

Compact wastewater treatment with MBBR

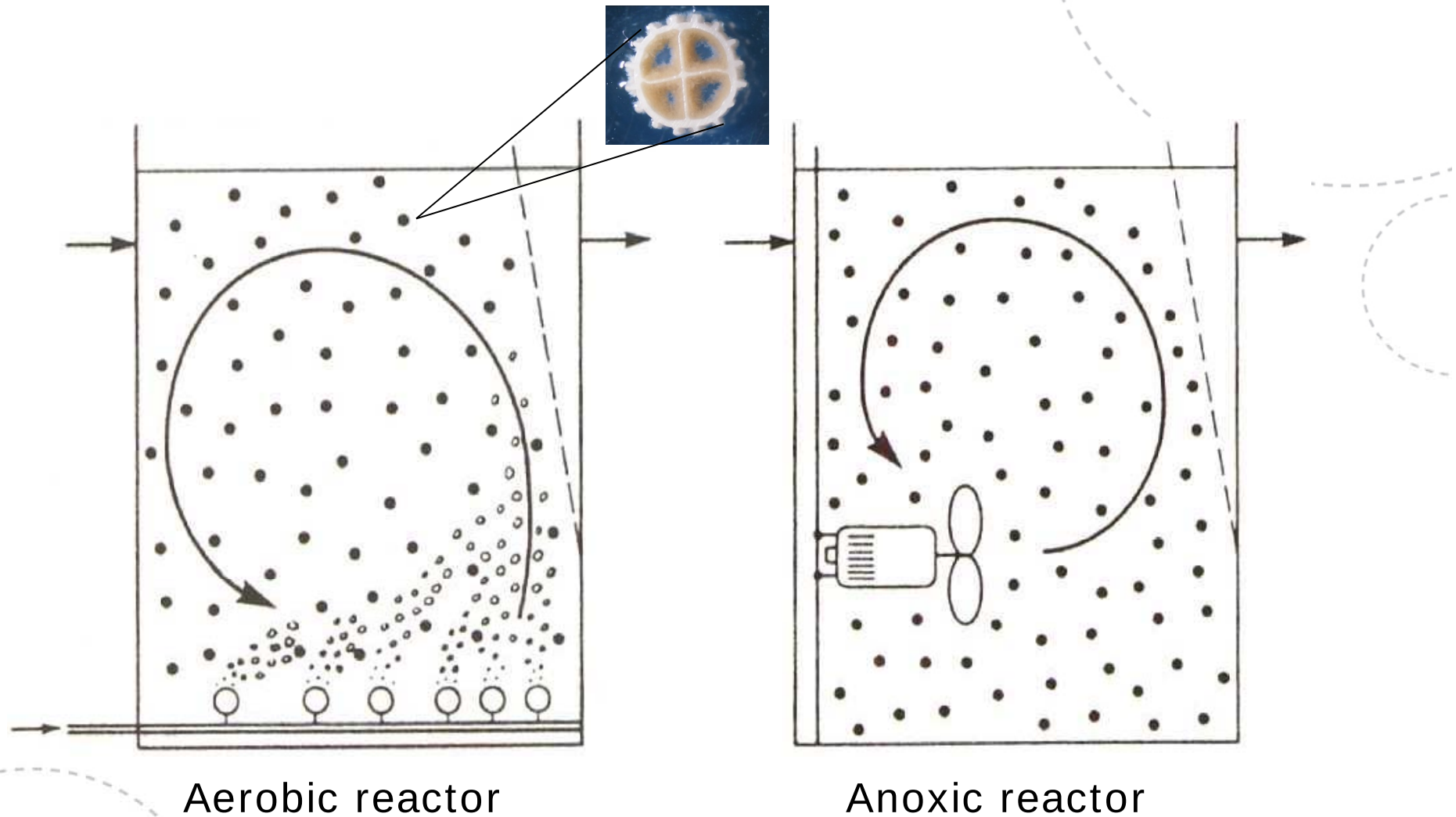
Hallvard Ødegaard

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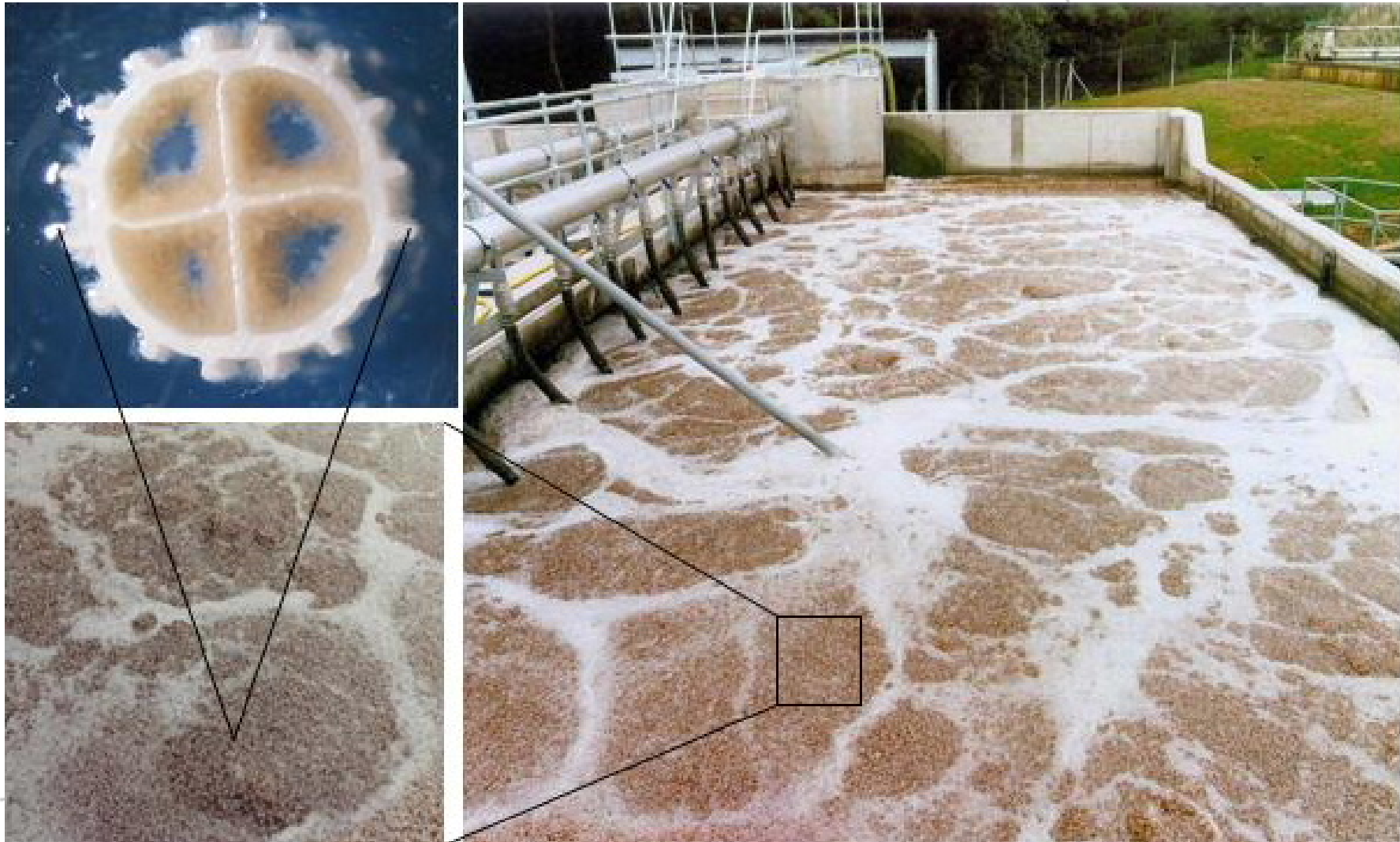
hallvard.odegaard@ntnu.no

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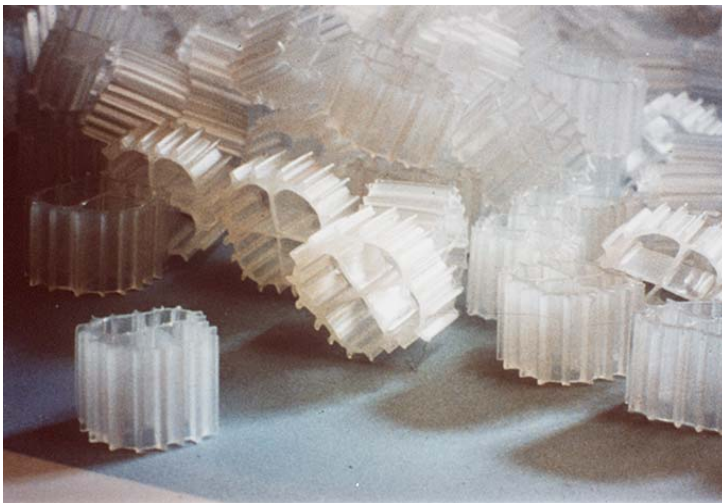
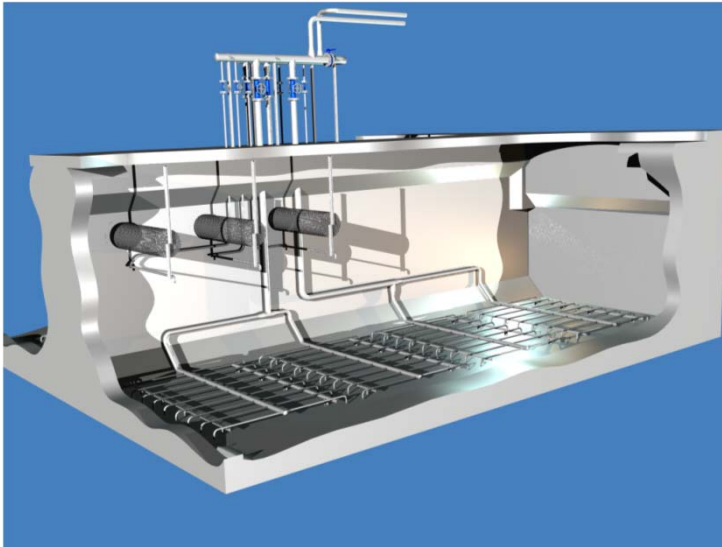
The principle of the moving bed biofilm reactor (MBBR) technology



The Moving Bed Biofilm Reactor (MBBR) in practice



The components of the MBBR treatment system



THE MAJOR COMPONENTS

- a) Tank
- b) Media
- c) Aeration System
- d) Sieve Assemblies
- e) Blowers
- f) Mixers

Carrier filling fraction (%)
(bulk volume occupied by media
in empty reactor):

Possible filling fraction: 0 – 70 %

Normal filling fraction: 50 – 65 %

The MBBR reactor

Rectangular/Circular open concrete reactors



Rectangular covered concrete reactors



Circular Steel Reactors (Bolted or Welded)



Circular fiber glass reactors



The (MBBR) carriers



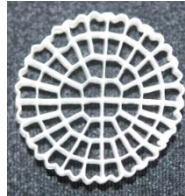
- 500 m²/m³ bulk
- 9.1 x 7.2 mm diameter/depth

K1



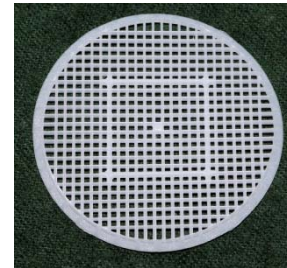
- 500 m²/m³ bulk
- 25 x 10 mm diameter/depth

K3



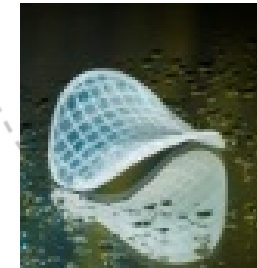
- 800 m²/m³ bulk
- 25 x 3.5 mm diameter/depth

