Advances on End-of-pipe treatment in marine RAS

Avances en el tratamiento de efluentes de RAS marinos

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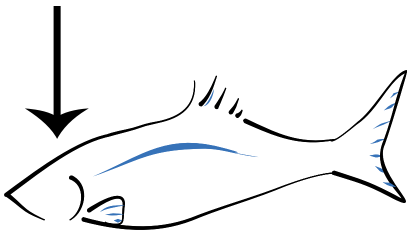
Environmental constrains

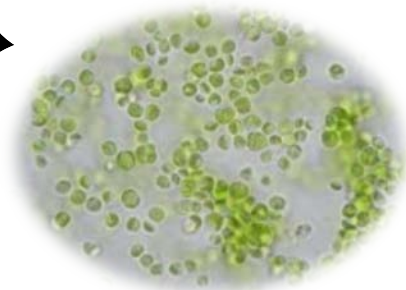
- The process of growing fish results in by-products which are potential to pollute water systems.

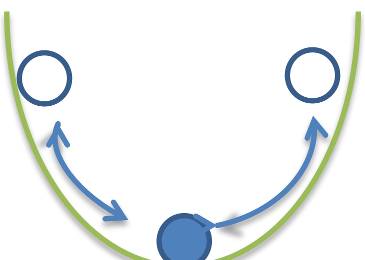


Organic matter

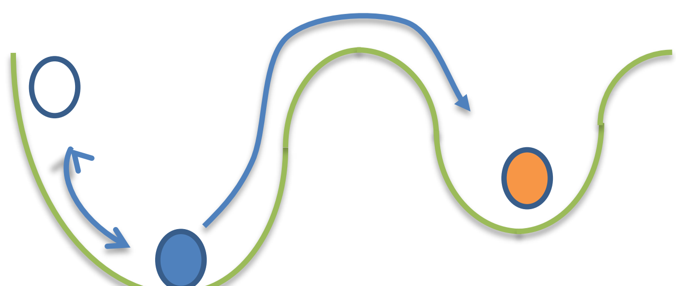
Nitrogen, Phosphorous

Nutrients discharged





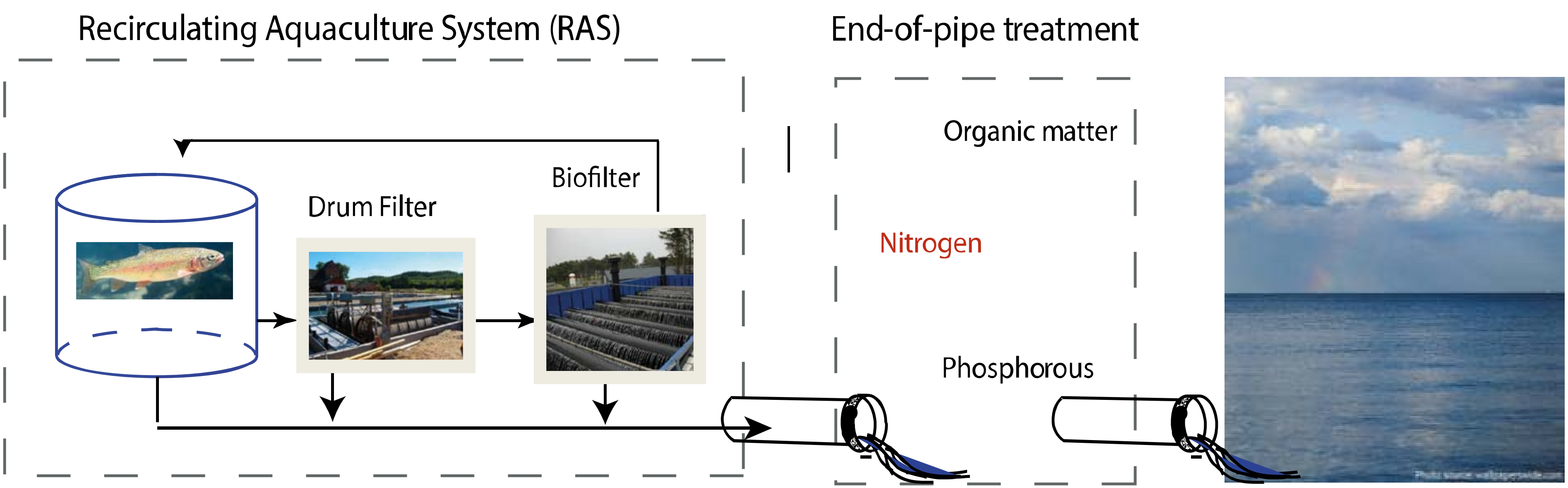
Engineering resilience (recover capacity)



Ecological resilience (reorganization capacity)

Situation

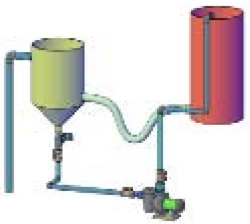
- ✓ More land based salt water recirculating aquaculture systems (RAS) are being constructed (1,000-90,000 tons/year).
- ✓ Condition: Industry must take care of effluent (saline).
- ✓ “end-of-pipe” treatment concept gets more relevance.



Outline

1. How are the ***masses*** of Nitrogen, Phosphorous and Organic matter discharged from a RAS.

2. **Nitrogen (N) removal**
   - Activated sludge system (ASS)
   - Granular sludge (UASB)



3. **Phosphorous (P) removal**
   Salts (Alum and Iron chloride)
   Effect on Total Suspended Solids (TSS), PO_4-P and Settled Sludge Volume final (SSVf)

4. **Organic matter (OM)**
   Biogas (CH_4) potential at different salinities

1. How are N, OM and P found in RAS effluent?

Total discharge: 1920 m^3/d
Feeding: 2 ton/day

Happy Salmon A/S

RAS

End-of-Pipe

1440 m^3/d **(75%)**
RAS Overflow

480 m^3/d **(25%)**
Sludge flow

- Majority T**N** in RAS **overflow**
- Majority **TOM**, **TSS** and **P** in **sludge flow**

T**otal** **N**itrogen

61.6 Kg/d **(80%)**

Total **O**rganic **M**atter: 646 Kg/d **(86%)**

Total **S**uspended **S**olids: 462 Kg/d **(99%)**

Total **P**hosphorous: 6.0 Kg/d **(92%)**

2. Nitrogen removal

$$TN = ORGANIC\ N + NH_3 + NH_4^+ + NO_2^- + NO_3^-$$

- Why denitrification?
  - Temperature, water usage, pumping costs
  - Not enough to convert NH_4^+ to NO_3^-

#	Component	Amount
1	$NaNO_3$ (Fisher BP360-500)	4.7 g/2 L
2	Na_2glycerophosphate $5H_2O$ (Sigma G 6501)	0.7 g/2 L
3	ES Fe Solution	325 mL/2 L
4	P-II Metal Solution	325 mL/2 L
5	HEPES buffer (Sigma H-3375)	6.5 g/2 L
6	Vitamin B_{12}	3 mL/2 L
7	Biotin Vitamin Solution	3 mL/2 L
8	Thiamine Vitamin Solution	3 mL/2 L

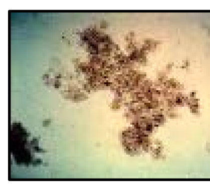
Enriched sea water medium (for culturing microalgae).

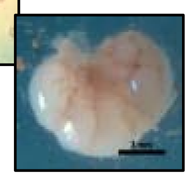
- Denitrification is a process in which NO_3^- is converted to N_2 (gas)

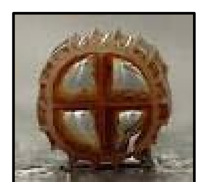
$$NO_3^- \rightarrow NO_2^- \rightarrow N_2$$

- 2 types technology

  - Activated sludge system
  - Granular sludge







- Comparison vs media-based laden

What is an activated sludge system?

- A system where bacteria lives freely in flocs within the reactor.

