Technical University of Denmark

Comparison of Different Biological Processes for End-of-Pipe Treatment of Recirculating Aquaculture System Effluent

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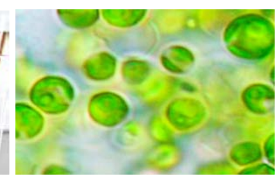
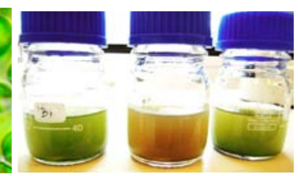
January 2013

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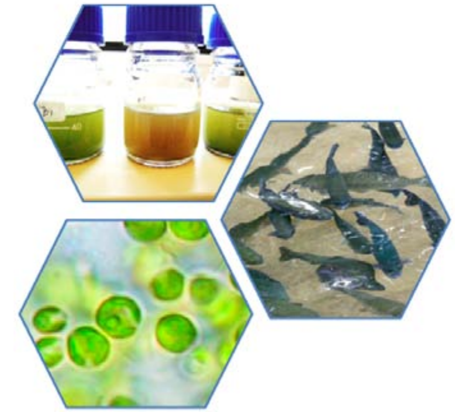


OUTLINE

- 1. INTRODUCTION TO THE PROBLEM
- 2. OBJECTIVES
- 3. MATERIAL AND METHODS
- 4. RESULTS AND DISCUSSIONS
- 5. COMPARISON OF THE RESULTS OBTAINED FROM DIFFERENT BIOLOGICAL PROCESSES
- 6. COMPARISON OF THE BEST FOUND TECHNOLOGY COMPARED WITH THE DANISH STATE OF ART (DAMBRUGSBEKENDTGØRELSEN BEK NR. 130 2012/CHAPTER 4).
- 7. CONCLUSIONS

1. INTRODUCTION TO THE PROBLEM

- Aquaculture is named to be a feasible solution to provide enough food for satisfying increasing market demand.
- EU want to consolidate its Aquaculture technology under global market by selling know-how.

(European comission, 2009)

- In Denmark discharged nutrients coming from commercial farms is a major challenge.
- Not allowing farmers to increase their production capacity and accomplish environmental regulations (Feed quota allowance/treatment discharge efficiency).

(Dambrugsbekendtgørelsen BEK nr. 130 2012)

1. INTRODUCTION TO THE PROBLEM

- Aquaculture recirculating systems (RAS)
  - ✓ More intensive production systems (30 – 50 Kg/m³)
  - ✓ Require less make up water (<5% volume/day)
  - ✓ Higher control over culture conditions, majorly NH_4 and NO_2 removal

- No major control is often applied for treating Nutrient (N and P) and organic matter from RAS effluent.
- For increasing aquaculture productive goals in Denmark and accomplish environmental legislation, major attention has gained End-of-Pipe treatment (MTF).
- The following project evaluated different biological treatment as End-of-Pipe treatment and compared against Model trout farm technology (Feed allowance quota).

2. OBJECTIVES

General Objective

The general objective of this thesis project is to compare microalgal culture, denitrification and anaerobic digestion for treating RAS effluent as End-of-Pipe treatment.

Specific Objectives

The specific objectives of this thesis project are to:

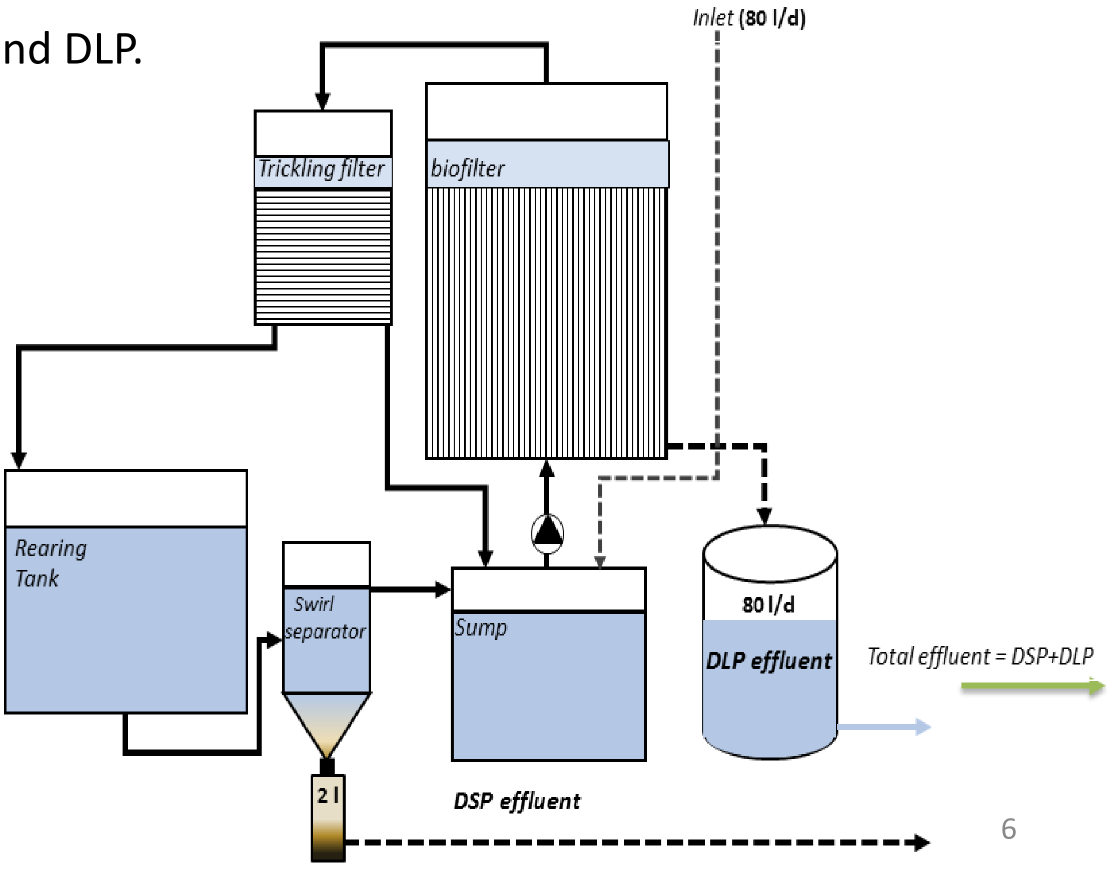
Characterize the composition of RAS effluent for nitrogenous compounds, PO_4-P and organic content (TS, TVS, COD).

