RECENT DEVELOPMENTS IN BIOLOGICAL NUTRIENT REMOVAL

Goudkoppies WWTP, South Africa (1975)

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THE DRIVER OF AS SIZE

- Sludge age (SRT) is defined by slowest growing organisms in AS system.
- These are the autotrophic nitrifiers.
- SRT must be long enough to sustain nitrifiers – this depends on maximum specific growth rate of nitrifiers (μ_{Am20}).
- Once SRT is defined, reactor volume, oxygen demand and clarifier area are defined by organic and hydraulic loads and AS sludge settleability.

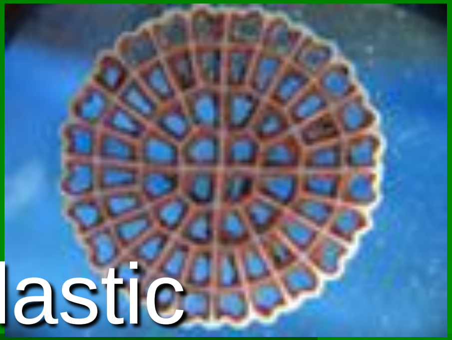
REDUCING AS SIZE

- If nitrification can be achieved at shorter SRT and
- Solid/liquid separation made less sensitive to sludge settleability….
- then AS system size (footprint) and energy consumption can be decreased.
- The pursuit of these two goals have led some remarkable inventions and discoveries in BNR technology.
- No doubt, many more will follow.

BNR DEVELOPMENTS

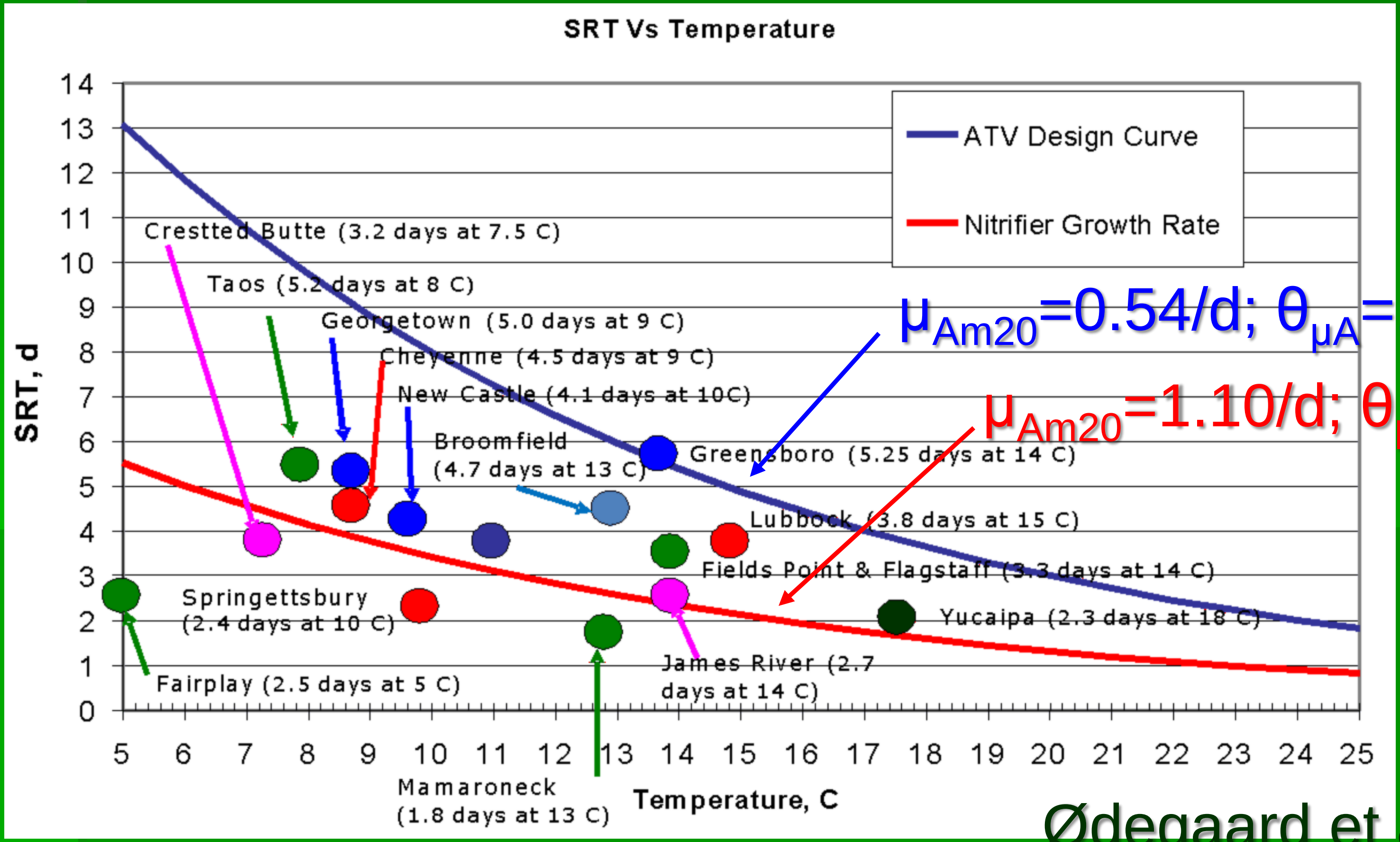
- (1) Integrated fixed film AS (IFAS)
- (2) External nitrification BNR.
- (3) Membrane solid/liquid separation.
- (4) Aerobic granulation AS
- (5) Short circuiting ND “Nitrite shunt”
- (6) Mainstream Anammox.
- These 6 inventions and discoveries will be briefly presented.

