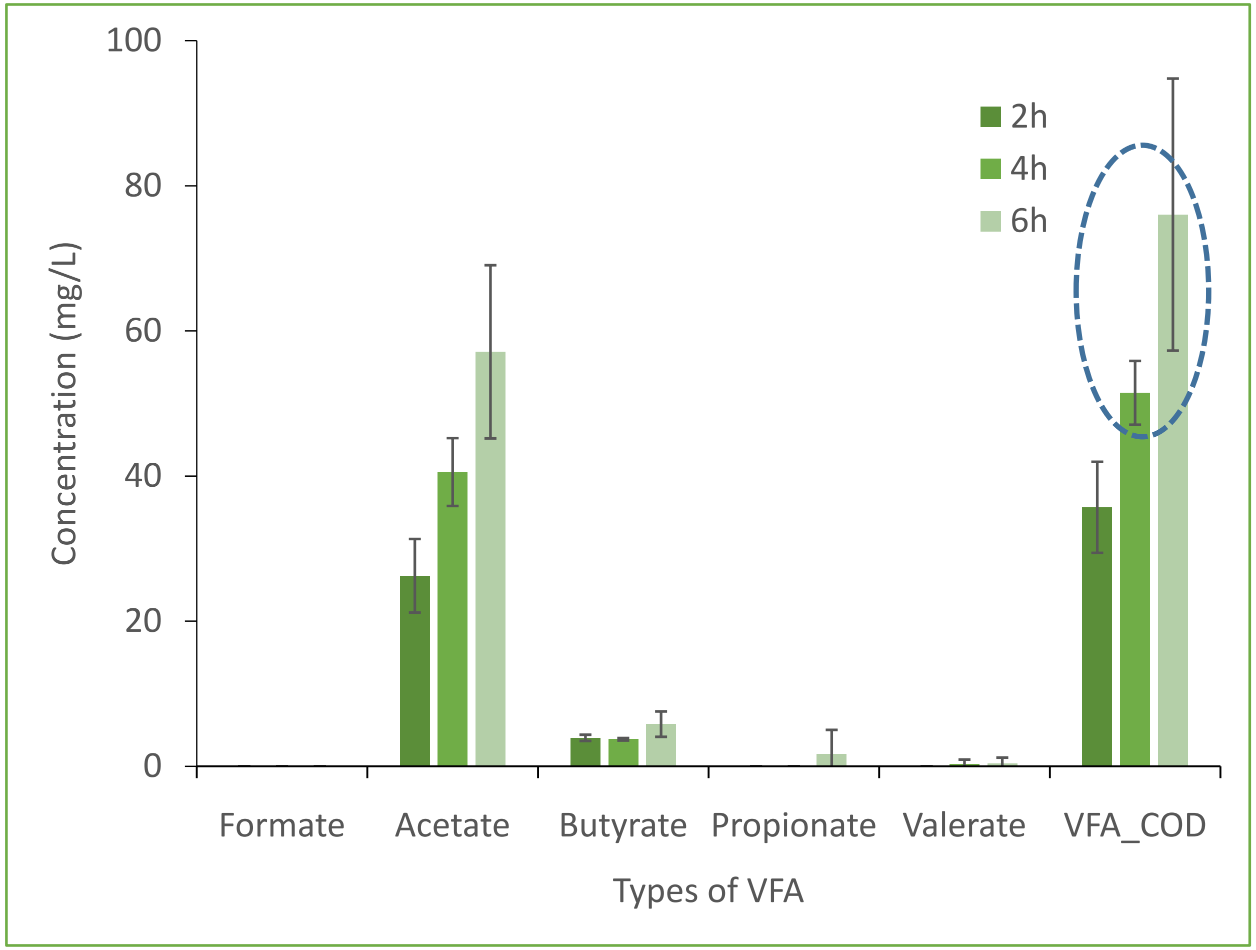
The effects of cycle operational time on denitrification rate with the presence of VFAs from FOW. n=4

- Self-fermentation was already initiated with the presence of VFAs.
- Population dynamics of denitrification bacteria groups altered.