- Opposite as media based systems

- **Advantages**:

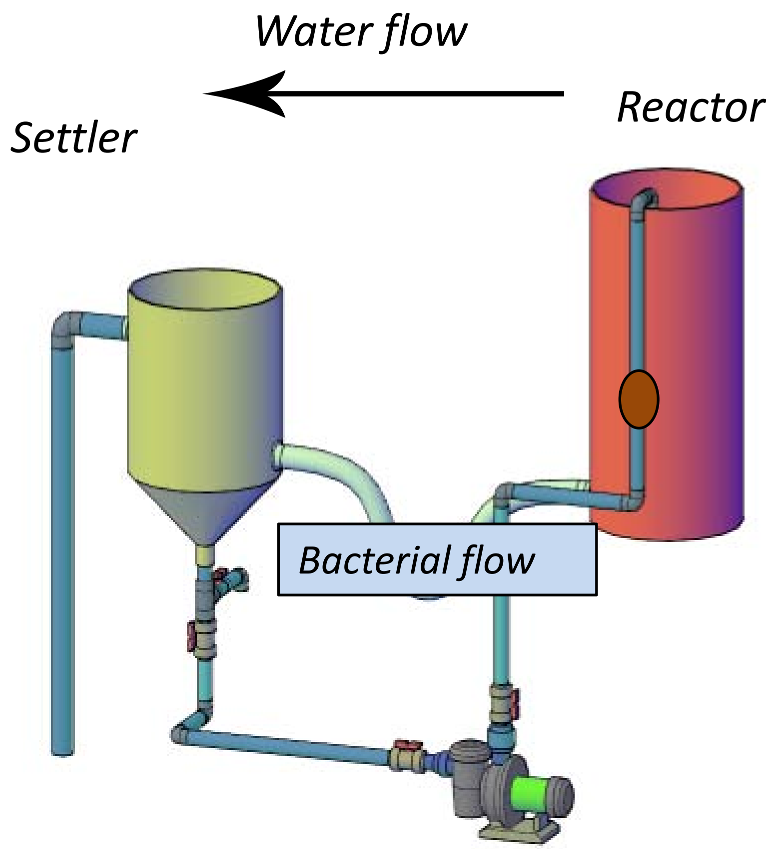
  - Does not clogg the reactors (no backwash).
  - Water channeling inside the reactor is improved.
  - No investment for media material.
  - Avoidance of H_2S formation

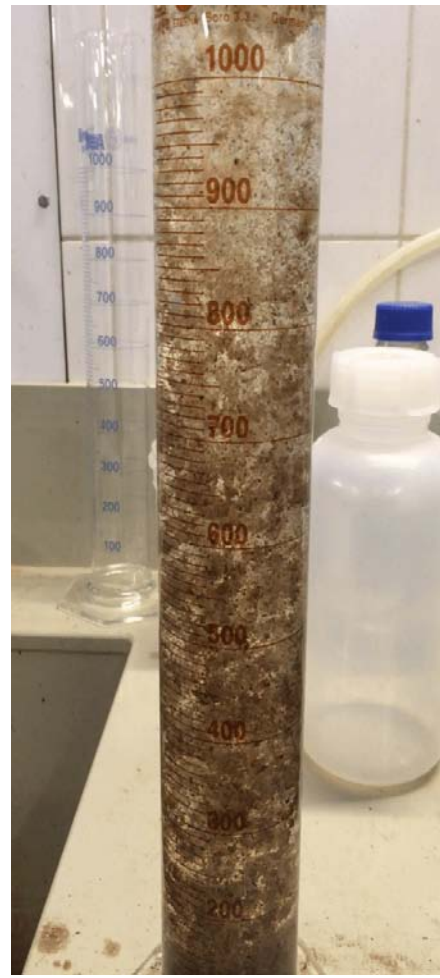
- **Disadvantages?**

  - Big footprint
  - High energetic costs
  - Produces sludge
  - Difficult to operate

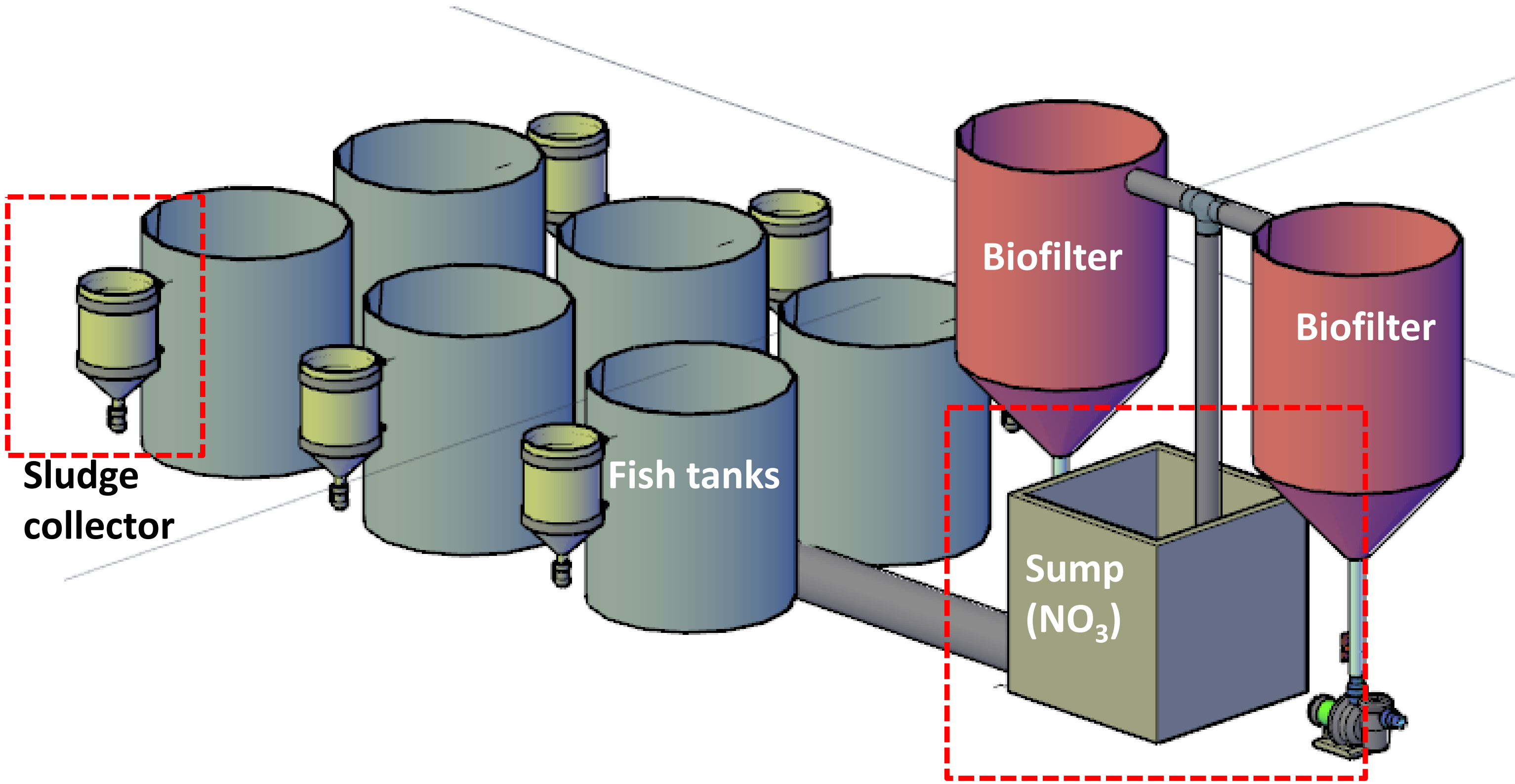
How does it work?

- Hydraulic retention time (HRT) **decoupled** from solid retention time (SRT)





RAS description



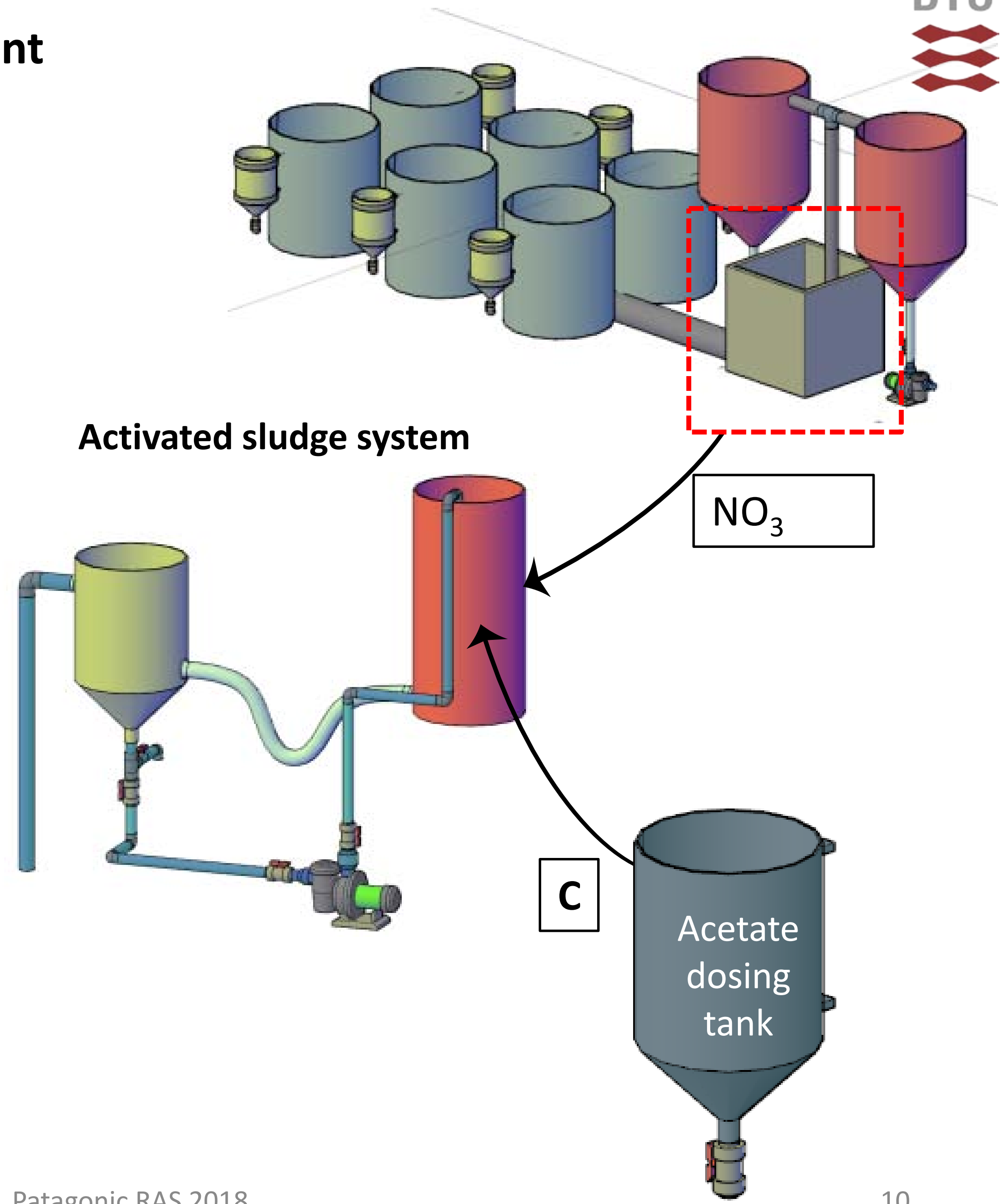
RAS: Rainbow trout at an intensity of 0.56 m^3/Kg feed (≈1 m^3 M.U.W./d)

