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One well-proven way for meeting the new EU directive standard on N-removal in Norway

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The tot.N and tot.P-standards

Parameter	The previous directive		The present directive		Norwegian environmental authorities	
	mg/l out	% rem.	mg/l out	% rem.	Old regulation	New regulation[1]
Tot N >150.000 pe <150.000 pe	 10 15	 70-80 70-80	 8 10	 80 80	 70 % (selected plants)	 80 % (>80 % for selected)
Tot P >100.000 pe <100.000 pe	 1,0 2,0	 80 80	 0,5 0,75	 90 87,5	 90 % (>95 % for selected)	 90 % (>95 % for selected)

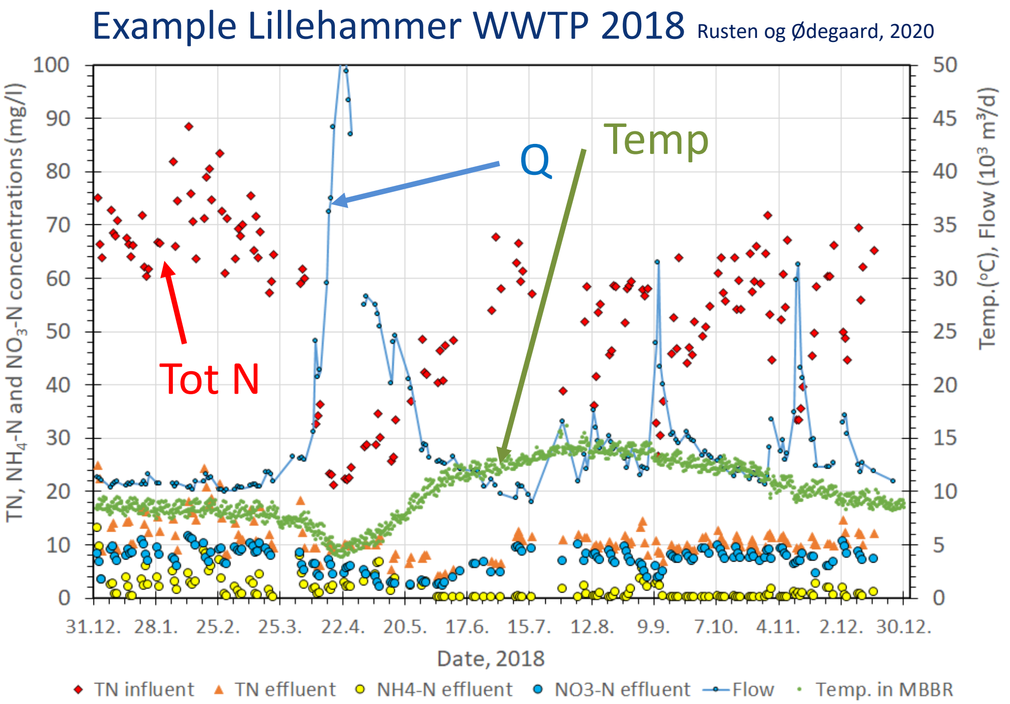
[1]Proposal

OBS!

- If the Norwegian proposal stands, the N-standard for most Norwegian plants, will be stricter than the EU-standard – for example: 35 mg Tot N_{in} require 7 mg Tot N_{out}
- I recommend to the authorities, that the directive is implemented in Norway - **as it is**

Norwegian challenges in N-removal

1. Large variation
   - Temperature
   - Flow
   - Tot N, BOD
2. Diluted wastewater
3. Low C/N
4. Space availability
   - In-door or under-ground plants
   - Compact processes needed



Typical in Norway: Snow-melt in spring gives high flow, low temp, low $C_{N,\ BOD}$ and low C/N

Rusten, B., Ødegaard, H. (2023) Nitrogen removal in MBBR plants at low temperatures - Experiences from Norway. Water, Sci. Technol., wst2023.154: https://doi.org/10.2166/wst.2023.154

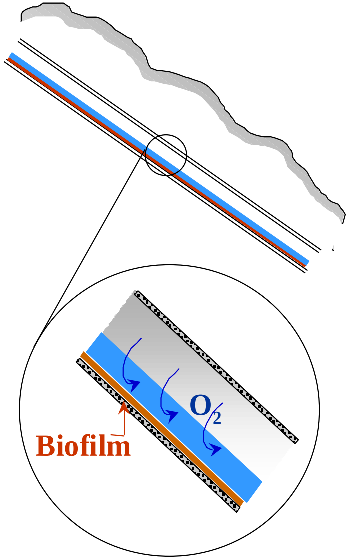
Why low C/N in many Norwegian plants ?