Result and Discussion: the effect of OCT on denitrification with **FFOW**



The effects of cycle operational time on denitrification rate with FFOW. n=4



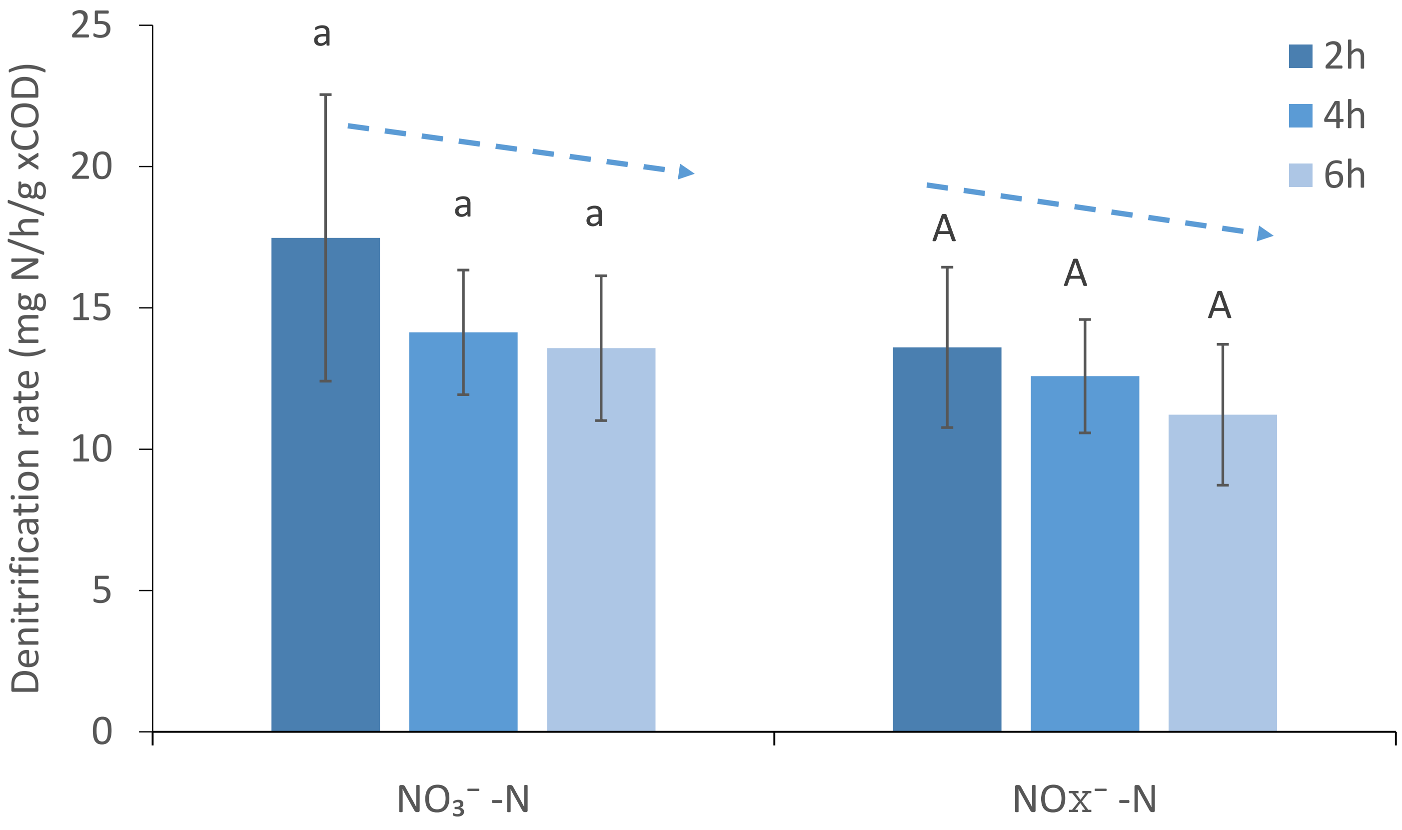
The initial VFA contents in mixed solutions of FFOW group.

