Engineering packed bed biofilm reactors for intensive recirculating aquaculture systems

Theme: Innovating Water Technologies for Efficient Water Conservation

Presented by

Saquib Sarosh

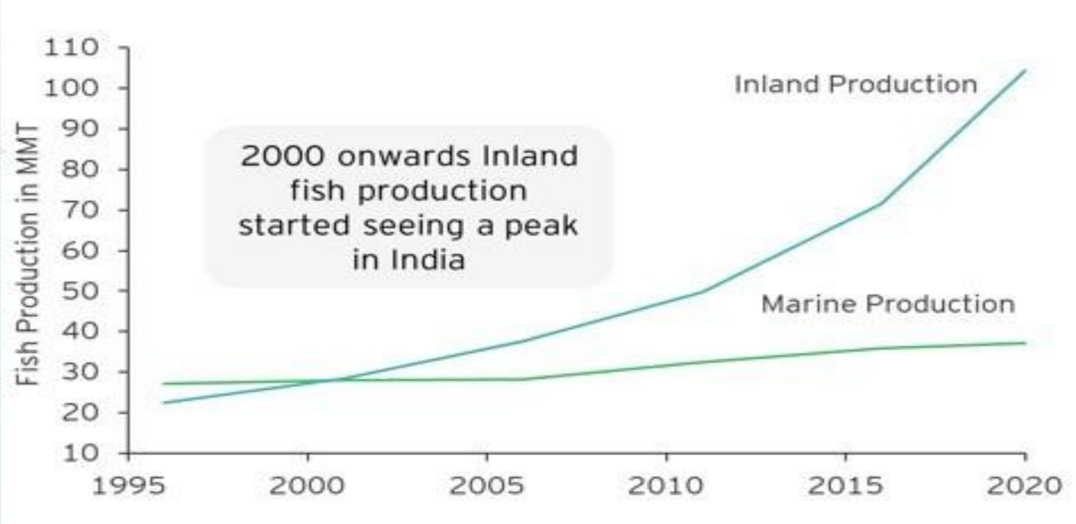
Centre for Sustainable Technologies, Indian Institute of Science
Bangalore, India

Prof. Sreenivasan Ramaswami

Centre for Sustainable Technologies, Indian Institute of Science
Bangalore, India

Introduction: relevance and market demand

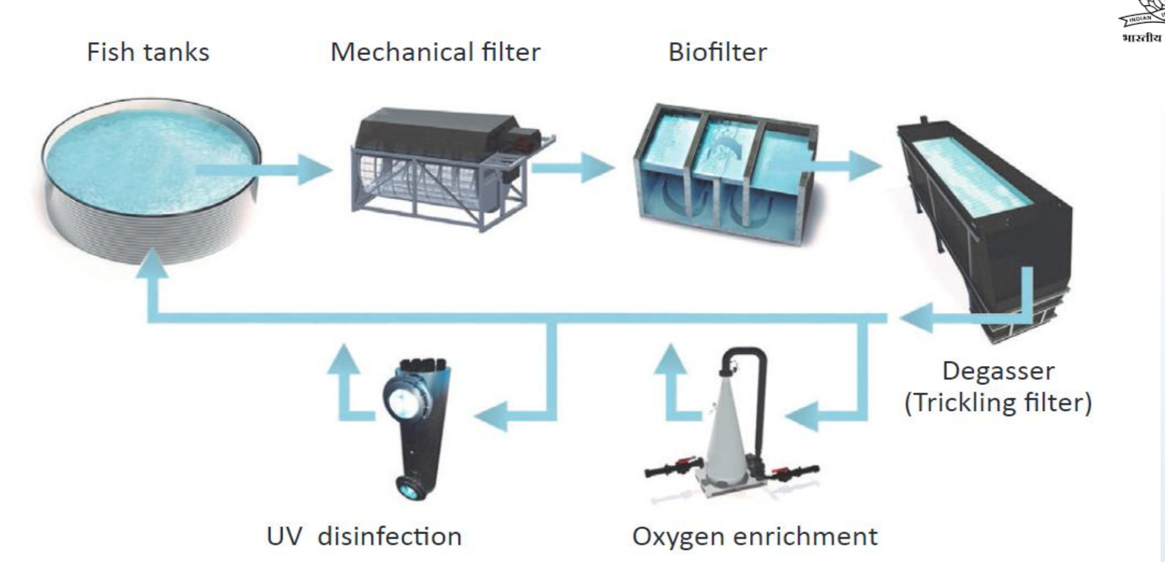
- Fisheries & Aquaculture: source of food, nutrition, income and livelihood for several millions,
- esp. “marginalized and vulnerable communities”
- Beneficiaries: women SHGs/ fisherman societies/ fish farmers/ entrepreneurs.