Evaluate the removal efficiency of microalgal culture, denitrification and anaerobic digestion for TN, organic content and PO_4-P.

Compare the proposed end of pipe treatment against the actual state of art technology using the feed allowance quota method.

3. MATERIAL AND METHODS

- Three different biological processes were evaluated (microalgal treatment, denitrification and anaerobic digestion).
- Effluent coming from 1700 L RAS cultivating rainbow trout (*Onchorynchus mykkis*) (25 Kg) and feeding rate of 300 g pellet/day was used for evaluation.
- The effluent was divided in DSP and DLP.



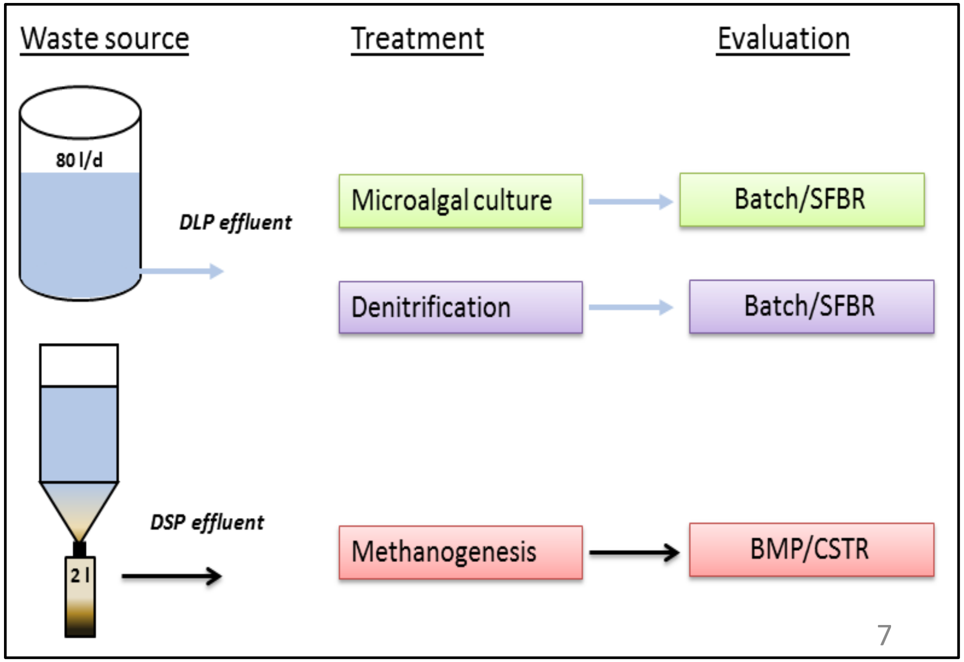
3. MATERIAL AND METHODS

Characterization of DSP and DLP

- Samples from DSP and DLP were taken daily and frozen for accumulation.
- Each type of waste was analyzed for:
    - Nutrients (N and P): NH_4-N, NO_3-N, NO_2-N, PO_4-P and TKN
    - Organic matter as COD and TVS

Removal Efficiencies

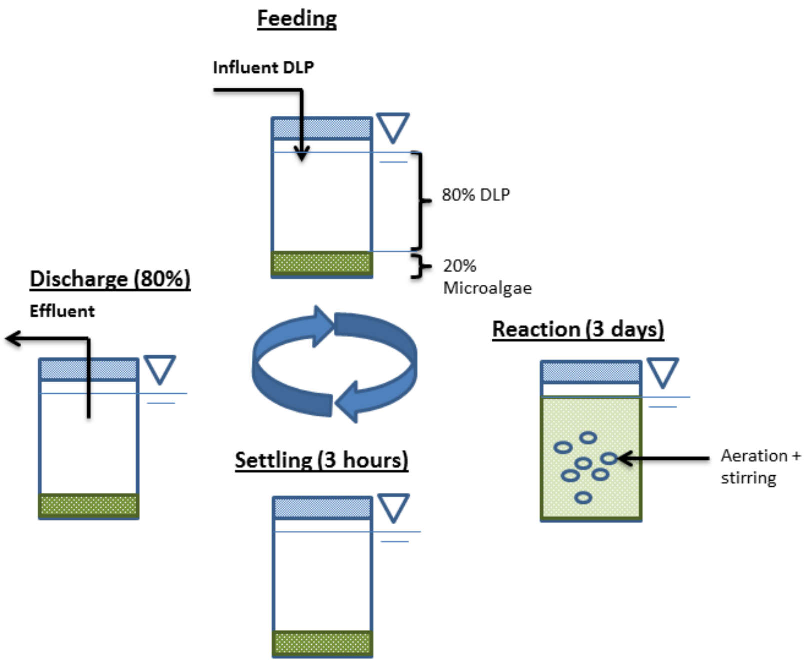
- A series of experiments were performed to evaluate removal efficiencies of TN, PO4-P and organic content from DSP and DLP.