K5



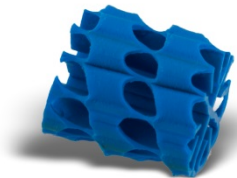
- 1200 m²/m³ bulk
- 48 x 2.2 mm diameter/depth

BiofilmChip M



Z-MBBR

Courtesy AnoxKaldnes



- 650 m²/m³ bulk
- 13 x 13 mm diameter/depth

ABC

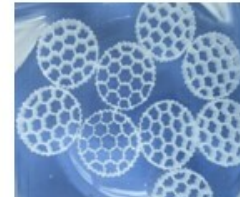
Courtesy Aqwise



- 650 m²/m³ bulk
- 18.5 x 14.5 x 7.3 mm length/width/depth

BWT S

Courtesy Biowater Technology



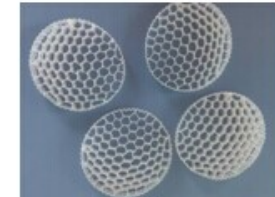
- 620 m²/m³ bulk
- 25 x 10 mm Diameter/depth

SPR-2



- 800 m²/m³ bulk
- 25 x 4 mm Diameter/depth

SPR-3



- 1200 m²/m³ bulk
- 36 x 4 mm Diameter/depth

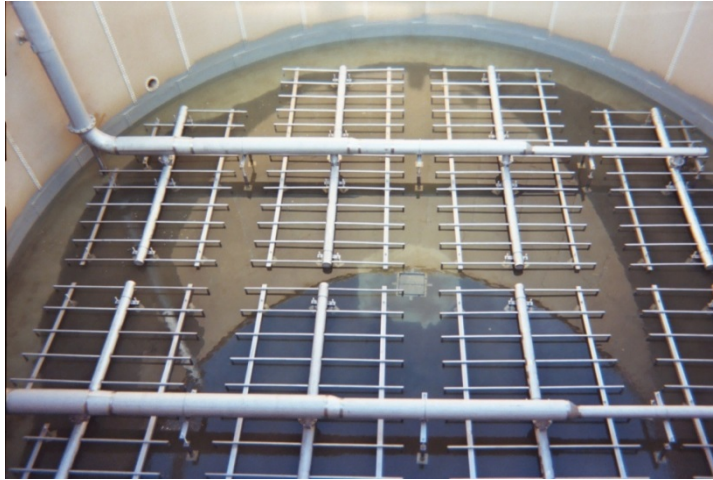
SPR-4

Courtesy Qingdao Spring

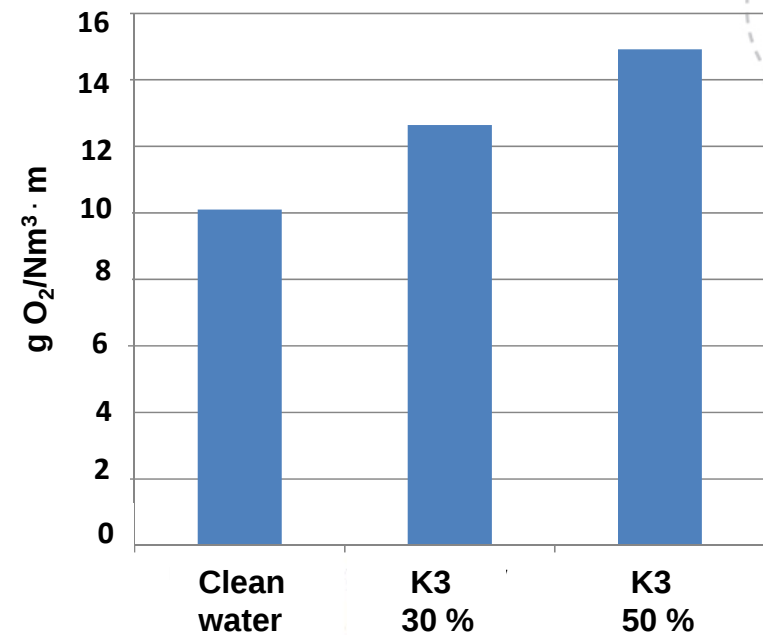
Carriers from the MBBR-based SANI pilot at Shatin



Aeration /oxygen transfer



- Oxygen transfer is enhanced by the presence of carriers
- The higher the filling fraction, the better SOTR
- Influence dependent on carrier design. Suppliers should provide SOTR data



Christensson, 2013

The sieve assembly

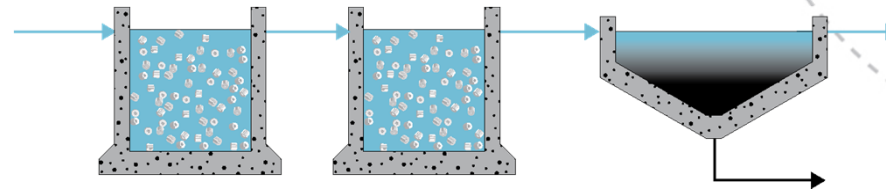


The mixers in anoxic reactors

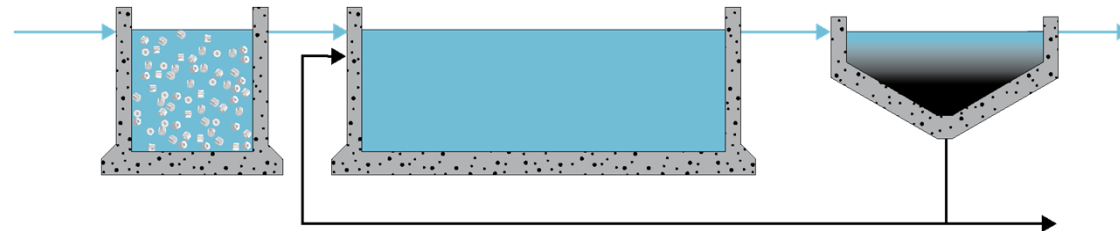


The principal moving bed reactor processes

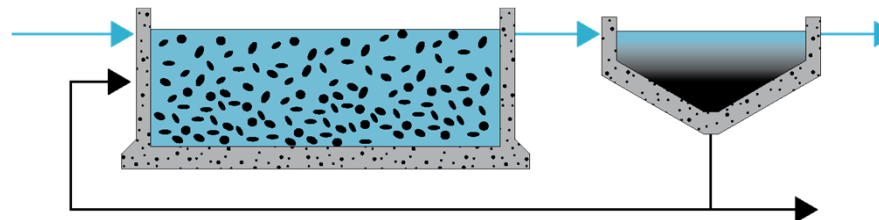
The basic MBBR processes



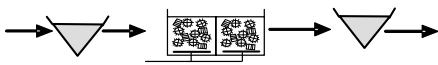
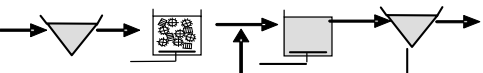
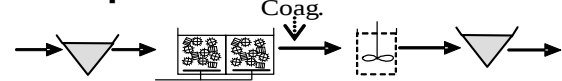
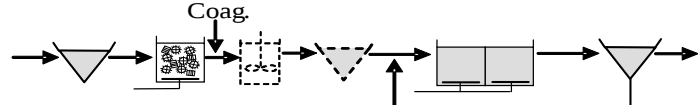
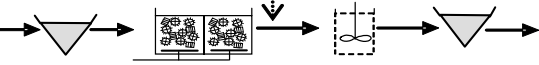
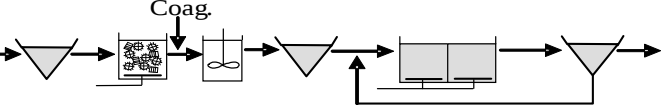
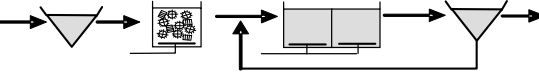
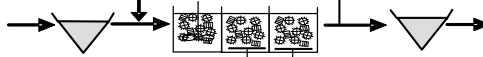
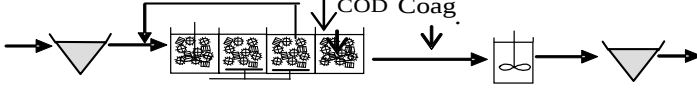
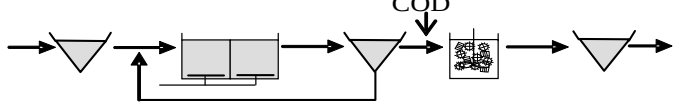
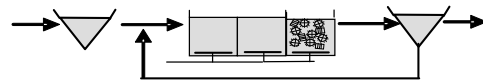
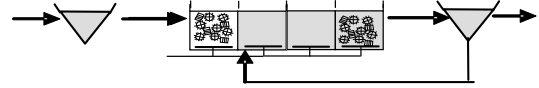
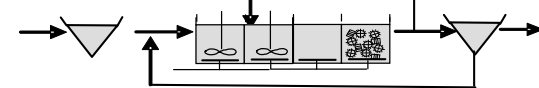
The high-rate MBBR processes



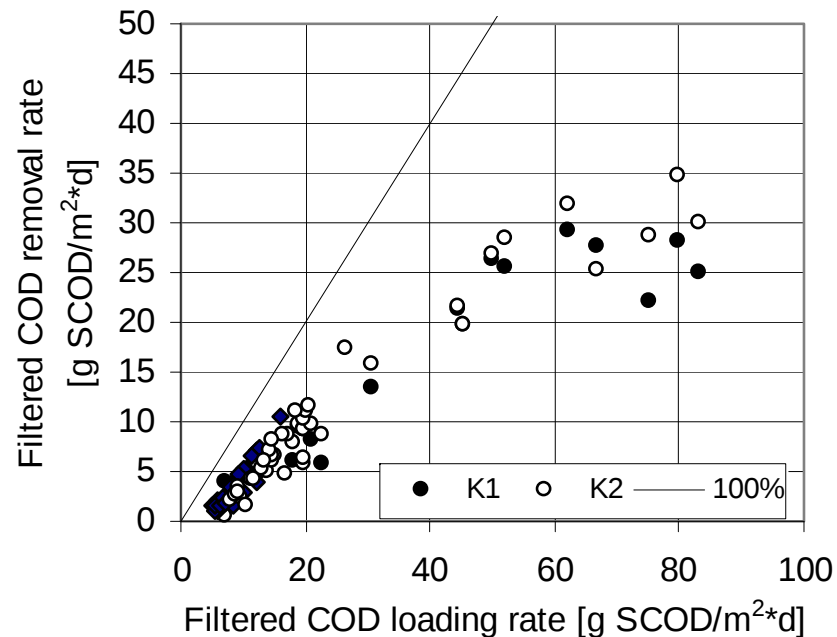
The IFAS processes



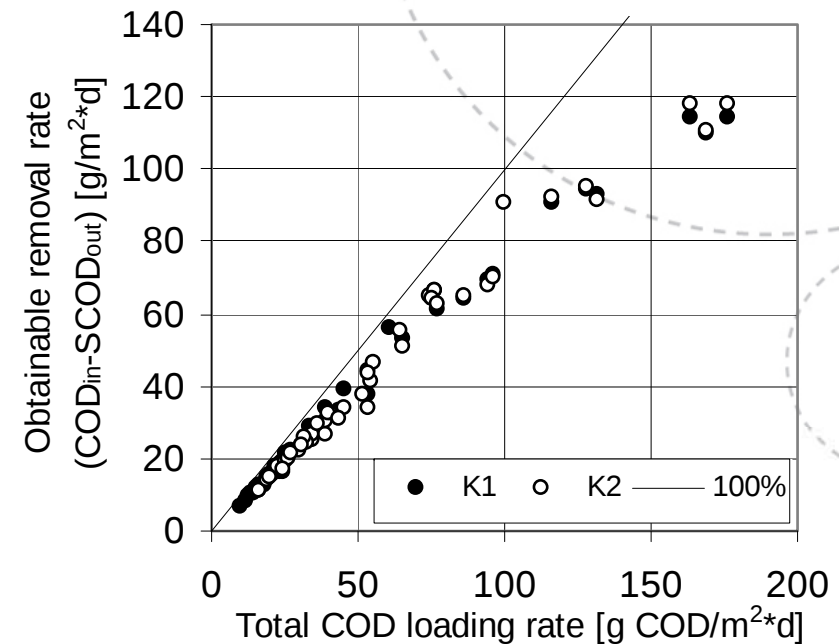
Flow diagrams for moving bed biofilm reactor (MBBR) processes for various applications