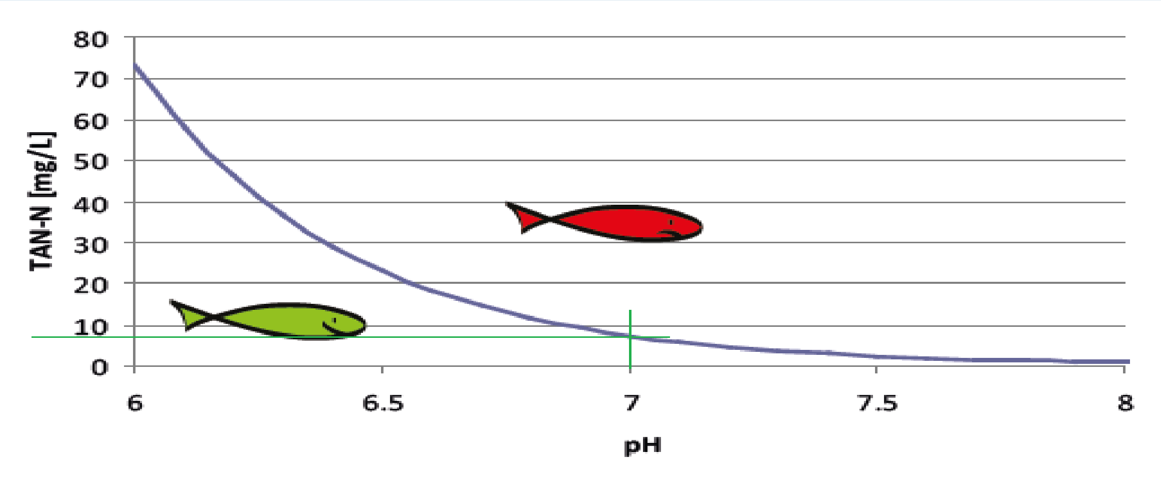
Source: Dept. of Fisheries, Govt. of India

- RAS: innovative & thrust area under the PMMSY.
- “RAS would be the next big thing to happen in Inland Fisheries Sector in the country” – DoF, 2020.

- RAS suitable for any species grown in aquaculture
- Currently limited to Tilapia & Pangasius
- Hardy fish species, high ammonia tolerance
- Stocking density (SD): 50 per m^3



Conventional Recirculatory aquaculture system (RAS)



The relation between measured pH and the amount of TAN available for breakdown in the biofilter, based upon a toxic ammonia concentration of 0.02 mg/L

Gap and Objectives

Existing knowledge:

- ❑ Stocking density ↑, RAS profitability ↑ → TAN load ↑
- ❑ Ammonia (TAN) → most critical parameter in RAS
- ❑ TAN < 2 mg/L required for most species
- ❑ Efficient & robust nitrification: bottleneck for RAS [1]
- ❑ Packed bed biofilm reactor (PBBR): most compact & robust for biological wastewater (WW) treatment
- ❑ NR for WWs >= 1000 g $N \cdot m^{-3} \cdot d^{-1}$ with PBBRs
- ❑ NR < 100 g $N \cdot m^{-3} \cdot d^{-1}$ only achieved in RAS with PBBRs → larger reactor volumes

Gap:

- ❑ Sound understanding of biofilter integration [1]
- ❑ Engineering PBBR for high-rate application in RAS

Objectives:

- To demonstrate the potential of packed bed biofilm reactors for achieving a high-rate nitrification in RAS
- The effect of inoculation & enrichment of nitrifiers and intensification of nitrification in RAS using PBBR

[1] Badiola et al. (2012). Recirculating aquaculture systems (RAS) analysis: main issues on management and future challenges, Aquacultural Engineering, 51, 26–35. doi: 10.1016/j.aquaeng.2012.07.004

Experimental Procedures

Study was conducted in two trials: trial 1 with inoculation of biocarrier within the reactor, trial 2 enriching the biocarriers in the separate inoculation tank (inoculum reactor)