(1.1) IFAS



- With integrated fixed film AS, plastic media are added to the aerobic reactor.
- Nitrifiers grow on media and…..
- so are not wasted with surplus sludge.
- This makes suspended sludge SRT shorter than fixed media SRT.
- Nitrifiers are sustained in ND system at suspended SRT < minimum for nitrification.

(1.2) IFAS



μ_{Am20}=0.54/d; $\theta_{\mu A}$=1.145

μ_{Am20}=1.10/d; $\theta_{\mu A}$=1.145

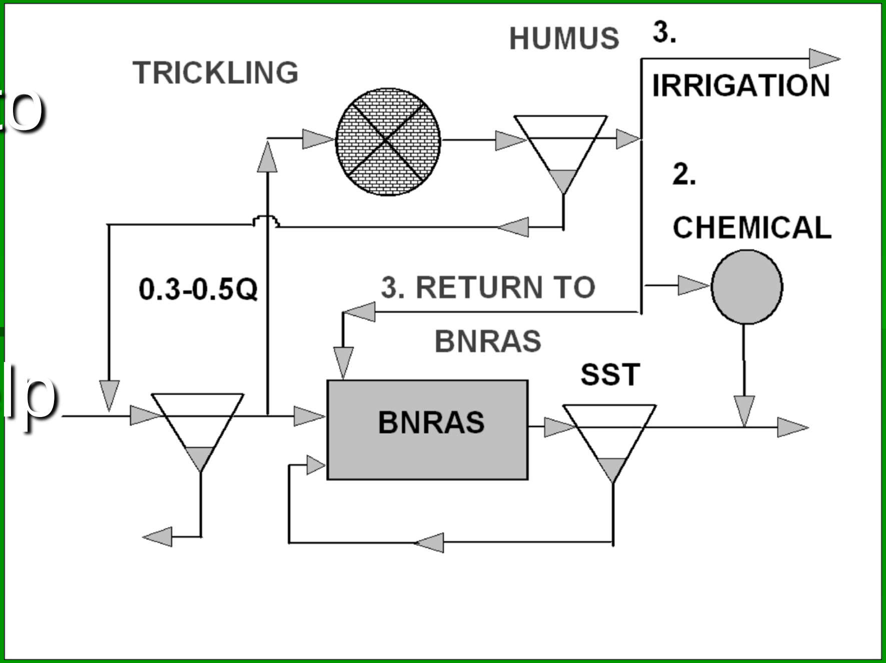
Ødegaard et al (2014)

(1.3) IFAS

- Halving suspended sludge SRT can halve reactor volume or double organic load (depending on WW characteristics)
- And decrease oxygen (energy) demand.

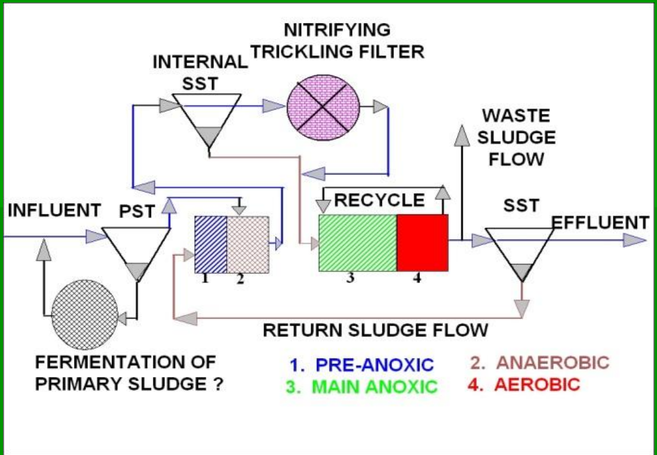
2.1 BIO-FILTER AND BNR PLANTS

- Some WWTP are extended by adding BNR AS to existing trickling filter (TF) plants.
- Discharging TF effluent to AS is NOT GOOD.
- TFs rob AS of strength (organics) and do not help AS with weakness (nitrification).



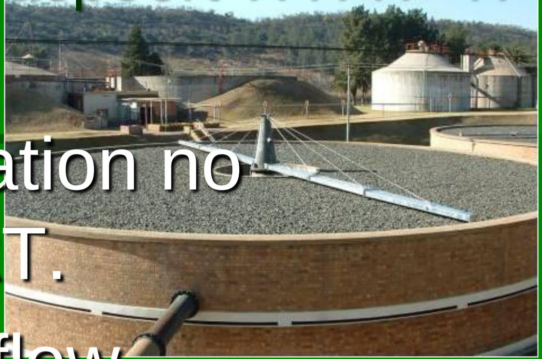
2.2 EXTERNAL NITRIFICATION

- Instead full (settled) WW flow is discharged to anaerobic reactor of BNR for organics removal.
- After anaerobic, solids are separated and returned to AS.
- Supernatant is nitrified on TFs
- And returned to anoxic for denitrification and P uptake.



2.3 WITH EXTERNAL NITRIFICATION…..

Daspoort WWTP TFs



- SRT can be halved to 6-8d - nitrification no longer required – EBPR defines SRT.
- N&P removal achieved on full WW flow.
- Nitrification oxygen demand is obtained “free” in TFs – reduces oxygen demand in BNR.
- Nitrate reduces oxygen demand in BNR also.
- This saves as much oxygen as if 40% WW is bypassed to TFs.
- Demonstrated at full scale (Daspoort WWTP).