BOD-removal	BOD- and P-removal
Pure MBBR-processes a)  b) 	Pure MBBR-processes c)  d) 
BOD- and NH ₄ -N-removal	BOD- and N/P-removal
Pure MBBR-processes (Coag.) e)  f)  g) 	Pure MBBR- processes h)  i)  j) 
IFAS-processes	IFAS-processes
IFAS-processes k)  l) 	IFAS-processes m)  n) 

Aerobic COD-removal rates (Ødegaard et al, 2004)



Soluble COD removal rate vs soluble COD loading rate



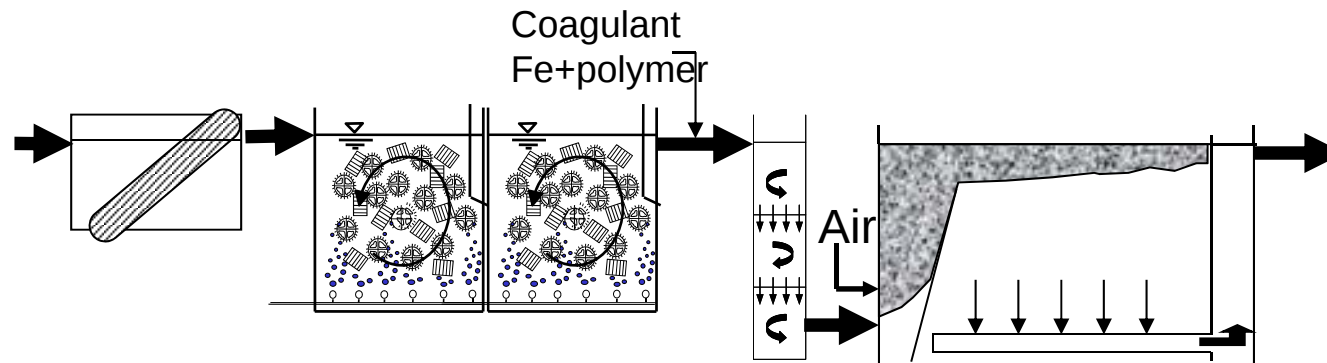
Obtainable COD removal rate vs total COD loading rate

"Obtainable" COD removal rate : $(\text{COD}_{\text{influent}} - \text{SCOD}_{\text{effluent}}) * Q/A$

Demonstrates removal rate of tot. COD if all particles > 1 µm were removed

High rate MBBR systems

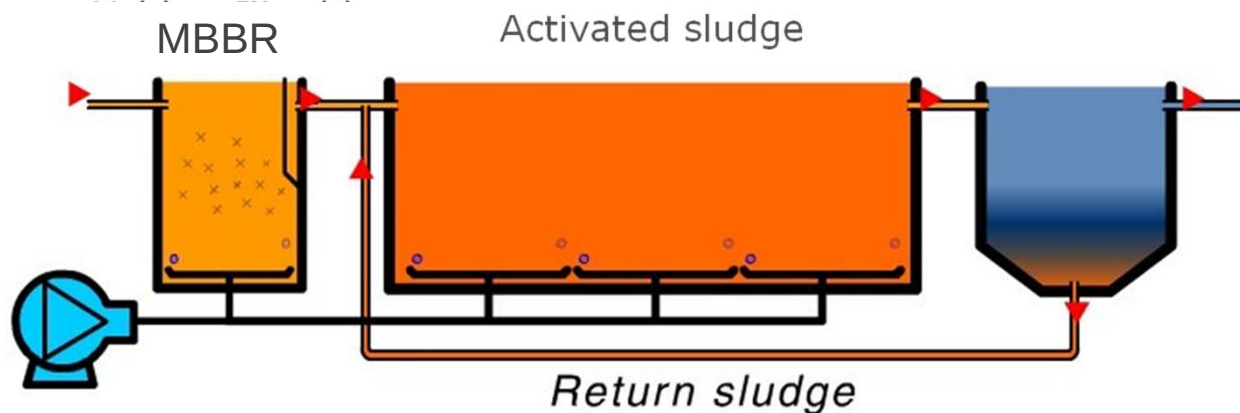
The high-rate MBBR-coagulation process



Secondary treatment
+ 90 % P-removal
could be met at a:

total HRT ~ 1 hr

The high-rate MBBR - AS process



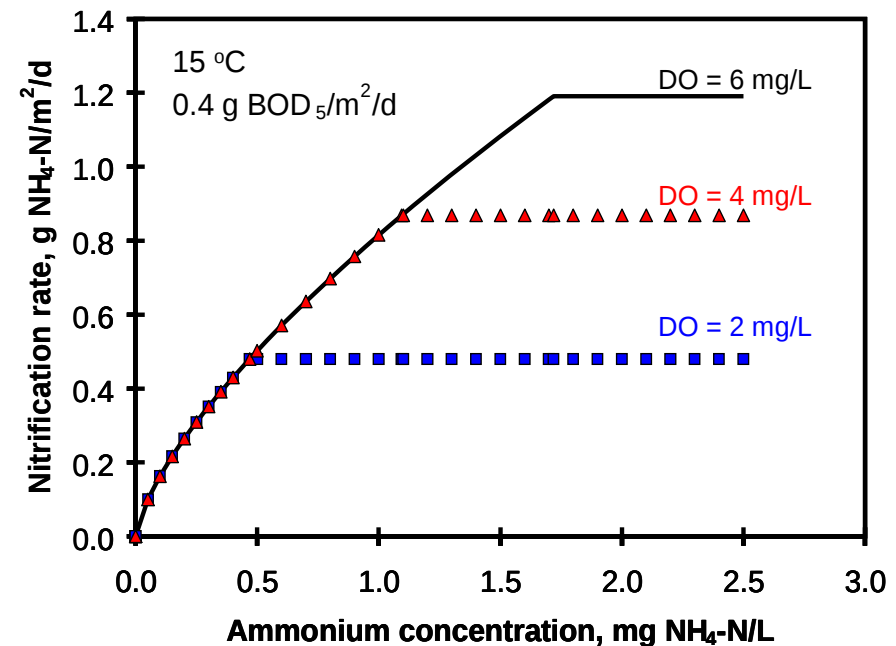
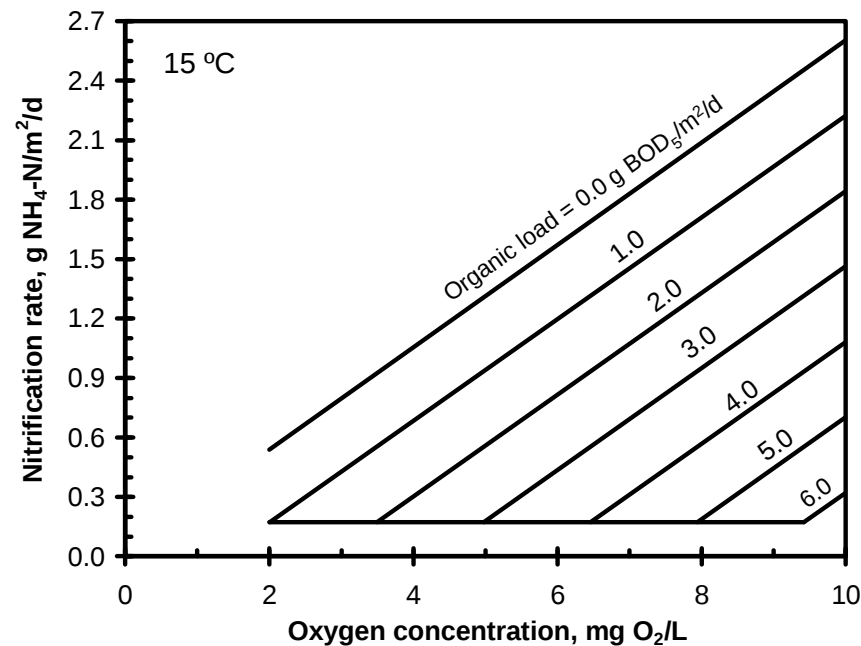
Frequently used in
industrial plants
e.g. pulp and paper

Factors determining the nitrification rate in MBBR's (Hem, Rusten and Ødegaard, 1994)

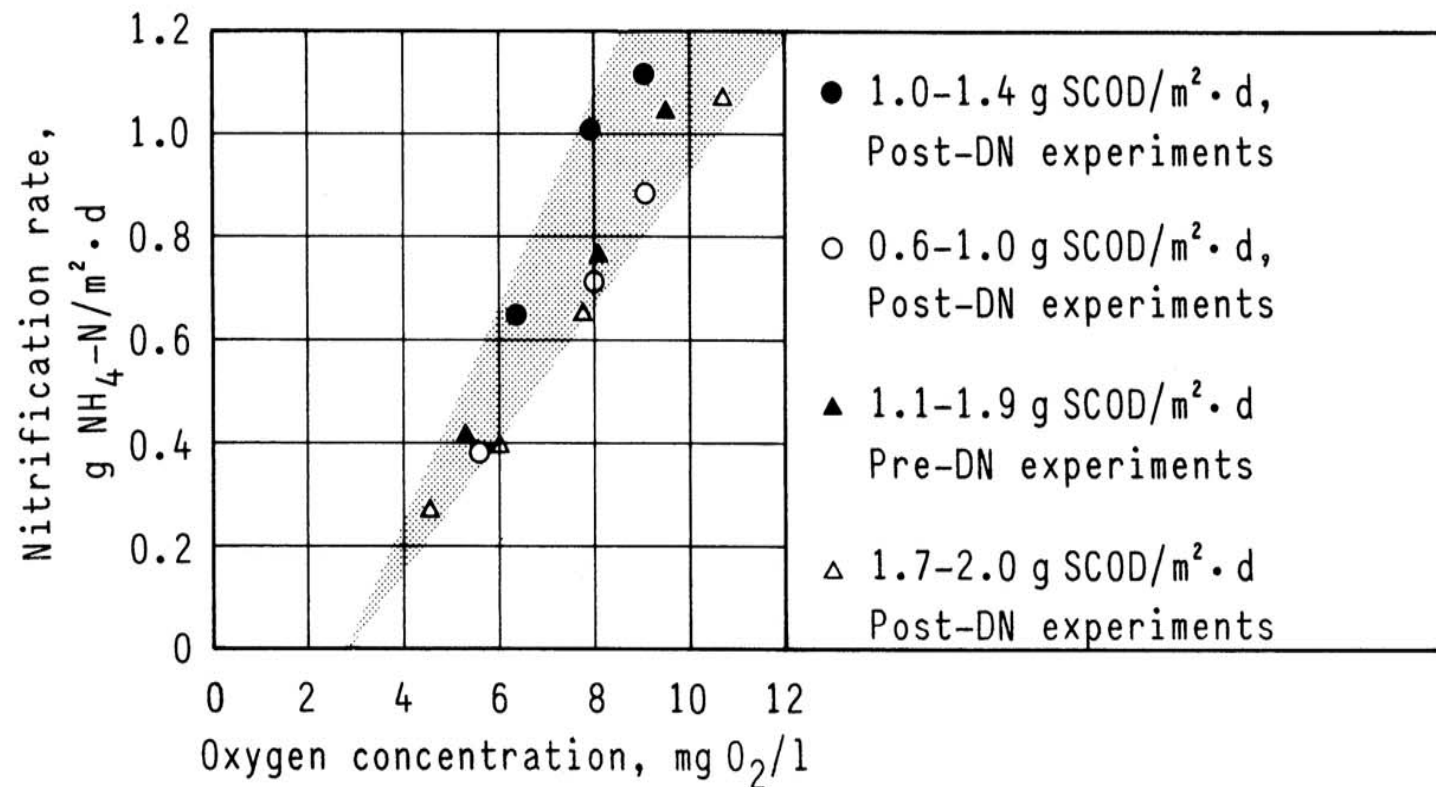
1. The load of organic matter
2. The oxygen concentration
3. The ammonium concentration