3. MATERIAL AND METHODS

Microalgal Treatment for DLP

- Mixotrophic *Chlorella protothecoides* was chosen as microalgal specie.
- Algae was maintained under low light conditions (40 $\mu E/m^2s^2$) with constant air supply.
- Microalgal growth (μ) was related to fluorescence measurements (Em. 445 nm Ex. 670 nm).
- 1 L batch reactors were used for estimating removal η (20% v/v inoculation).
- SFBR were used for long term evaluation under 5 full cycles (20% v/v inoculation).

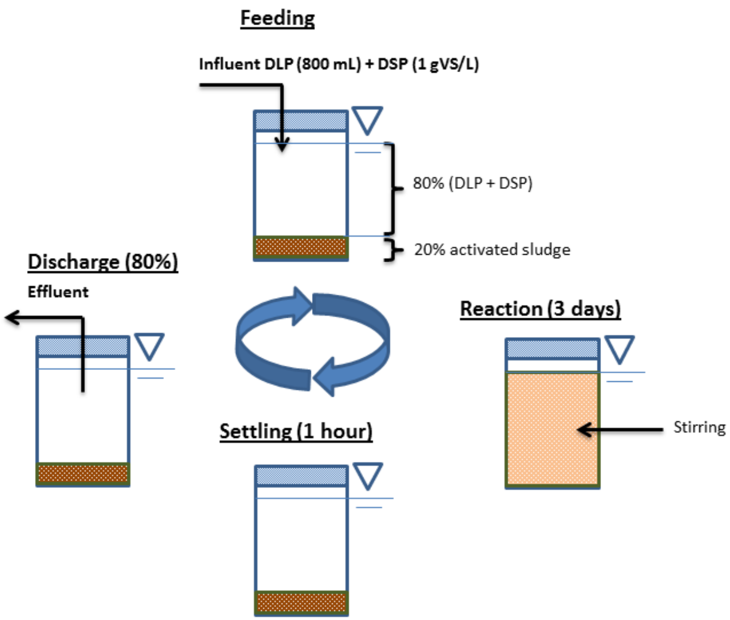


3. MATERIAL AND METHODS

Denitrification Treatment for DLP

+ 1 g/L TVS DSP

- Inoculum obtained from activated sludge reactor in the wastewater plant of Lundtofte.
- The medium consisted of 800 mL DLP, 200 mL of inoculum and 25 mL (1 g/L TVS) of DSP in order to supply a fresh organic source.
- Nitrogen was purged to achieve anoxic conditions.
- 1 L batch reactors were used for estimating removal η.
- SFBR were used for long term evaluation under 4 full cycles.



3. MATERIAL AND METHODS

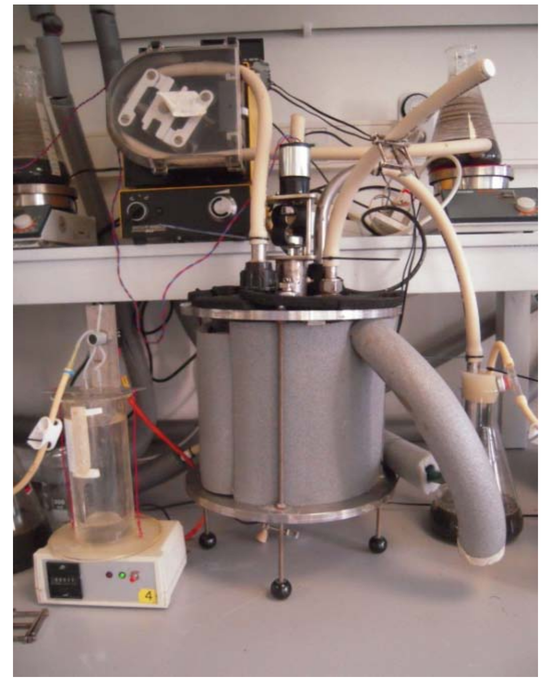
Anaerobic digestion for DSP

- Biochemical methane potential assay was performed using rubber closed bottles (540 mL).
- Three concentrations of DSP were evaluated 8 g/L TVS (25%), 4 g/L TVS (12.5%) and 2 g/L TVS (6.35%) using digested cow manure as inoculum.
- Avicel was used as control (0.5 g).
- Nitrogen was purged to achieve anaerobic conditions and incubated at 35°C for 21 days.
- Methane content was measured constantly using gas chromatography.