High gradient areas

Aerobic conditions in sewer

⇩

VFA + O_2 → cells



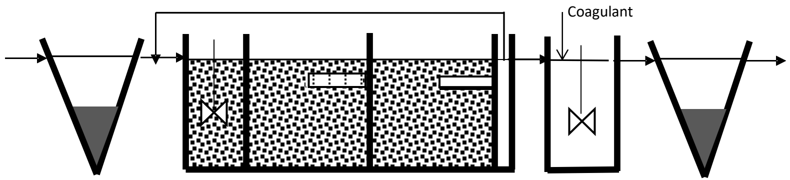
In Norway we have normally a quite high fraction of the organic matter on particulate form
Hence, quite good organic matter removal is experienced in purely chemical plants

Tot N and C/N of some Norwegian WWTPs

WWTP	Size of plant (ca. persons connected)	Year	Tot N, incoming water		C/N (BOD/TotN)	C/N (SBOD/NH_4-N)
			Yearly aver.	Min. – Max.	Yearly aver.	Yearly aver. (calculated)
Average 10 plants	> 10.000	1991	24,8	14,6 – 45,0	4,9	2,1
VEAS, Oslo	800.000	2024	30,6	15,1 – 49,4	3,8	1,8
BRA, Oslo	320.000	2024	27,7	13,6 – 42,2	4,3	1,6
SNJ, Stavanger	260.000	2024	37,7	14,0 – 52,0	6,0	2,3
Høvringen, Trondheim	150.000	2024	32,6	16,0 – 50,6	4,8	1,8
NRA, Lillestrøm	135.000	2018	30,6	14,7 – 52,2	4,0	1,5
LRA, Lillehammer	65.000	2019	52,6	27,4 – 88,5	5,5	2,1
GRA, Gardermoen	45.000	2020	61,0	30,0 – 82,0	3,6	1,4
NFRA, Nordre Follo	40.000	2020	44,7	13,0 – 74,8	2,8	1,5
SFRA, Søndre Follo	30.000	2022	56,0	35,0 – 75,0	3,7	1,4
MIRA, Midtre Follo	20.000	2024	66,4	35,0 – 95,0	4,6	1,7

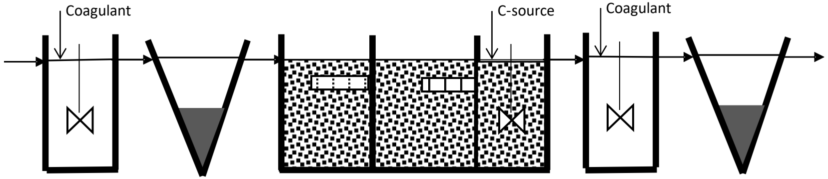
Removal of nutrients in MBBR (FAN-project, 1988-92)

a. Pre-denitrification with post-precipitation



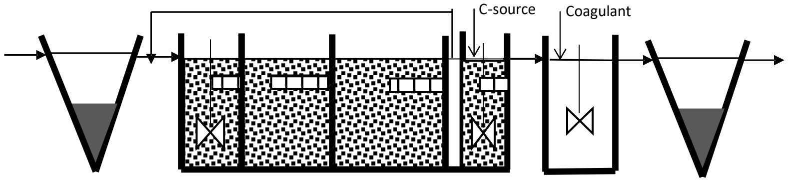
- Limited N-removal (< 70%)
- No need for external carbon source
- Require high in-coming C/N-ratio

b. Pre-precipitation with post-denitrification



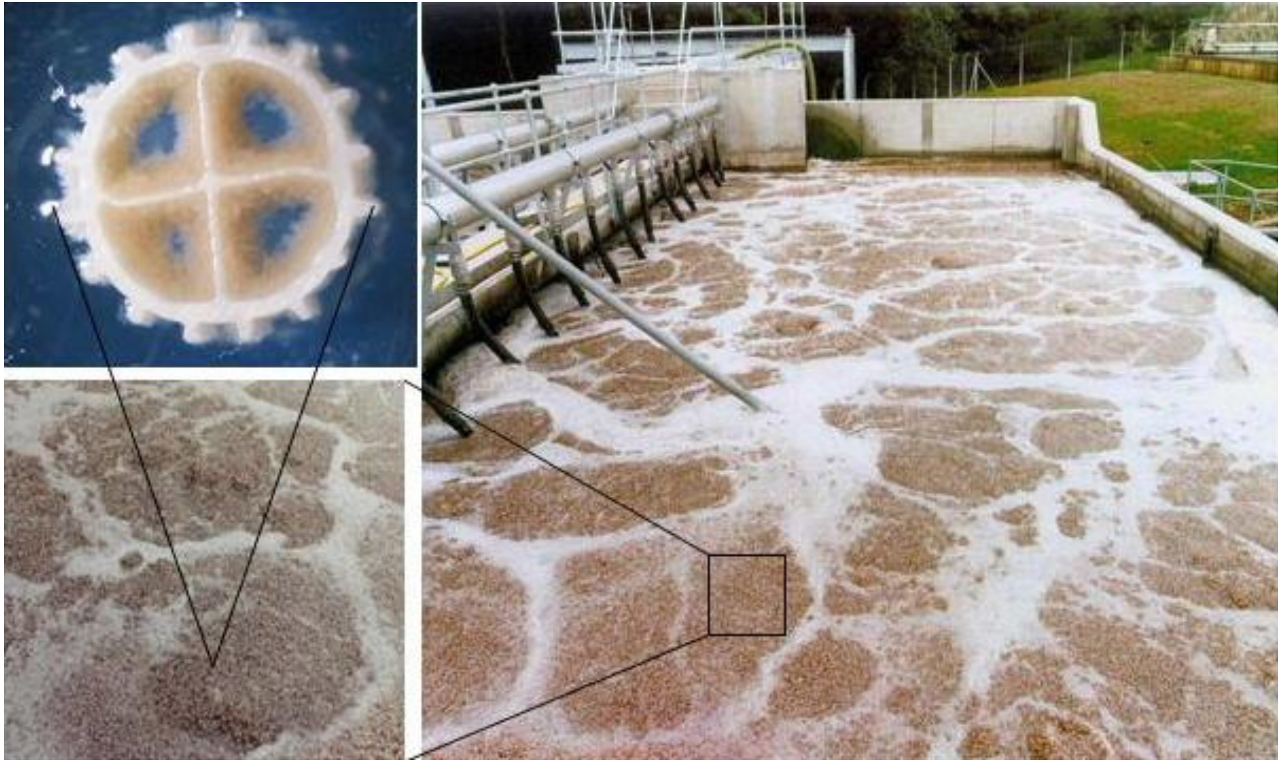
- No limit to N-removal (> 90%)
- Need for external carbon source
- Independent of in-coming C/N-ratio