Result and Discussion: the effect of OCT on denitrification with **FFOW**

C/N ratio in FFOW group with the presence of VFAs. n=4

Cycle time	2h	4h	6h
C/N	3.17±0.28	3.33±0.19	3.00±0.57

Existence of fermentation-denitrification



The effects of operational cycle time on denitrification rates with FFOW in VFA-present stage. n=4

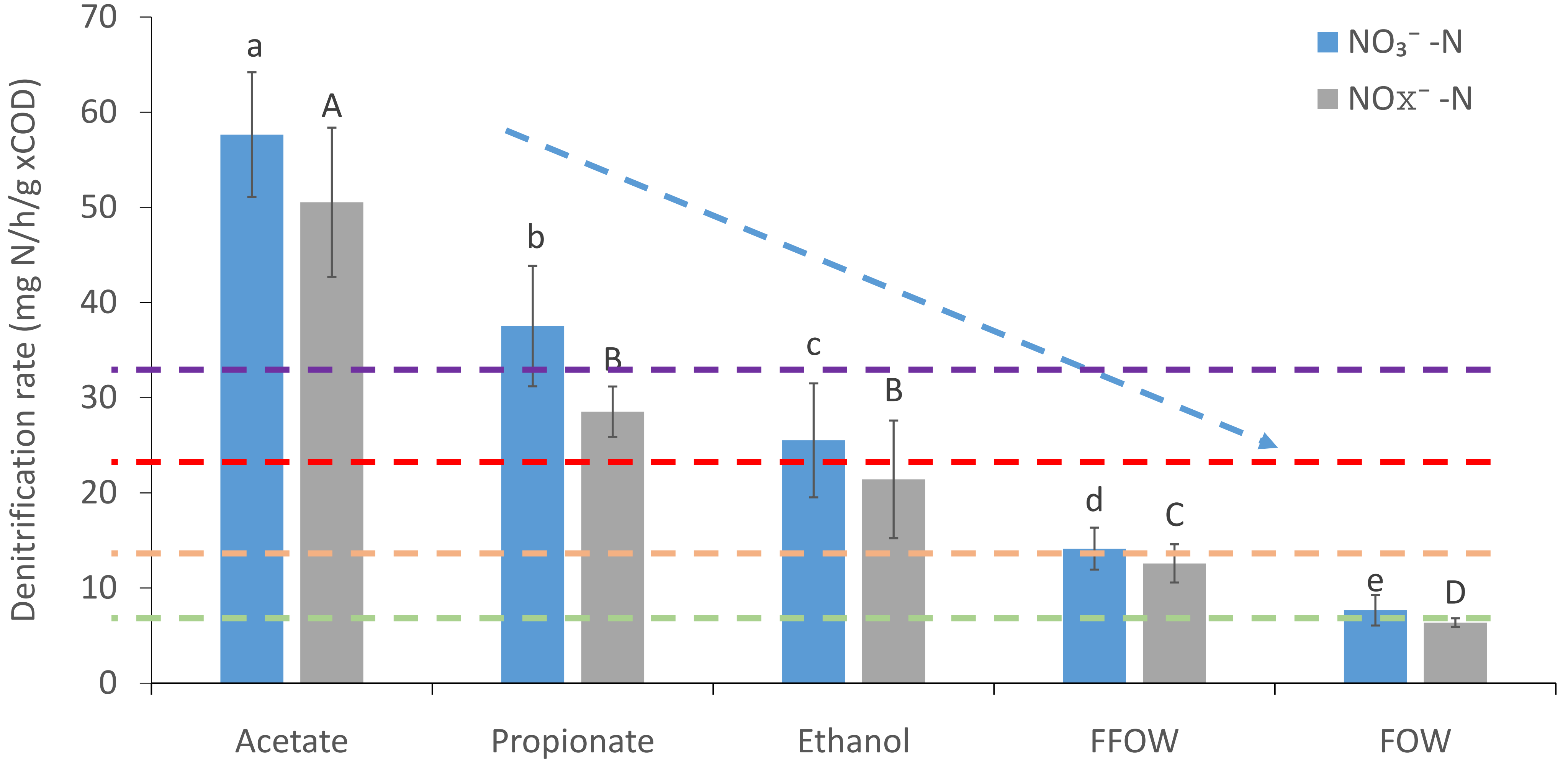
OCT had no significant impact.

