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Activated sludge: 100 *plus* 1 years
New trends and perspectives
University of Palermo, 11.05.2015

Hybrid activated sludge/biofilm processes (IFAS)

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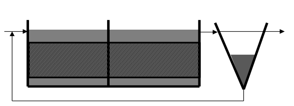
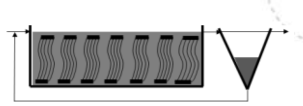
What is an Integrated Fixed-film Activated Sludge (IFAS) system ?

An IFAS system involves the combination of a suspended biomass (activated sludge) and an attached biomass (biofilm) in the same reactor

Examples of systems that are less used today

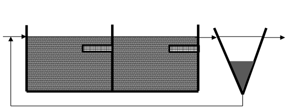


Fixed media IFAS system



Ringlace IFAS system

The system that are most commonly used today



MBBR IFAS system

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Various fixed and moving carriers

a. AccuFAS

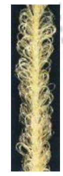
Courtesy Brentwood Ind.

b. Bio-Blok

Courtesy Expo-Net

c. PU foam cubes

Courtesy Exile Machine



d. Ringlace

Courtesy Kajima Aquatech

e. Biotextil Cleartec

Courtesy HYDROK

Various suspended (MBBR) carriers

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

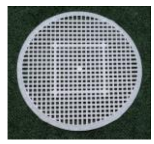
f. K1

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

g. K3

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

h. K5



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

i. BiofilmChip M

Courtesy AnoxKaldnes

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

j. ABC

Courtesy Aqwise

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

k. BWT S

Courtesy Biowater Technology

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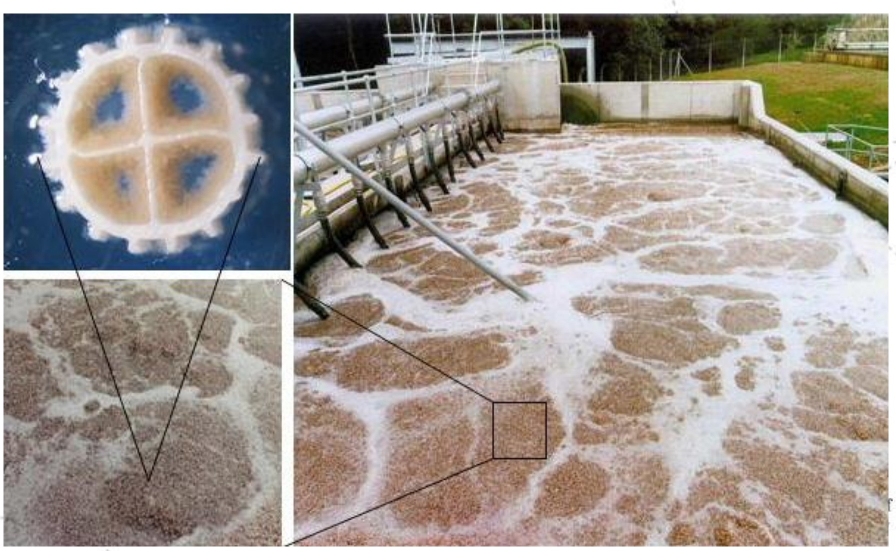
The Moving Bed Biofilm Reactor (MBBR)



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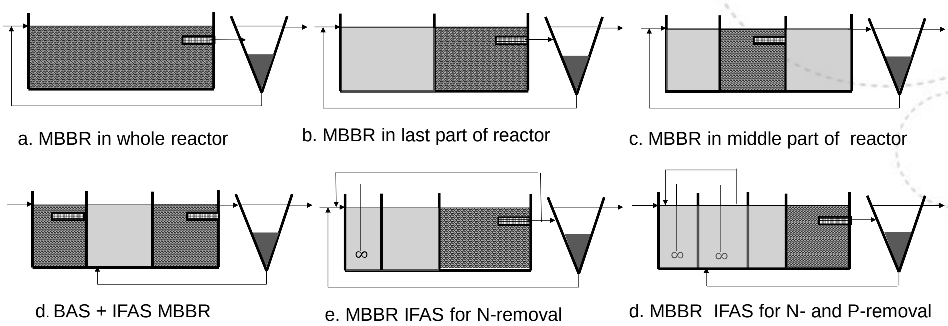
The MBBR-based IFAS - system



- Carrier filling fraction: anything from 0% to 65 %
- Commonly 50-55 % in anoxic and 55-60 % in aerobic reactors

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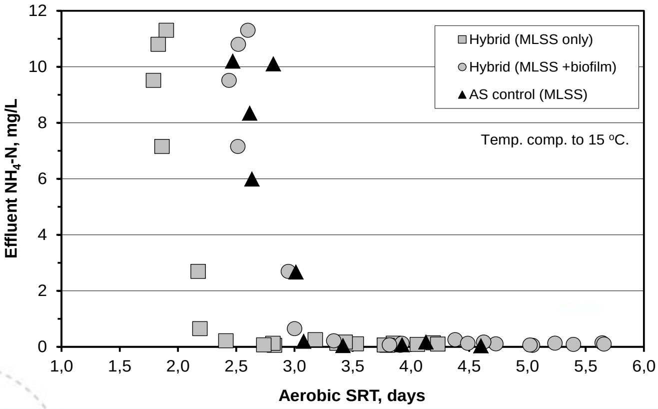
Some early Norwegian IFAS experiments