Temperature dependency:

$$k_{T2} = k_{T1} \cdot \theta^{(T2-T1)}, \quad \theta = 1.06-1.08$$



Influence of oxygen on nitrification rate - practical experiences



Nitrification process design

Organic matter removal prior to nitrification:

$$r_{\text{BOD}} = 3,9 \text{ g BOD}_5/\text{m}^2\text{d} \quad (10^\circ\text{C}) \quad (k_T = 1.06^{(T-10)})$$

Nitrification rate (when $\text{NH}_4\text{-N}$ is the limiting substrate)

$$r_N = k \cdot (S_n)^n$$

r_N = nitrification rate (g $\text{NH}_4\text{-N}/\text{m}^2\text{-d}$)

S_N = $\text{NH}_4\text{-N}$ concentration in the reactor

n = reaction rate order - n is normally set at 0,7

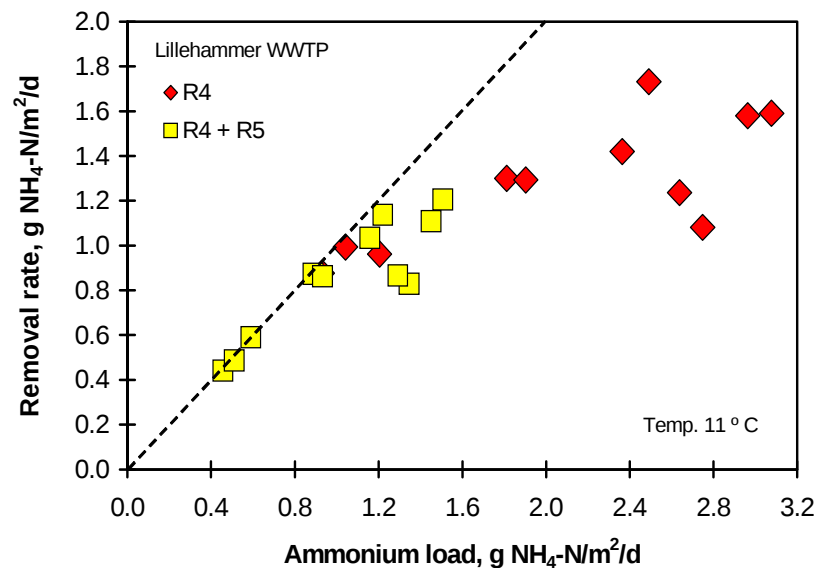
k = reactor rate constant – 0,4 – 0,6 (varies with the organic load, i.e pre-treatment)

$\text{NH}_4\text{-N}$ is only rate limiting at low $\text{NH}_4\text{-N}$ -concentrations (ca 1-2 mg $\text{NH}_4\text{-N}/\text{l}$).

At higher concentrations, S_N will be determined by the bulk liquid DO concentration and S_n should be replaced by $S_{n,\text{transition}}$

$$S_{n,\text{transition}} = (\text{DO}-0,5) / 3,2$$

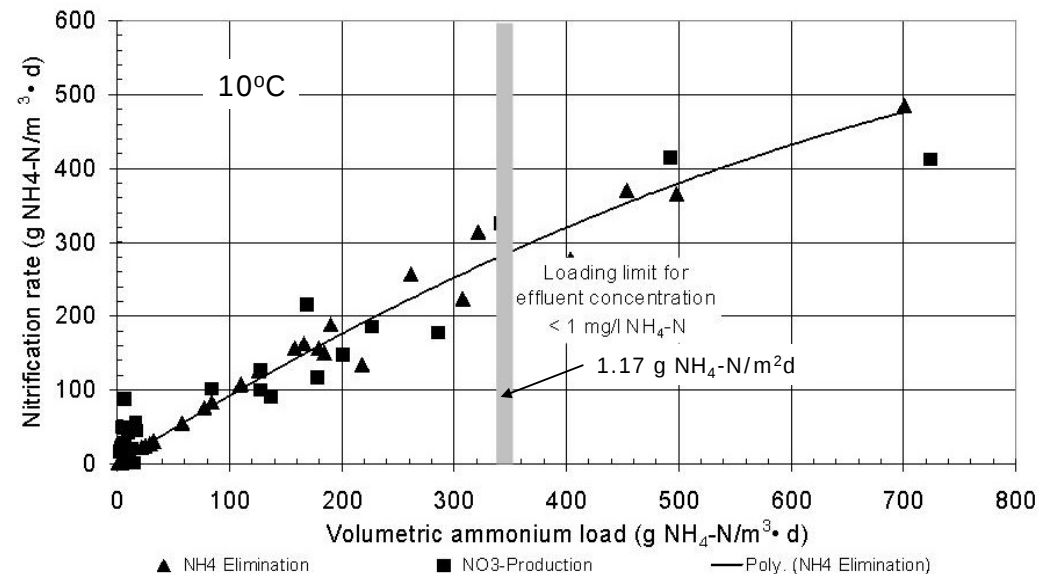
Nitrification rates in full-scale plants



Intensive study at Lillehammer WWTP

- Very high max rates (1,4 g $\text{NH}_4/\text{m}^2\cdot\text{d}$)
- Complete nitrification at < 1,2 g $\text{NH}_4/\text{m}^2\cdot\text{d}$

(Rusten and Ødegaard, 2007)



Nitrification performance at Givaudan WWTP Switzerland (Tschui, personal comm.)

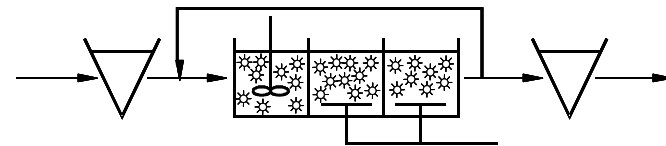
Challenge: Alkalinity limitation. Recommendation $\geq 1,5$ meq./l residual alkalinity

N-removal

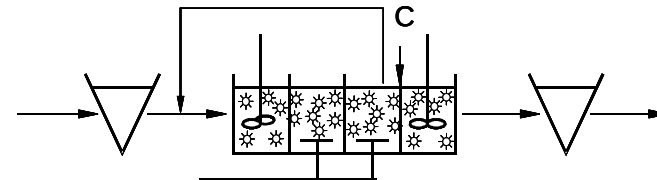
Choice of process is primarily dependent on availability of internal carbon source for denitrification and treatment efficiency requirement:

1. If carbon source is abundant and treatment efficiency needed is $< 75\%$, pre-DN is preferable
2. If carbon source is limited and treatment efficiency required is $> 75\%$, combined-DN is preferable
3. If, in addition to 2., space is very limited, post-DN may be preferable

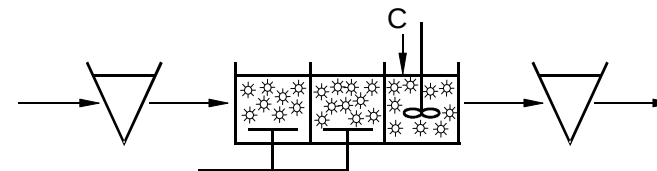
Pre-denitrification



Combined denitrification

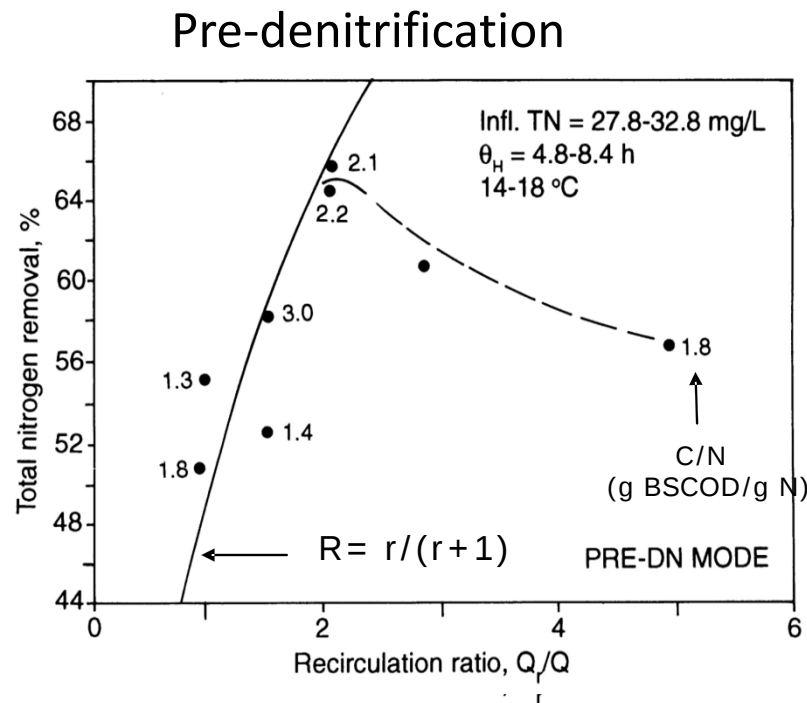


Post-denitrification



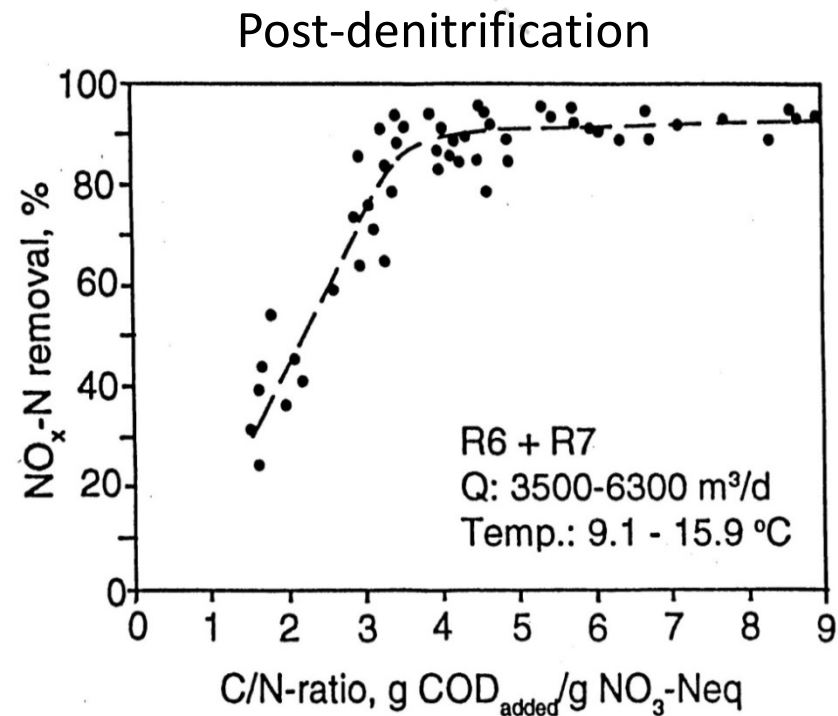
Denitrification

$$r_{DN} = k * [S_{COD}/(S_{COD}+K_{S,COD})] * [S_{NO3}/(S_{NO3}+K_{S,NO3})]$$



There is a limit to treatment efficiency in conventional pre-DN caused by the oxygen recycle

