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Compact wastewater treatment with MBBR

Hallvard Ødegaard

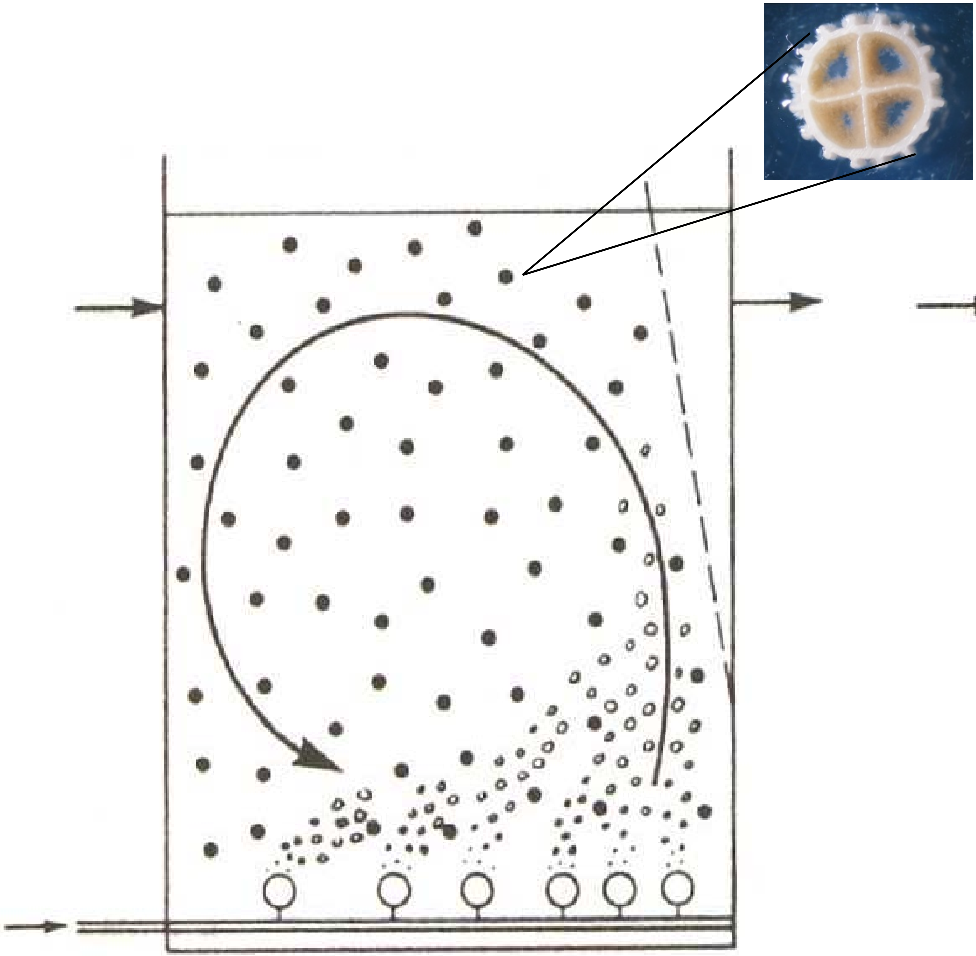
Prof. em. Norwegian University of Science and Technology (NTNU)
CEO Scandinavian Environmental Technology (SET) AS

hallvard.odegaard@ntnu.no

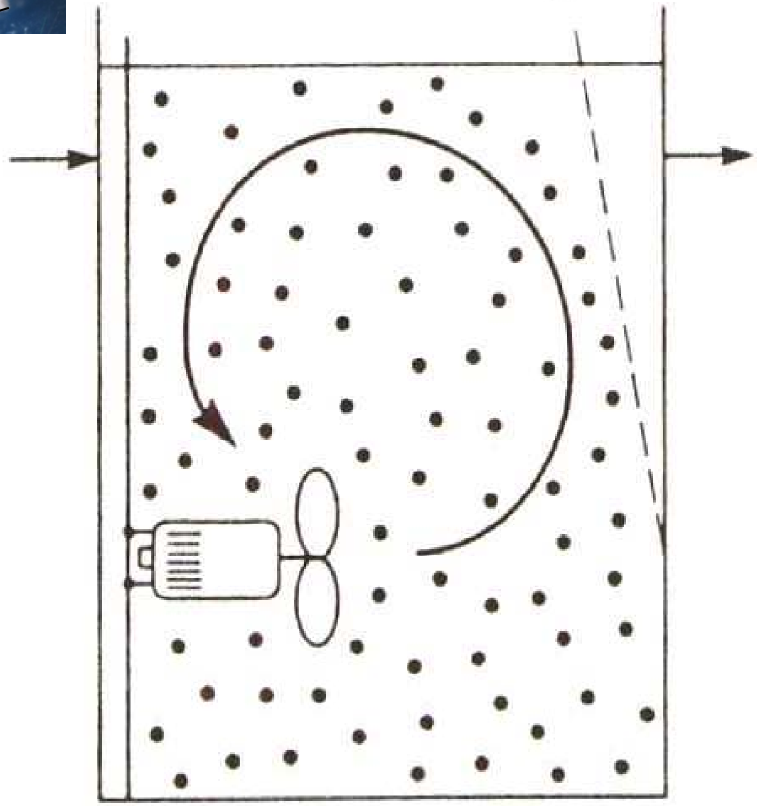
NTNU

scandinavian environmental technology a.s.

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

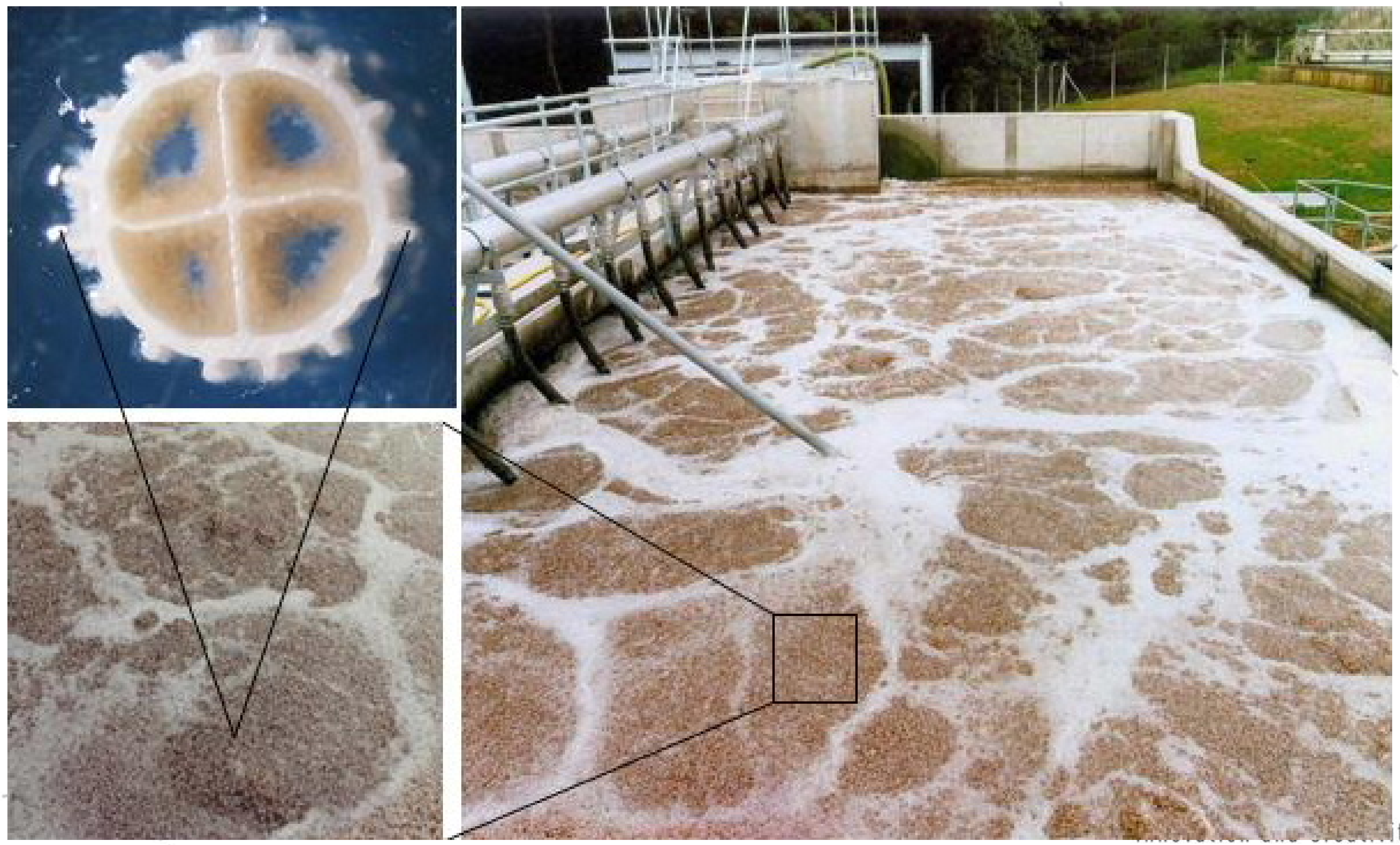


Aerobic reactor

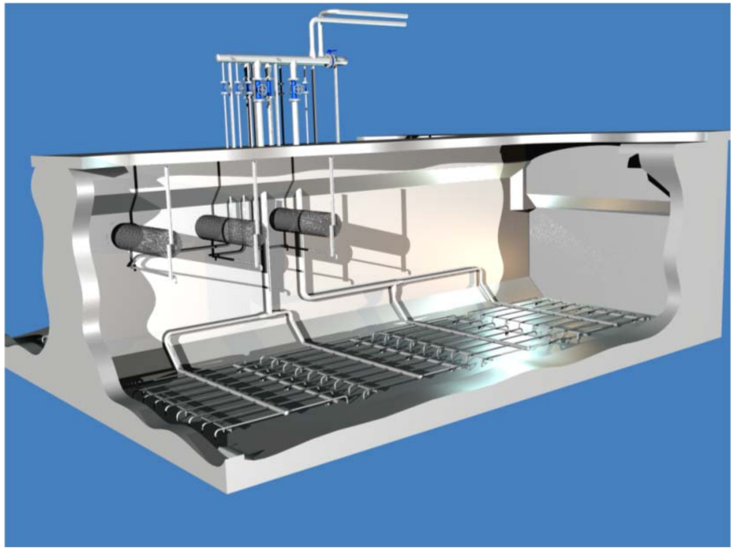


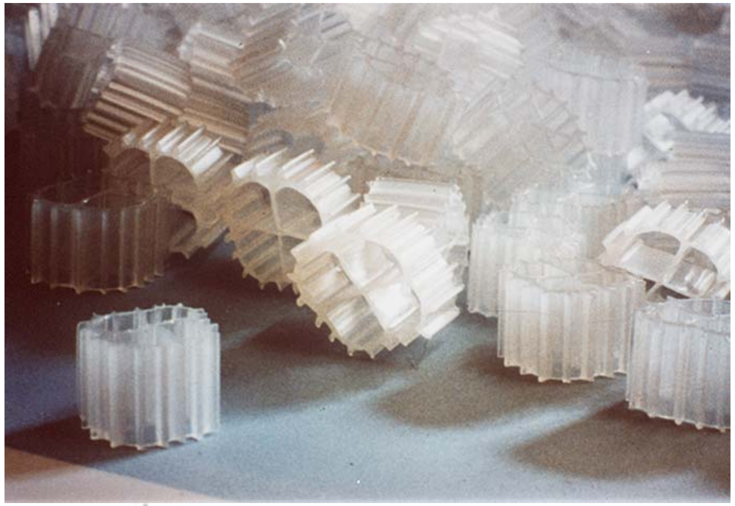
Anoxic reactor

The Moving Bed Biofilm Reactor (MBBR) in practice



The components of the MBBR treatment system





THE MAJOR COMPONENTS

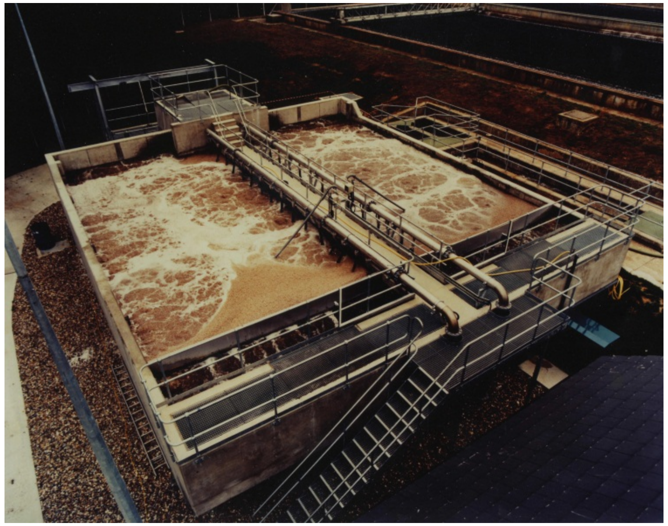
a) Tank
b) Media
c) Aeration System
d) Sieve Assemblies
e) Blowers
f) Mixers