3. MATERIAL AND METHODS

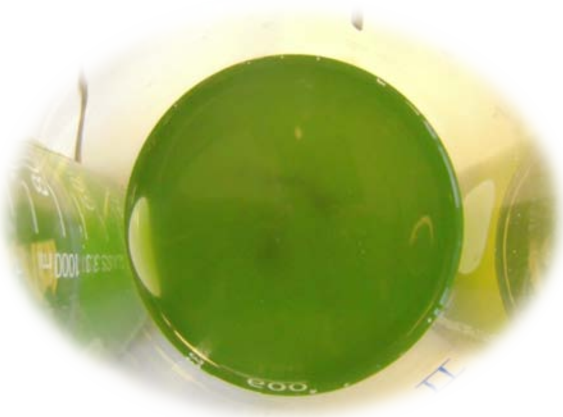
Anaerobic digestion of DSP

- The treatment of DSP was evaluated under 2 CSTR with reaction volume of 2.5 L.
- HRT of 16 days was used supplying 160 mL/d of substrate.
- For registering steady state conditions recycle effluent from WWTP was used before adding DSP.
- Once obtained steady state conditions reactor 1 was fed with 100% DSP and reactor 2 with 50% previous substrate and 50% DSP.
- Gas analysis using gas cromathograph and pH values were measured constantly to control process status.

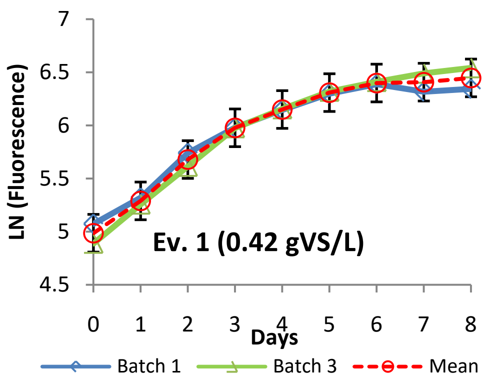


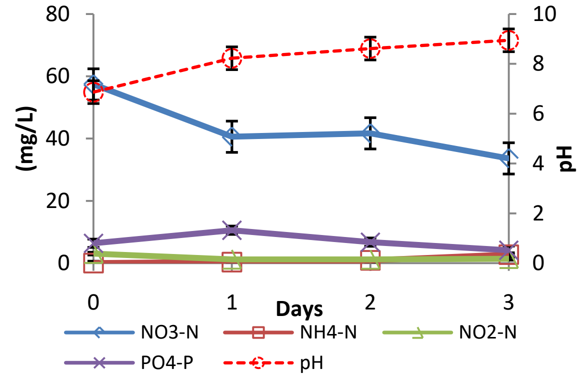
4. RESULTS AND DISCUSSION

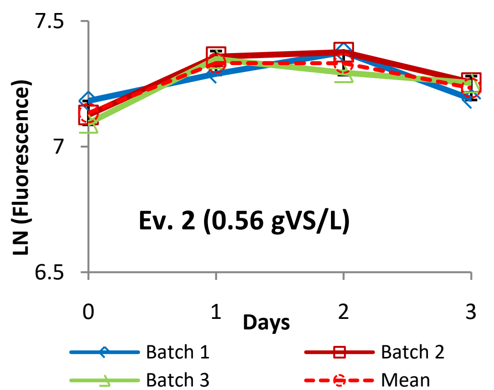
MICROALGAL BATCH AND STEP FED BATCH REACTOR (SFBR) EXPERIMENT

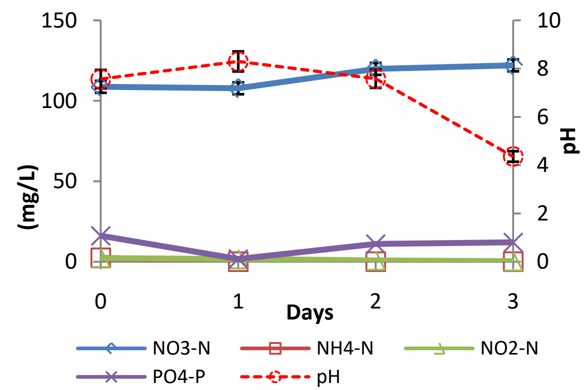


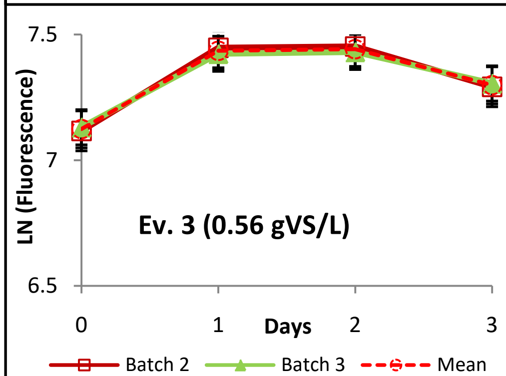
Microalgae Batch Evaluation

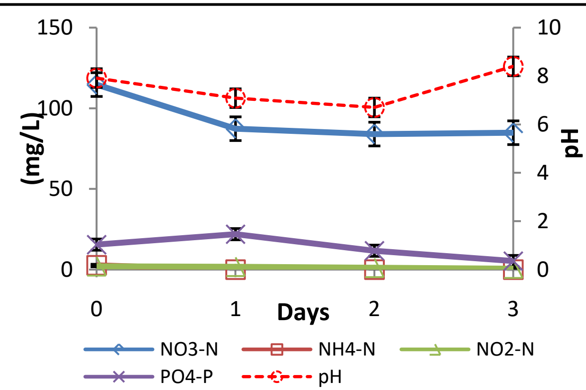












Microalgae Growth

	μ d^{-1}	Generation Time/day	Division/ day	Std. Desv.	CV
Evaluation 1	0.33	2.07	0.48	0.03	8%
Evaluation 2	0.11	6.5	0.16	0.01	9%
Evaluation 3	0.16	4.5	0.22	0.01	7%