- Temperature 16±0.7 ^oC and salinity of 26 ppt.
- Steady state discharge 50 mg NO_3-N/L
- 2 discharge sources (sump ”**NO_3**” and settler cones ”**C**”)
- 100% sump effluent treated with Activated sludge system

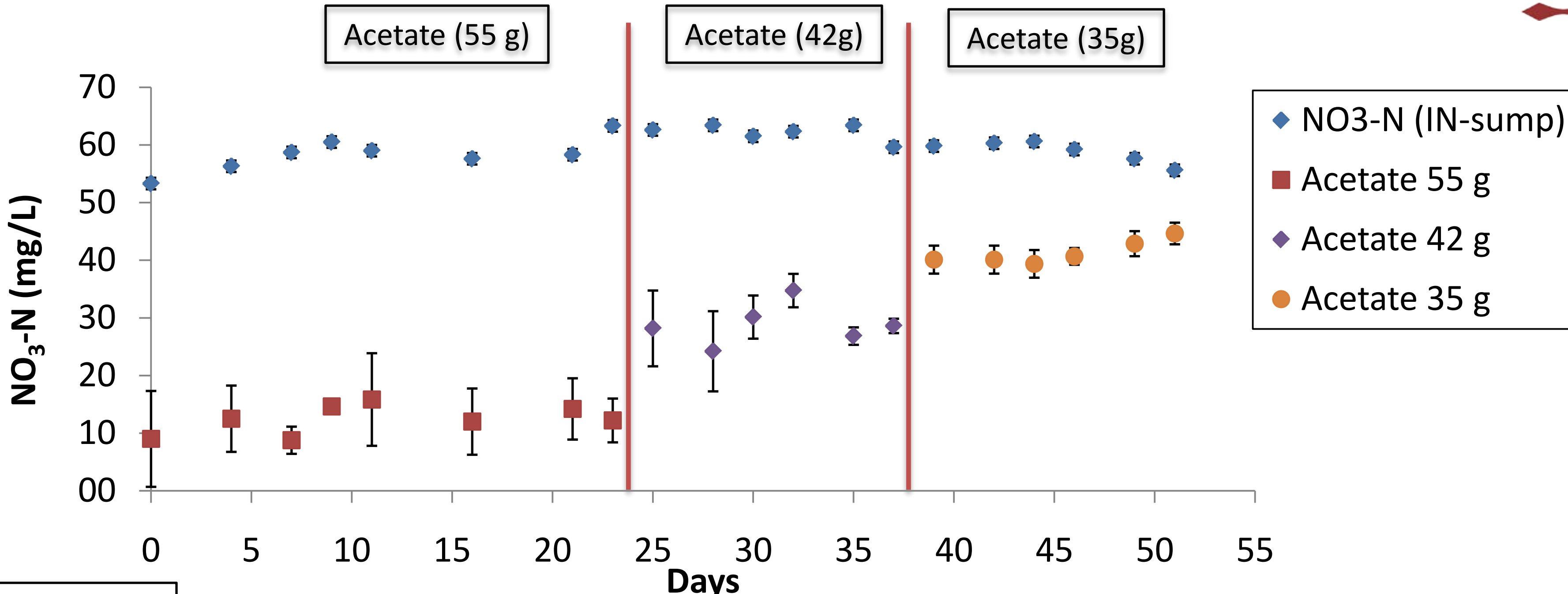
Activated sludge system experiment
(External carbon source)

<u>3 Levels of Carbon</u>

- Acetate 1 = 55 g
- Acetate 2 = 42 g
- Acetate 3 = 35 g

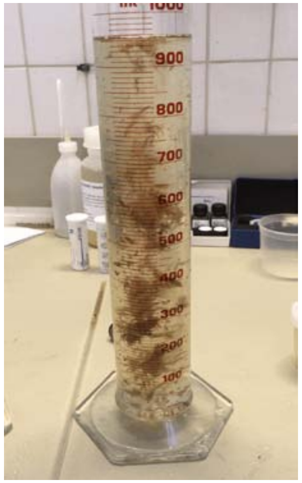


Results: External Carbon Source



n = 3 ± S.D.

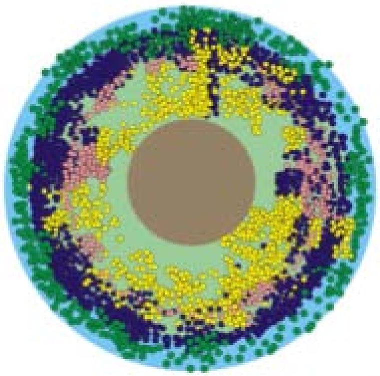
Acetate

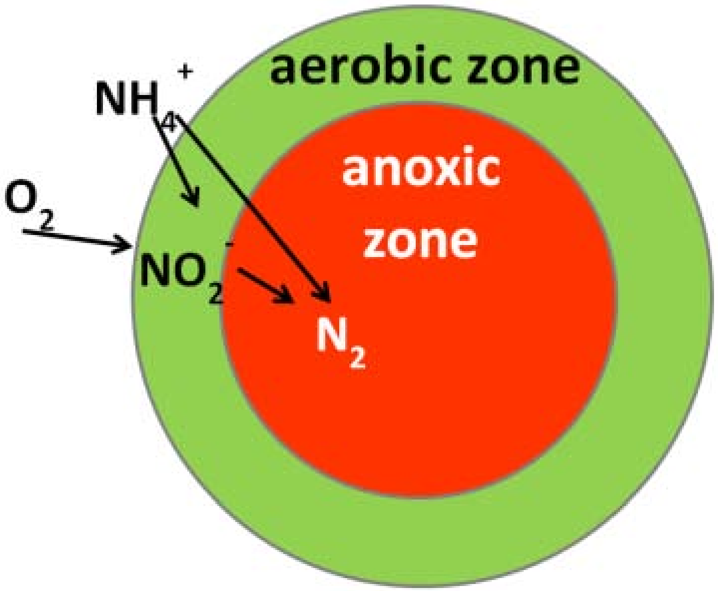


Removal of Total <u>mass</u> discharged

	Acetate (55 g)	Acetate (42 g)	Acetate (35 g)
NO_3-N	**74%**	54%	30%
Organic matter	**46%**	30%	38%
HRT (hours)	3.1 h	3.1 h	3.1 h
VDNR (gNO_3-$N/m^3/d$)	**334**	260	136