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

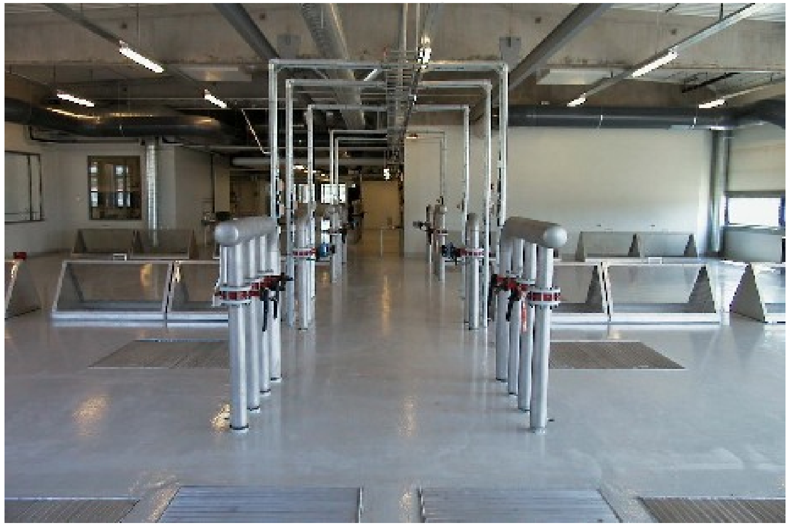
Possible filling fraction: 0 – 70 %
Normal filling fraction: 50 – 65 %

The MBBR reactor

Rectangular/Circular open concrete reactors



Rectangular covered concrete reactors



Circular Steel Reactors (Bolted or Welded)

Circular fiber glass reactors

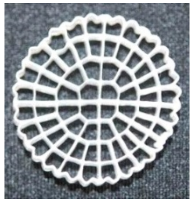
The (MBBR) carriers

- 500 m^2/m^3 bulk
- 9.1 x 7.2 mm diameter/depth

K1

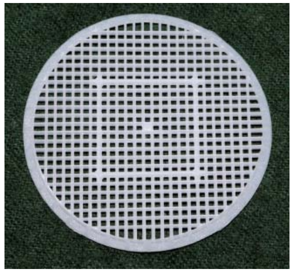
- 500 m^2/m^3 bulk
- 25 x 10 mm diameter/depth

K3



- 800 m^2/m^3 bulk
- 25 x 3.5 mm diameter/depth

K**5**

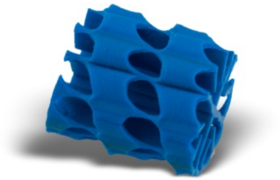


- 1200 m^2/m^3 bulk
- 48 x 2.2 mm diameter/depth

BiofilmChip M

Z-MBBR

Courtesy AnoxKaldnes



- 650 m^2/m^3 bulk
- 13 x 13 mm diameter/depth

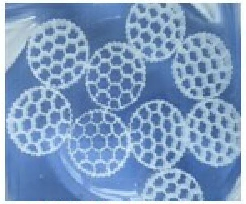
ABC

Courtesy Aqwise

- 650 m^2/m^3 bulk
- 18.5 x 14.5 x 7.3 mm length/width/depth

BWT S

Courtesy Biowater Technology



- 620 m^2/m^3 bulk
- 25 × 10mm Diameter/depth

SPR-2

- 800 m^2/m^3 bulk
- 25 × 4mm Diameter/depth

SPR-3

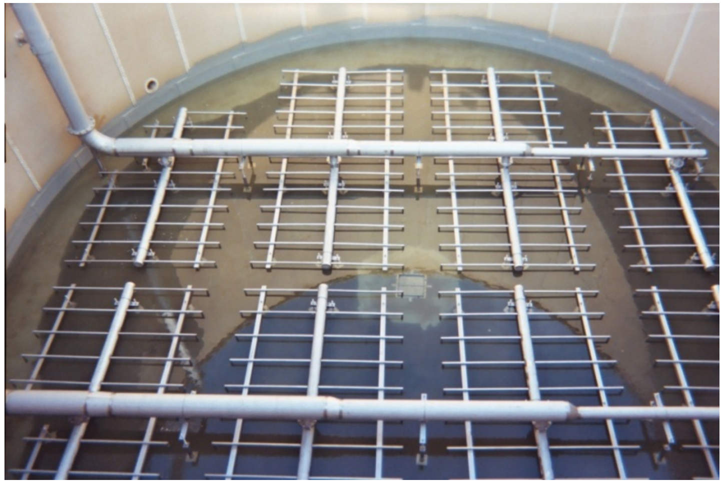
- 1200 m^2/m^3 bulk
- 36 × 4mm Diameter/depth

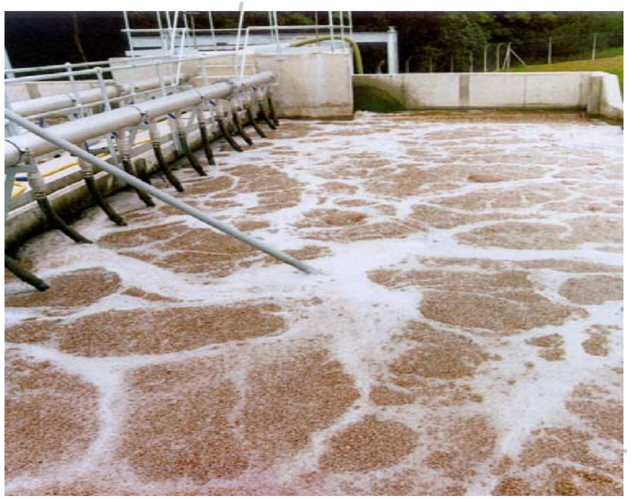
SPR-4

Courtesy Qingdao Spring

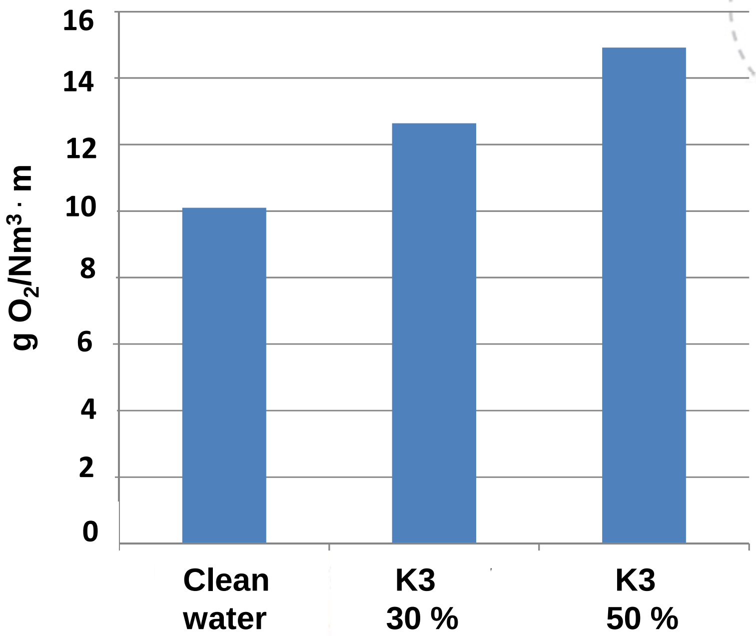
Carriers from the MBBR-based SANI pilot at Shatin