Biocarriers

commercial biocarrier hel-x® 13 biomedium (oase gmbh, hörstel, germany) were used

specific surface area = 955 m^2/m^3

Model Aquaculture effluents

Salts	Concentration
NH_4Cl	Based on ALR (as N-NH_4^+)
$NaHCO_3$	A pH controller (Model BL100, Hanna Instruments) was used to maintain the pH at 7.5 ± 0.1 by dosing 70 g/L $NaHCO_3$ solution
Na_2HPO_4	5 mg/L of P
KH_2PO_4	10 mg/L of K
$MgSO_4 \cdot 7H_2O$	1 mg/L of Mg
$FeCl_3$	0.2 mg/L of Fe

* Prepared using tap water

Navada et al., 2019 and Zhu et al., 2016

Inoculating within the reactor in trial 1

Sludge supernatant of about 1.5 L was added directly into the reactor.

NH_4Cl stock corresponding to 100 mg/L was added directly into the reactor and reactor was only aerated for the duration of two days.

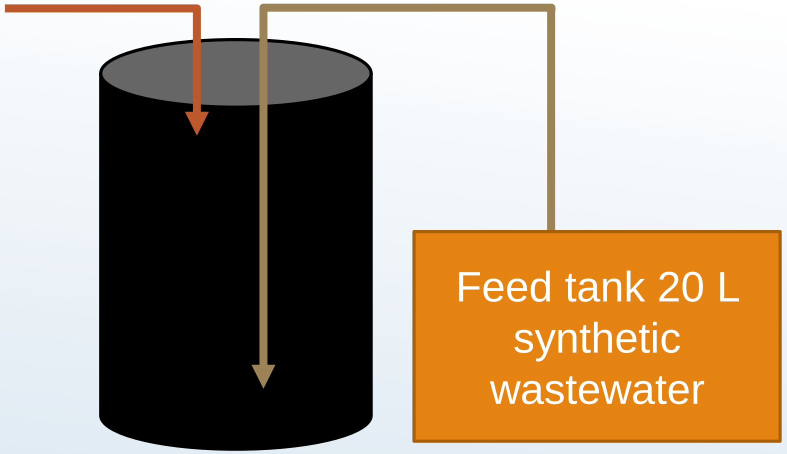
From 3rd day onwards system was fed normally with synthetically model feed corresponding to ALR = 100 $g/m^3.d$.

ALR increased further in steps from 100 to 200 and then to 400 $g/m^3.d$

Development of biofilm : Inoculum reactor for trial 2

2 L Sludge added (collected from IISc STP) on Day 0

Inoculum tank (35 L water + carriers, aerated)



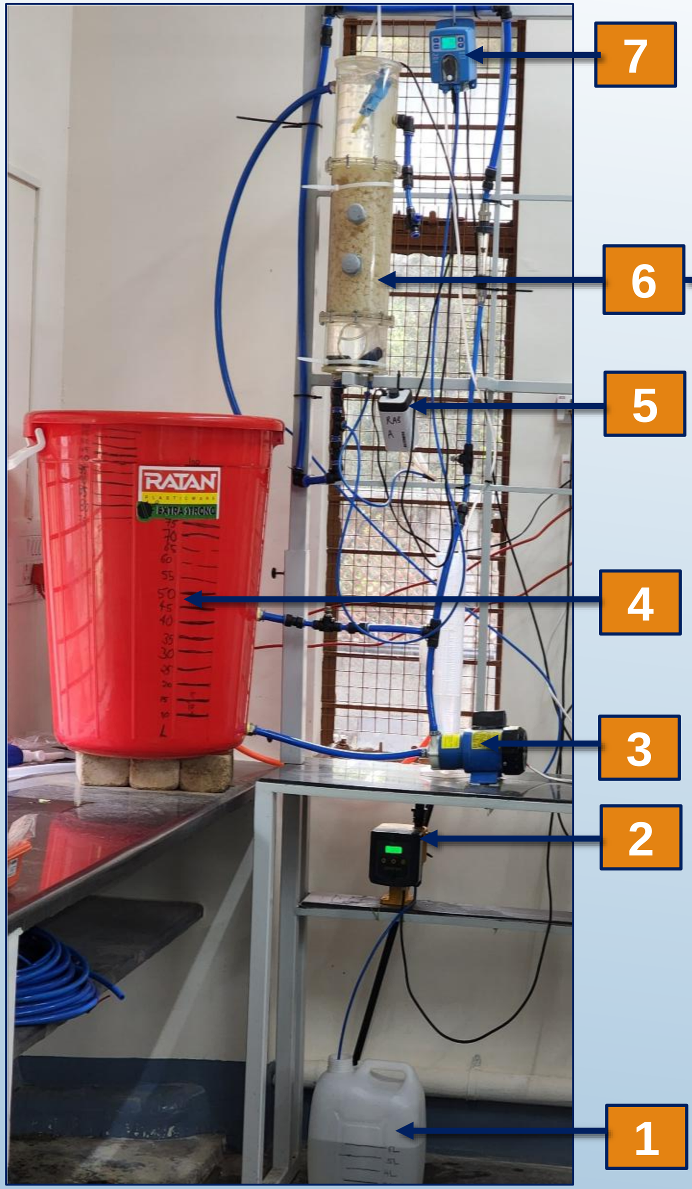
Dosing the inoculum reactor with model wastewater (NH_4Cl, $NaHCO_3$, Na_2HPO_4, K_2HPO_4, $MgCl_2 \cdot 7H_2O$, $CaCl_2 \cdot 2H_2O$, $FeCl_3$) 20 L per day