3.1 MEMBRANES (MBR)

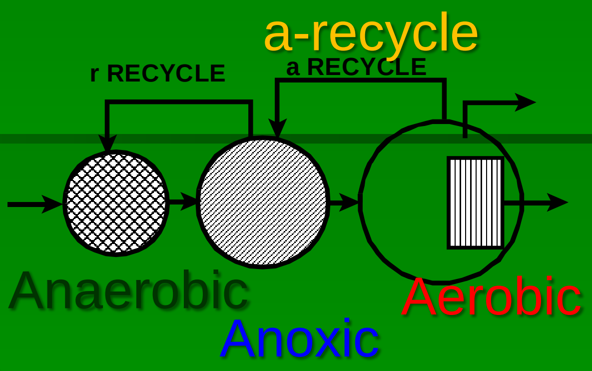
- Membranes replace final clarifiers for solid/liquid separation.
- Membranes are placed in the activated sludge reactor.
- Solid/liquid separation becomes independent of sludge settleability

3.2 MEMBRANES (MBR)

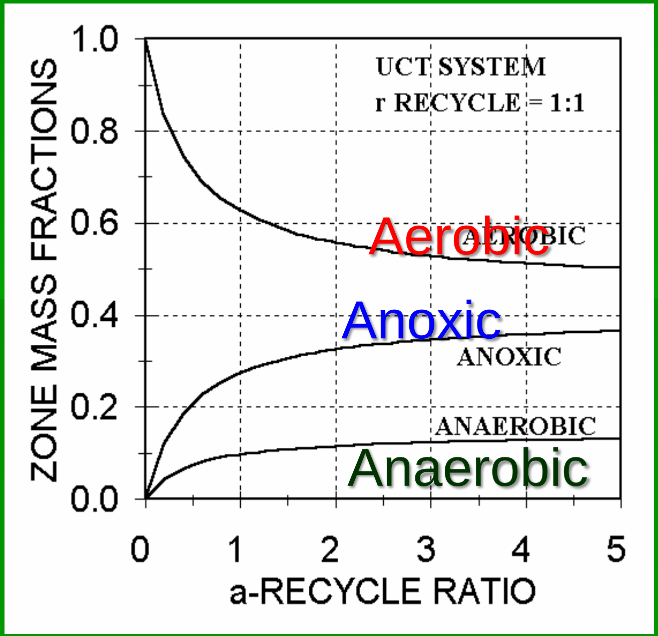
- Insensitivity to activated sludge properties (settleability, flocculation, pin-point floc).
- No longer require clarifiers (less space).
- High reactor conc (8-12 gTSS/l) – smaller biological reactor (less space).
- High quality effluent for reuse - no tertiary filtration.
- Possibly disinfected effluent (0.01um dynamic pore size?).

3.3 MEMBRANES (MBR)

- Variable anaerobic, anoxic and aerobic mass fractions in BNR systems with varying a-recycle ratio.



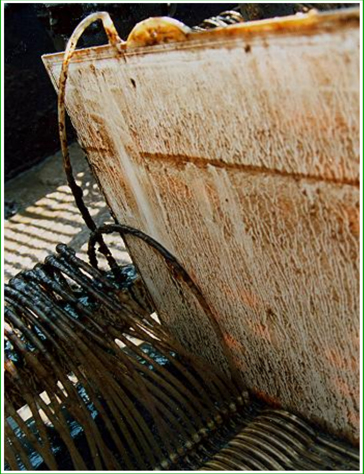
- Increasing a-recycle ratio increasing N removal.



- This flexibility is absent with clarifier BNRs

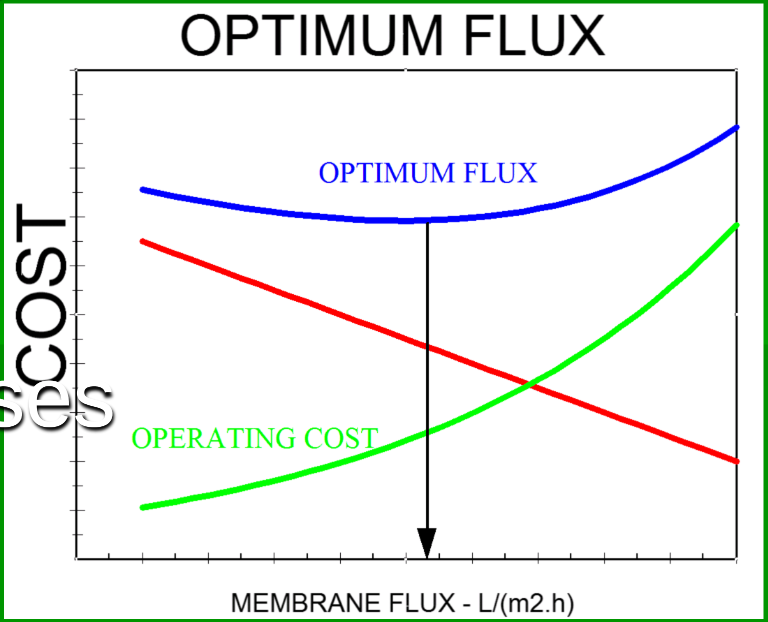
3.4 MEMBRANES (MBR)

- BUT advantages come at a cost!
- (1) Higher aeration energy due to higher alpha value in aeration from higher reactor TSS concentration.
- (2) Controlling membrane fouling
- – the higher the flux, the worse the fouling,
- – the lower the flux, the more membrane area required.