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



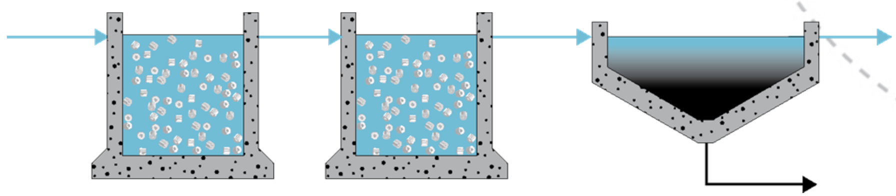
Christensson, 2013

The sieve assembly

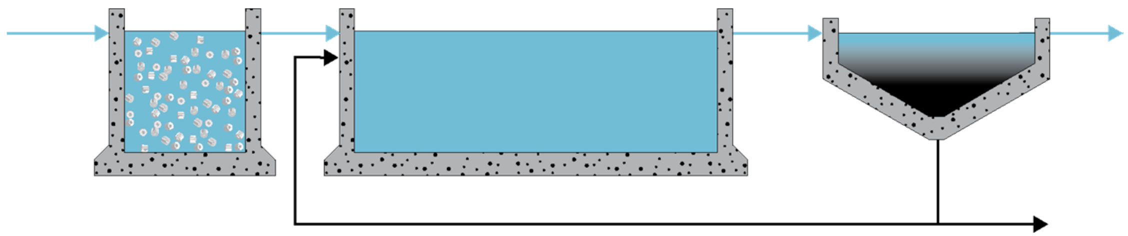
The mixers in anoxic reactors

The principal moving bed reactor processes

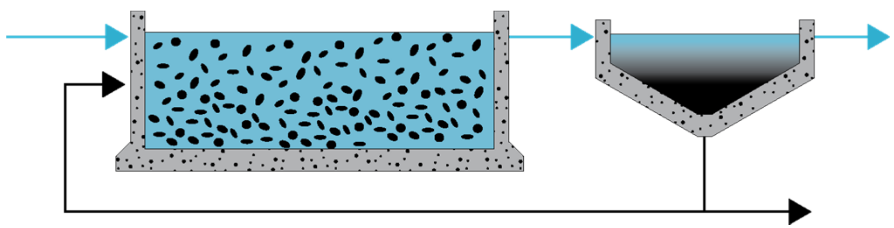
The basic MBBR processes



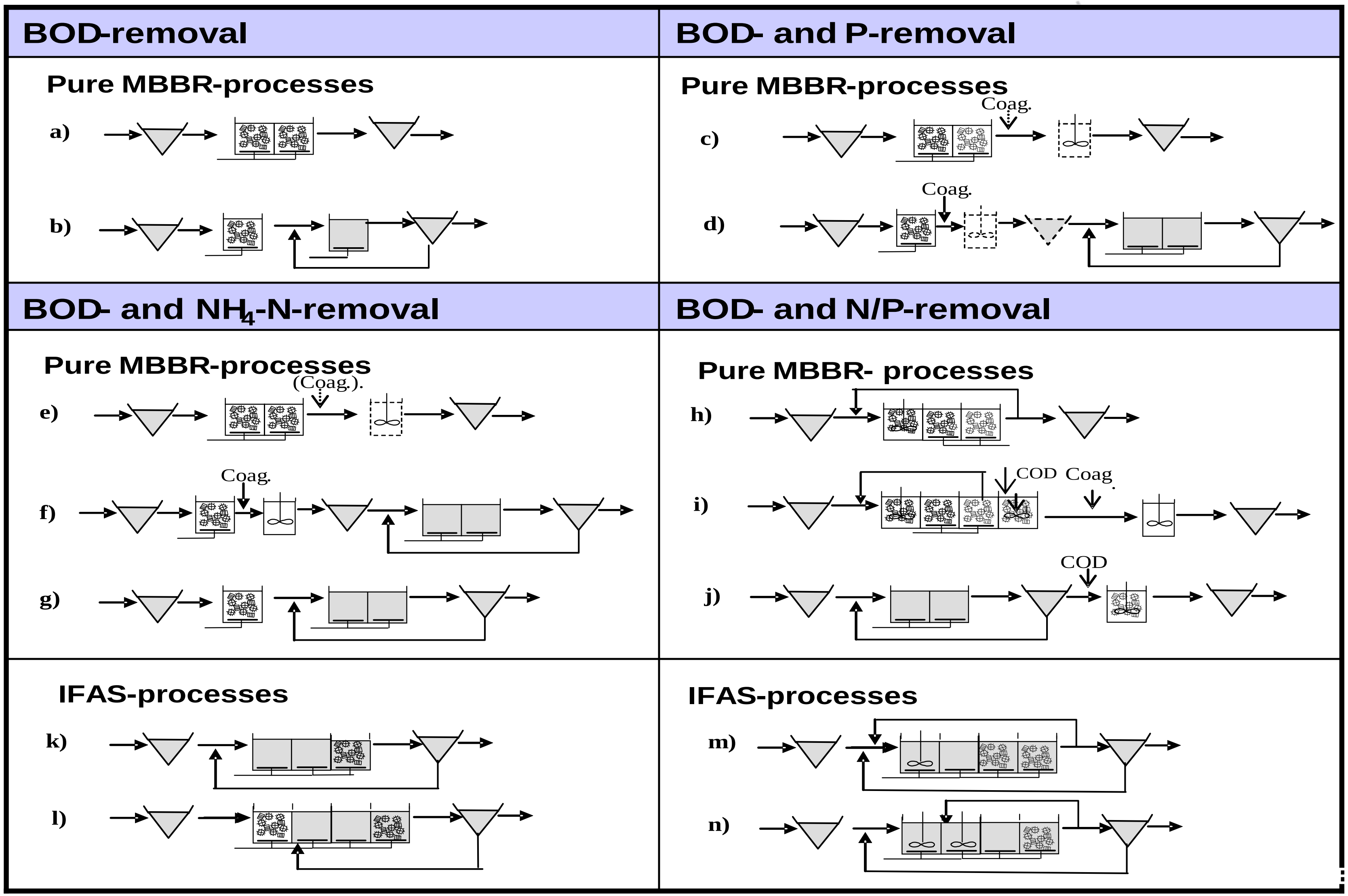
The high-rate MBBR processes



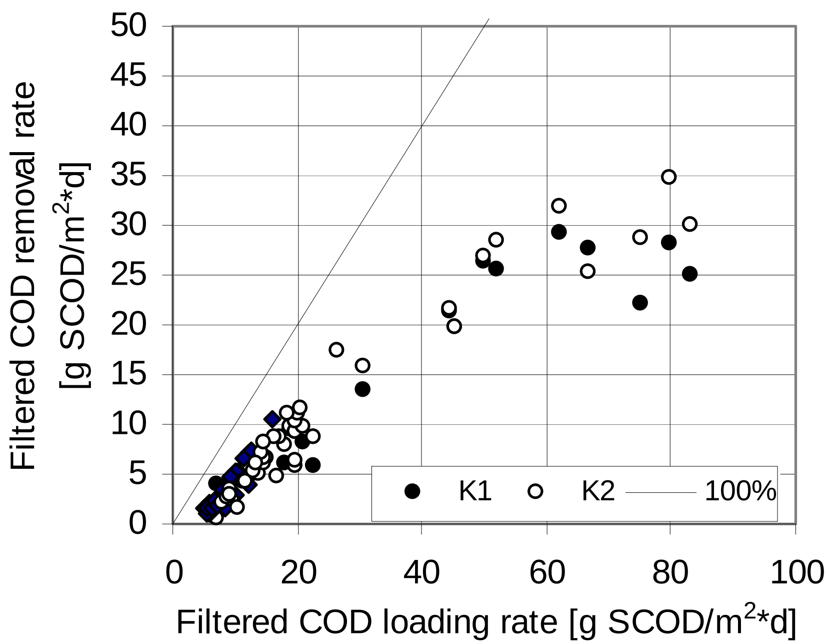
The IFAS processes



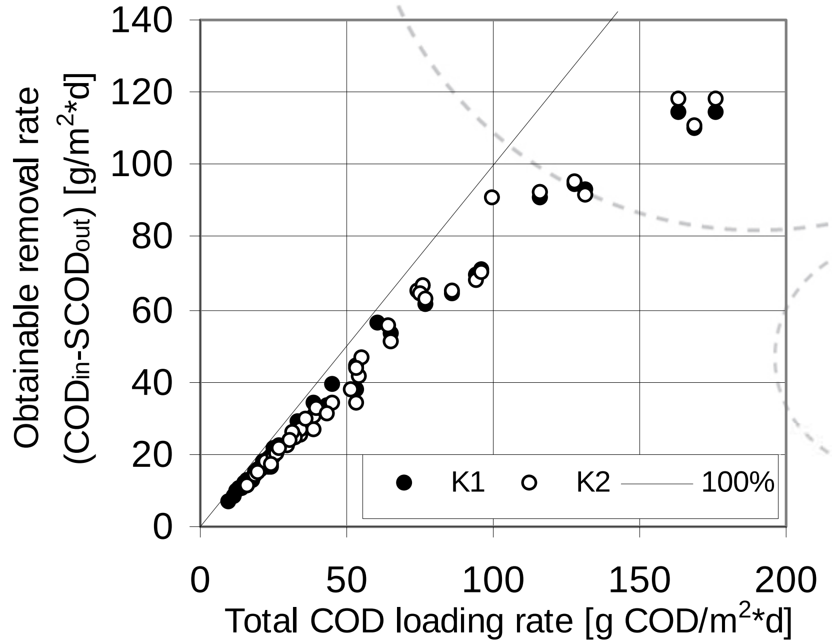
Flow diagrams for moving bed biofilm reactor (MBBR) processes for various applications



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



Soluble COD removal rate vs soluble COD loading rate



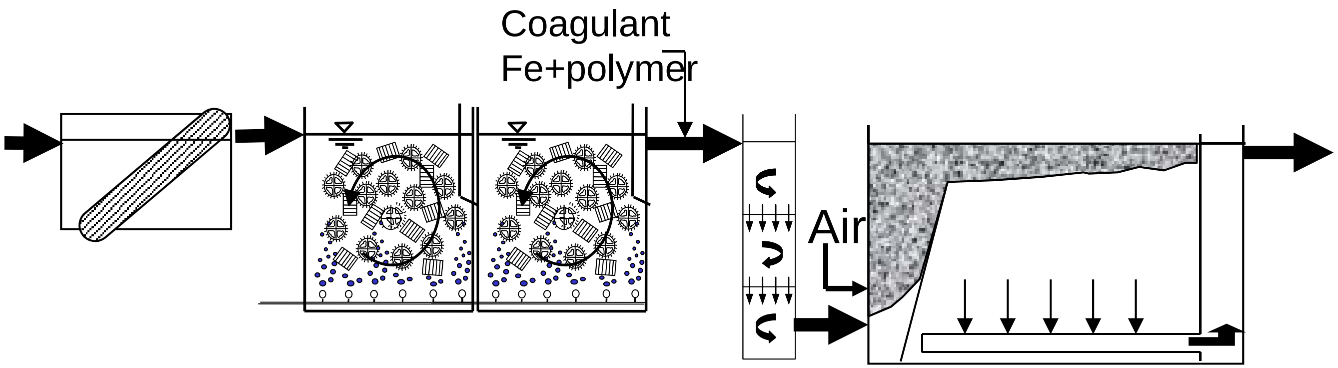
Obtainable COD removal rate vs total COD loading rate

"Obtainable" COD removal rate : $(COD_{influent}-SCOD_{effluent})*Q/A$

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

High rate MBBR systems

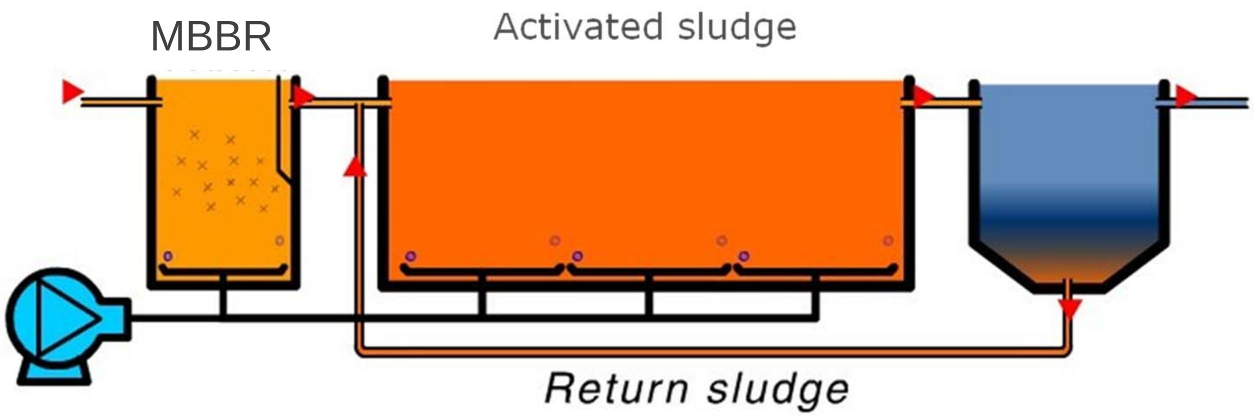
The high-rate MBBR-coagulation process



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

total HRT ~ 1 hr

The high-rate MBBR - AS process



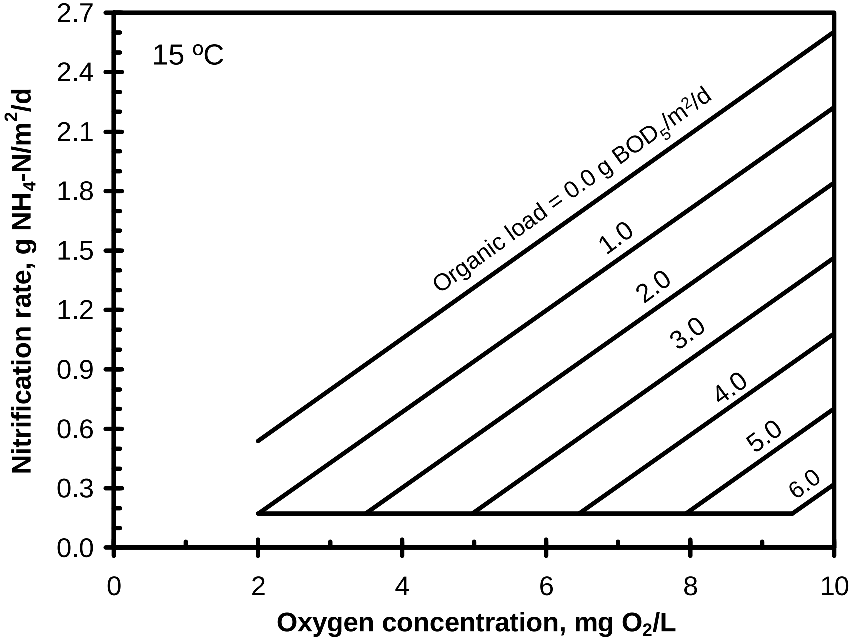
Frequently used in industrial plants e.g. pulp and paper