c. Combined pre- and post-denitrification



- No limit to N-removal (> 90%)
- Need for external carbon source
- Less dependent of in-coming C/N-ratio

The Moving Bed Biofilm Reactor (MBBR) (1987-1990)



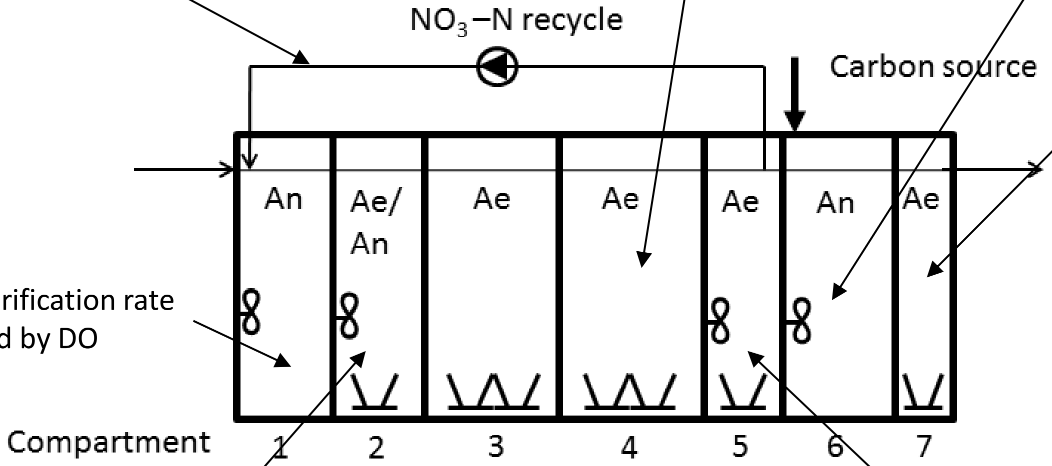
The combined pre- and post-DN MBBR process

Recycle controlled by DO in pre-DN

Nitrification rate controlled through DO

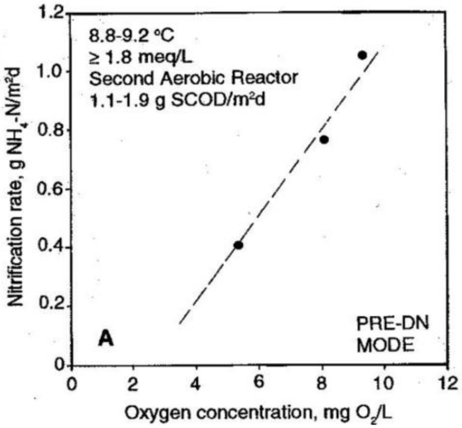
DN-rate controlled by carbon addition

Re-aeration for removal of potentially residual COD from carbon source



Pre-denitrification rate controlled by DO

$r_{NH4\text{-}N} \sim 0{,}15\ DO - 0{,}39$

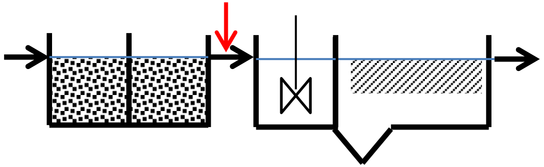


- Aerated when larger nitrification volume is needed (winter).
- Not aerated in summer – more pre-DN volume – higher recycle in summer

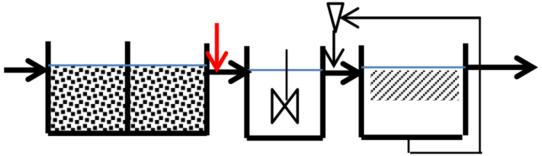
Not aerated nitrification
De-oxygenation - in order to reduce the amount of recycled O_2

MBBR biomass separation alternatives

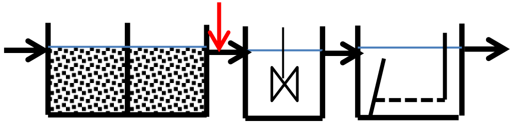
At high biomass concentration (primary sep.)