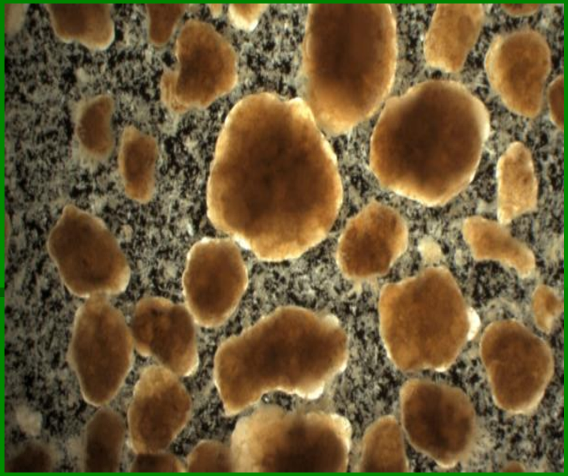
3.5 MEMBRANES (MBR)

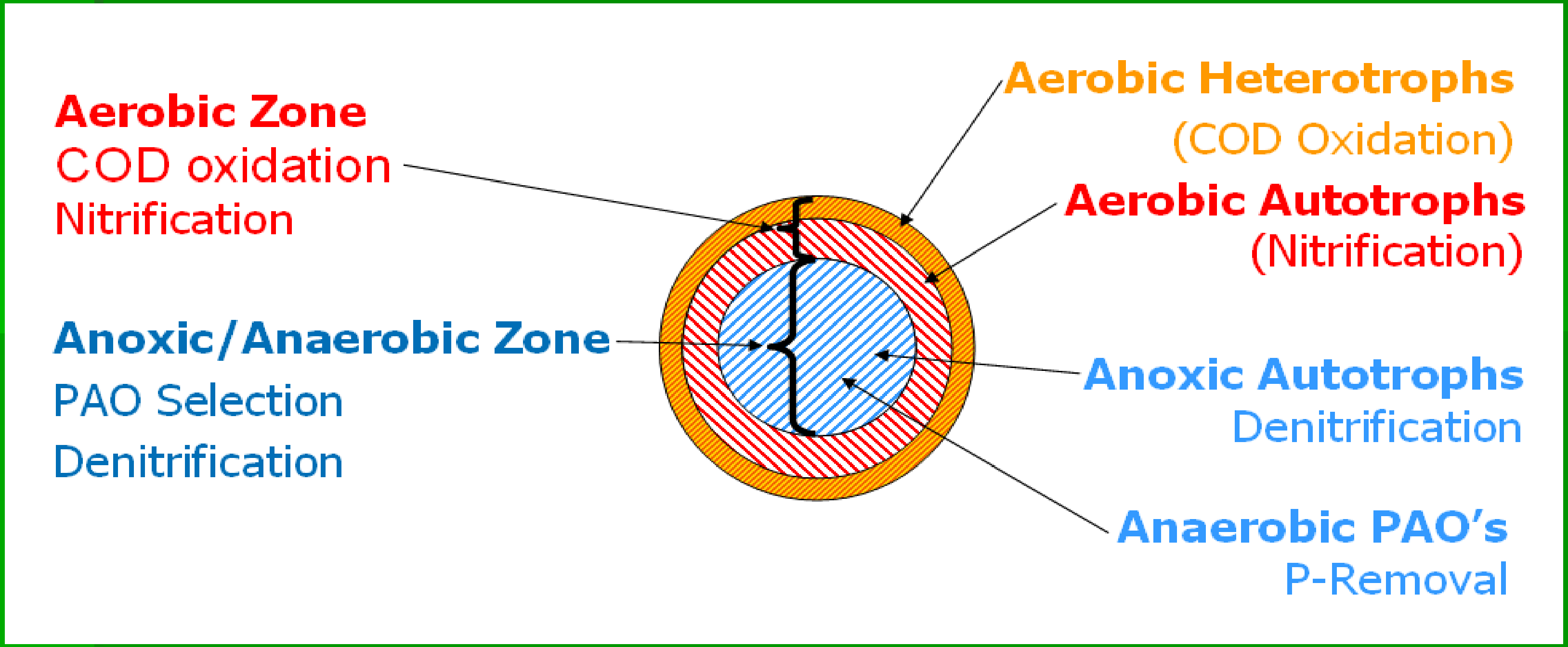
- Design approach is finding optimum membrane flux for lowest total cost.
- As design membrane flux increases, capital cost decreases (fewer membranes)
- But operating cost increases (higher aeration, more cleaning).



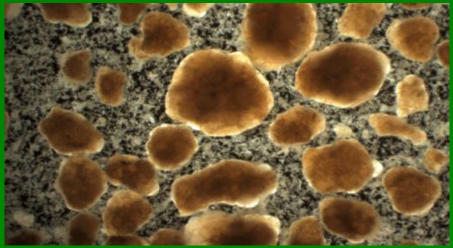
4.1 GRANULAR AS

- By operating AS in a specific SBR mode, it gradually transforms to granules.