Result and Discussion: the effect of carbon source on denitrification

4h operational cycle was adopted:

- Sampling with 30min time step was enough to describe NO_3^- and NO_x^- reductions.
- The denitrification rate with ethanol or propionate was usually half with acetate. Thus, 2h cycle was too risky to complete nitrate removal.

Result and Discussion: the effect of carbon source on denitrification



Denitrification rates with different biodegradable organics (acetate, FOW, FFOW, ethanol and propionate) in 4h cycle when readily biodegradable organics presented. n=4.

Result and Discussion: the effect of carbon source on denitrification

SBR had OK performance.

Carbon source	Denitrification rate	Unit	Salinity	S	
Acetate	25.1	mg N/h/g VSS	freshwater	b	[illegible]
	76.2	mg N/h/g biomass	freshwater	F	[illegible] 1995
	50	mg N/h/g MLSS	36 ppt	S[illegible]	[illegible]stein,1999
	57.6	mg N/h/g xCOD	36 ppt	SBR	4h OCT, this study
	85.8	mg N/h/g xCOD	36 ppt	SBR	2h OCT, this study
Propionate	15.08	mg N/h/g VSS	freshwater	batch	Yatong, 1996
	92.4	mg N/h/g biomass	freshwater	FBR	Aboutboul et al., 1995
	37.5	mg N/h/g xCOD	36 ppt	SBR	4h OCT, this study
Ethanol[1]	14.5	mg N/h/g VSS	freshwater	batch	Yatong, 1996
Ethanol[2]	17.3	mg N/h/g VSS	freshwater	batch	Yatong, 1996
	25.5	mg N/h/g xCOD	36 ppt	SBR	4h OCT, this study
Fermented liquid	2	mg N/h/g MLVSS	freshwater	batch	Min et al., 2002
	7.94	mg N/h/g MLVSS	freshwater	SBR	Sun et al., 2016
FFOW	14.1	mg N/h/g xCOD[3]	36 ppt	SBR	4h OCT, this study
	9.2	mg N/h/g xCOD[4]	36 ppt	SBR	4h OCT, this study

1. Activated sludge acclimated to mixed VFAs; 2. Activated sludge acclimated to ethanol; 3: Reaction in VFA-present stage; 4: Reaction in the whole denitrification process; 5: Fluidized bed reactor (FBR:); 6: anoxic/oxic-membrane bioreactor (A/O-MBR).

Result and Discussion: the effect of carbon source on denitrification

Comparison of external carbon utilization (acetate, ethanol and propionate) with stoichiometric study.