Granular sludge



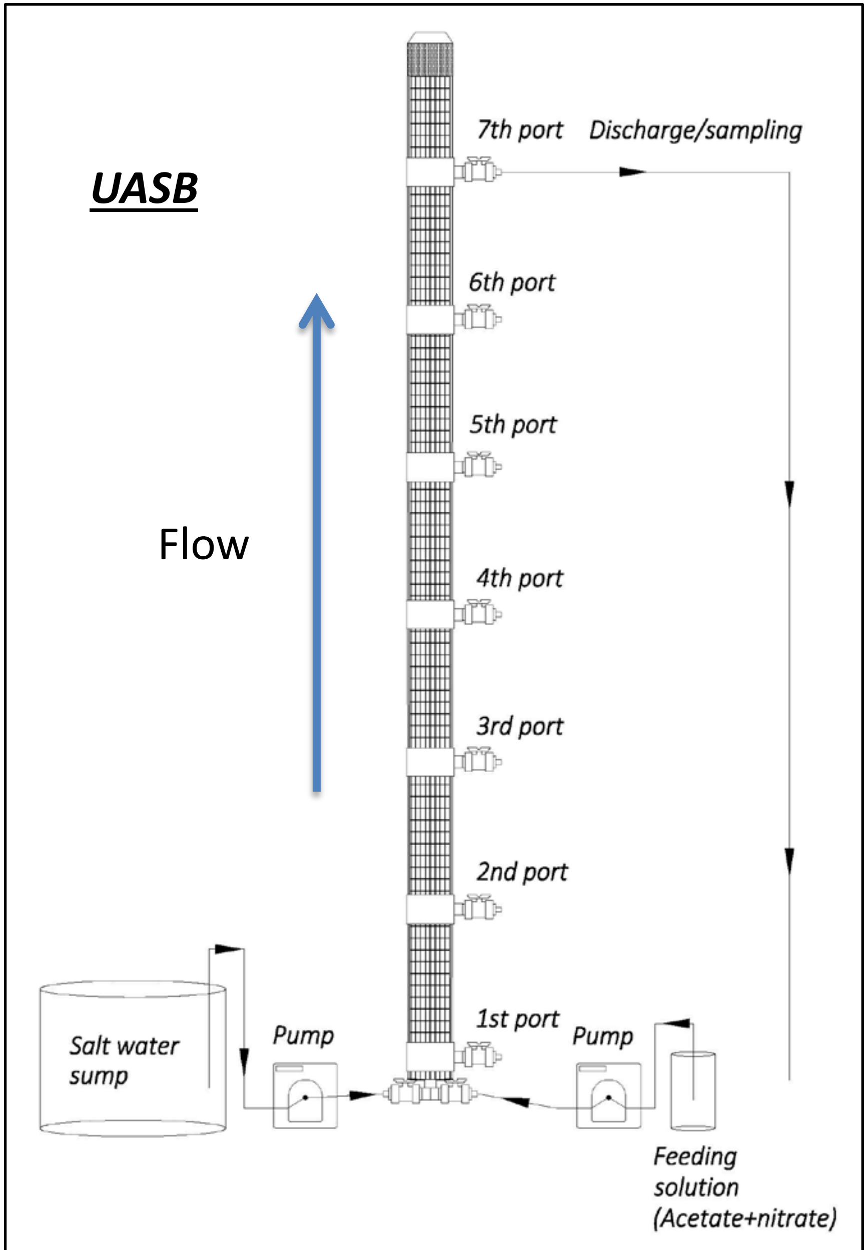


Advantages

No inert carrier required

More biomass in less volume

Simultaneous processes can happen in the same reactor (layers of bacteria)



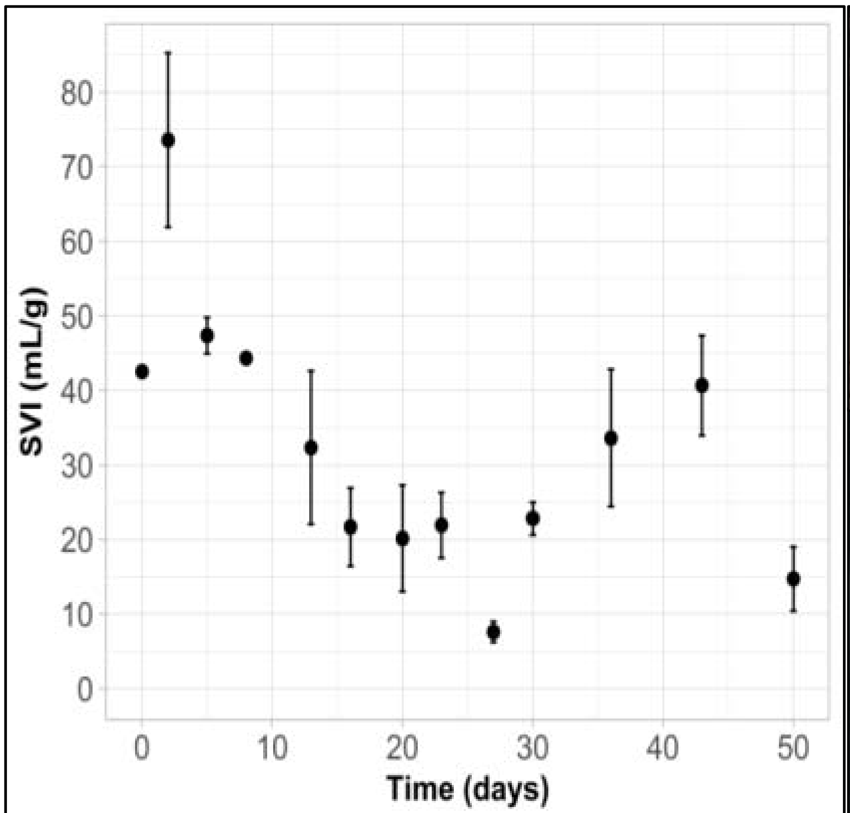
Granular sludge experiment
(External carbon source)

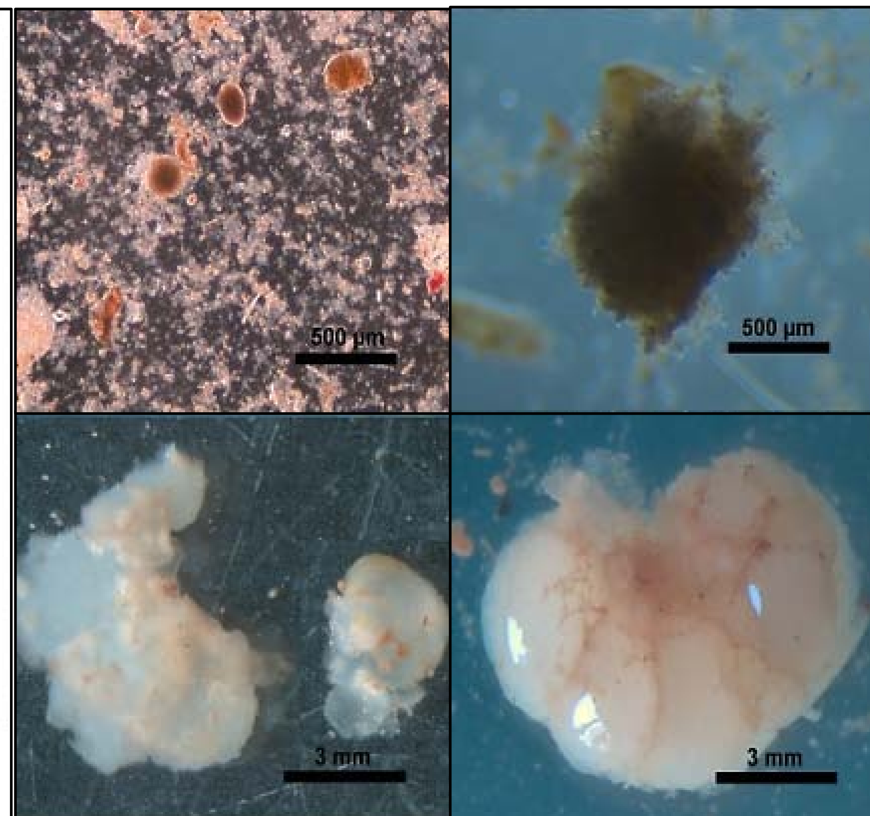
- UASB: Up flow Anoxic Sludge Bed reactor
- An effluent with 100 mg NO_3-N was treated
- Acetate was used as Carbon source (C:N = 6)
- Seven up flow velocities were tested against NO_3 removal in a UASB reactor

Results: Granulation Phase

- A reduction in **S**ludge **V**olume **I**ndex (**SVI**) shows granular formation