Enriched at room temperature for over 150 days

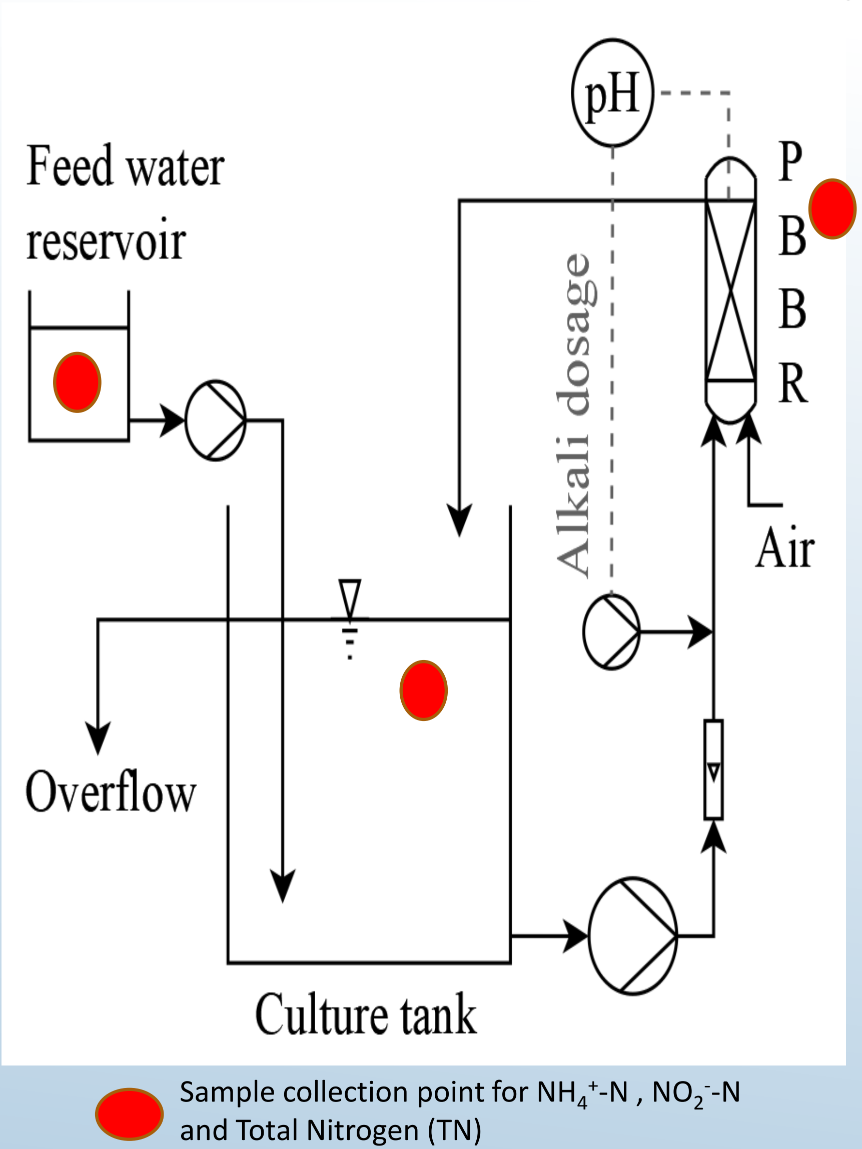
Enriched carriers were then transferred into the reactors.