MBBR – Settling/Lamella settling

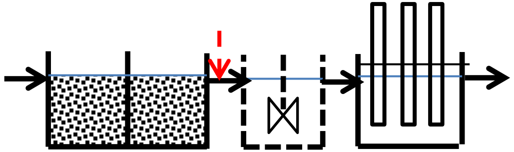


MBBR – Microsand ballasted lamella settling

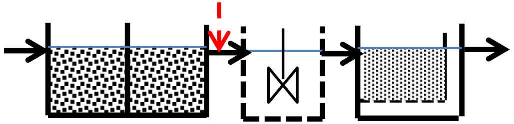


MBBR – Dissolved air flotation (DAF)

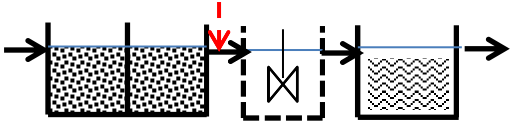
At low biomass concentration (secondary sep.)



MBBR – Microscreening



MBBR – Sand filtration

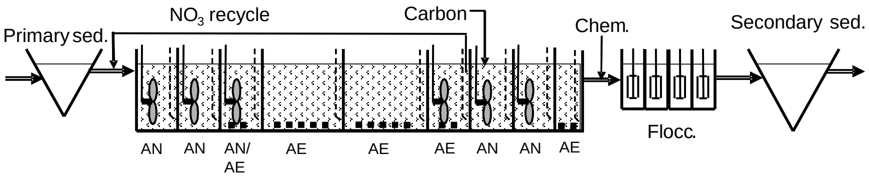


MBBR – Membrane (UF or MF) filtration

Experiences from four combined DN-plants

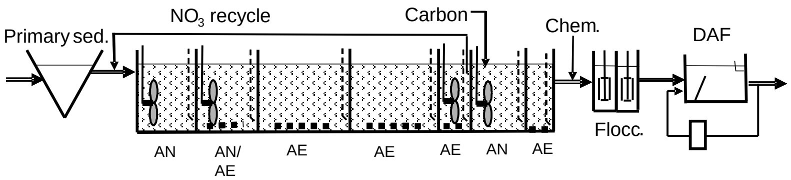
Lillehammer WWTP

a)



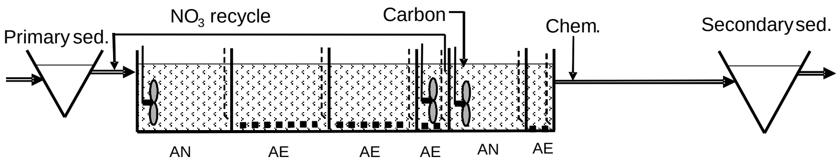
Nordre Follo and Gardermoen WWTP

b)

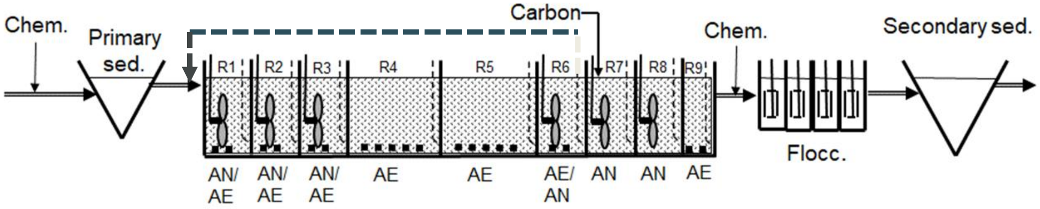


Nedre Romerike WWTP

c)



Lillehammer WWTP



Originally built in 1994 as a combined-DN plant, today post-DN (ethanol) with pre-precipitation

Parameter	Removal (%)		Effluent concentration (mg/l)	
	2018	2019	2018	2019
Tot. COD	96,5	96,2	25	25
Tot. P	98,4	98,1	0.11	0.11
Tot. N	82,3	77,3	10,3	11,6