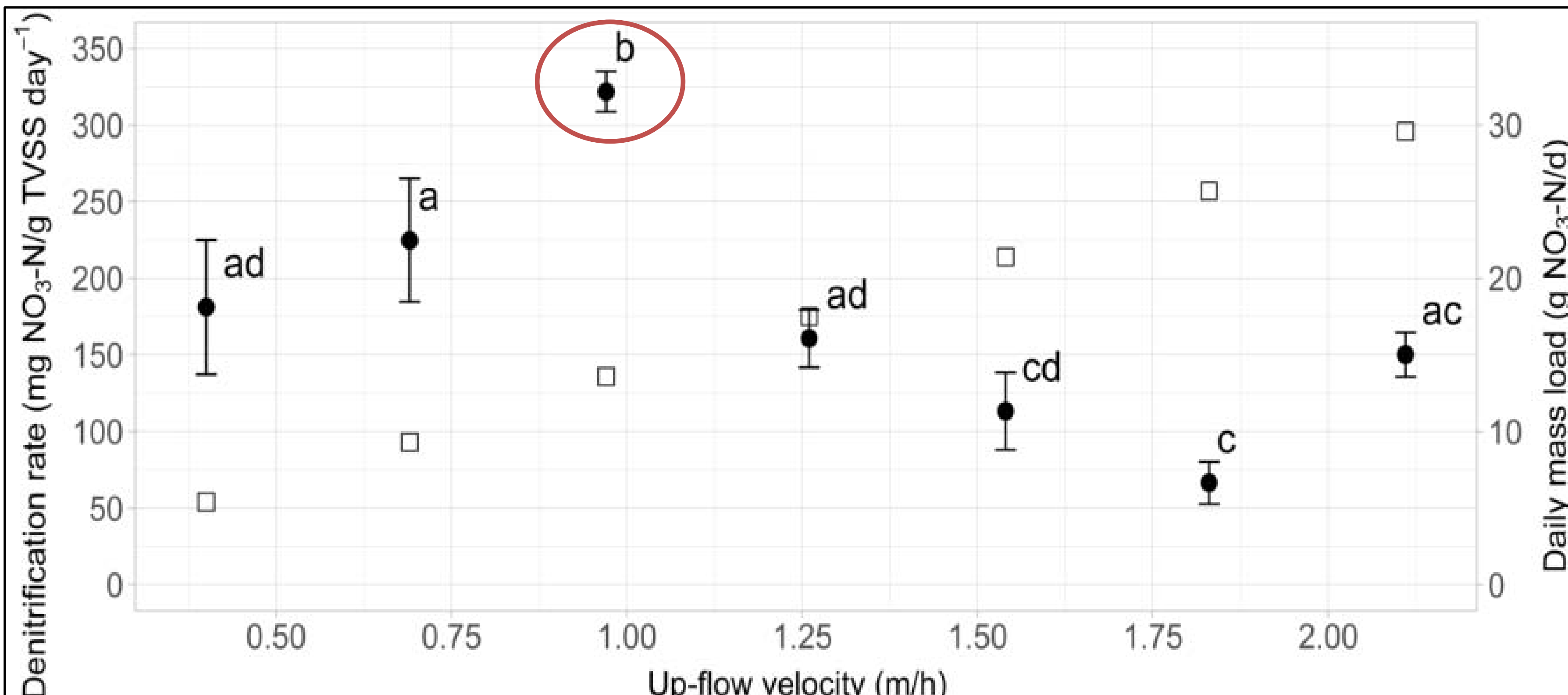
- 50 days took to obtained granules (5-9 mm)





Results: Performance Phase

- Best up flow velocity 3rd (0.95 m/h)
- Denitrification rate: 321 mg NO_3-N/ g TVSS *d^{-1} ; TSS= 40 g/L
- Volumetric denitrification rate: 14.9 Kg NO_3-N/ m^3*d^{-1}



Comparison between N removal technologies

Parameter	**Recirculating Aquaculture System (RAS)**
Daily feeding rate	**3 Ton feed (≈1,000 ton fish /year)**
NO_3-N production	93 kg NO_3-N/d

	Fixed bed reactor	***Activated sludge system (ASS)***	***Granular sludge (UASB)***
Volumetric denitrification rate (gNO_3-$N/m^3/d$)	100-185	334	14,900
HRT (h)	4-5	3.1	1.4
Reactor volume (m^3)	930-501	~278	6.2

3. Phosphorous removal

How coagulants work?

For PO_4:

Phosphate precipitation with aluminum:

$$Al^{3+} + H_nPO_4^{3-n} \leftrightarrow AlPO_4 + nH^+$$

Phosphate precipitation with iron:

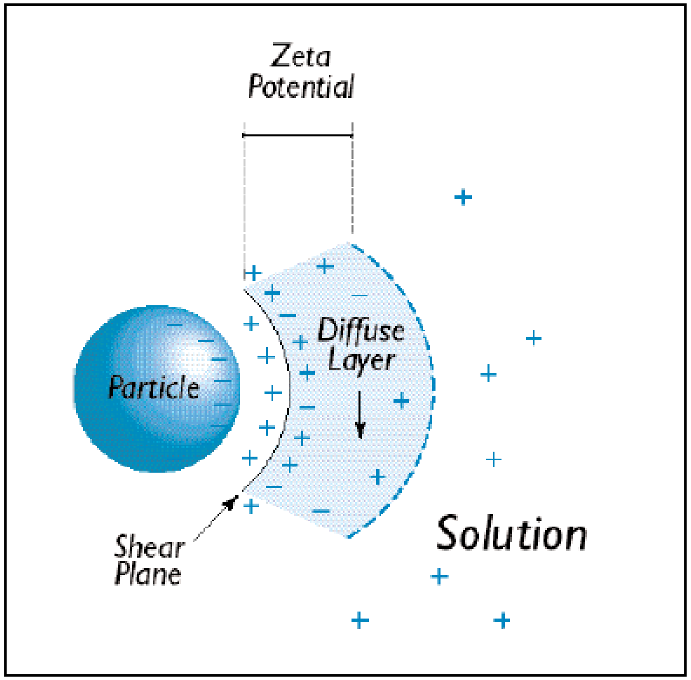
$$Fe^{3+} + H_nPO_4^{3-n} \leftrightarrow FePO_4 + nH^+$$

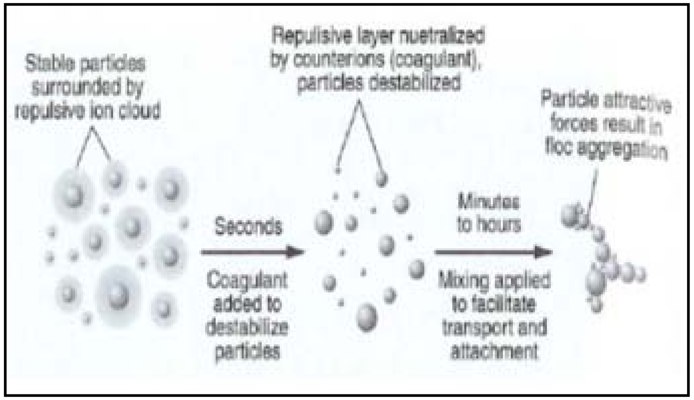
For TSS:

Destabilization of colloidal suspension

- Isoelectric point: **Zeta potential** reduced to 0 (particles agglomerate)
    - Fresh Water: 4 nm
    - Salt Water: 0.4 nm

TSS (Total suspended solids)

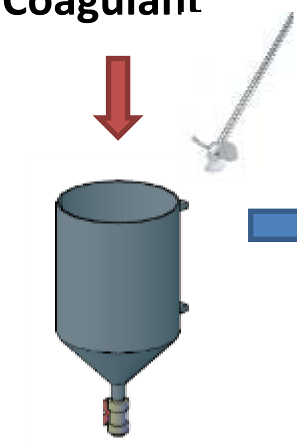




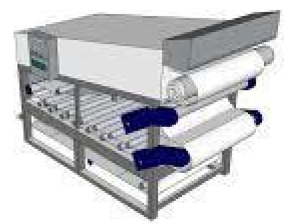
Common precipitation system

Influent Sludge flow (2-3 % DM)

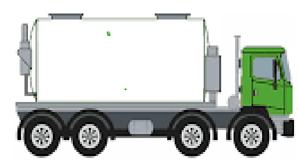
Coagulant



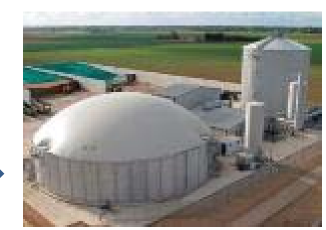
Belt Filter



Waste sludge 25% DM



Biogas Plant



- Removal of P and Organic matter at same time

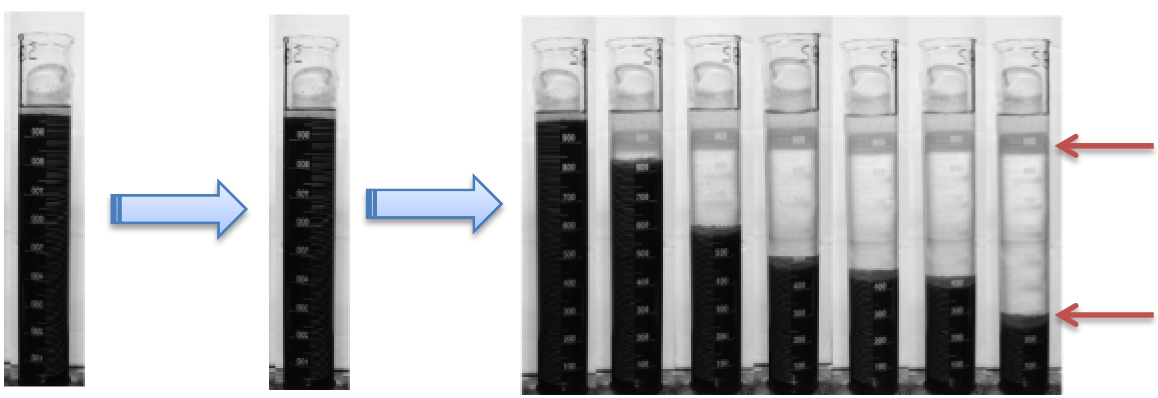
- Organic waste is not accepted in landfills

- Biogas plants pick up the sludge

How do we measure Coagulants efficiency?