In this trial also ALR was increased in steps from 200 to 400 and then to 600 $g/m^3.d$

Experimental setup



1. Feed tank
2. Dosing pump
3. Magnetic pump
4. Culture tank
5. Aeration pump
6. PBBR
7. pH Controller



Sample collection point for NH_4^+-N , NO_2^--N and Total Nitrogen (TN)

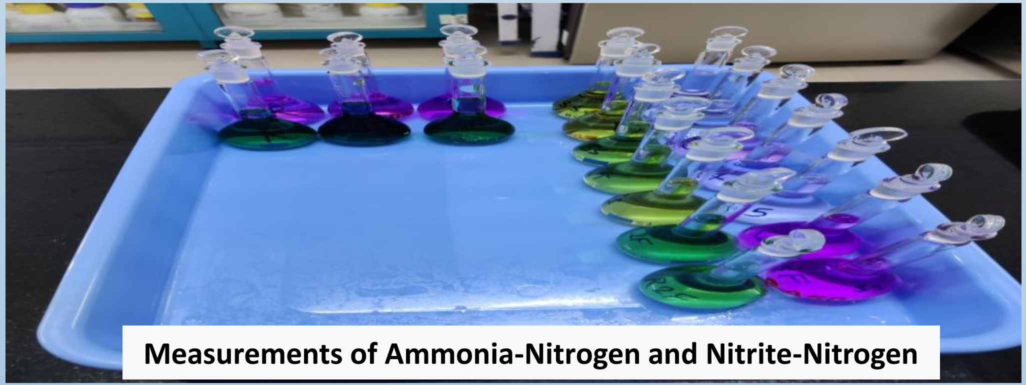
Schematic of the RAS experimental setup

Analysis of feed tank sample, culture tank sample and effluent from PBBR sample

Analytica jena Multi N/C 3000


Hach PHC101, Hach LDO101, Hach CDC401 probes and meter


SHIMADZU UV-Vis Spectrophotometer


Measurements of Ammonia-Nitrogen and Nitrite-Nitrogen

Measurements for determining Nitrogen balance

Analyte	Instrument used	Protocol followed
NH_4^+-N	SHIMADZU UV-Vis Spectrophotometer	ISO 7150
NO_2^--N	SHIMADZU UV-Vis Spectrophotometer	ISO 6777
Total Nitrogen	Analytica jena Multi N/C 3000	ISO 20236

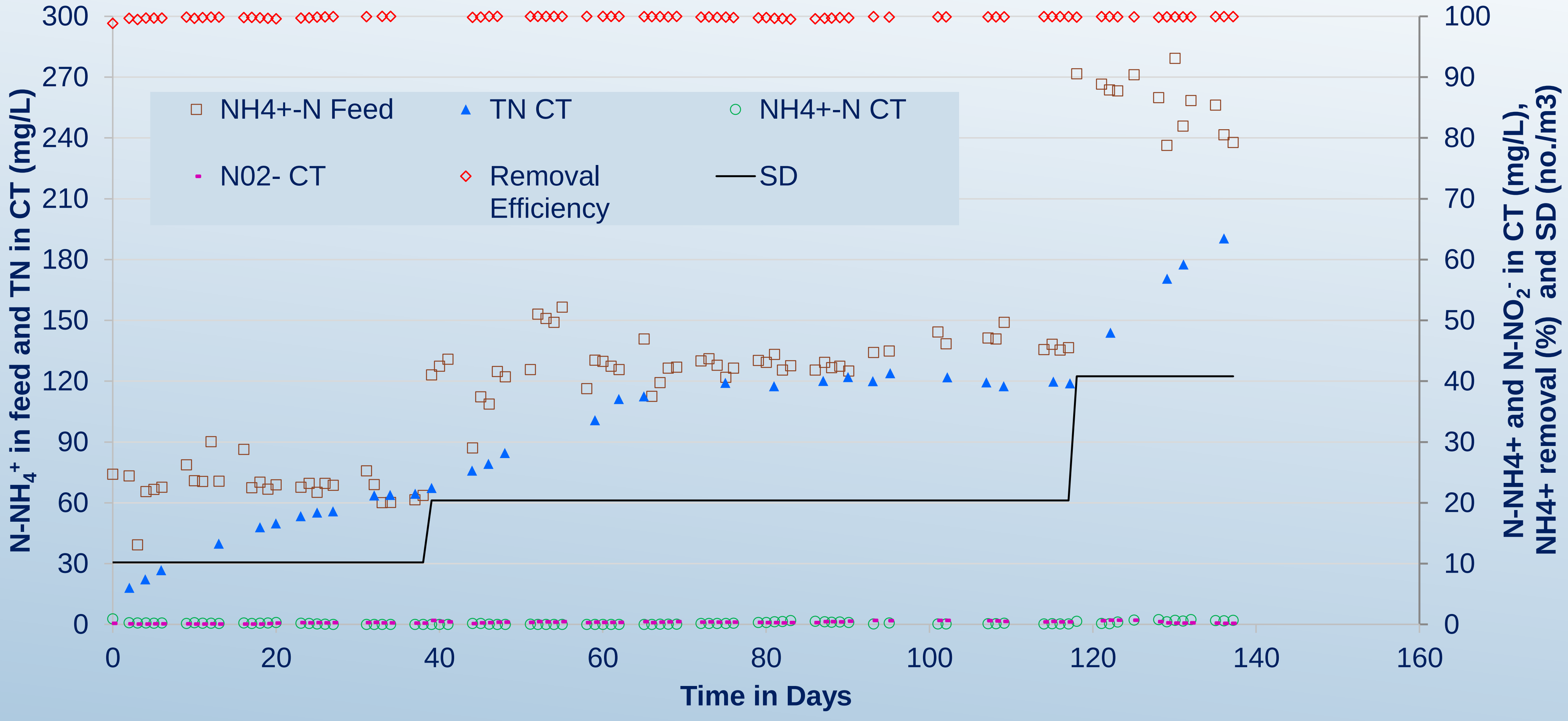
Measurements of Water Quality parameters