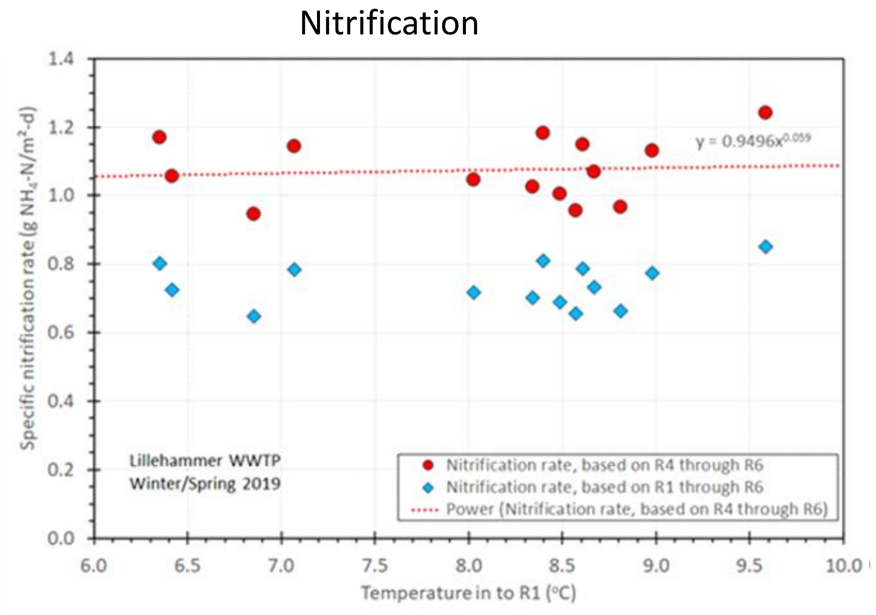
Temperature, ºC	2018	2020
Average	~10	~10
Minimum	3,9	5,3

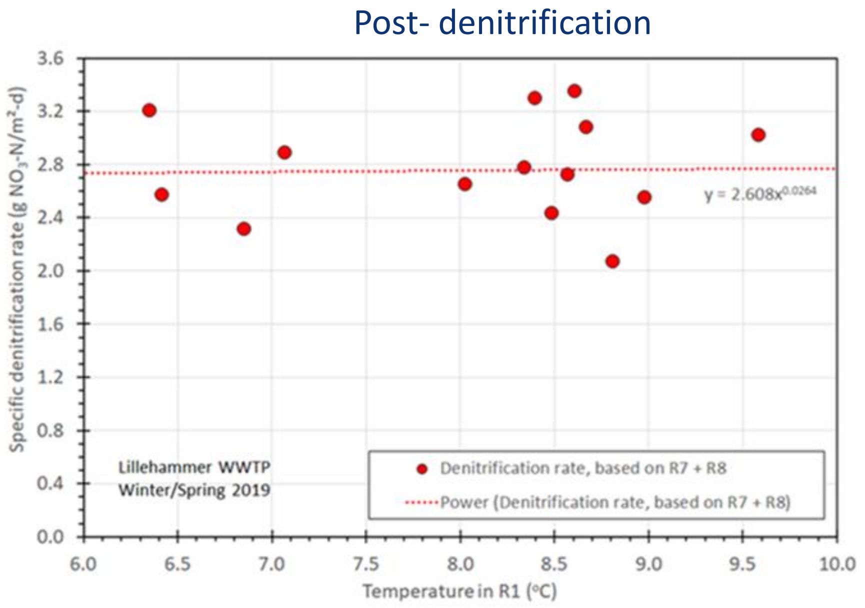
- The average MBBR HRT over the spring of 2018 (01.04.18–01.06.18) was only around 3.5 hrs .

Ødegaard, H. and Rusten, B. (2021) Wastewater treatment for N-removal in MBBR-based plants receiving cold wastewater - A knowledge compilation. Translated to Swedish in IVL-Report Nr: B2464, Stockholm, Mars 2023

Nitrification and post-denitrification rate

Lillehammer spring/winter of 2019

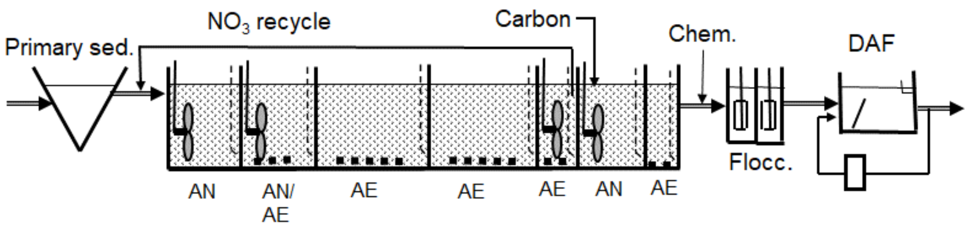




- Reduced nitrification rate with decreasing temperature is compensated for by increased DO
- Reduced de-nitrification rate is compensated for by increased carbon source addition

Rusten, B., Ødegaard, H. (2023) Nitrogen removal in MBBR plants at low temperatures - Experiences from Norway. Water, Sci. Technol., wst2023.154: https://doi.org/10.2166/wst.2023.154

Example: Gardermoen WWTP (GRA)



Built as combined-DN MBBR plant, with flotation (DAF) in 1998

Today expanded to triple capacity with same process + filtration

Parameter	Removal (%)		Effluent concentration (mg/l)	
	2019	2020	2019	2020
Tot. COD	97.0	95.9	22	27
Tot. P	96.1	96.7	0.32	0.26
Tot. N	84.0	86.8	11.2	7.9