Evaluation 1

Concentration (mg/L)	Day 0	Day 1	Day 2	Day 3	Total Removal
NO_3-N	59.80	24.13	33.40	26.80	55%
NH_4-N	0.05	0.43	1.20	4.02	0%
NO_2-N	2.92	1.12	1.05	1.16	60%
PO_4-P	6.34	9.97	7.73	5.07	20%
TIN (mg/L)	**62.77**	**25.68**	**35.65**	**31.98**	**49%**

Evaluation 2

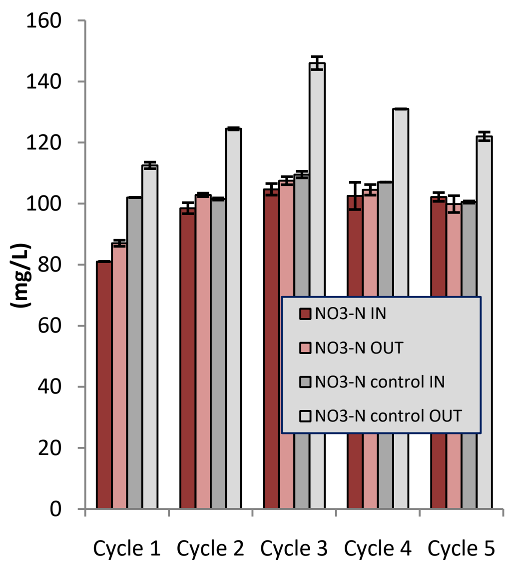
Concentration (mg/L)	Day 0	Day 1	Day 2	Day 3	Total removal
NO_3-N	108.67	107.75	119.83	122.00	0%
NH_4-N	2.42	0.06	0.05	0.05	98%
NO_2-N	2.20	1.69	0.78	0.30	86%
PO_4-P	16.07	1.73	11.03	12.00	25%
TIN (mg/L)	**113.28**	**109.50**	**120.65**	**122.32**	**0%**

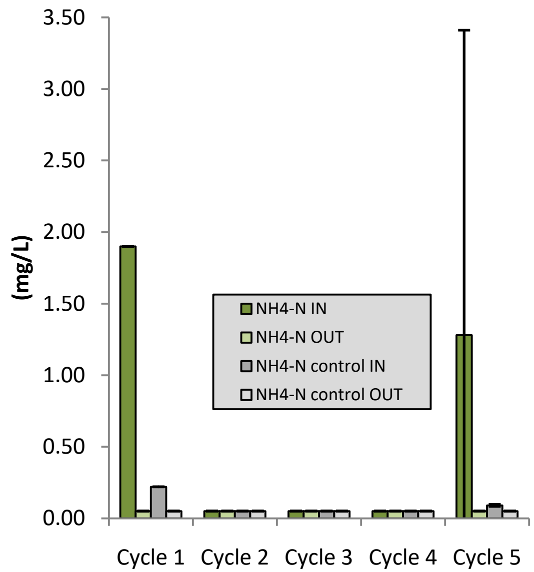
Evaluation 3

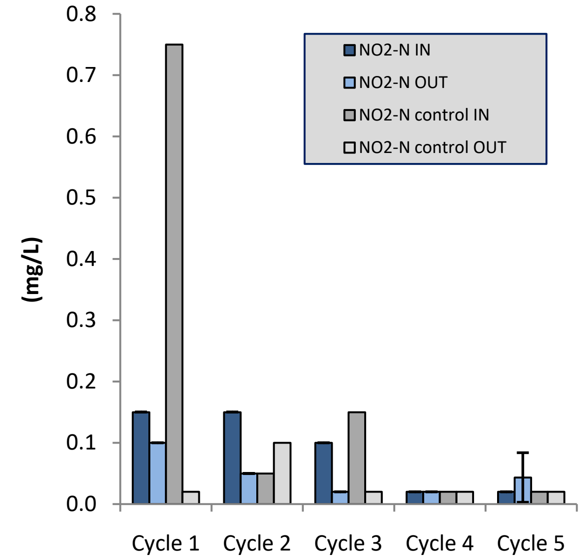
Concentration (mg/L)	Day 0	Day 1	Day 2	Day 3	Total removal
NO_3-N	114.67	87.33	84.00	84.83	26%
NH_4-N	2.67	0.05	0.05	0.05	99%
NO_2-N	2.08	1.78	1.13	0.62	70%
PO_4-P	15.50	21.97	11.72	5.33	66%
TIN (mg/L)	**119.42**	**89.15**	**85.18**	**85.45**	**28%**