Methodolgy applied (Jar test)

1: Flash mix **2: Slow mix** **3: Sedimentation**



Measure
80% height

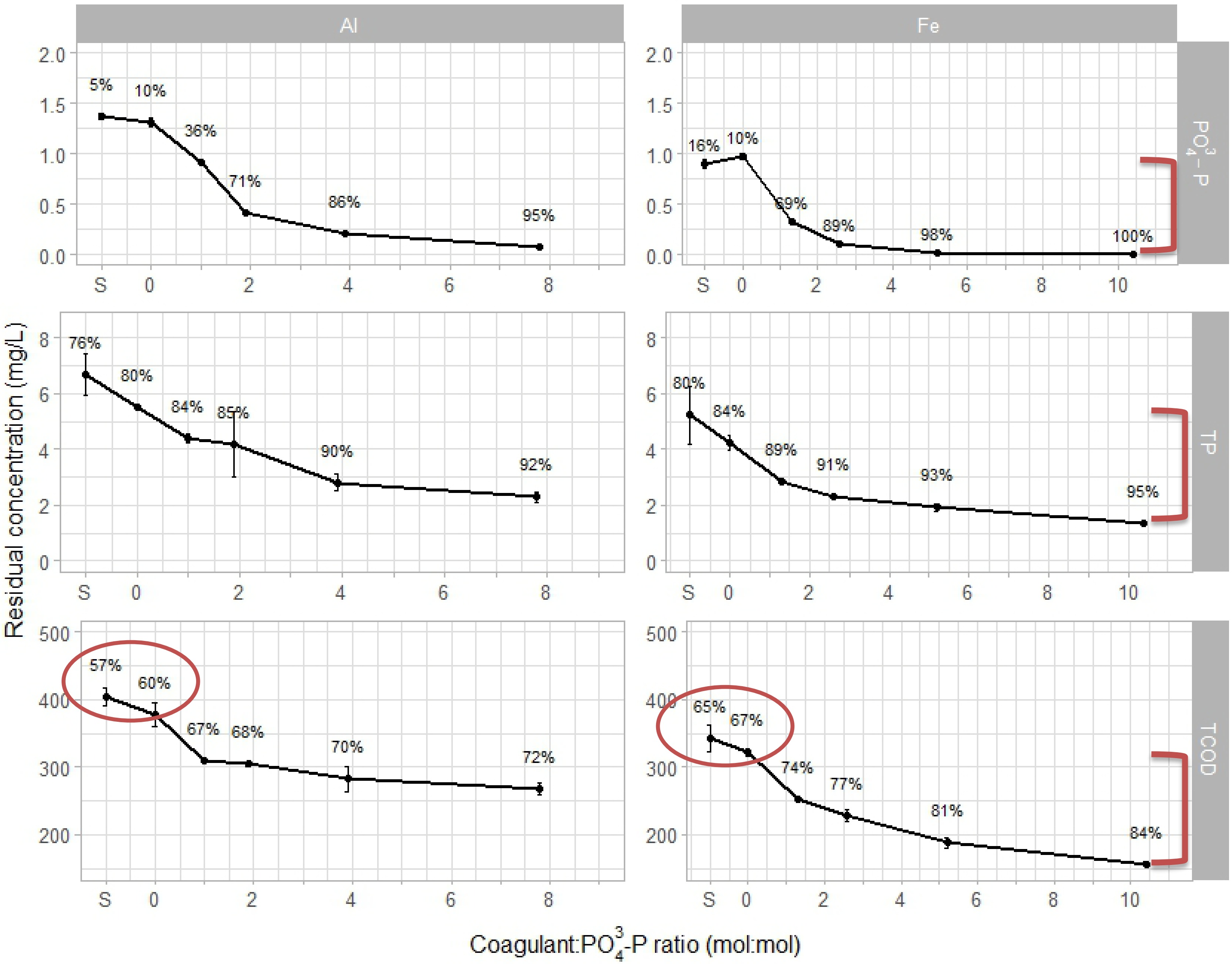
Measure
SSVf
(Settle sludge volume final)

500 rpm 5 min

250 rpm 25 min

Settling: 30 min

Results P removal FeCl III vs $AlSO_4$ (Sludge flow)

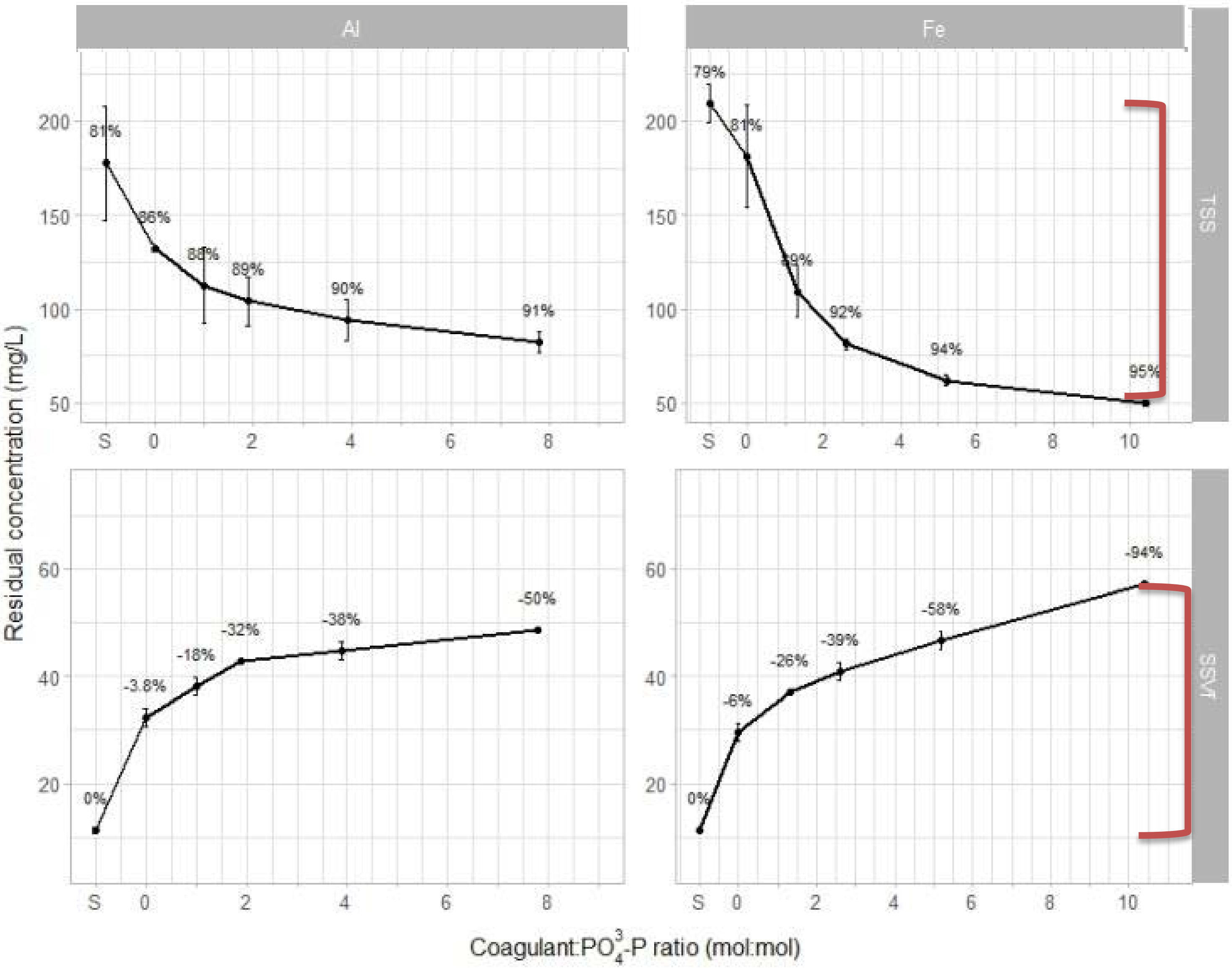


≈80-90% effect PO_4-P

≈15% effect TP

≈20% effect Org. Matter

Results P removal FeCl III vs $AlSO_4$ (Sludge flow)