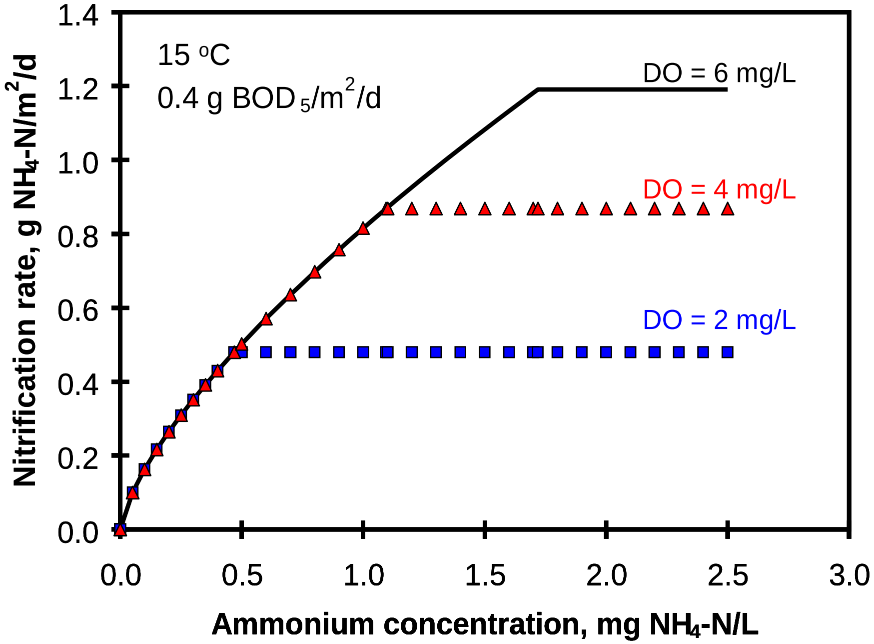
Factors determining the nitrification rate in MBBR's (Hem, Rusten and Ødegaard, 1994)

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

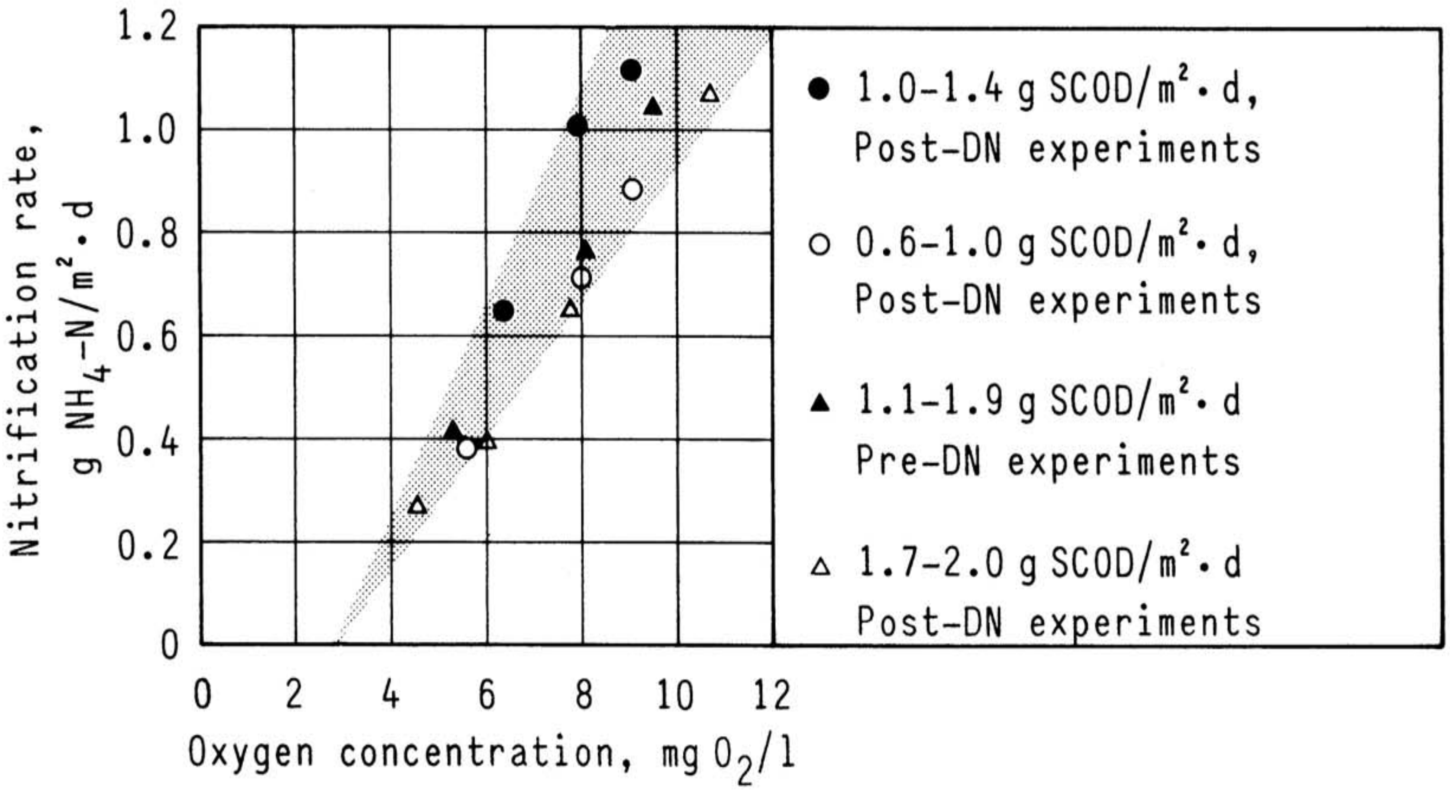
Temperature dependency:

$k_{T2} = k_{T1} \cdot \theta^{(T2-T1)}$, θ = 1,06-1,08





Influence of oxygen on nitrification rate - practical experiences



Nitrification process design

Organic matter removal prior to nitrification:

$r_{BOD} = 3{,}9$ g BOD_5/m^2d (10 ^oC) ($k_T = 1.06^{(T-10)}$)

Nitrification rate (when NH_4-N is the limiting substrate)

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

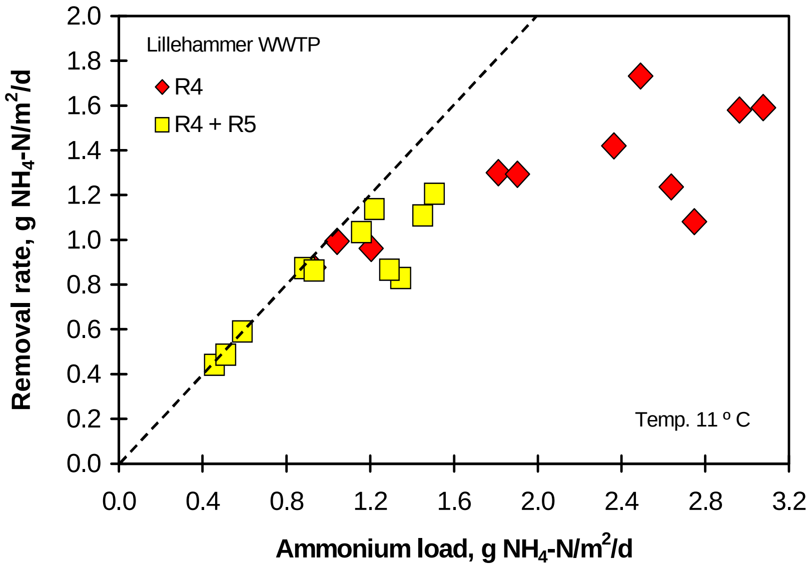
r_N = nitrification rate (g NH_4-N/$m^2 \cdot$d)
S_N = NH_4-N concentration in the reactor
n = reaction rate order - n is normally set at 0,7
k = reactor rate constant – 0,4 – 0,6 (varies with the organic load, i.e pre-treatment)

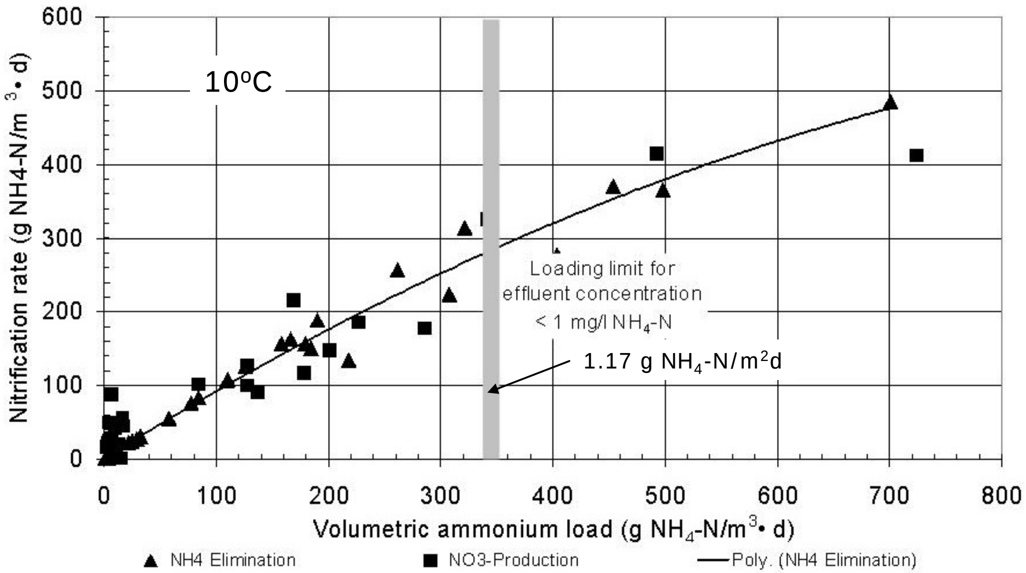
NH_4-N is only rate limiting at low NH_4-concentrations (ca 1-2 mg NH_4-N/l).

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

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

Nitrification rates in full-scale plants





Intensive study at Lillehammer WWTP
- Very high max rates (1,4 g $NH_4/m^2 \cdot d$)
- Complete nitrification at < 1,2 g $NH_4/m^2 \cdot d$

(Rusten and Ødegaard, 2007)

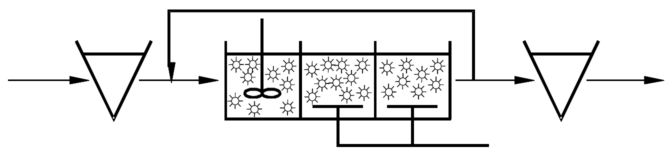
Nitrification performance at Givaudan WWTP Switzerland (Tschui, personal comm.)

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

N-removal

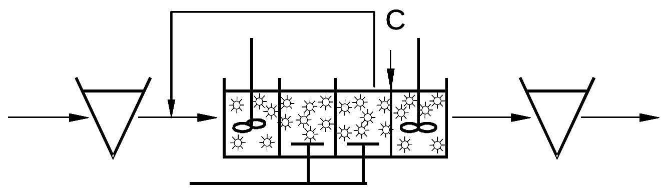
Choice of process is primarily dependent on availability of internal carbon source for denitrification and treatment efficiency requirement:

Pre-denitrification



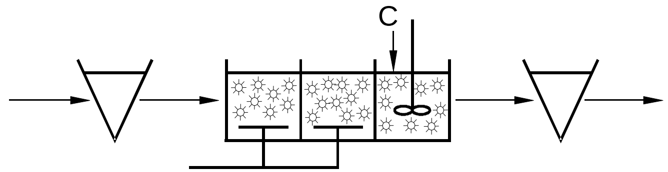
1. If carbon source is abundant and treatment efficiency needed is < 75 %, pre-DN is preferable