Parameters	Probe used
pH	Hach PHC101*
Dissolved oxygen (mg/L)	Hach LDO101*
Conductivity (µS/cm)	Hach CDC401*
Salinity (‰)	Hach CDC4018*
Temperature (°C)	Hach CDC401 *

*HQd Portable Meter was used to record the readings

Results and Discussions

Results from Trial 1 – ammonia-N concentration in feed tank; ammonia-N, nitrite-N & total nitrogen concentrations in culture tank; corresponding ammonia removal efficiency and stocking density (SD) at different ALRs.



Results from Trial 2 – ammonia-N concentration in feed tank; ammonia-N, nitrite-N & total nitrogen concentrations in culture tank; corresponding ammonia removal efficiency and stocking density (SD) at different ALRs.

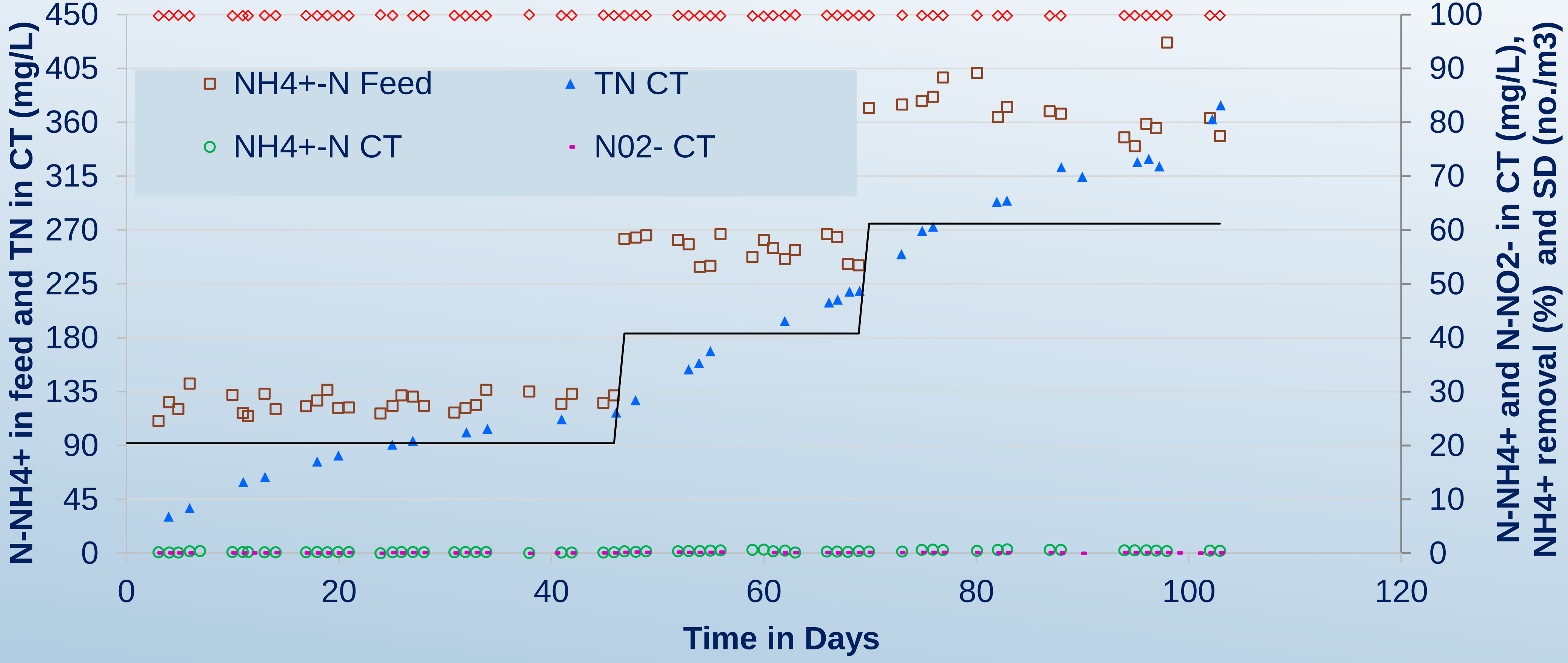


Table 1. Performance of the PBBR represented as average at different ALRs in trial 1 and trial 2

Nominal ALR	100	200		400		600	$g/(m^3 \cdot d)$
Trials	1	1	2	1	2	2	
Stocking density	10.20	20.40	20.4	40.80	40.8	61.2	$no./m^3$
ALR applied	105 ± 10	199 ± 14	189 ± 11	388 ± 20	384 ± 15	565 ± 31	$g/(m^3 \cdot d)$
$N\text{-}NH_4^+$ in feed	69 ± 9	130 ± 12	126 ± 7	258 ± 13	255 ± 10	372 ± 21	mg/L
$N\text{-}NH_4^+$ in CT	0.12 ± 0.09	0.20 ± 0.15	0.22 ± 0.07	0.55 ± 0.21	0.43 ± 0.13	0.55 ± 0.11	mg/L
NO_2^- in CT	0.20 ± 0.10	0.45 ± 0.11	0.12 ± 0.03	0.42 ± 0.21	0.18 ± 0.05	0.17 ± 0.08	mg/L
$N\text{-}NH_4^+$ removal	99.78 ± 0.23	99.90 ± 0.12	99.83 ± 0.05	99.93 ± 0.03	99.83 ± 0.06	99.85 ± 0.03	%

Take away points