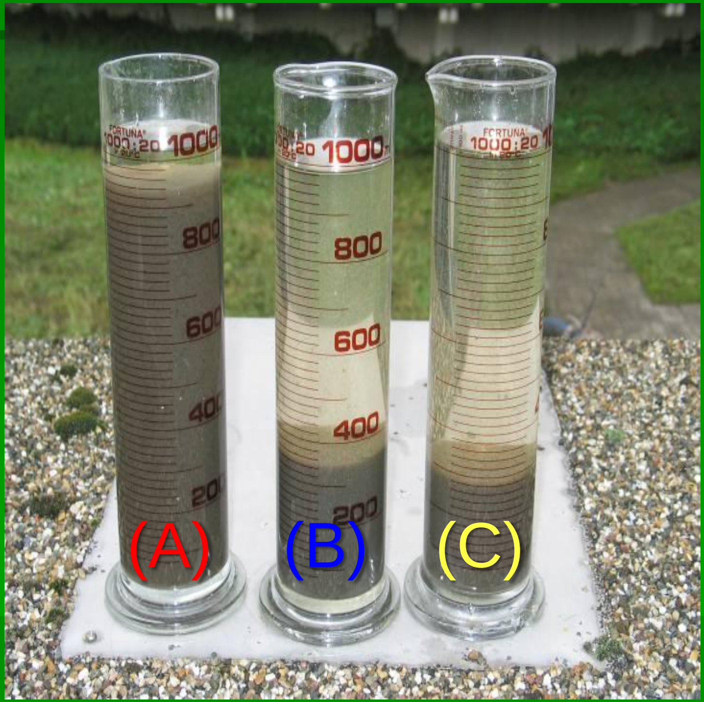




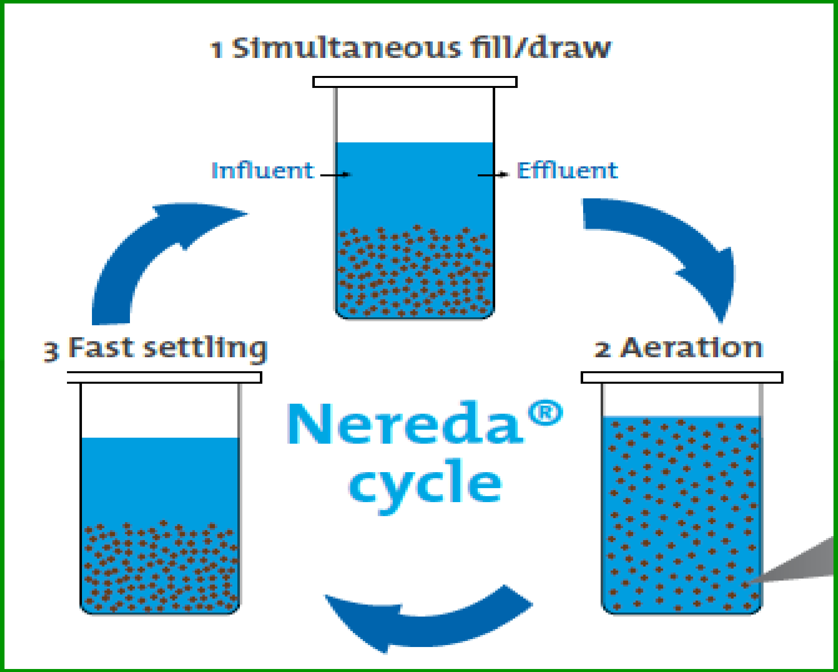
4.3 GRANULAR AS



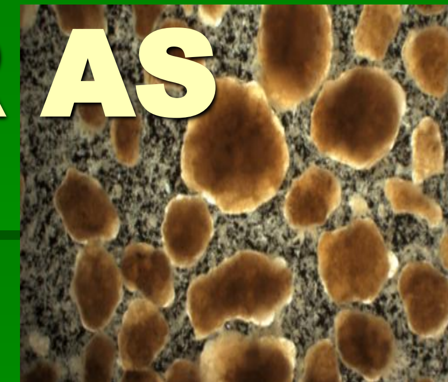
- (1) Simultaneous inflow and overflow.
- (2) Aeration
- (3) Very fast settling.