Rusten, Hem and Ødegaard, 1995

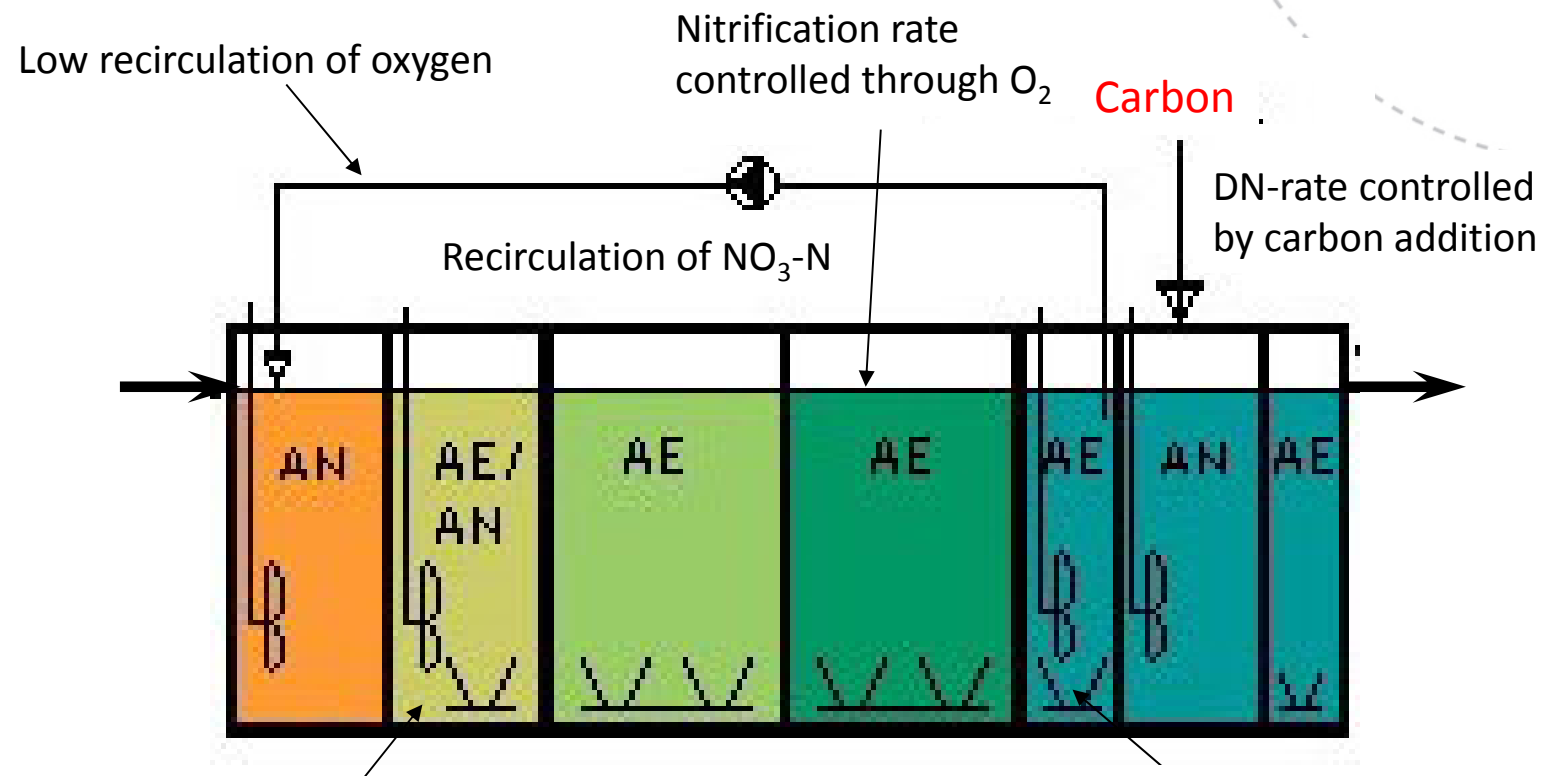


No carbon limitation as long as:

- g COD_{added} / g NO_3 -N_{equiv.} is > 3,5
- NO_3 -N may be the limiting factor at low NO_3 -N

Rusten, Hem and Ødegaard, 1995

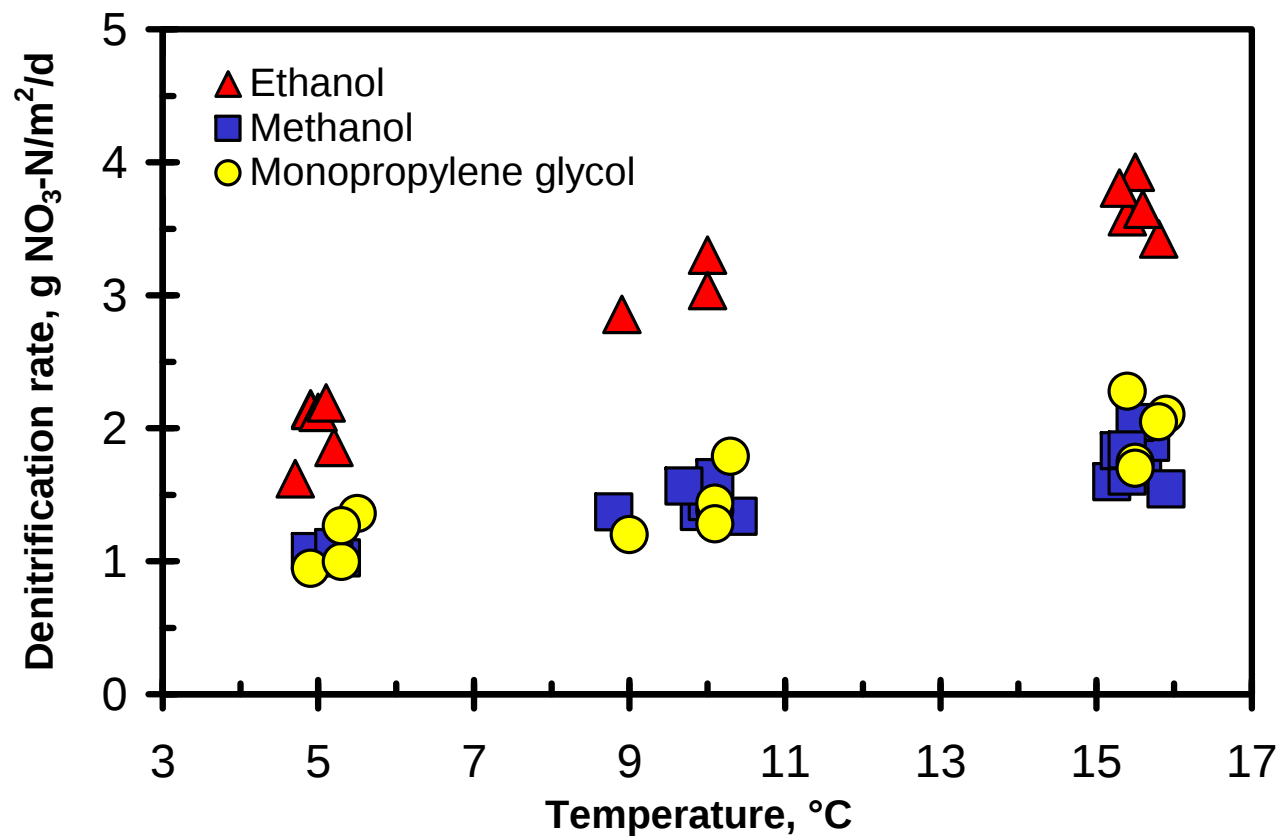
The combined pre- and post-DN MBBR process



- Aerated when larger nitrification volume is needed (winter).
- Not aerated in summer – more pre-DN volume – higher recycle in summer

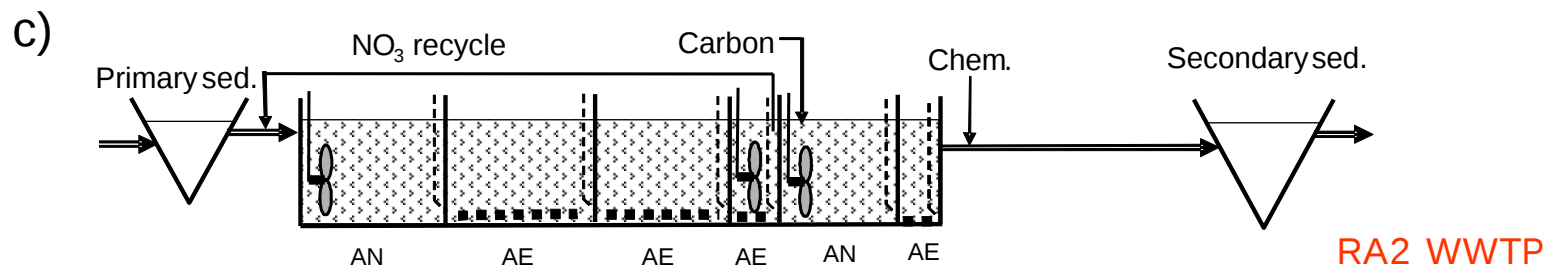
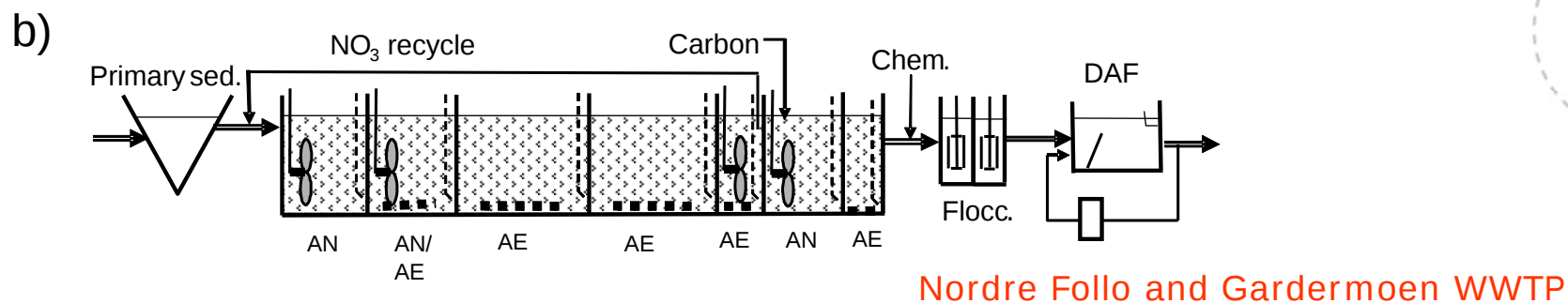
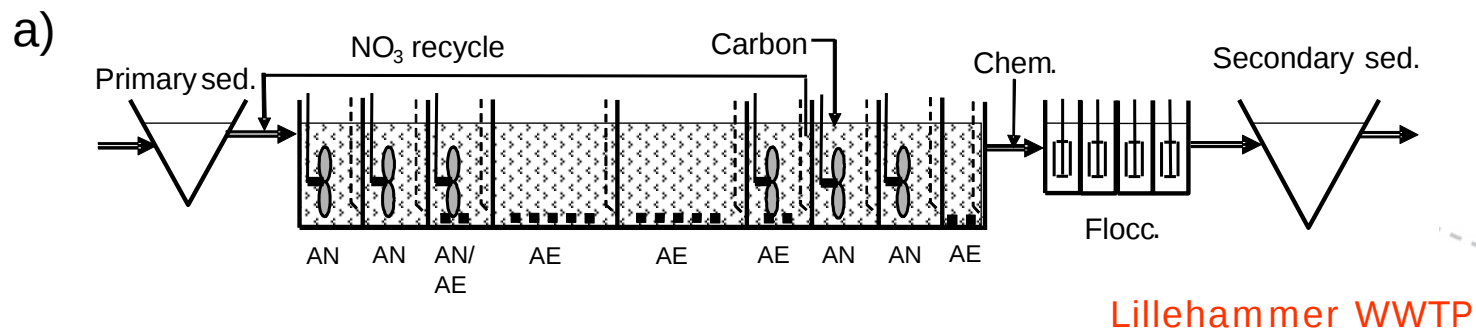
Not aerated nitrification
 O_2 consumption only -
 in order to reduce the
 amount of recycled O_2

DN-rates with external carbon sources (practical results from combined-DN plant)