Combined denitrification



2. If carbon source is limited and treatment efficiency required is > 75 %, combined-DN is preferable

Post-denitrification

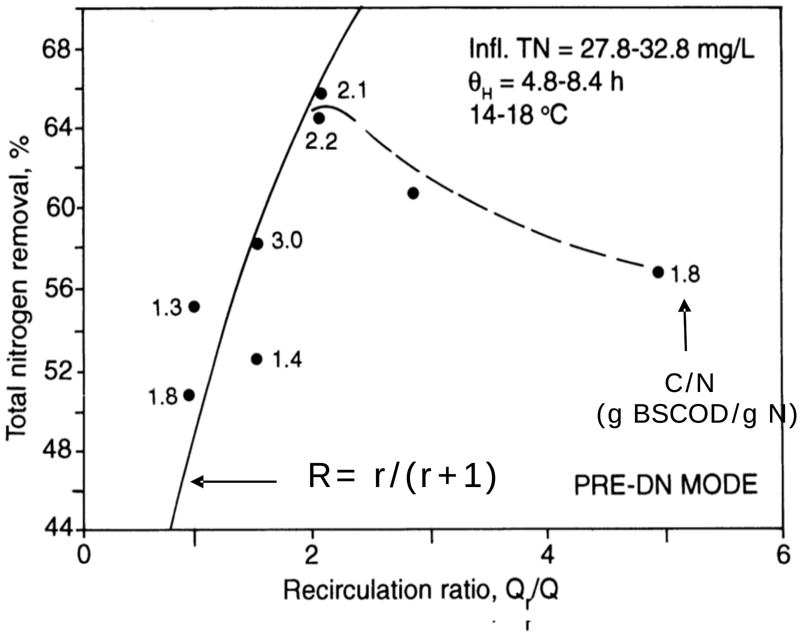


3. If, in addition to 2., space is very limited, post-DN may be preferable

Denitrification

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

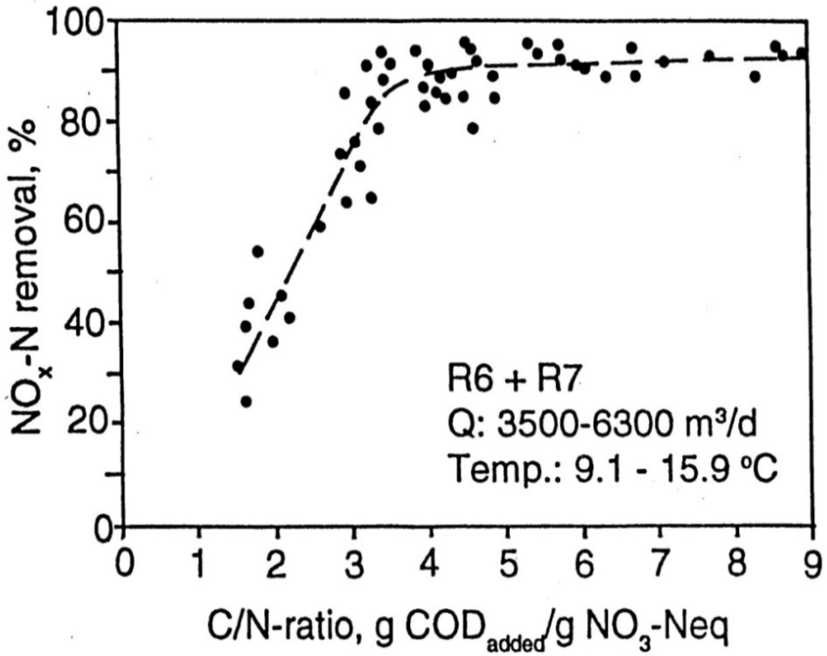
Pre-denitrification



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

Rusten, Hem and Ødegaard, 1995

Post-denitrification

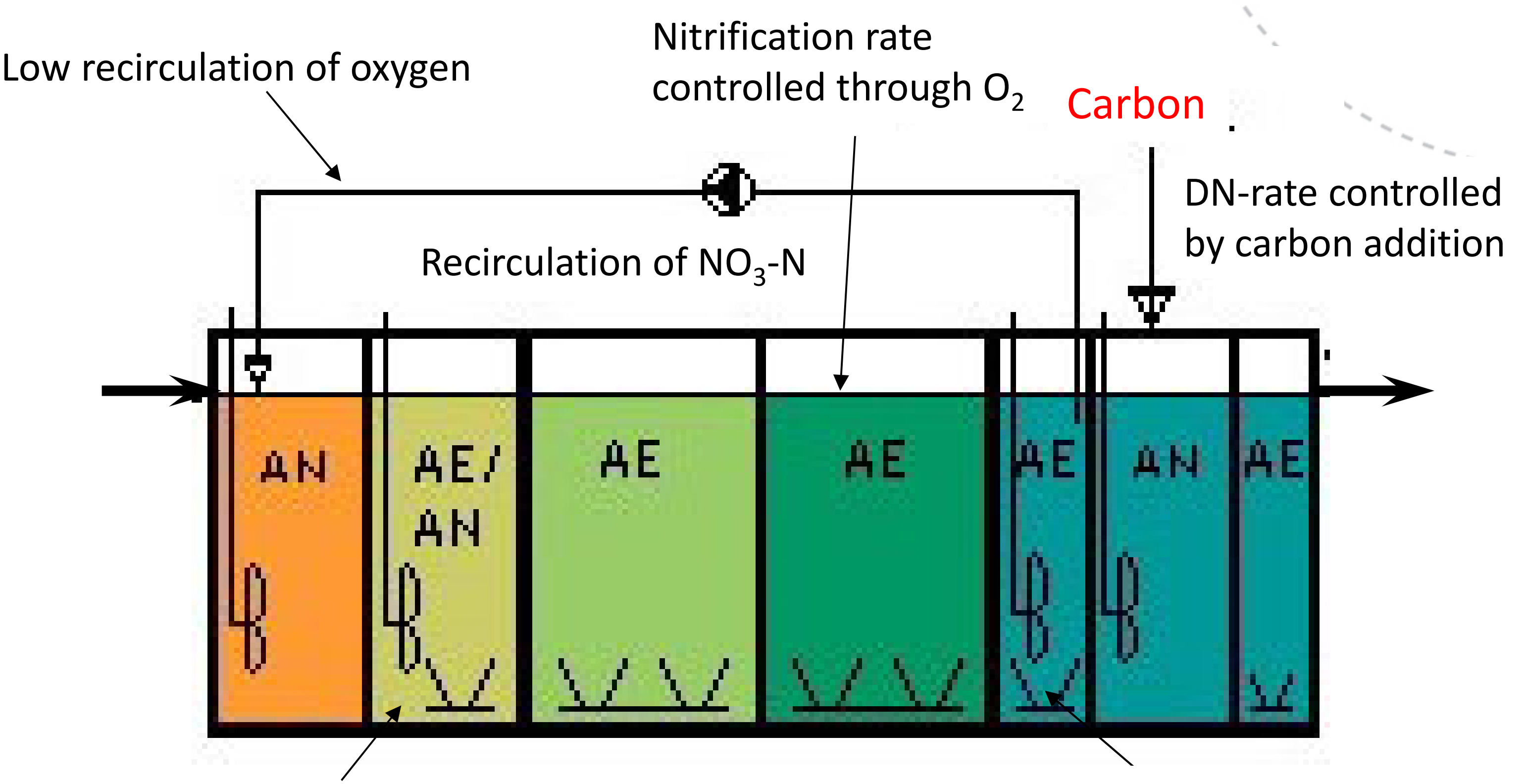


No carbon limitation as long as:

- 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

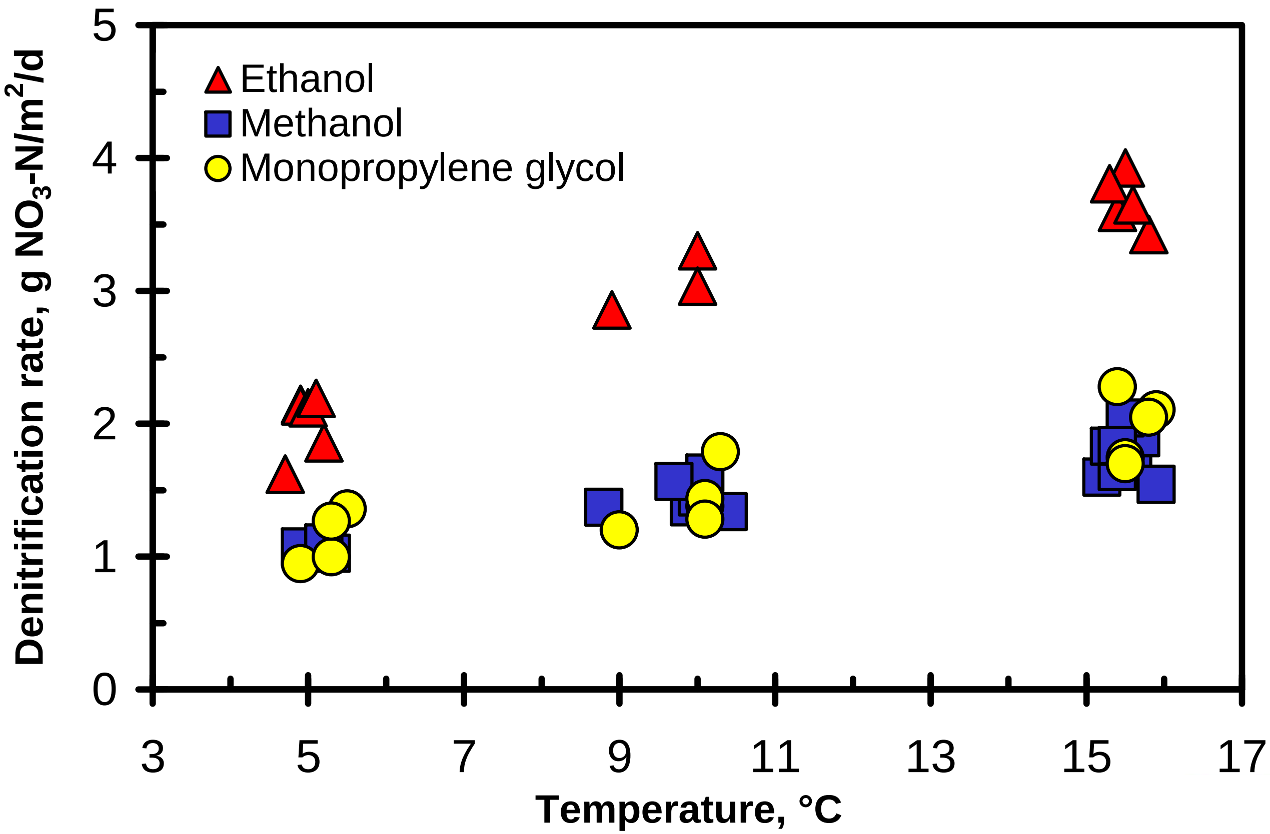
The combined pre- and post-DN MBBR process



- 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

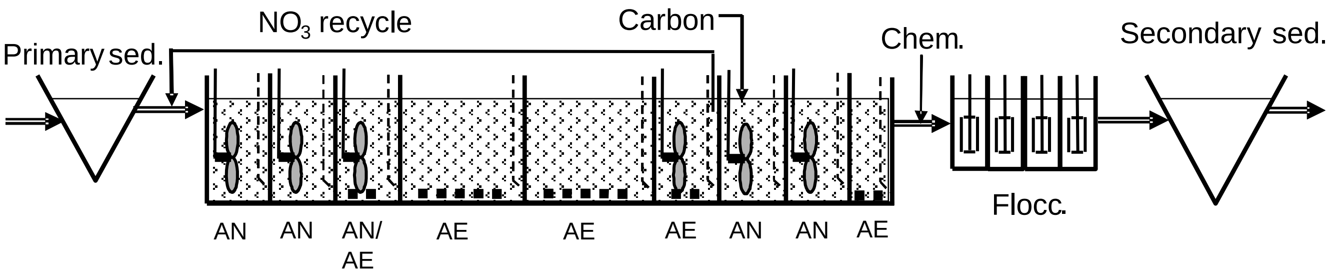
DN-rates with external carbon sources
(practical results from combined-DN plant)



Rusten et al, 1996

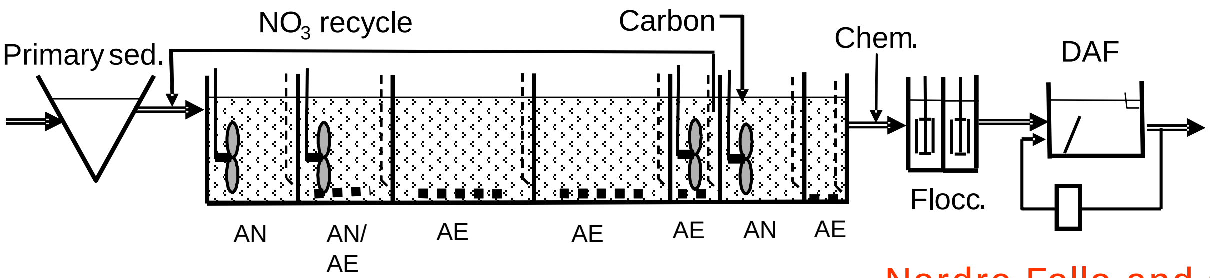
Four Norwegian combined DN-plants

a)