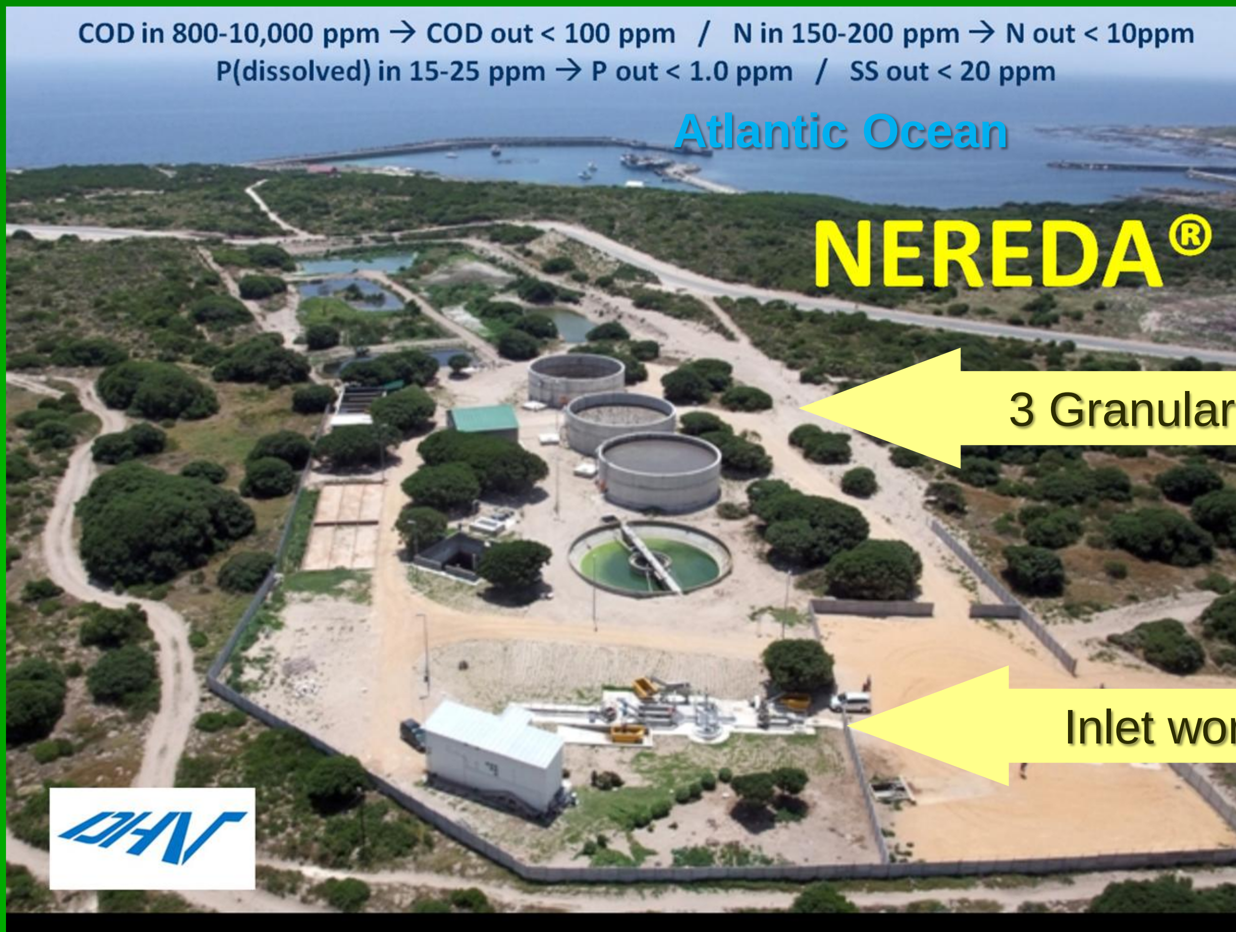


(A) Common AS – 5 min
(B) Granular AS – 5 min
(C) Granular AS – 30 min



4.2 GANSBAAI (SOUTH AFRICA) GRANULAR AS



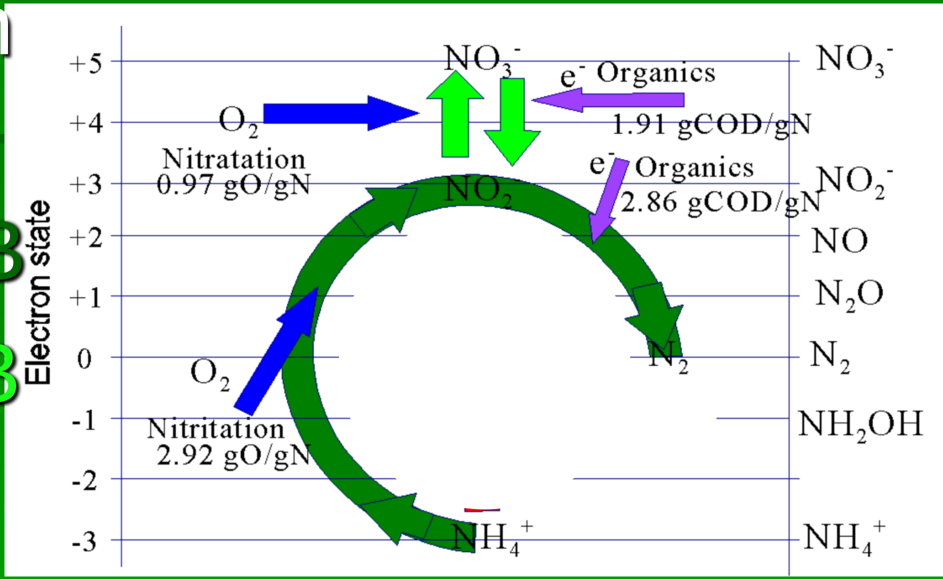


3 Granular EBPR AS reactors

Inlet works (no PSTs)

5.1 NITRITE SHUNT

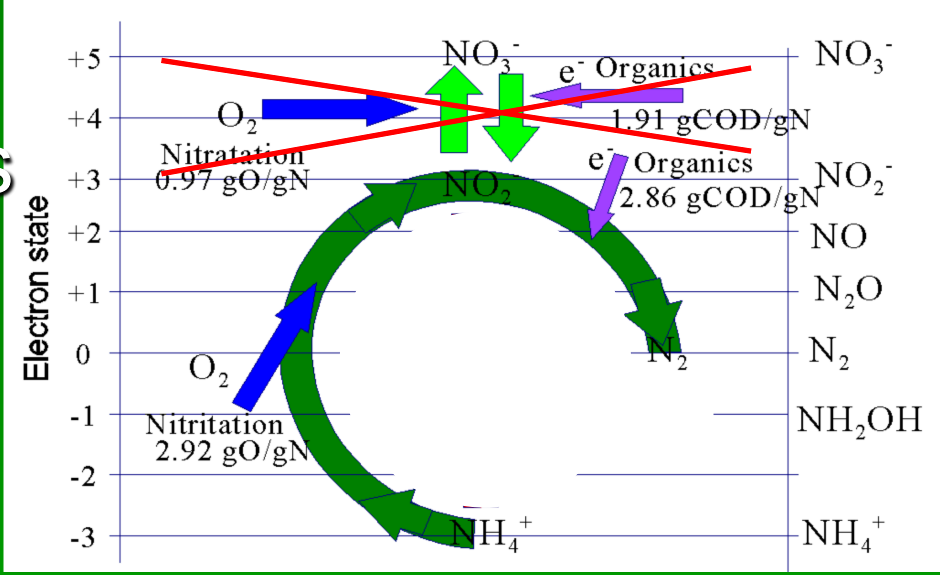
- Nitrification proceeds in two steps:
- 1. NH_4^+ to NO_2^- by AOB
- 2. NO_2^- to NO_3^- by NOB
- Need 3.0 & 1.0 gO/gN