Rusten et al, 1996

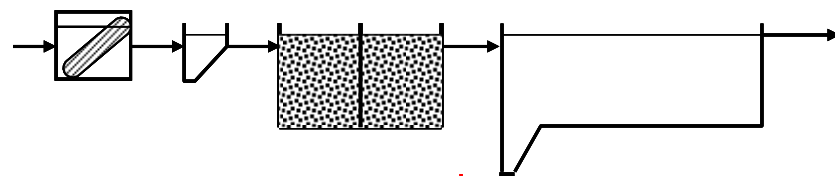
Four Norwegian combined DN-plants



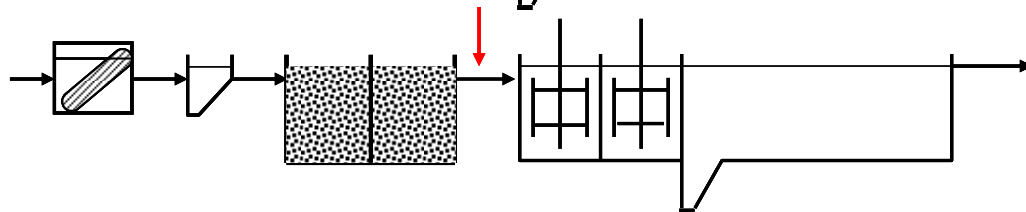
MBBR design/operating values and performances

Parameter	Lille- hammer	Nordre Follo	Garder- moen	NRA				
Average flow (m³/h)	1200	750	920	2300				
Max flow (m³/h)	1900	1125	1300	7200				
Temperature (°C)	3-14	6-14	4-14	7-14				
MBBR								
Total volume (m³)	3840	3710	5790	19370				
Carrier fill fraction (%)	65,0	66,2	58.5	42,7				
Average(max) HRT (hrs)	3,2 (2,0)	4,9 (3,3)	6,3 (4,5)	8,4 (2,7)				
Carbon source	Ethanol	Methanol	Glycol	Methanol				
g COD _{added} /g TN _{equiv}	3.3	(now glycol) 2.2	2.4	(now glycol) -				
Efficiency, 2005								
Average out conc. and treatment efficiency	Out mg/l	Rem %	Out mg/l	Rem %	Out mg/l	Rem %	Out mg/l	Rem %
BOD ₅	2,2	99	2,8	98	3,2	98	4,0	95
COD	35	93	39	91	25	96	27	93
Tot N	2,9	92	9,7	73	7,0	87	5,0	83
Tot P	0.12	98	0.20	96	0.18	98	0.05	99

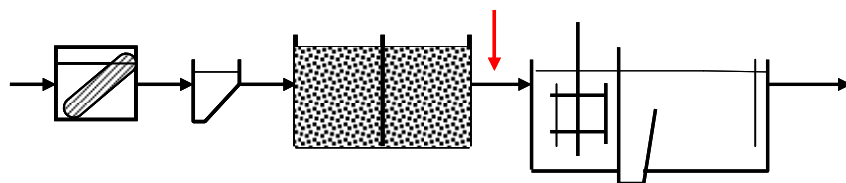
MBBR biomass separation alternatives



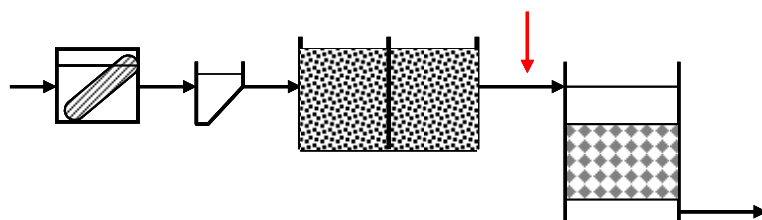
MBBR - settling



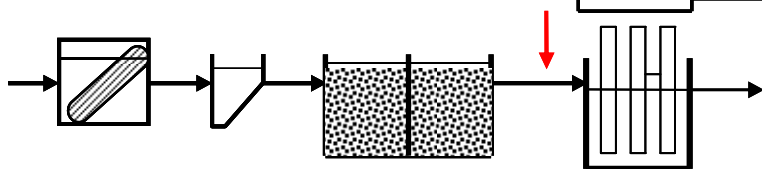
MBBR – Coag./settling
(also Actiflo)



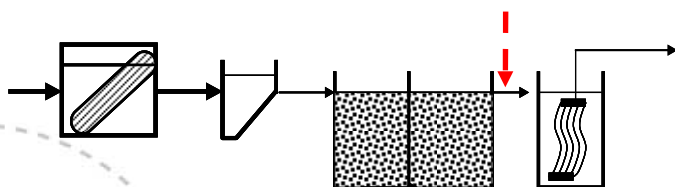
MBBR - flotation



MBBR – media filtration



MBBR – microscreening
(i.e. Disc filtration)



MBBR – Membrane filtration

Anaerobic ammonium oxidation (Anammox):



Advantages

- No carbon source needed
- Less air needed (than in N/DN):
~1,8 g O₂/g N (60 % less)
- Very low sludge production
~ 0,11 g SS/g NH₄-N
- Less CO₂ - production/
less alkalinity consumption

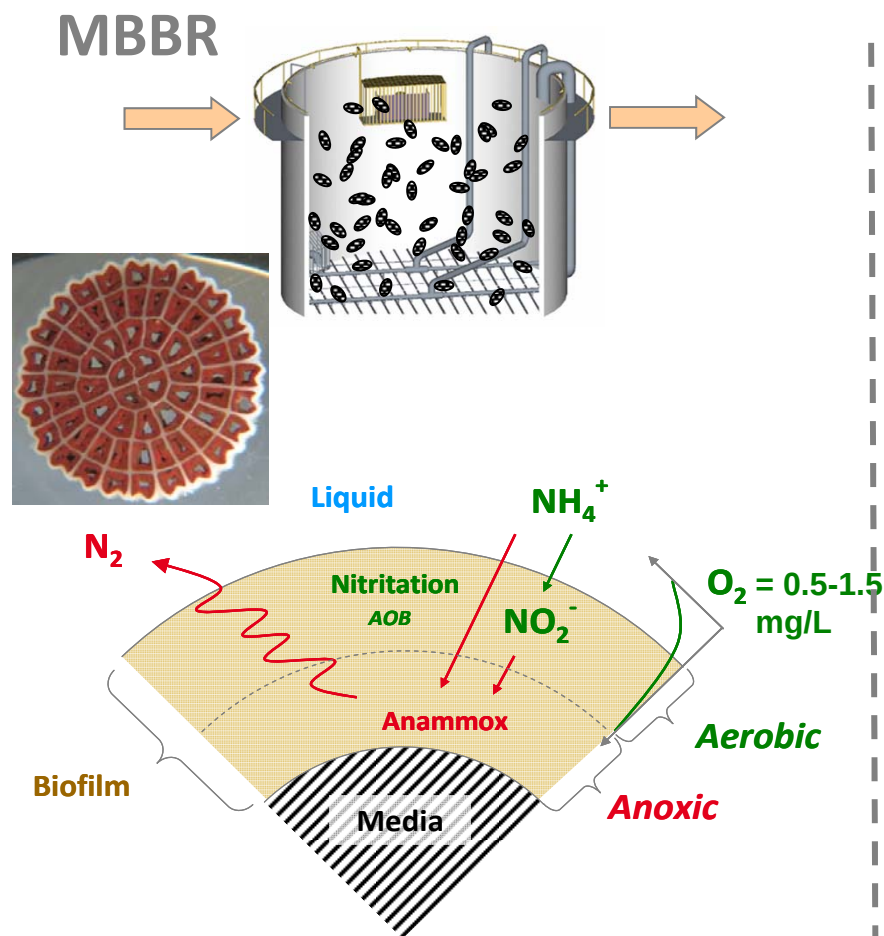
Disadvantages

- Some nitrate is formed:
i.e max N-removal ca 80 %
- Nitrite has to be generated
- Slow growth rate - long start-up
- Necessary to have a long SRT
(Biofilm or granules favorable)

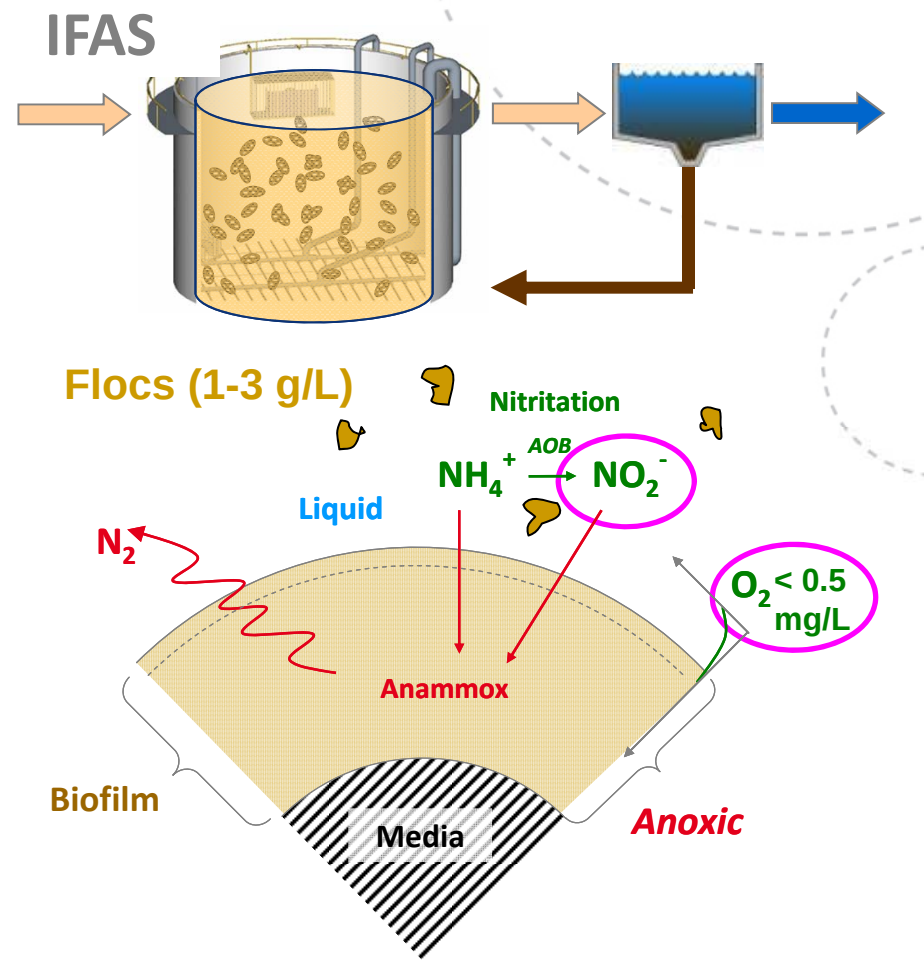


Primarily used for N-removal in sludge water treatment

Anammox with MBBR (Christensson et al, 2013)

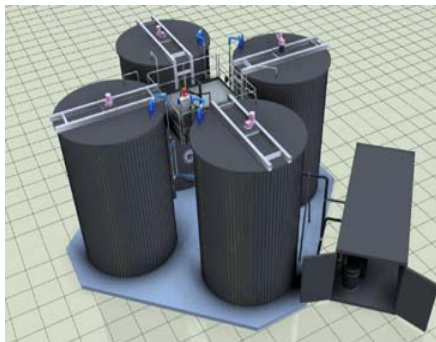


AOB in biofilm = NO_2^- limitation

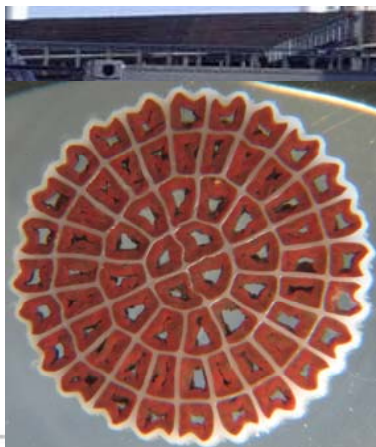


AOB in flocs = less NO_2^- limitation

ANITA™ Mox – Sjölanda WWTP, Malmö (Sweden)