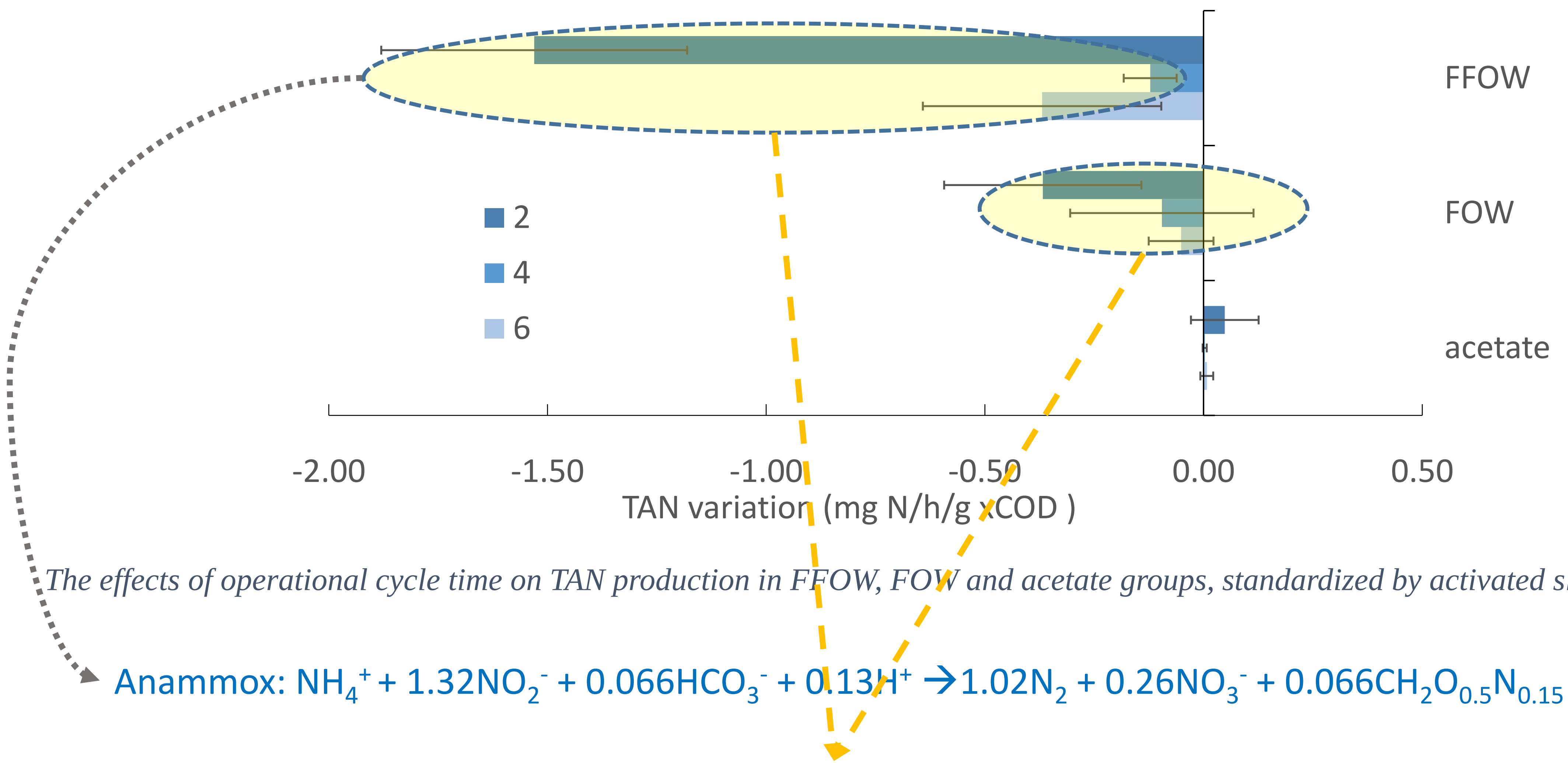
Carbon source	Prop. for denitrifying (%)		C/N ratio (COD/NO_3^{-}-N)	
	This study	Stoichiometric*	This study	Stoichiometric *
Acetate	77.24±3.73	76.31[1]	3.85±0.15	3.74[1]
Ethanol	78.18±3.85	67.97[1]	3.66±0.17	4.20[1]
Propionate	79.41±5.34	58.93[2]	3.61±0.24	4.85[2]

* Stoichiometric results excluded the impact of initial dissolved oxygen; 1. Calculated from Burghate & Ingole (2014); 2. Calculated from Elefsiniotis & Wareham (2007).

Usually 20-30% of COD for cellular growth → C/N ratio: 3.56-4.07

New stoichiometric equations for ethanol and propionate were developed.