4. RESULTS AND DISCUSSION

Microalgal SFBR – Nutrient Removal



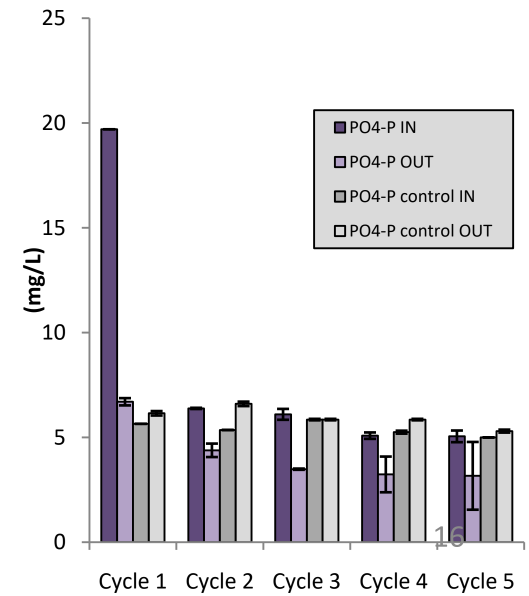




	Cycle 1 Removal η1	Cycle 2 Removal η2	Cycle 3 Removal η3	Cycle 4 Removal η4	Cycle 5 Removal η5
NO_3-N	0%	0%	0%	0%	2%
NH_4-N	97%	0%	0%	0%	96%
NO_2-N	33%	58%	90%	0%	0%
PO_4-P	66%	31%	43%	36%	37%
TIN (mg/L)	**0%**	**0%**	**0%**	**0%**	**3%**

COD in SFBR	Removal η1	Removal η2	Removal η3	Removal η4	Removal η5
B1	82%	89%	93%	94%	77%
B2	78%	89%	91%	90%	99%
B3	81%	88%	81%	92%	87%
Control	94%	94%	94%	94%	94%
Mean	80%	89%	88%	92%	88%