Temperature, °C	2019	2020
Average	11.2	10.7
Minimum	6.7	5.4

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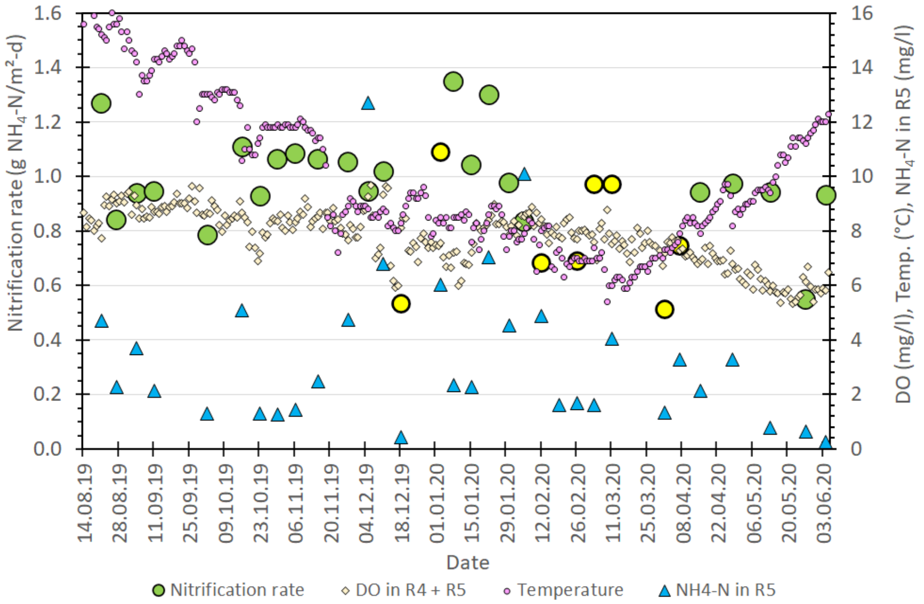
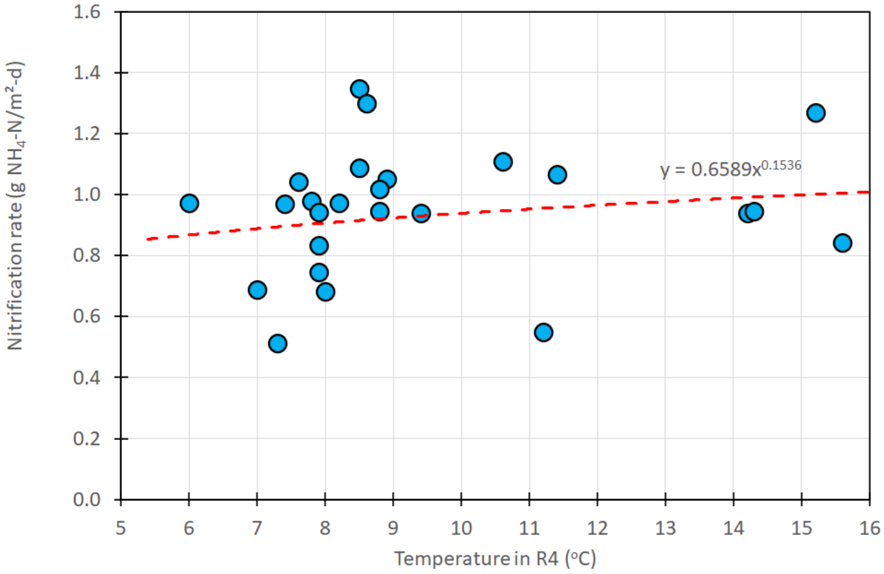
Nitrification rates, Gardermoen WWTP 2019/2020