- 4 x 50m³ MBBR
- Capacity = 200 kgN/d
- 800-1200 mgN-NH₄/L
- 1st ANITA™ Mox reference
- Flexibility for fullscale testing



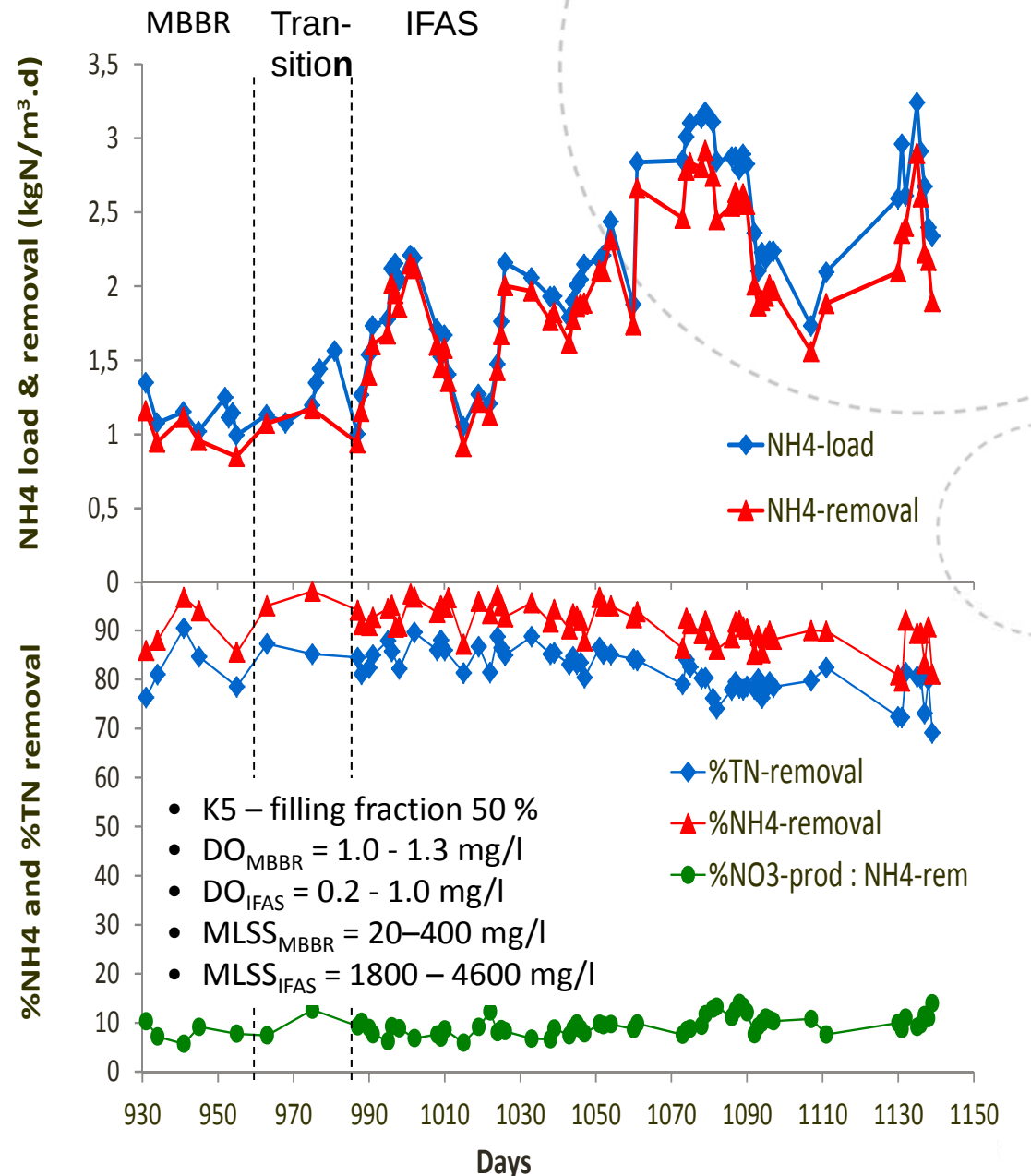
Seeded carriers



→ BioFarm concept = Providing seeded carriers for rapid start-up of future full-scale ANITA™ Mox units

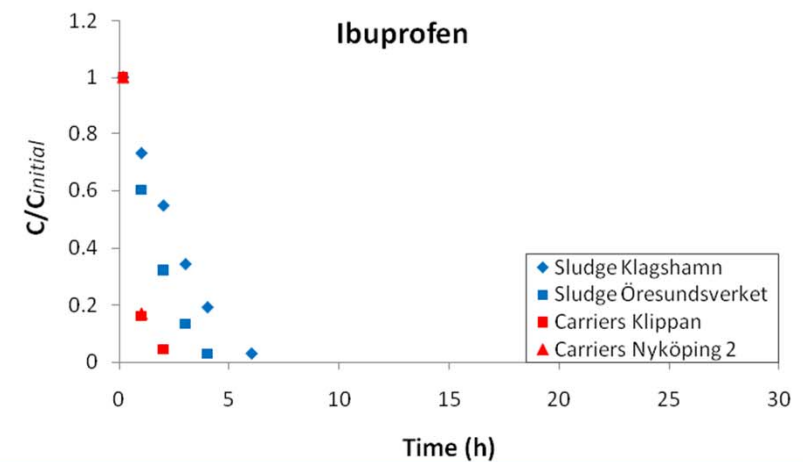
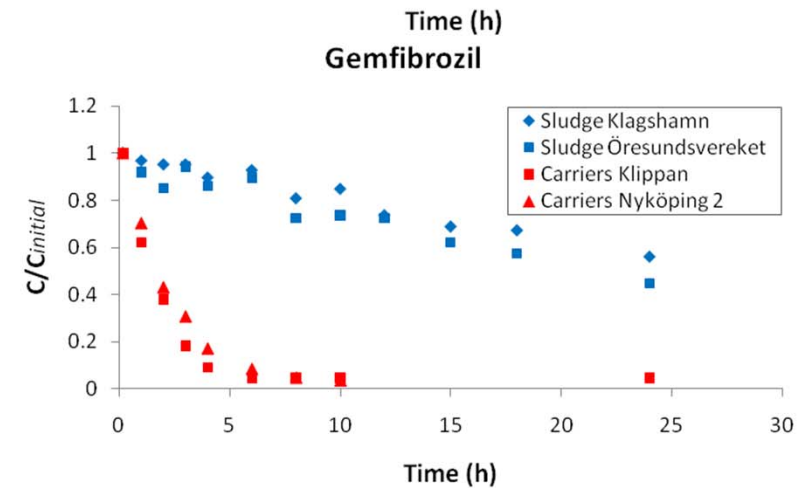
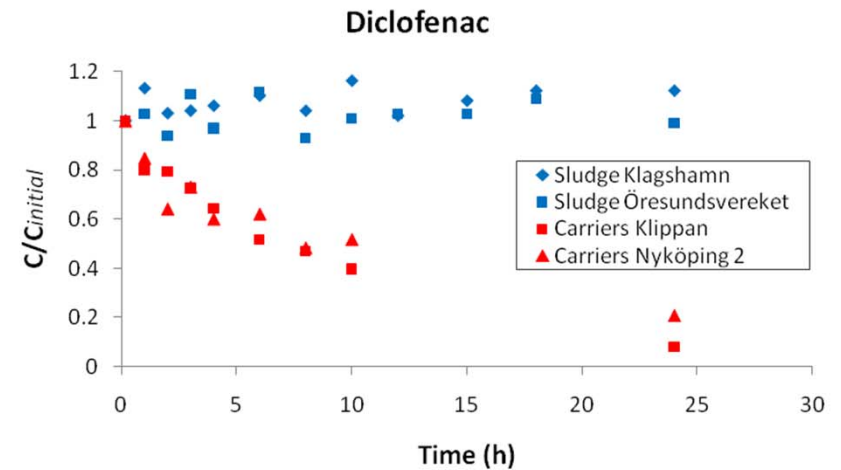
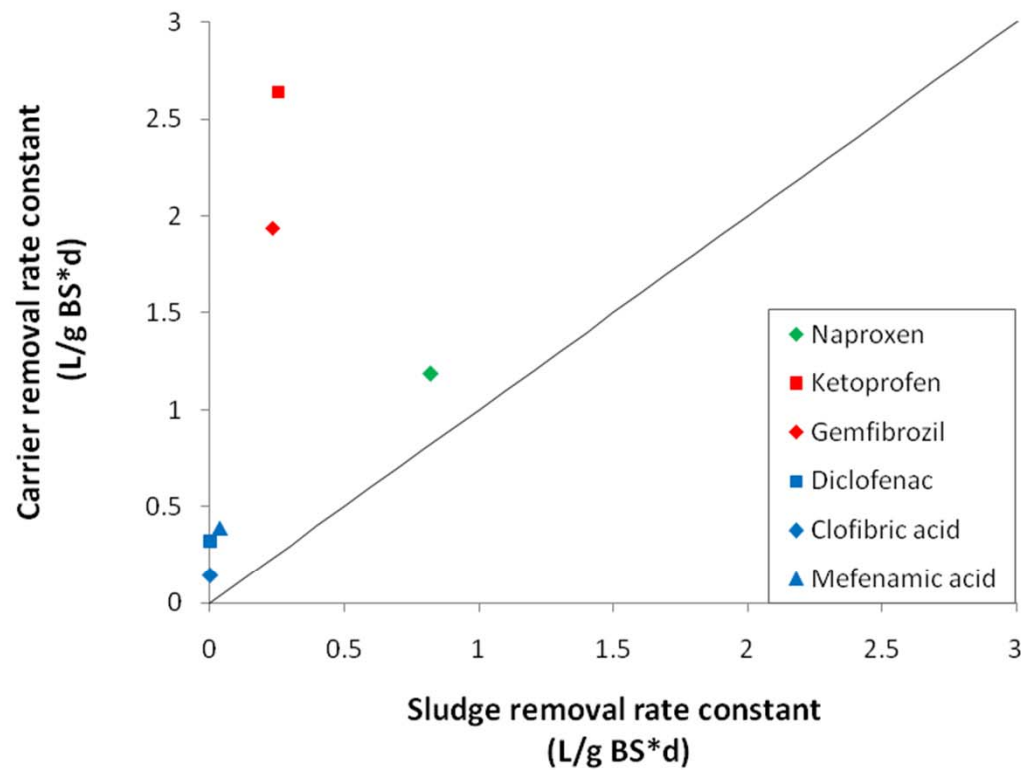
Full-scale test results ANITA™ Mox , Sjölunda WWTP (Christensson et al, 2013)

- High removal rates and good N-removal with MBBR
- Very high removal rate with IFAS - up to 3 kg $\text{NH}_4\text{-N}/\text{m}^3\cdot\text{d}$ (7.5 g $\text{NH}_4\text{-N}/\text{m}^2\cdot\text{d}$)
- Energy consumption :
1.2 kWh/kg $\text{NH}_4\text{-N}$ removed