COD IN:
820 mg/L

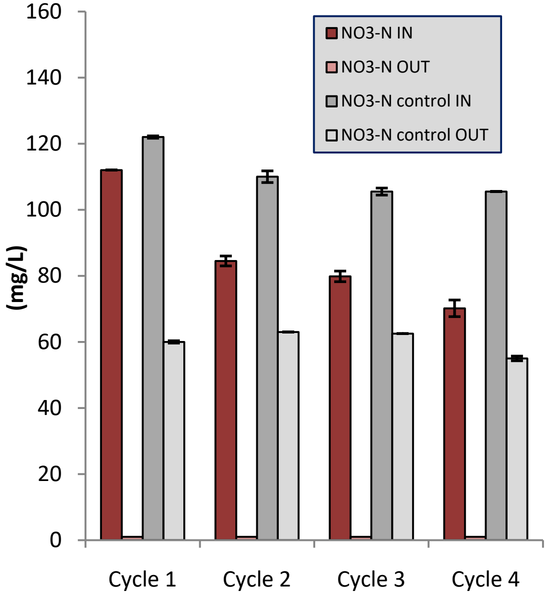


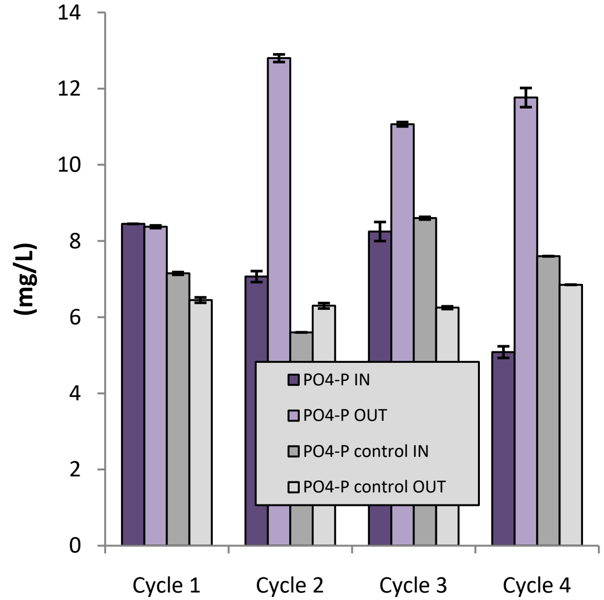
4. RESULTS AND DISCUSSION

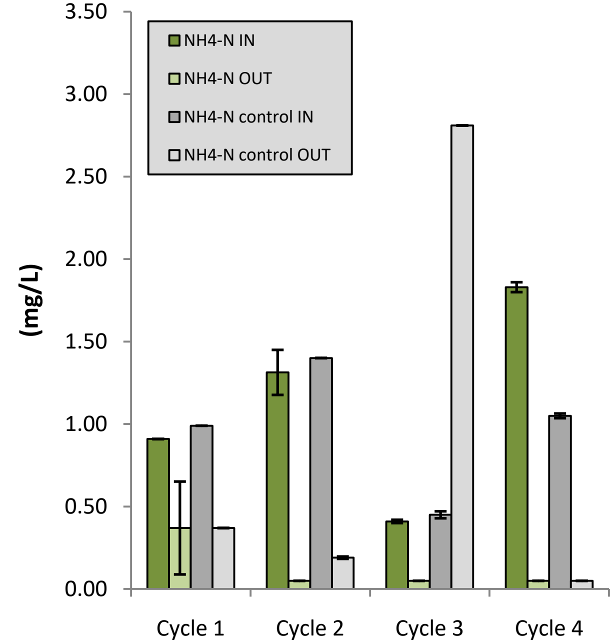
DENITRIFICATION BATCH AND STEP FED BATCH REACTOR (SFBR) EXPERIMENT

4. RESULTS AND DISCUSSION

Denitrification SFBR



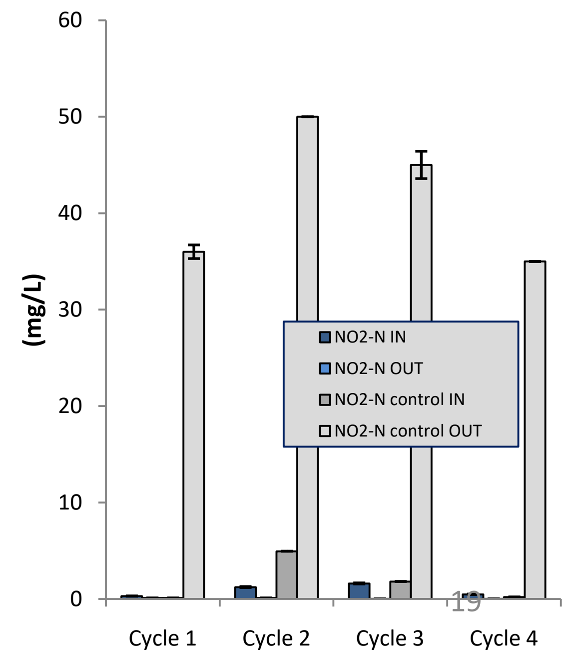




	Cycle 1 Removal η1	Cycle 2 Removal η2	Cycle 3 Removal η3	Cycle 4 Removal η4
NO_3-N	99%	99%	99%	99%
NH_4-N	59%	96%	88%	97%
NO_2-N	67%	92%	99%	96%
PO_4-P	1%	0%	0%	0%
TIN (mg/L)	99%	99%	99%	99%

COD in SFBR	Removal η1	Removal η2	Removal η3	Removal η4
B1	78%	88%	90%	88%
B2	88%	86%	88%	92%
B3	90%	90%	90%	91%
Mean	85%	88%	89%	91%
Control	87%	95%	95%	91%

COD IN
1.27 g/L



4. RESULTS AND DISCUSSION

ANAEROBIC DIGESTION TREATMENT

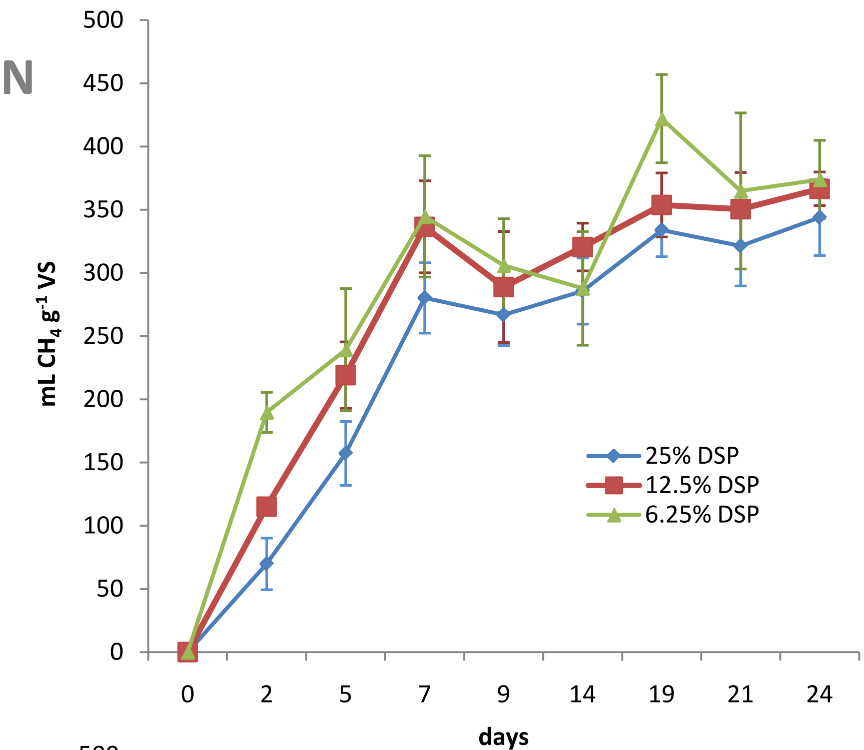
4. RESULTS AND DISCUSSION

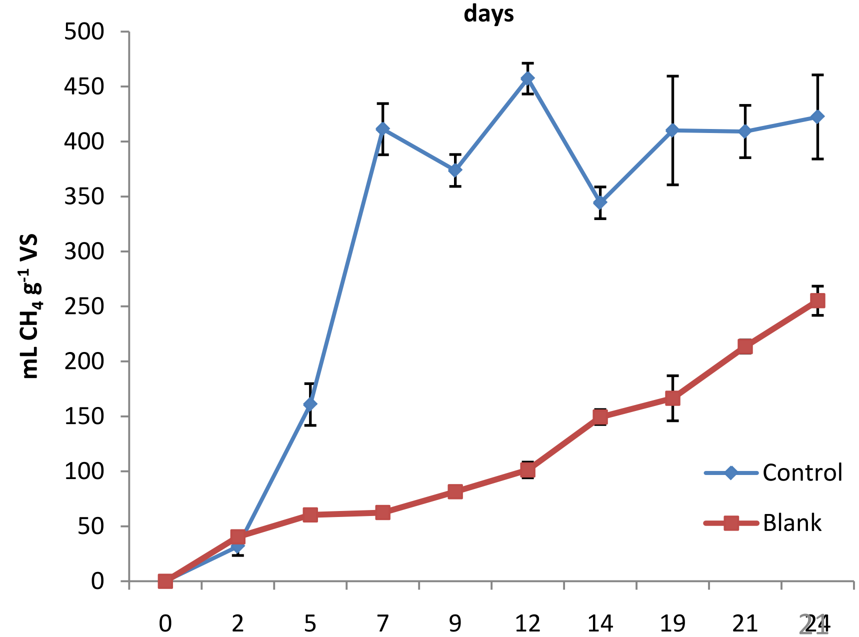
Biochemical methane potential

Energetic balance	Values	
Fish biomass	25	Kg
DSP Volume/d	2.2	L
Waste ratio	0.09	LDSP/Kgfish
CH_4 Yield	0.35	LCH4/gTVS
SRA CH4 potential	14	LCH4/LDSP
	0.01	LCh4/kW
Energy production	0.14	kW/L_DSP*d
	0.01	kW/L_DSP*h
Comercial tank system	80 MT fish production	
	7040 L DSP/d	
	98560 LCH4	
	14.4 kW/h	