Nitrification rates, DO and temperature in R4+R5

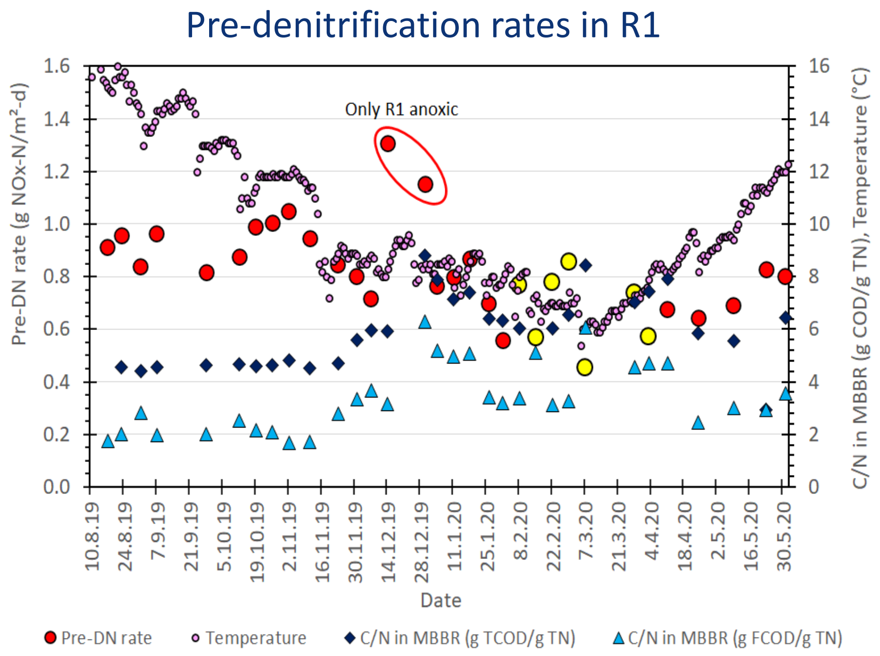


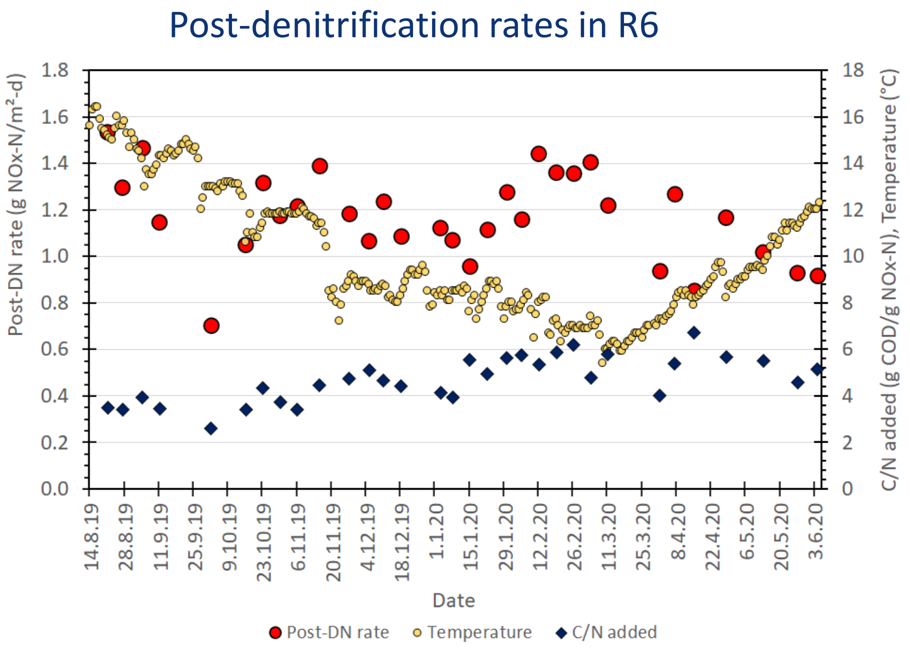
Nitrification rates (in R4+R5) versus temperature.



Denitrification rates, Gardermoen WWTP 2019/2020

with corresponding temperatures and C/N-ratios.





Take home messages on N-removal in MBBRs

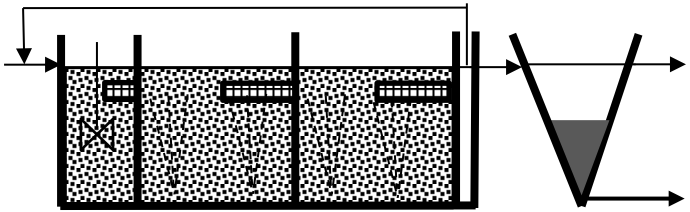
- Nitrification and denitrification in MBBRs are significantly influenced by temperature
- Nitrification rate is strongly (linearly) dependent on DO
- Reduced nitrification rate with decreasing temperature can be compensated for by increased DO

  A nitrification reactor will have the same nitrification rate (0.5 g NH_4/m^2d) at

  - 15 °C and a DO of 3.0 mg/l
  - 10 °C and a DO of 5.0 mg/l
  - 6 °C and a DO of 7.5 mg/l
- Since DO increases with decreasing temperature, the reduced nitrification rate with reduced temperature is masked because of the increased DO
- The denitrification rate is strongly dependent on the type and dose of carbon source
- Reduced de-nitrification rate can be compensated for by increased carbon source addition

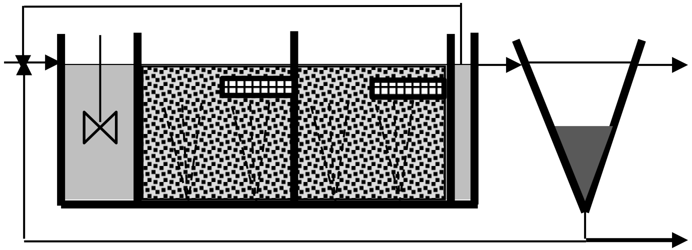
Two different uses of MBBR-based systems

Moving bed biofilm reactor (MBBR)