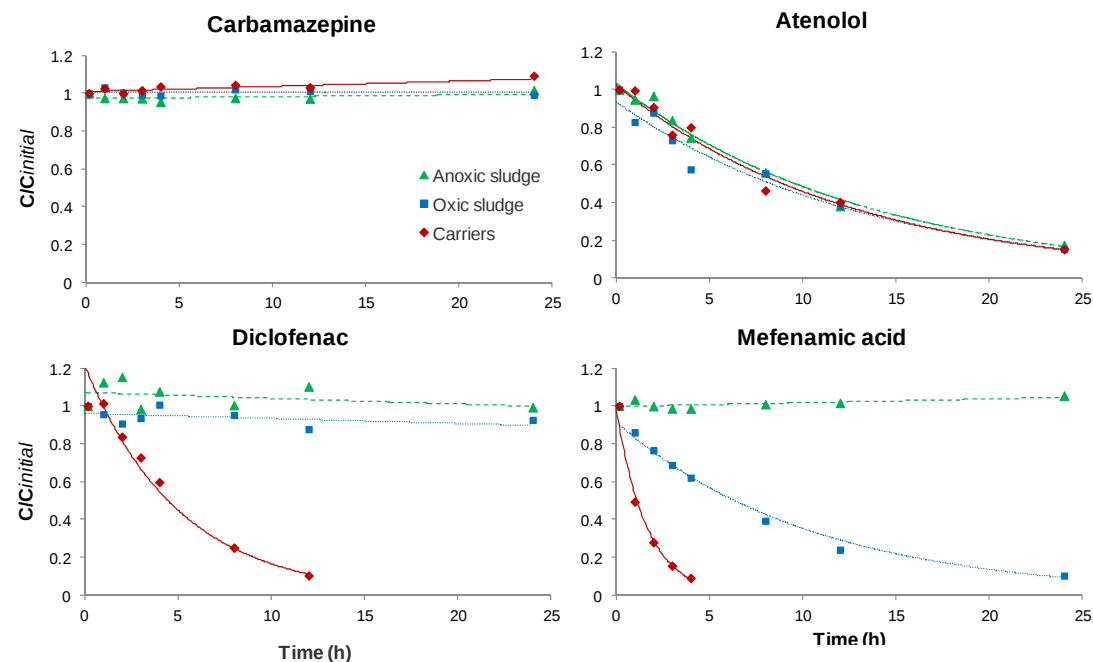
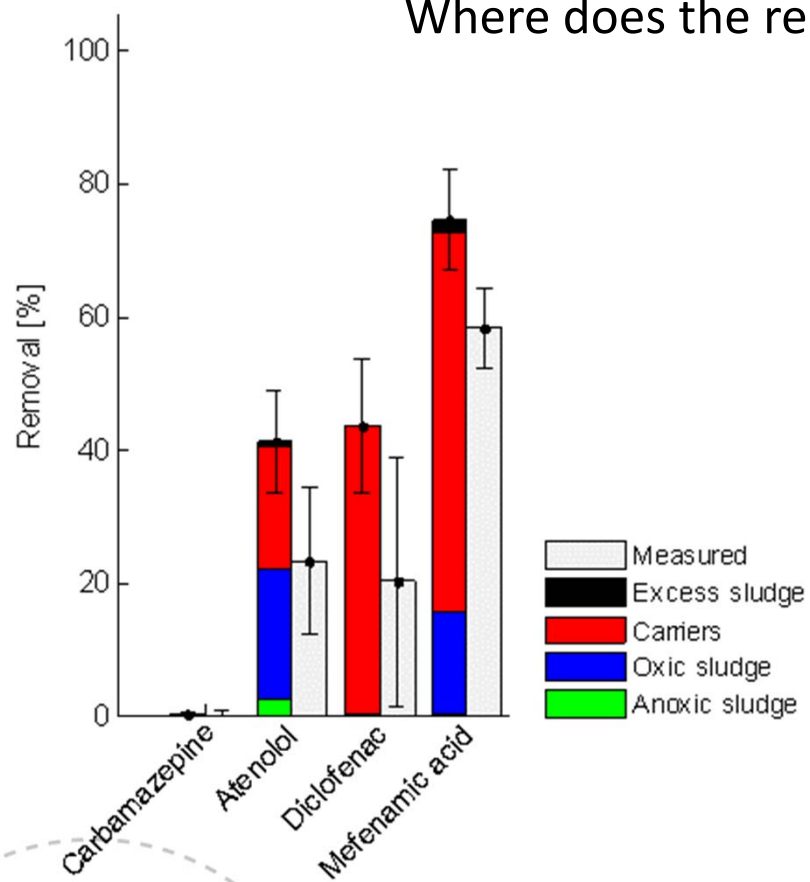
Removal of pharmaceuticals (Falås, 2013)

Comparison between activated sludge and carrier-based processes



Removal of pharmaceuticals in the biomass from an IFAS plant (Bad Ragaz WWTP, CH)

Where does the removal take place?



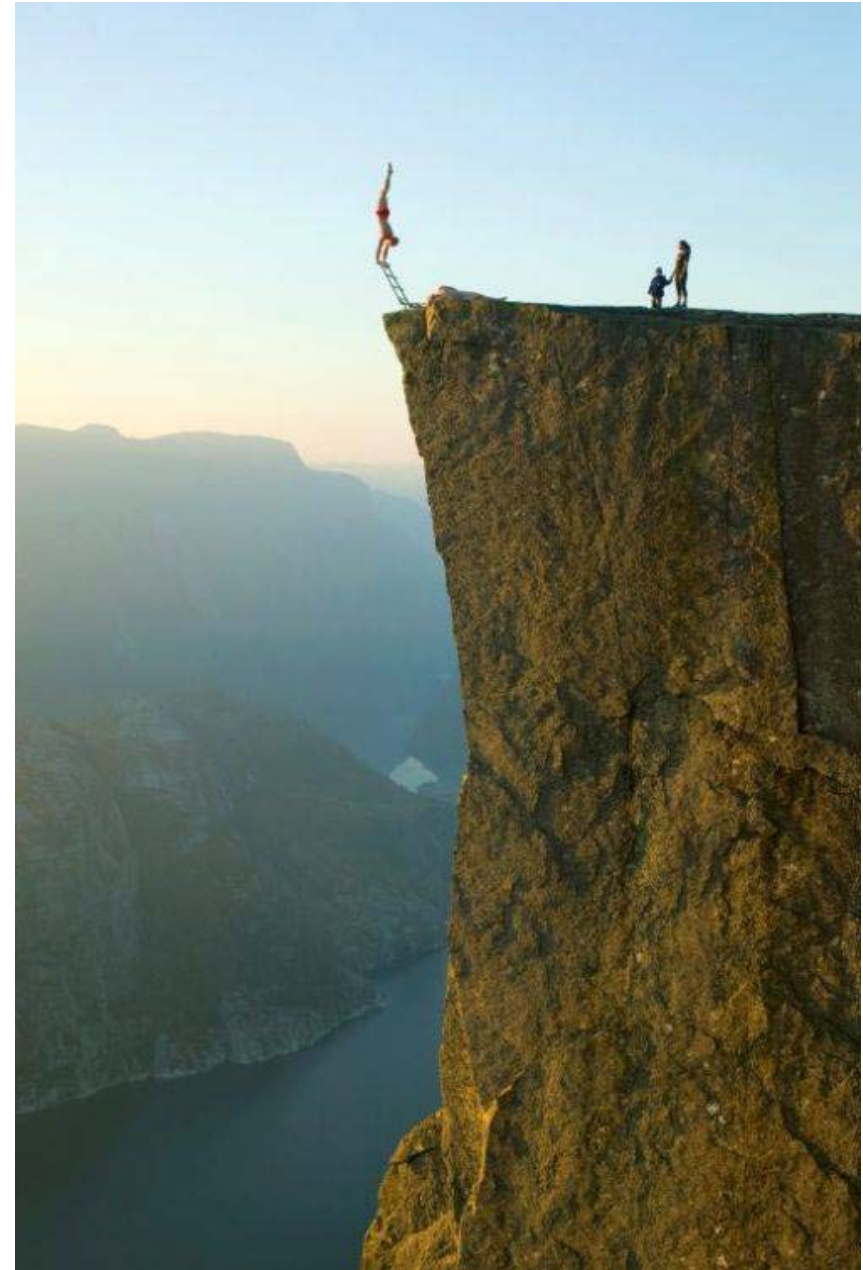
(Falås et al, 2014)

Conclusions

1. The MBBR is a well-proven, robust and very compact technology
(Now altogether > 800 plants in > 50 countries – 50/50 industrial/municipal).
2. The MBBR is used in pure biofilm processes as well as in hybrid processes (IFAS)
3. The combined pre- and post denitrification MBBR process is especially suitable for low C/N waters and offers great flexibility in operation
4. The MBBR is very efficient in the upgrading of activated sludge plants:
 - a. as "roughing" reactor before AS in order to reduce organic matter loading
 - b. in an IFAS-process in order to achieve: nitrification, N-removal and or P-removal
5. The MBBR-based processes are especially suitable for developing special cultures – for instance for:
 - a. N-removal by anammox processes
 - b. Organic micropollutants removal

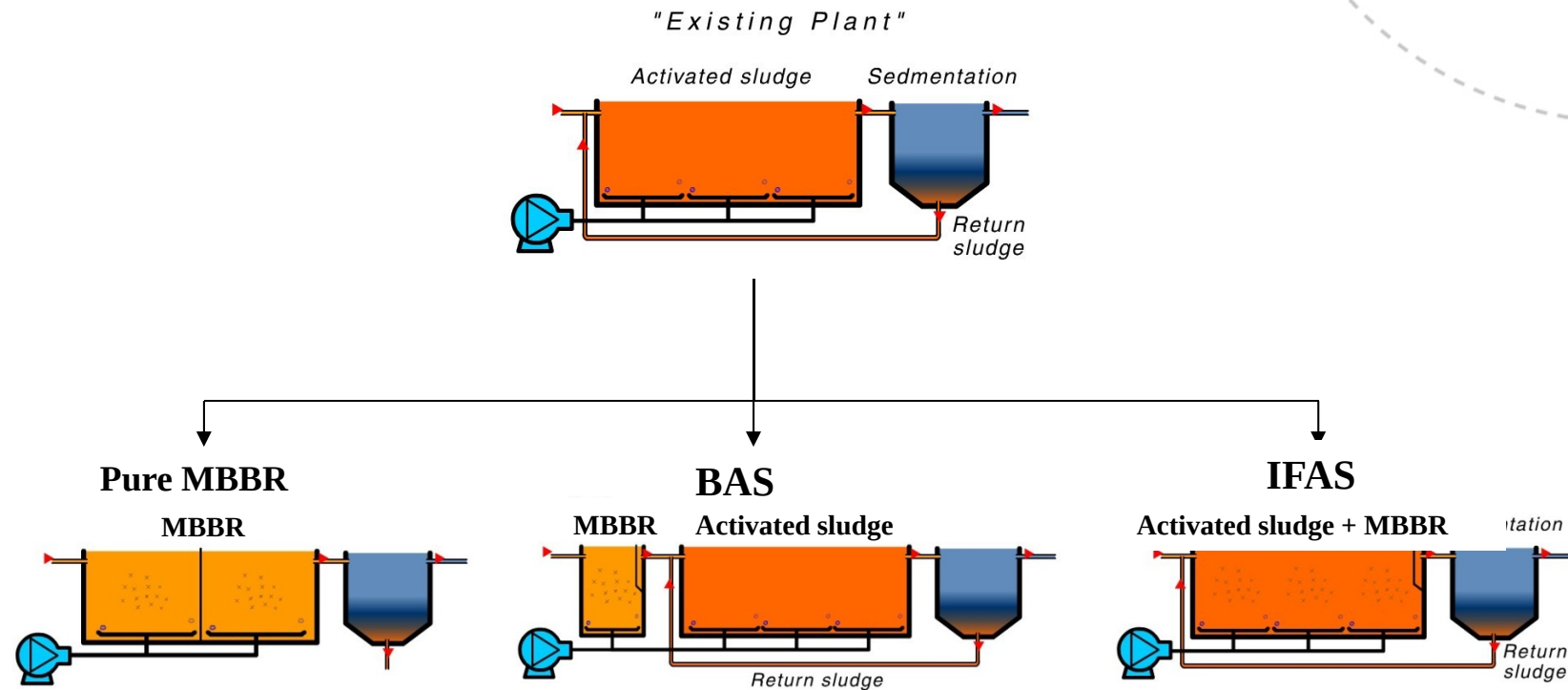
Thanks
a lot
for listening

The Pulpit, Lysefjord, Norway



Upgrading AS-plants by the use of MBBR

Three options for nitrification



Design SRT vs temp for full scale IFAS systems (installed by ANOXKALDNES)