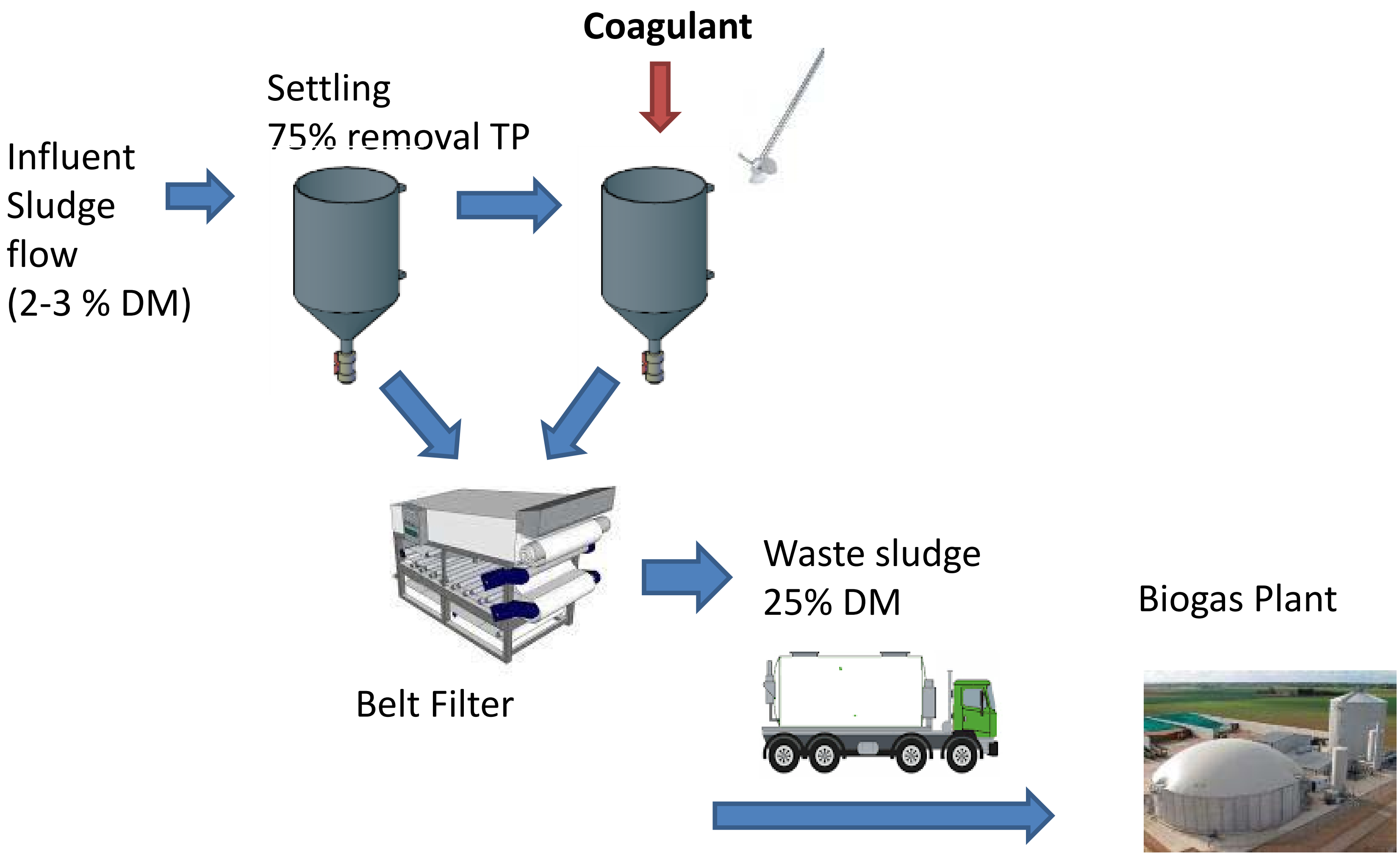


≈15% effect TSS

≈-50-90% Negative effect SSVf -production of sludge-

Next to do:

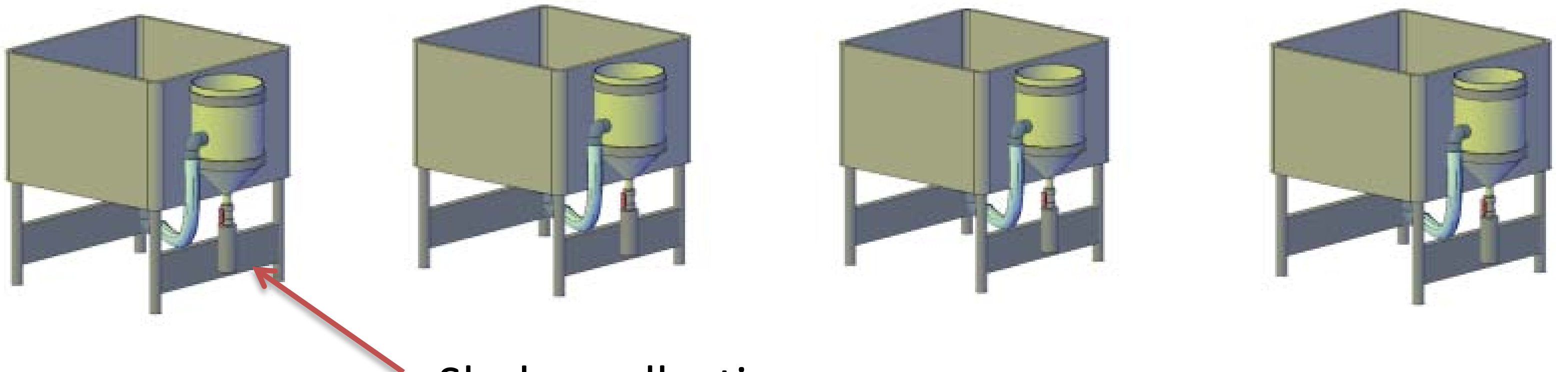
- Leave sludge settle and apply flocculant on effluent
- Reduction on coagulant use
- Needs to be evaluated



Summary P-removal

- ✓ PO_4-P removal depends on coagulant dose
- ✓ Increasing dose increases SSVf (more pronounced with FeCl III)
- ✓ 75% TCOD (organic matter) removal only by settling
- ✓ 68-86 % TP removal only by settling due to more P in solids
- ✓ Low effect on TSS removal using $AlSO_4$ and FeCl III (15% improvement)
- ✓ Between a dose of 2-4 mol:mol (5.6 mg/L FeCl III; 45 mg/L Alum) better and significant results were obtained
- ✓ Iron chloride is recommended over Alum ($AlSO_4$)due to post toxicity and H_2S reduction

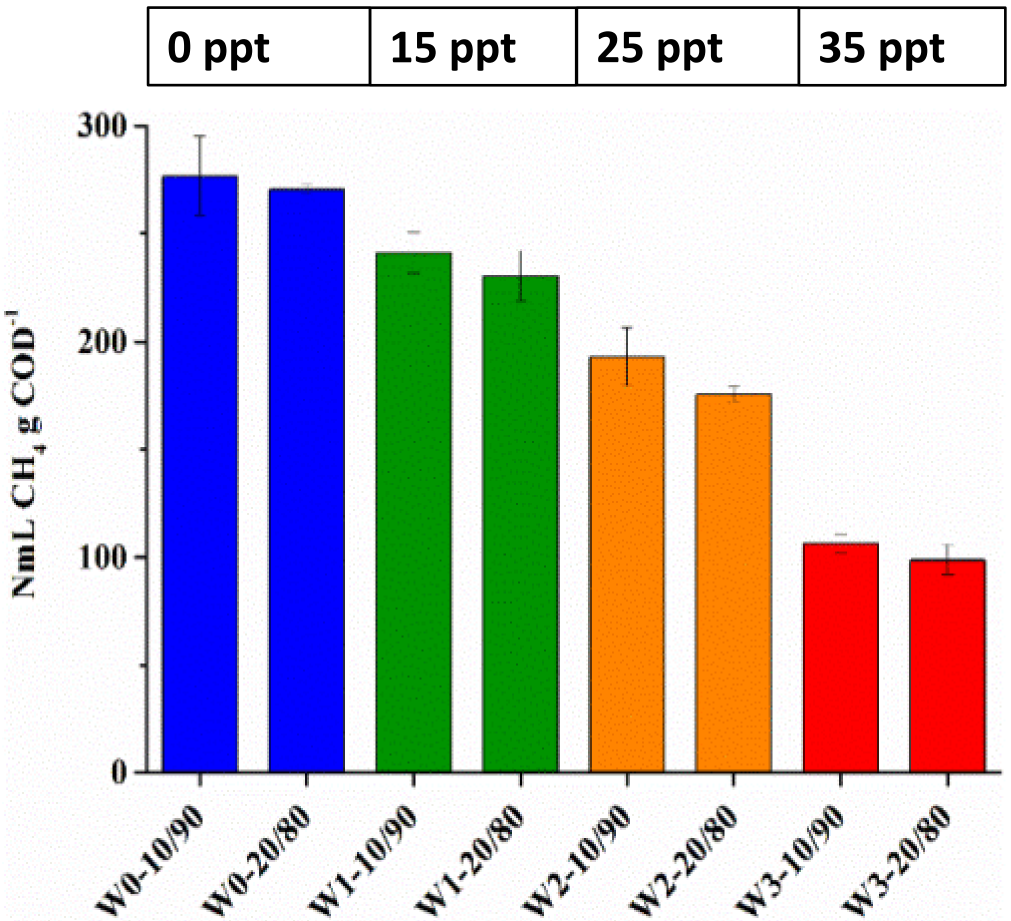
4. Biogas potential at different salinities
(rainbow trout *Oncorhynchus mykiss*)