- BOD-removal and nitrification take place in series – BOD-removal primarily in the attached biomass of the first reactor and nitrification primarily in the last

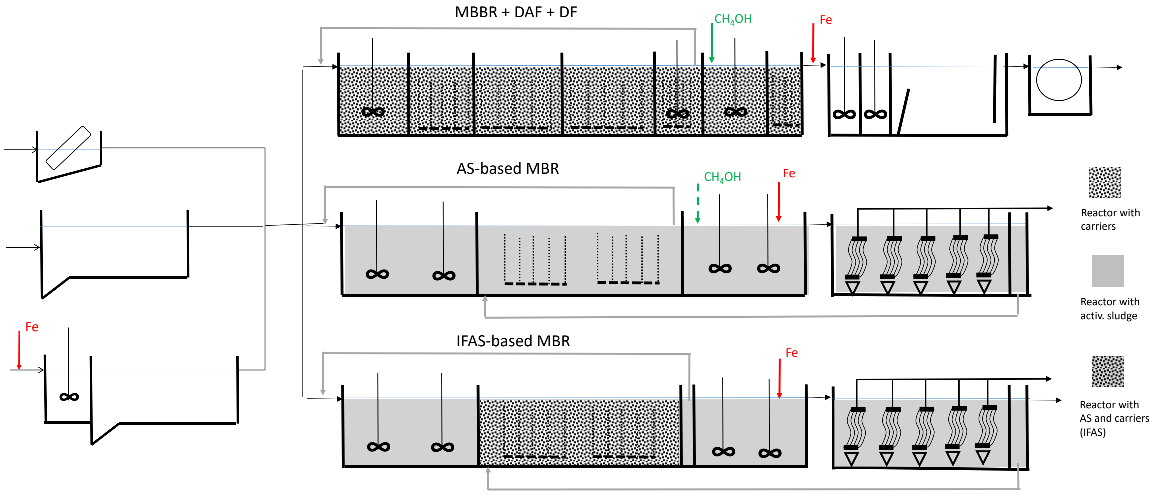
Integrated fixed film/activated sludge system (IFAS)

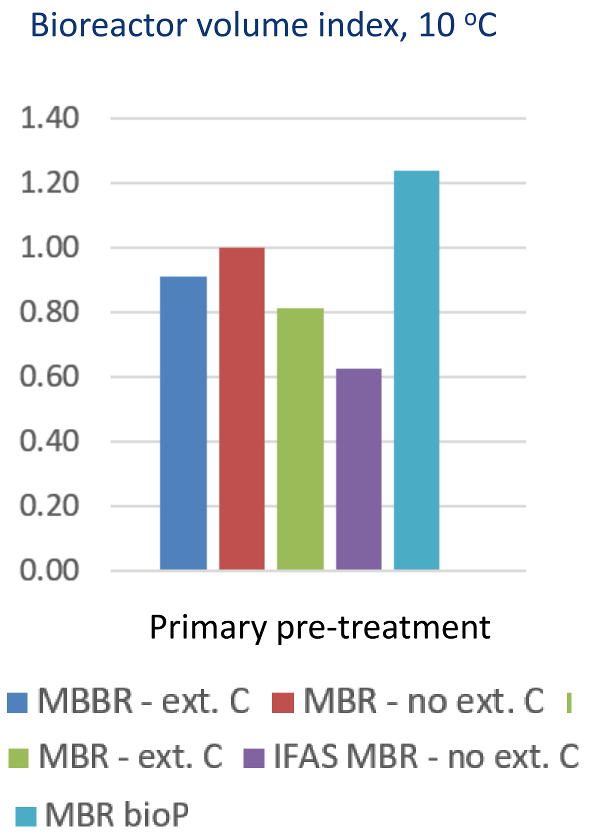


- BOD-removal and nitrification take place in parallel – BOD-removal primarily in the suspended biomass and nitrification primarily in the attached biomass

Systems comparison (2018)

1. Combined pre-and post-denitrification MBBR + DAF + DF
2. Combined pre- and post-denitrification AS MBR
3. Combined pre- and post-denitrification IFAS MBR
   (with three different pre-treatments)





Ødegaard, H. (2018) MBBR and IFAS systems. Chapter 3 of: Mannina, G., Ekama, G., Odegaard, H. and Olsson, G. (2018) Advances in Wastewater Treatment. IWA Publishing, London. ISBN: 9781780409702

Conclusions

- Norway has been lagging behind the rest of Europe for 25 years, when it comes to N-removal. Hence N-removal represents now (after revised UWWD) a considerable challenge in Norway
- I strongly recommend that the Norwegian Environmental Authorities implement the revised UWWD as it is written, including standards for both % removal and effluent concentration
- We have >30 years of experience with the combined nitrification/denitrification MBBR process, that was developed during the «Removal of N» R&D program (FAN) in the early 90'ies (1989-1992)
- It is now well documented that this process solution is able to meet the revised UWWD with respect to the effluent standards for nitrogen under typical Norwegian wastewater conditions