Result and Discussion: total ammonia nitrogen (TAN) in SBR



The effects of operational cycle time on TAN production in FFOW, FOW and acetate groups, standardized by activated sludge biomass. n=4

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

Introducing TAN in the effluent

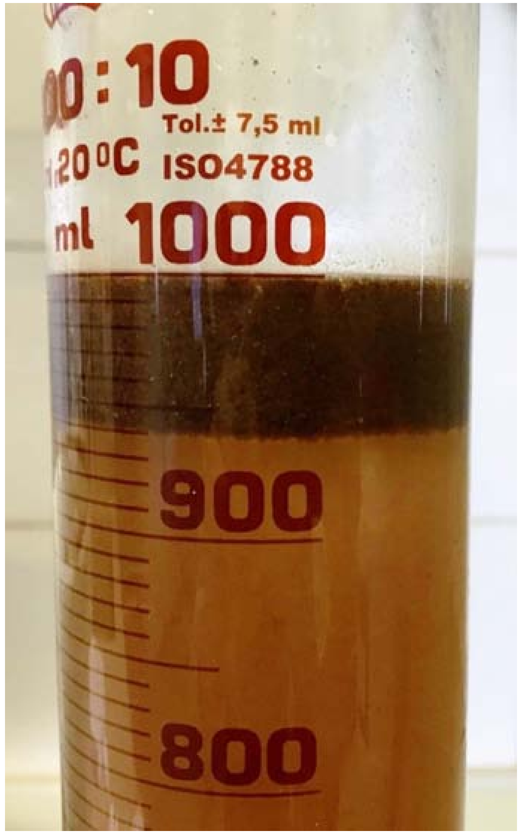
Result and Discussion: total sulfide production in SBR

Only 2 cases in FFOW group reached around 2 mg S/L after the 6h operation

The effluent of the rest groups remained below 0.4 mg S/L at the end of the operation.

Result and Discussion: foam formation

Activated sludge with FFOW and propionate after 30min settling in 4h cycle operation: the left was the activated sludge sample from FFOW group, while the right from propionate group.