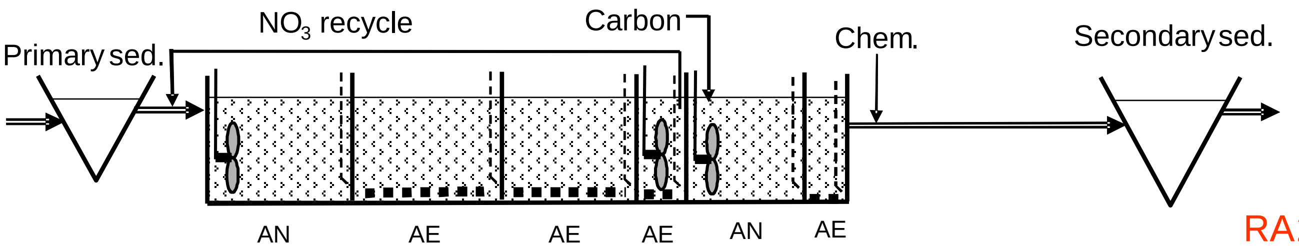
Lillehammer WWTP

b)



Nordre Follo and Gardermoen WWTP

c)



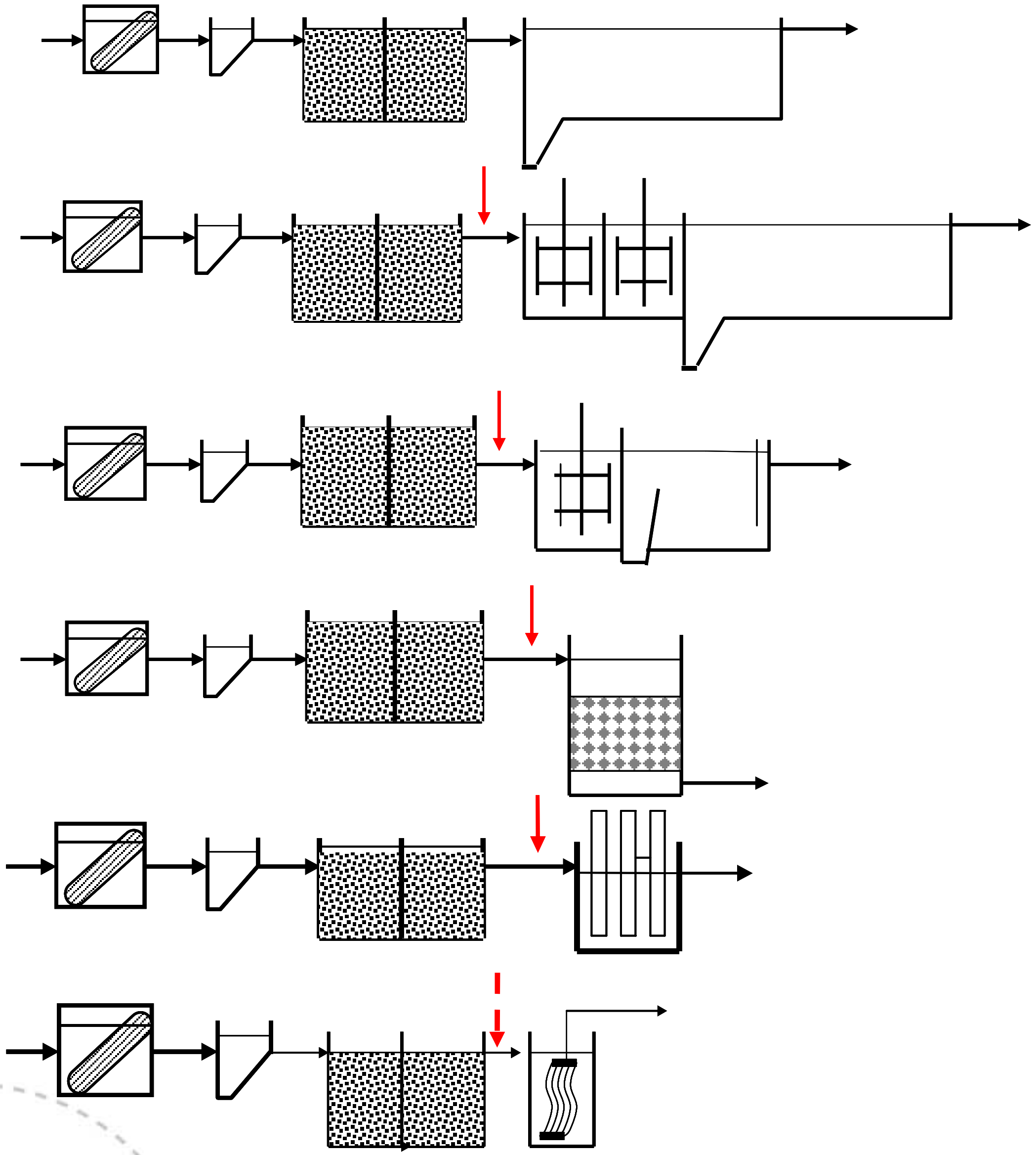
RA2 WWTP

MBBR design/operating values and performances

Parameter	Lille-hammer	Nordre Follo	Garder-moen	NRA
Average flow (m^3/h)	1200	750	920	2300
Max flow (m^3/h)	1900	1125	1300	7200
Temperature (^oC)	3-14	6-14	4-14	7-14
MBBR				
Total volume (m^3)	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 (now glycol)	Glycol	Methanol (now glycol)
g COD_{added}/g TN_{equiv}	3.3	2.2	2.4	-

Efficiency, 2005	Lille-hammer		Nordre Follo		Garder-moen		NRA	
Average out conc.	Out	Rem	Out	Rem	Out	Rem	Out	Rem
and treatment efficiency	mg/l	%	mg/l	%	mg/l	%	mg/l	%
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):

$NH_4^+ + NO_2^- \rightarrow N_2 + 2H_20$

Advantages

- No carbon source needed
- Less air needed (than in N/DN):
  ~1,8 g O_2/g N (60 % less)
- Very low sludge production
  ~ 0,11 g SS/g NH_4-N
- Less CO_2 - production/
  less alkalinity consumption

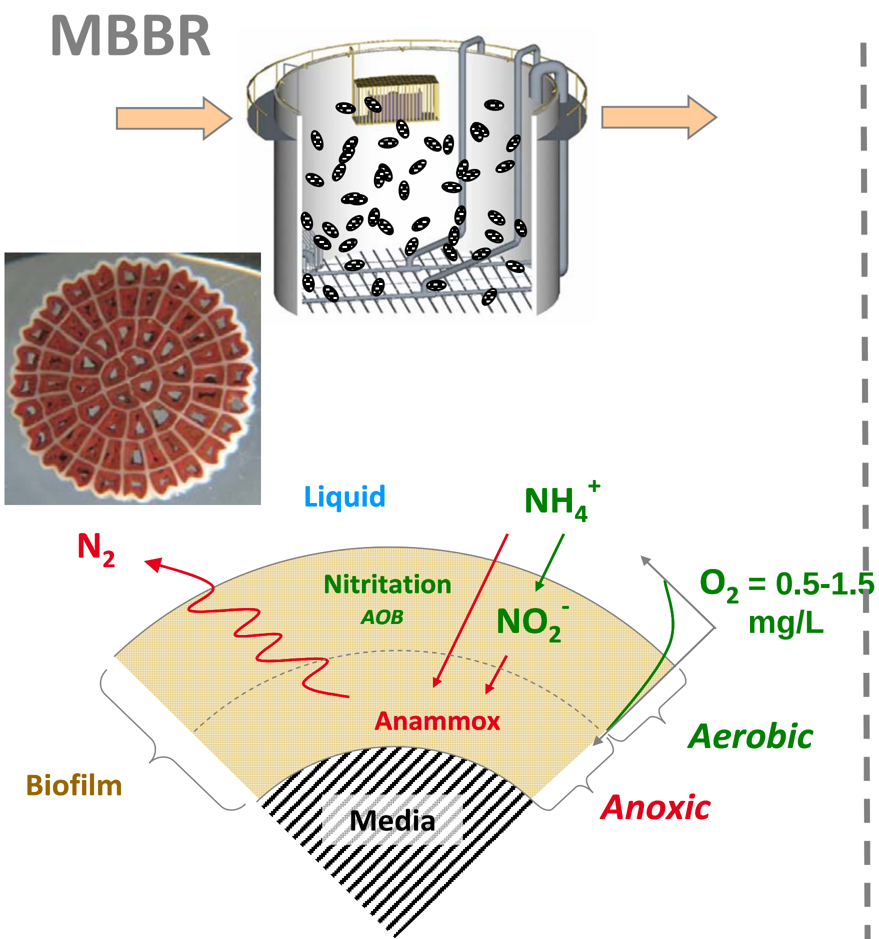
Disadvantages

- 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)

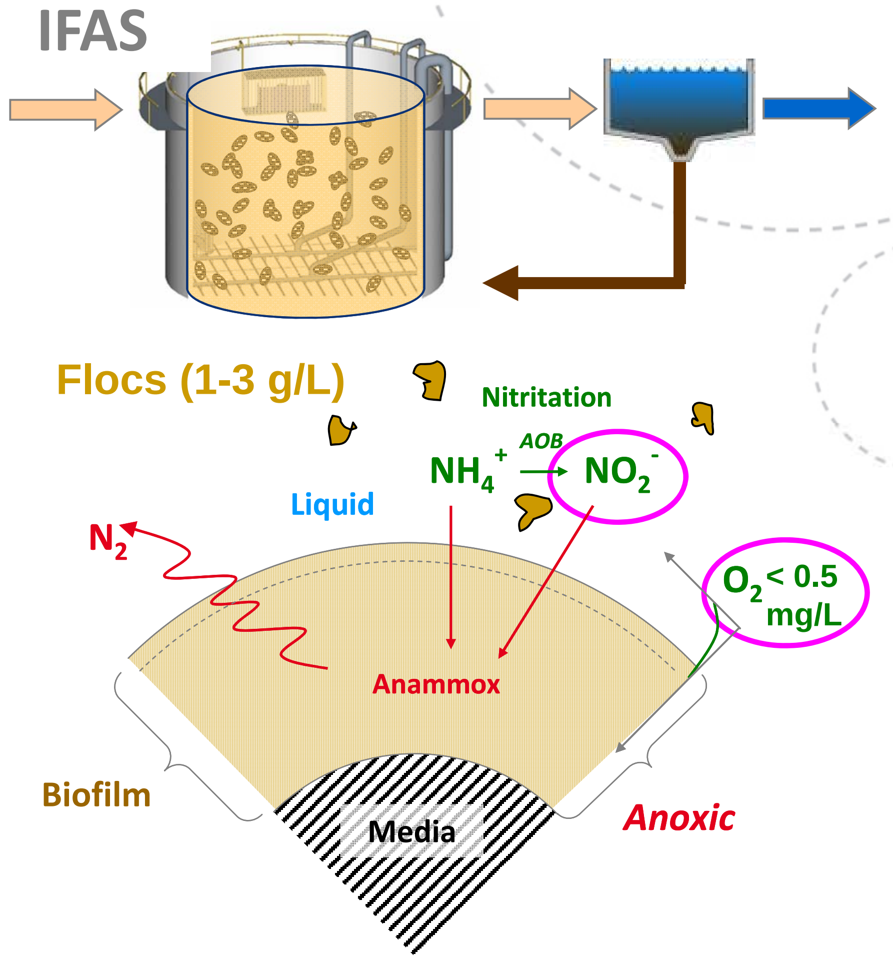
↓

Primarily used for N-removal in sludge water treatment

Anammox with MBBR (Christensson et al, 2013)