- Denitrification also proceeds in two steps:
- 1. NO_3^- to NO_2^- by FHO; needs 2gCOD/gN
- 2. NO_2^- to N_2 by FHO; needs 3gCOD/gN

5.2 NITRITE SHUNT

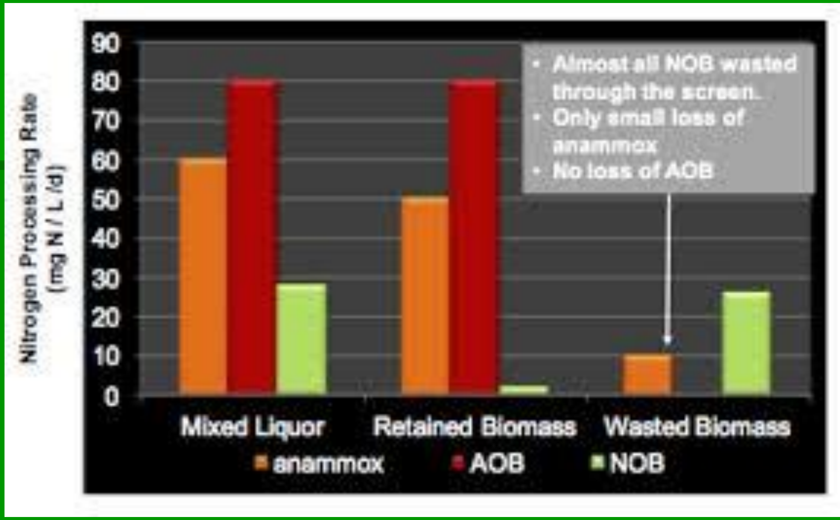
- If NOBs (Step 2) can be stopped, ND takes place over NO_2^-.
- ND over NO_2^- saves:
- 1 gO/gN nitrified and
- 2 gCOD/gN denitrified.



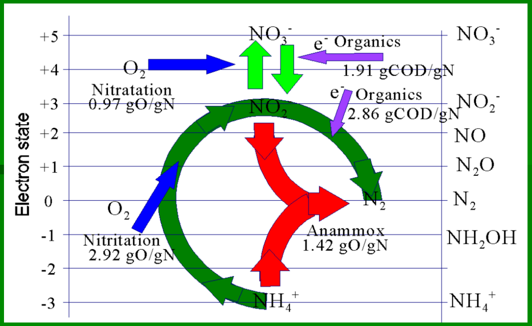
- Suppressing NOBs in reject water treatment is well understood, but replicating these conditions in mainstream ND is challenging,
- BUT, who knows, soon it may be standard.

5.3 NITRITE SHUNT

- Size and density differences between organism flocs/granules/groups are more important than differences in kinetic rates.
- Carefully sized screens can retain anammox and AOBs but waste almost all NOBs.



6.1 MAINSTREAM ANAMMOX

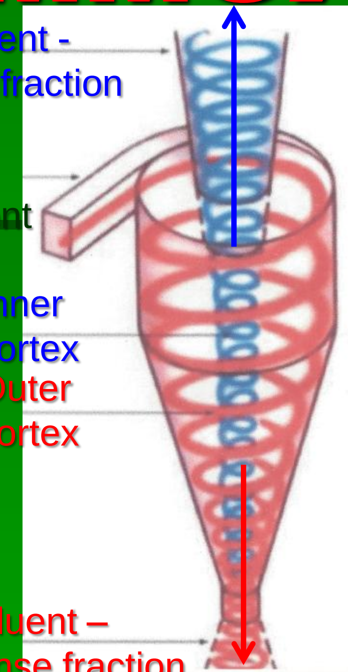


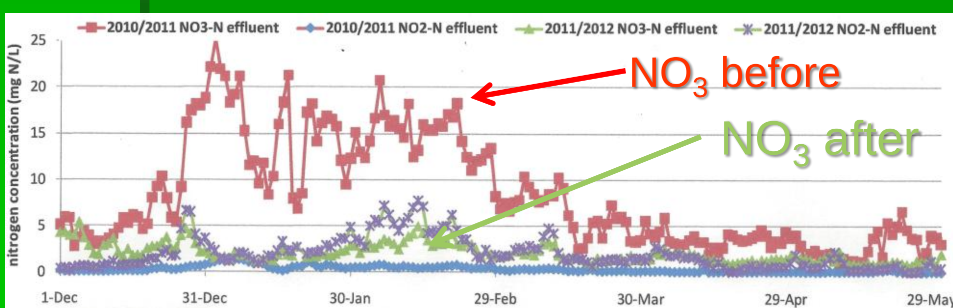
- Anammox (ANX) bacteria use NH_4^+ as e^- donor and NO_2^- as e^- acceptor forming N_2 gas.
- ANX have been successfully exploited for N removal from high N wastewater like AD reject water.

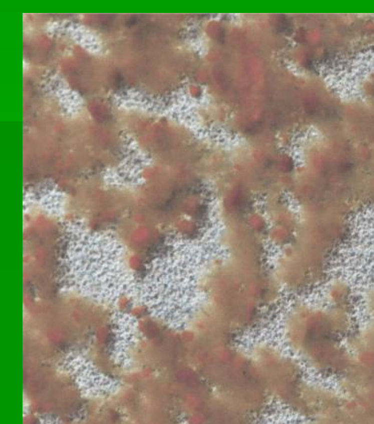
- ANX can grow in granules which are denser than activated sludge.
- ANX accumulate in aerobic granular AS.