Theoretical nutrient and organic removal efficiencies

- COD removal 60% mesophilic conditions (Gebauer and Eibrokk, 2006).
- 0.23 Kg COD(b)/Kg COD(s) (Henze *et al*., 2002).
  - ✓ N content in bacteria of 7%
  - ✓ P content in bacteria of 1.4%
- Thus
  - 29.64 gCOD available for bacteria/L DSP
  - 6.8 g/L bacterial mass
  - Requiring 476 mgN/L DSP and 95 mgP/L DSP





COMPARISON OF TECHNOLOGIES

5. COMPARISON OF THE RESULTS OBTAINED FROM DIFFERENT BIOLOGICAL PROCESSES

DSP					**DLP**				
	Concentration		**Mass**			**Concentration**		**Mass**	
NH_4-N	0.23	mg/L	0.0003	g/d	NH_4-N	0.24	mg/L	0.02	g/d
NO_2-N	0.45	mg/L	0.001	g/d	NO_2-N	0.75	mg/L	0.06	g/d
NO_3-N	2.4	mg/L	0.006	g/d	NO_3-N	102	mg/L	7.9	g/d
PO_4-N	**25**	**mg/L**	**0.06**	**g/d**	**PO_4-N**	**5.65**	**mg/L**	**0.4**	**g/d**
TKN	1.21	g/L	2.7	g/d	TKN	0.08	g/L	6.2	g/d
COD	**49.4**	**g/L**	**108.7**	**g/d**	**COD**	**0.82**	**g/L**	**63.8**	**g/d**
TN	**1.21**	**g/L**	**2.7**	**g/d**	**TN**	**0.18**	**g/L**	**14.2**	**g/d**

Technology	COD (%)	TN (%)	TP (%)	Added value
Microalgae (*Chlorella protothecoides*)	33	34	44	0.13 g microalgae/mgNH4-N
Denitrification	96	95	-13	3.57 mg$CaCO_3$/mgNO_3-N
Anaerobic digestion (biogas)	38	9.9	11	14 LCH_4/LDSP

6. COMPARISON OF THE BEST FOUND TECHNOLOGY WITH THE DANISH STATE OF ART UNDER DAMBRUGSBEKENDTGØRELSEN BEK NR. 130 2012/CHAPTER 4.

System	TN	TP	BOD	Feed allowance (ton)	Cultivable Ton Fish
Traditional	7%	20%	20%	100	143
Type 3	15%	65%	80%	109	156
Type 3 (Wetland)	50%	76%	93%	186	266
Proposed technology (denitrification)	95%	-13%	96%(*)	1860	2660

(*)value reported as COD

7. CONCLUSIONS

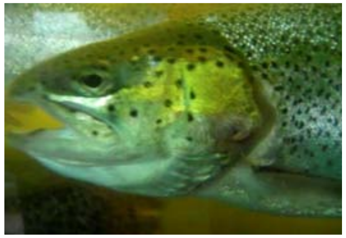
- Source segregation into DSP and DLP effluent fractions from the RAS facilitate the selection of the technology to be applied, due to different masses, nutrients and organic distribution.

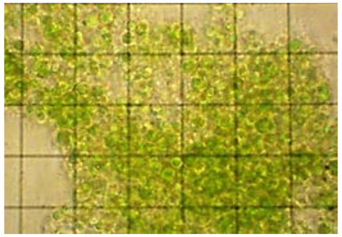
- Denitrification showed to be the best option for treating RAS wastewater although phosphorous removal is the major limiting condition for the application of this technology (additional treatment must be considered for its removal).

- The DSP had a higher organic content making it a good substrate for anaerobic digestion. The main drawback of the technology was its low nutrient removal, additional treatment must be considered if anaerobic digestion is chosen for the production of energy in a RAS.

- *Chlorella protothecoides* did not favor growth if NH_4 -N was not present in the medium, and the low or null NO_3^-N uptake negatively supported the use of this strain for treating RAS effluent (screening of species capable of removing nitrate is fundamental).

- The incorporation of End-of-pipe treatment biological technologies to RAS allow a more sustainable approach, reducing the nutrient emissions and increasing the allowed production capacity, although further research must be done under commercial conditions for the selected technology.

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   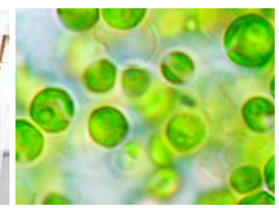 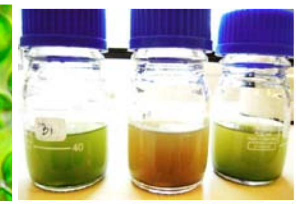 

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