- In both trials, **ammonia-N <1 mg/L** (within the limit required for most fishes to survive in the culture tank).
- In trial 1 and trial 2, the maximum ammonia-N = 270 and 400 mg/L respectively with ammonia-N <1mg/L in the culture tank.
- Demonstrates the potential of packed bed reactors for nitrification in RAS.
- Results were better in trial 2 in terms of ammonia-N and nitrite-N concentration at the same ALR, suggesting that **enrichment** of nitrifying organisms in the biocarriers is beneficial to achieve efficient operation early on.
- Corresponding to the highest ALR of 600 g $N\text{-}NH_4^+ \cdot m^{-3}\ d^{-1}$ in trial 2, the calculated **stocking density is 61.2** fishes/m^3 (assuming 500 g fish as market size of fishes).
- Demonstrating the application of a small (compact) biofilter → ammonia removal efficiency ↑ → stocking densities ↑, with the reuse of maximum water available in the culture tank.
- This system (RAS with high-rate PBBR) → tackle water scarcity → land constraint issues for sustainable culture of fish in smaller areas with high stocking densities.
- **Ammonia removal efficiency > 99.75 %** (achieving complete nitrification) at all ALRs in both the trials demonstrates the prospective to attain high-rate nitrification.
- PBBRs in RAS till date have not realized nitrification rates > 100 g $N\text{-}NH_4^+ \cdot m^{-3}\ d^{-1}$. This study reveals the potential for achieving intensive and more profitable RAS in our country.