6.2 MAINSTREAM ANAMMOX

- Because ANX accumulate in the dense fraction of AS, they can be concentrated in BNR systems with hydro-cyclones and wasting the light fraction of the WAS.







Wett et al (2013) www.essdemon.com/libraries.files/Vancouver_Mainstream_Deammonification_Wett2.pdf

7.1 OTHER INVENTIONS

- Inventions outside the BNR system:
- (1) Source separation of urine - without urine, N conc in WW decrease 80%, P conc 50% and micropollutants ~60%.
- This is low enough to not require ND.
- (2) Seawater toilet flushing and the SANI system – **S**ulphate reduction **A**utotrophic denitrification **N**itrification **I**ntegrated developed here in Hong Kong.

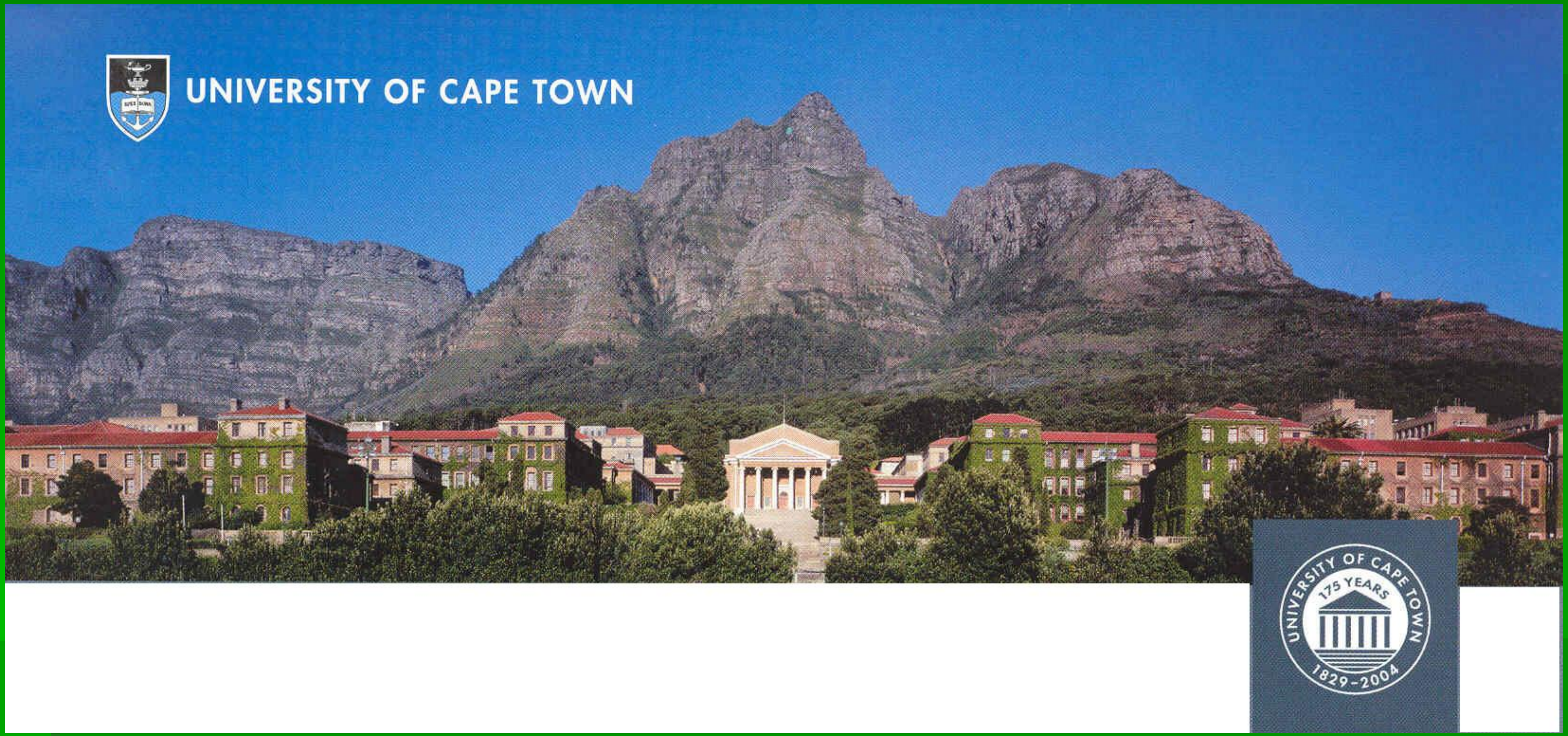
7.2 CLOSURE

- Briefly presented six inventions and discoveries within BNR activated sludge that make footprint of this global workhorse of WWT smaller and more sustainable.
- (1) IFAS, (2) external nitrification, (3) MBR, (4) Granulation; (5) nitrite shunt and (6) mainstream anammox.
- These operate in freshwater BNR systems, but work is starting to see impact of salinity.

7.3 CLOSURE

- Which of these six do I think has the strongest future?
- I think……
  - (4) Granulation and
  - (6) Mainstream anammox
- Granulation offers similar space saving as MBR without membranes and lower energy consumption.
- Mainstream anammox is easy to add to existing BNR plants.

ACKNOWLEDGEMENTS



- University of Cape Town for giving me leave to be here.
- Conference organizers for inviting me.