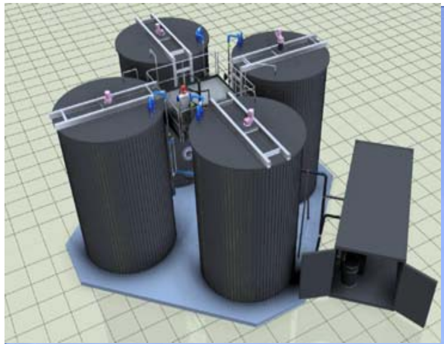


AOB in biofilm = NO_2^- limitation

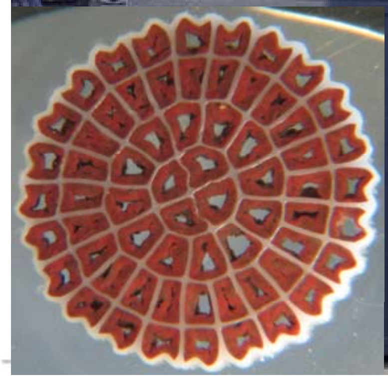


AOB in flocs = less NO_2^- limitation

ANITA™ Mox – Sjölunda WWTP, Malmö (Sweden)



- 4 x 50m³ MBBR
- Capacity = 200 kgN/d
- 800-1200 mgN-NH_4/L
- 1st ANITA™ Mox reference
- Flexibility for fullscale testing



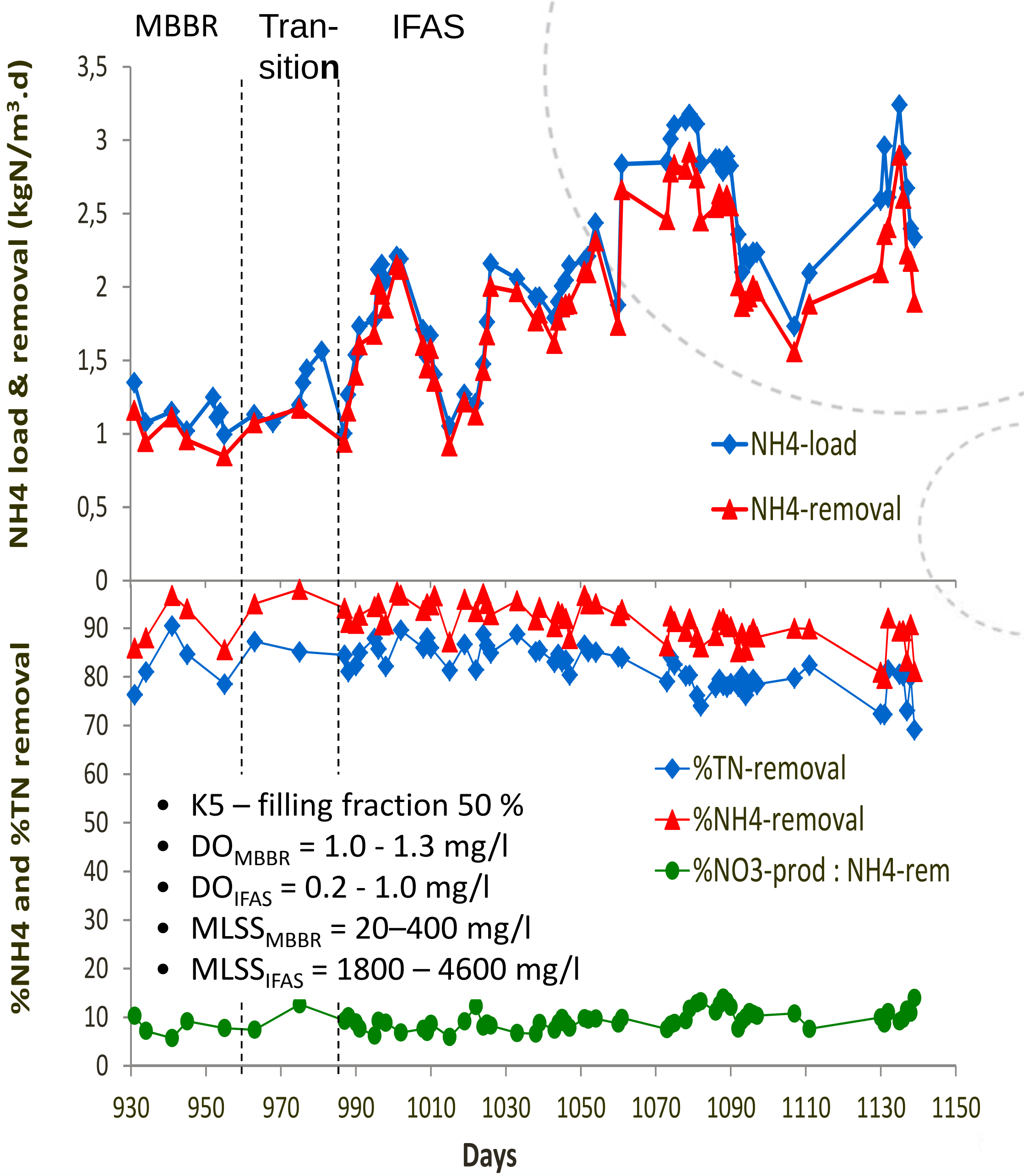
Seeded carriers

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

Full-scale test results ANITA™Mox , Sjölunda WWTP

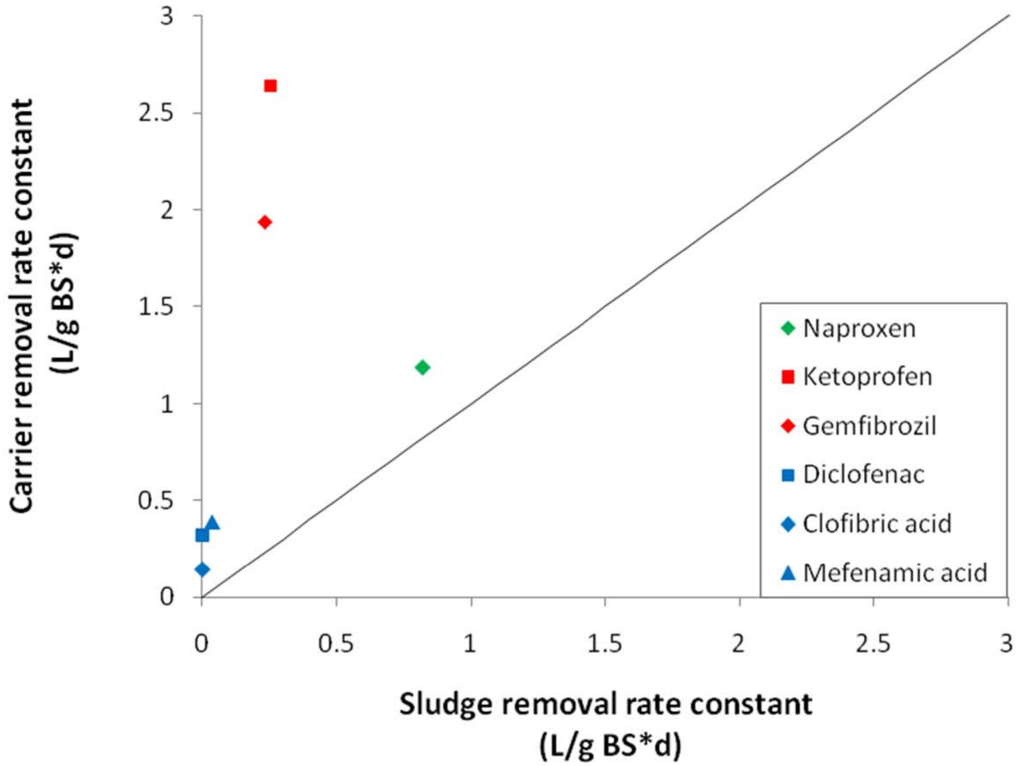
(Christensson et al, 2013)

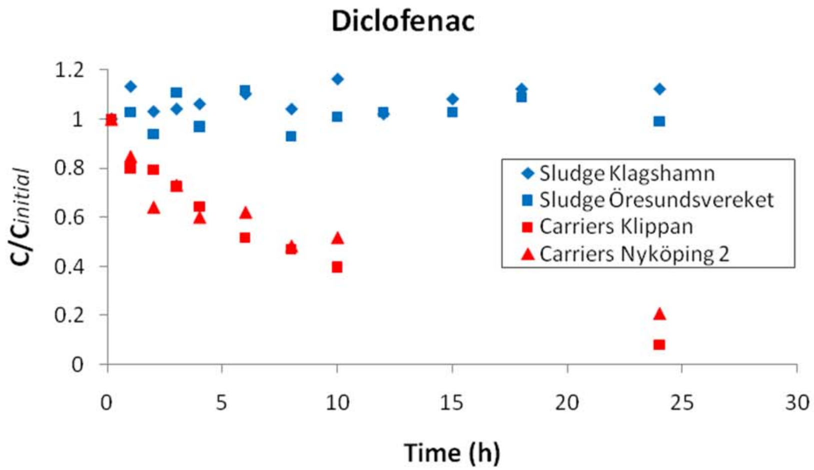
- High removal rates and good N-removal with MBBR
- Very high removal rate with IFAS - up to 3 kg NH_4-N/m^3·d (7.5 g NH_4-N/m^2·d)
- Energy consumption : 1.2 kWh/kg NH_4-N removed

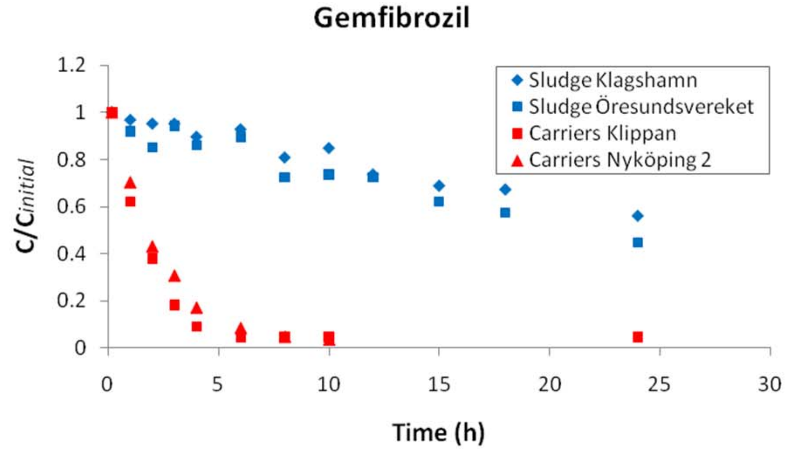


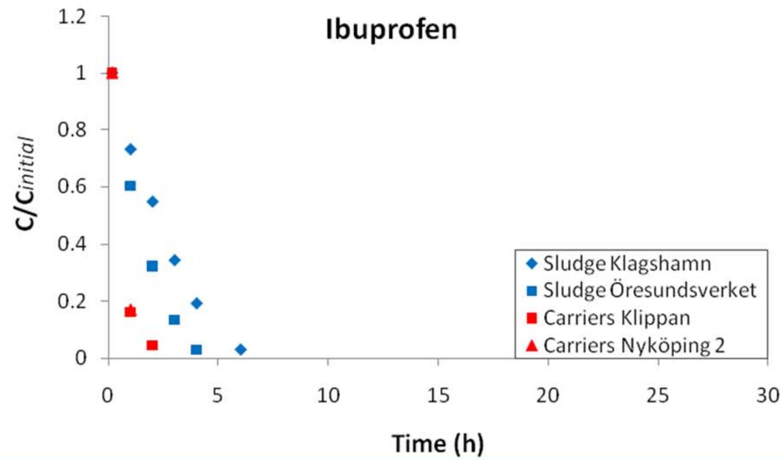
Removal of pharmaceuticals
(Falås, 2013)