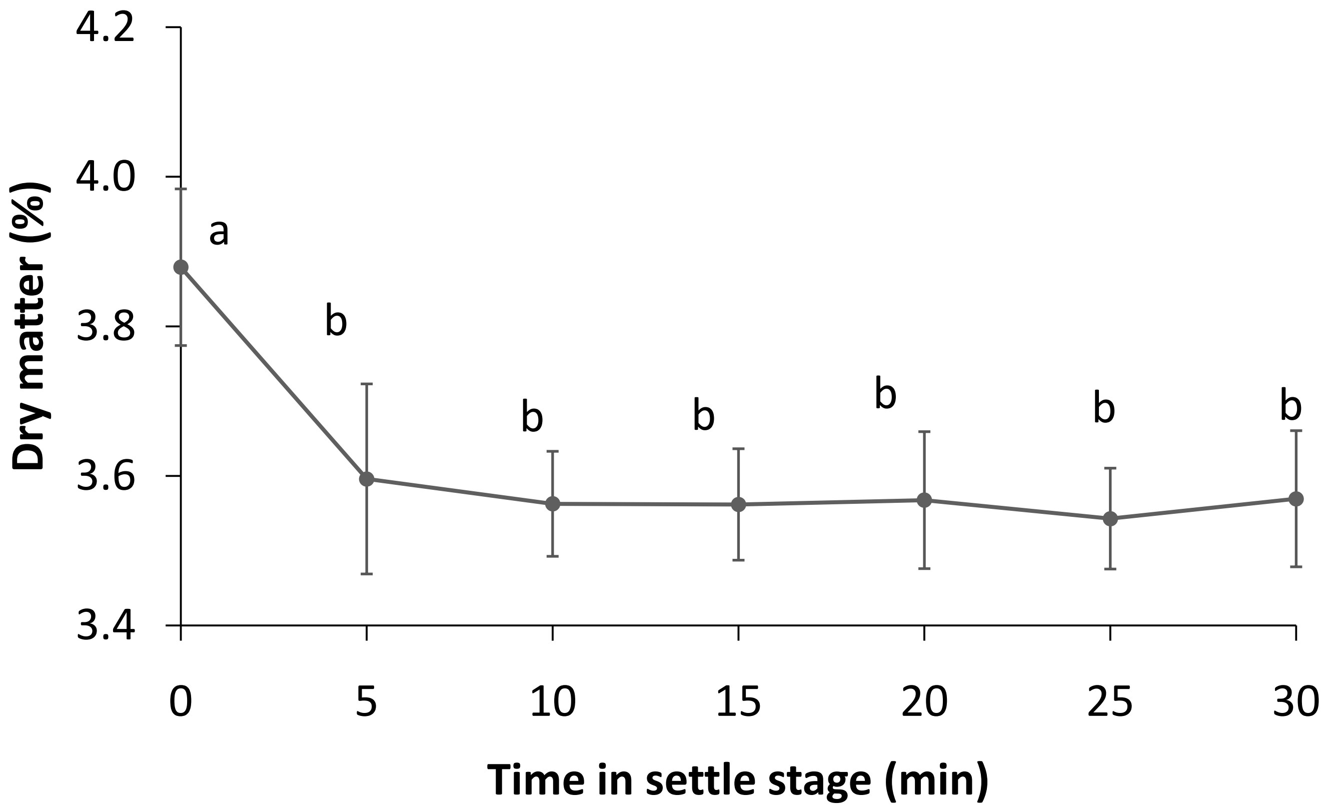


Thick brownish flocs

Result and Discussion: decision of OCT setup

How about the other stages of SBR?

- Acetate: recommended to shorten
- FOW: not recommended to shorten
- FFOW: recommended to shorten



The change of total suspended solid content in settle stage (activated sludge fed on propionate). n=3

Result and Discussion: assessment of carbon sources

Estimated cost of substrates for nitrate removal.

Carbon sources (sodium salt)	Substrate cost* (DKK/kg substrate)	C/N ratio	Cost of denitrification (DKK/kg N)
Acetate	3.2	3.85	15.77
Propionate	9.6	3.66	30.22
Ethanol	8.1	3.61	14.04

* The information of substrate cost was collected on *http://www.alibaba.com* (Alibaba Group, China).

Result and Discussion: a case study

The dimension of different denitrification systems in the case study: a RAS farm had annual production of 1000 ton, with daily NO_3^--N *production of 119 kg.*

Reactor	Salinity	Carbon source	Denitrification rate	Total working volume (m^3)	
SBR	Seawater	Acetate	80 mg N/h/g xCOD	198	a
Biofilter	Freshwater	Methanol/acetic	0.67–0.68 kg N/d/m^3 media	178	b
MBBR	Seawater	Methanol	2.7 kg N/d/m^3 biomedia	147	c
MBBR	Seawater	Methanol	1.77 kg N/d/m^3 biomedia	269	d
Fixed bed	Seawater	Ethanol	2.4 kg N/d/m^3 packing	49.6	e

Reference
a: This study
b: Hamlin et al., 2008
c: Dupla et al., 2006
d: Labelle et al., 2005
e: Sauthier et al., 1998

SBR is competitive.

Conclusion

- Operational cycle time (OCT) had different impacts on the denitrification rates with acetate, FOW and FFOW.
- In the VFA-present stage, FOW group had different strategies to obtain VFAs from FFOW group.
- Denitrification rates ranked descendingly as acetate, propionate, ethanol, FFOW and FOW.
- TAN level varied in different patterns regarding to carbon types.
- SBR had control of total sulfide production with external carbon.
- Foam formation caused the variance of activated sludge biomass.

Conclusion

- Comparing to media-based reactors, SBR is still competitive in daily handling capacity, system dimension and system maintenance through a case study.
- Therefore, further tests on a larger or commercial scale SBR treating marine aquaculture wastewater are recommended.

Acknowledge

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