BMP Method

- Biochemical methane potential assay is performed using rubber closed bottles (118 mL).
- Four different salinities were tested (0, 15, 25 and 35 ppt)
- Methane content is measured constantly using gas chromatography.

Results: Biogas potential at different salinities



- Biogas potential decreases as salinity increases

  (277 → 99 mL CH_4/g COD)

- No inhibition due to TAN

- IC 50 at 5 ppt

- 1 ton feed = 90 m^3 CH_4 ≈ 90 kW*h

- Recommendation:

Safe to codigest saline sludge with non saline sludge at:

  - 10% 15 ppt
  - 6% 25 ppt
  - 4% 35 ppt

Summary: Biogas Potential

- All four wastewaters had an exploitable bio-methane potential.
- Toxicity test revealed that only 5 ppt salinity were enough to inhibit methane production by 50%.
- The overall inhibition of the AD process was the product of the combined inhibitory effect of salinity (main inhibitor), and sulphate reduction (secondary inhibitor).
- It is considered safe to mix 10, 6 and 4% of RAS saline organic waste (15, 25 and 35 ppt) with a salinity-free co-substrate and use it as feedstock in AD reactors.

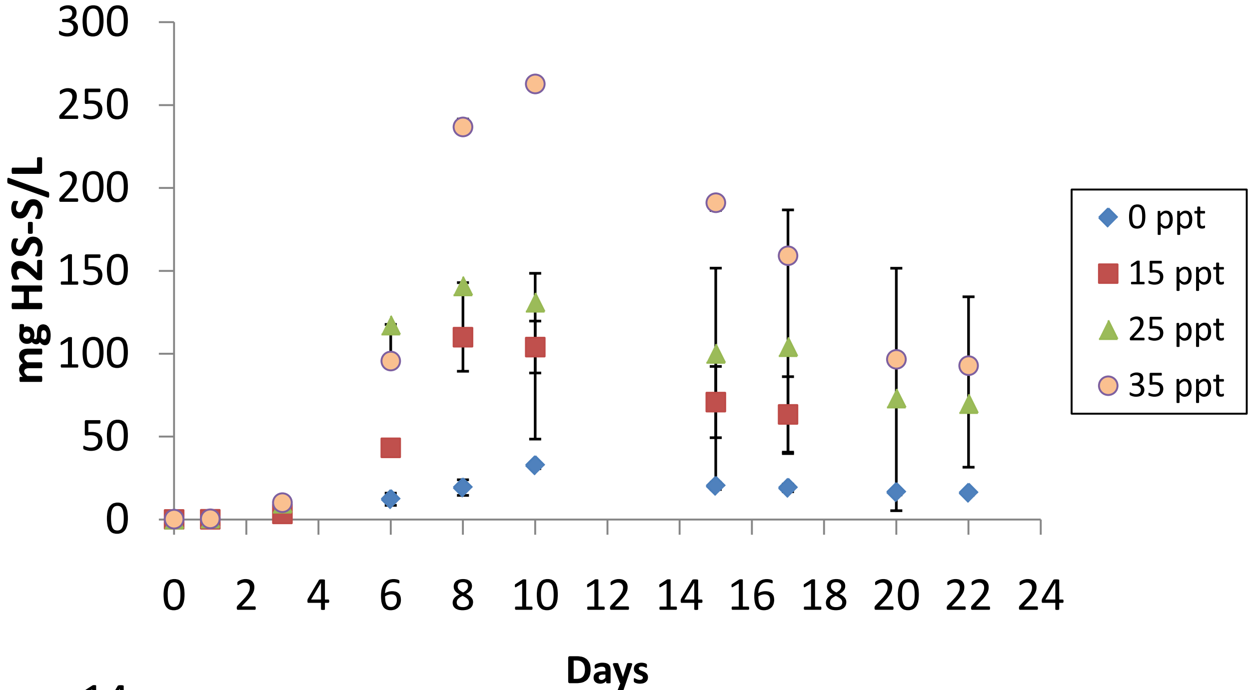
How does salinity relates to H_2S production?

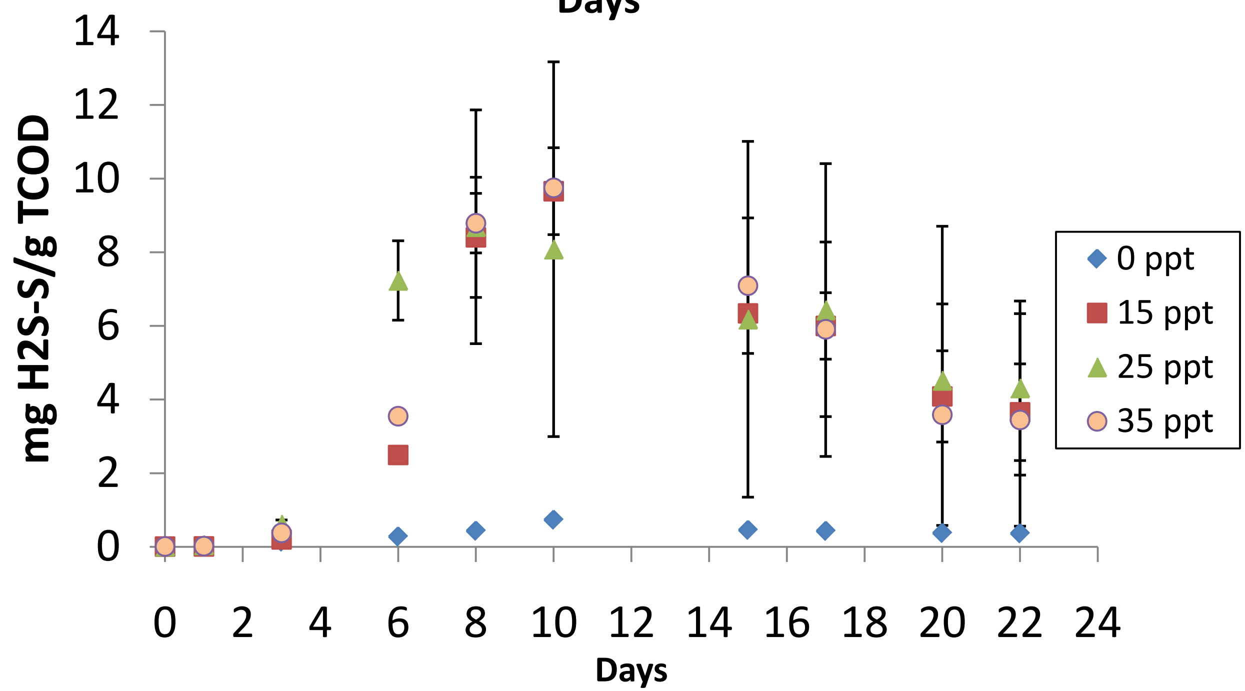
Salt water: 1-2 g/L SO_4

10 mg H_2S/g TCOD

Affects:

- **Denitrification using internal C source**
- **Biogas Production**
- **Bad odor (community)**
- **Kills fish fast**





Final Summary

- There is not an absolute technology, its application depends on the needs (environmental or operational).
- N removal technology (ASS and UASB) demostrated to perform good, the main objetive now is to reduce costs on carbon.
- For P removal aim at the sludge flow, dont overdose.
- Fish organic matter has good biogas potential but is affected by salinity.
- Most important: spend resources on growing the fish.

Thank you for your attention!

Phosphorous

Granules

Biogas potential

This research was funded by The Ministry of Food, Agriculture and Fisheries of Denmark through the project WASTE-TREAT (GUDP 39190) “Cost effective solutions for End-of-pipe treatment in salt water RAS” The technical skills and invaluable assistance of Brian Møller, Ulla Sproegel (DTU AQUA) are highly appreciated.

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