Comparison between activated sludge and carrier-based processes



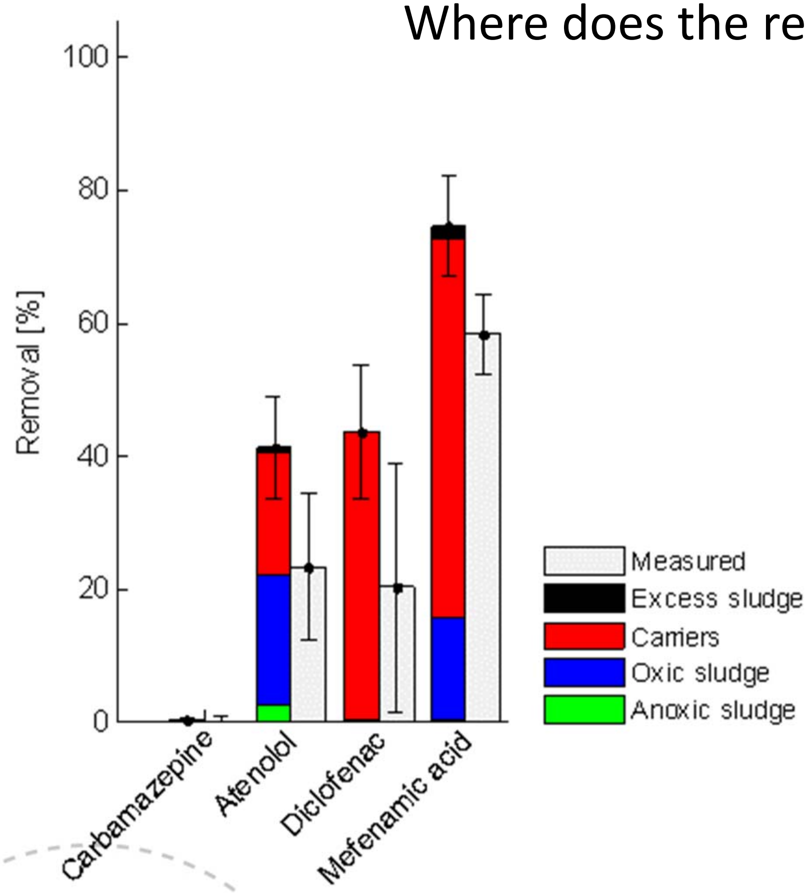


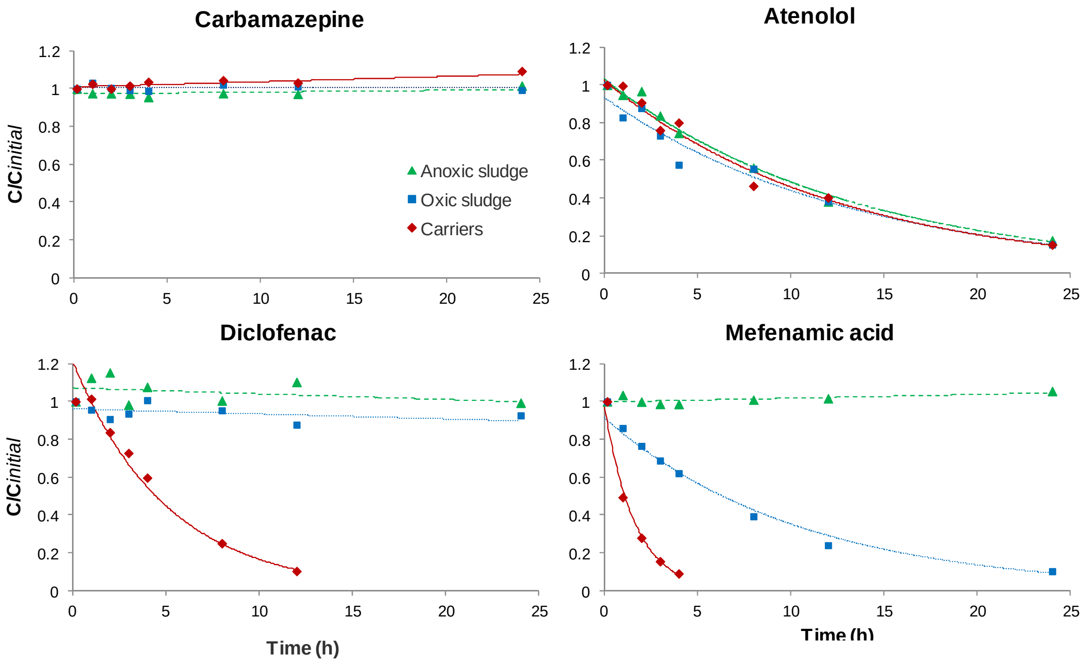




Removal og pharmaceuticals in the biomass from an IFAS plant (Bad Ragaz WWTP, CH)

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)

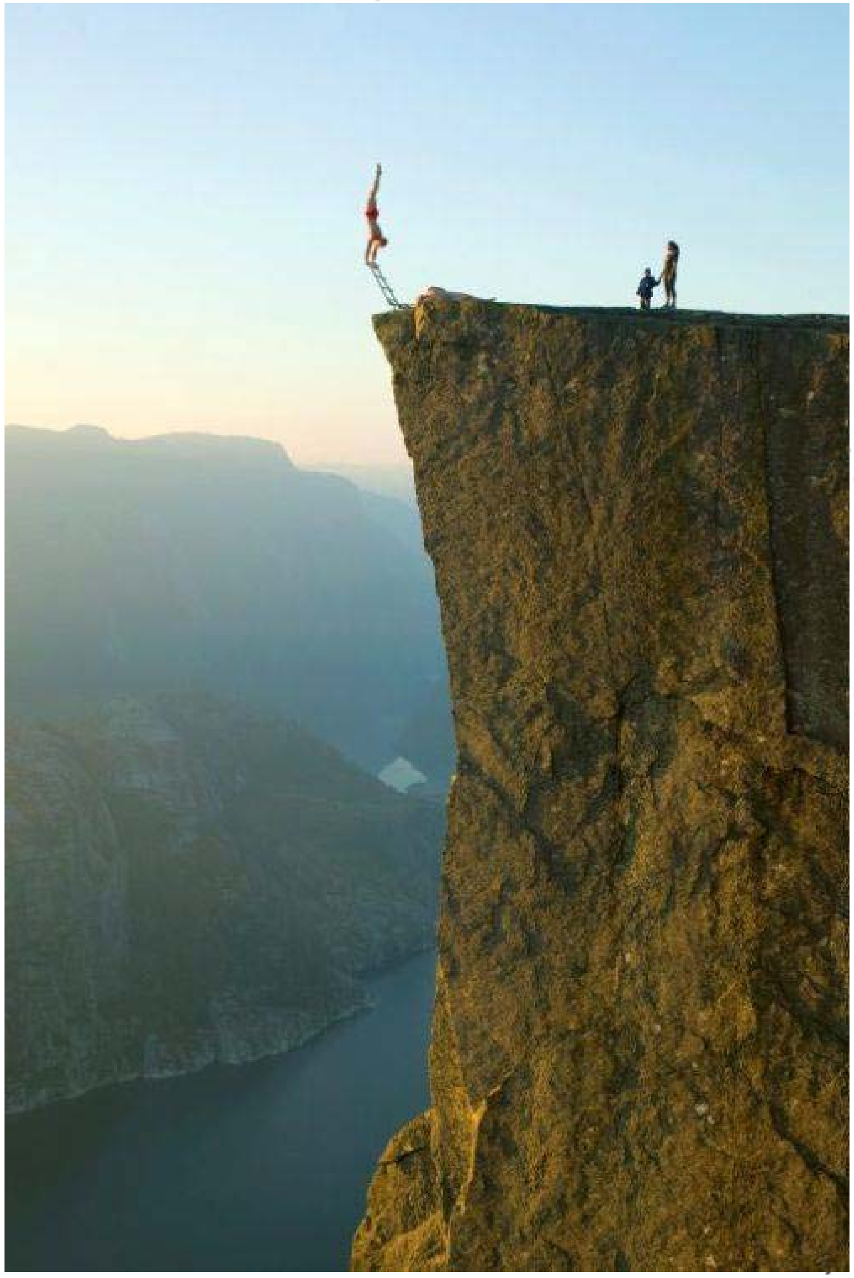
3. The combined pre- and post denitrification MBBR process is especially suitable for low C/N waters and offers great flexibility in operation

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

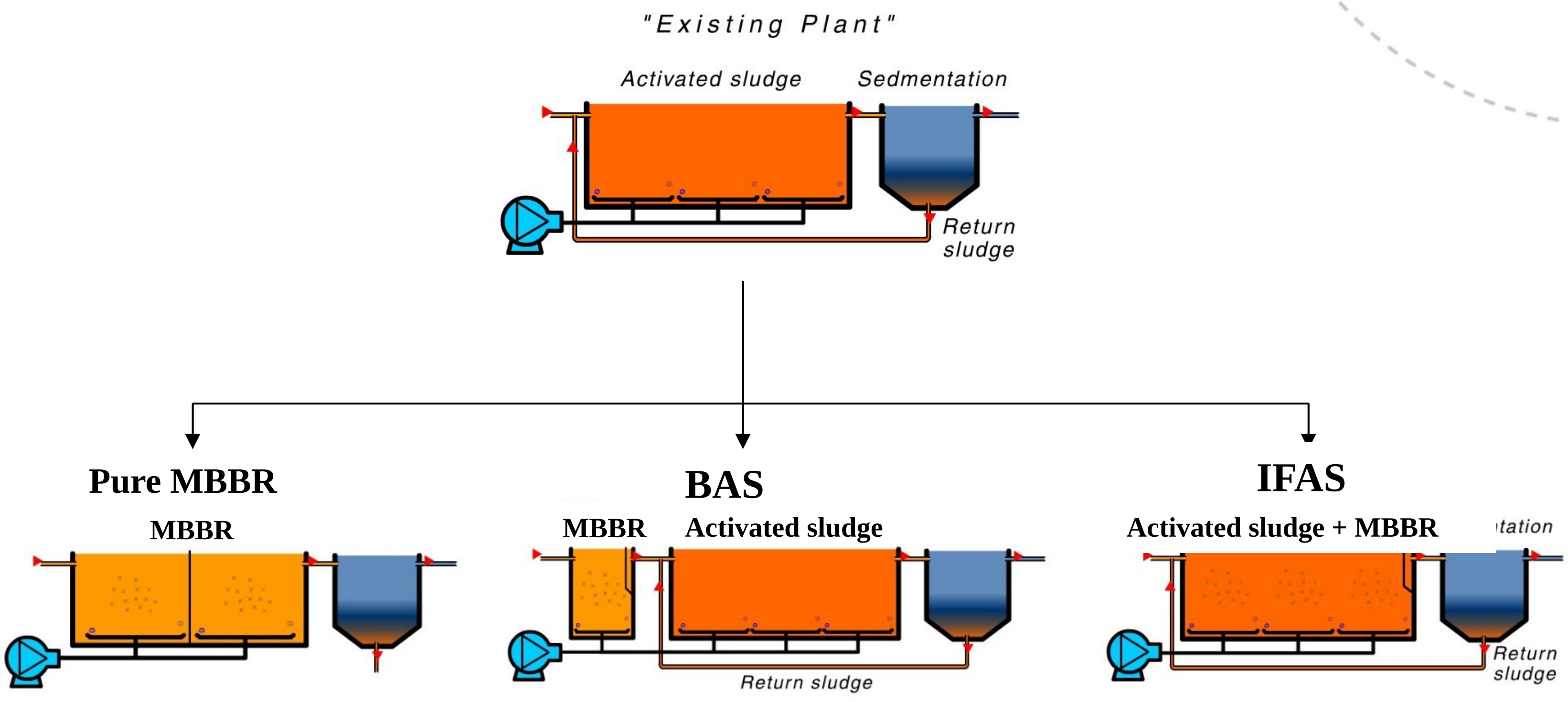
5. The MBBR-based processes are especially suitable for developing special cultures – for instance for:
   a. N-removal by anammox processes
   b. Organic micropollutants removal

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)