(Rusten et al, 2003)

Effluent NH_4-N concentrations versus aerobic SRT's for IFAS and AS pilot-plant control trains – filling fraction: 18 %



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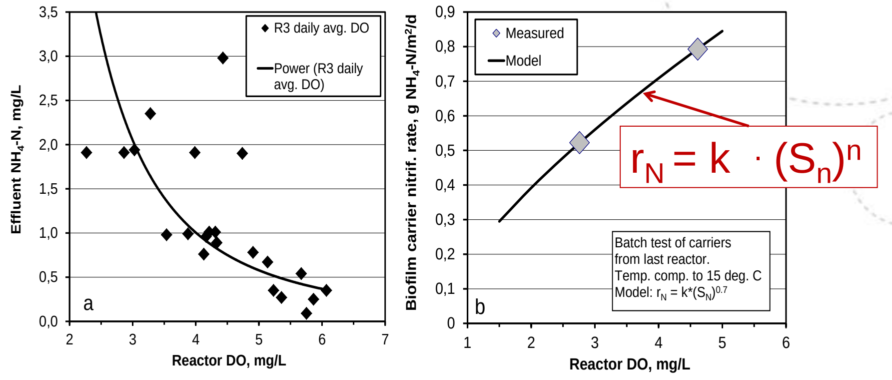
Influence of reactor DO on effluent NH_4-conc. and biofilm carrier nitrification rate (Broomfield pilot plant)



r_N = nitrification rate (g NH_4-N/m$^{2\cdot}$ d)
k = reaction rate coefficient
n = reaction order constant, can be estimated at n = 0.7
S_n = rate-determining ammonium concentration, mg NH_4-N/L
(can be estimated at $S_n = (DO_{bulk} - 0.5)/3.2$

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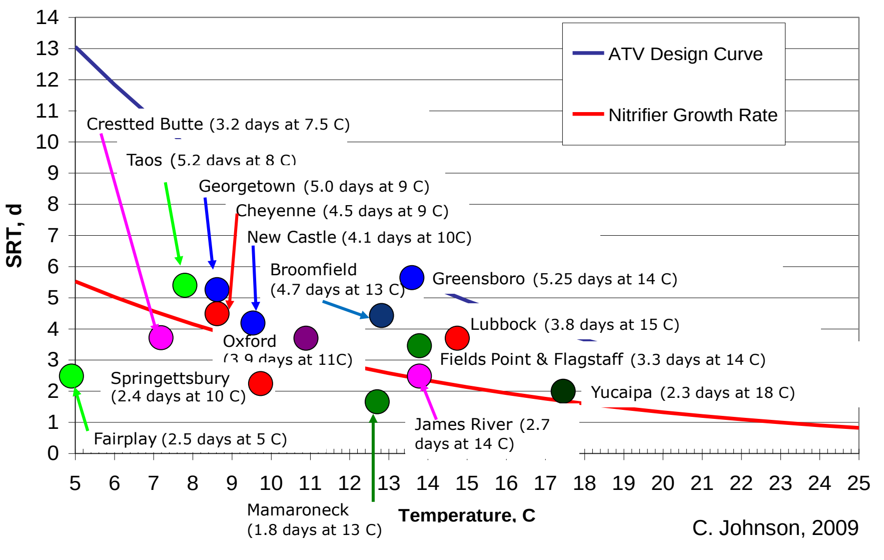
Design SRT vs temp for full scale IFAS systems (installed by ANOXKALDNES)



C. Johnson, 2009

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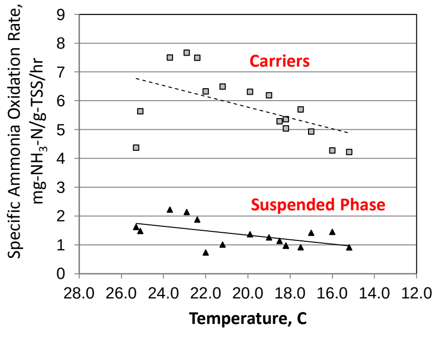
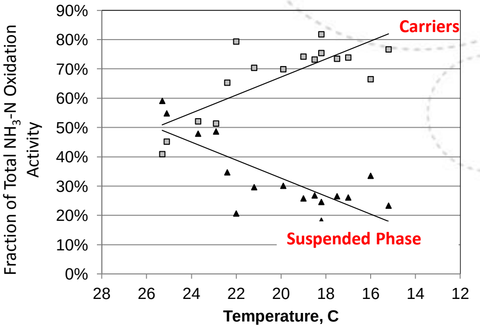
Distribution of nitrification activity between attached and suspended biomass



Specific nitrification activity in attached and suspended biomass versus temperature



Fraction of NH_3-N oxidation activity in attached and suspended biomass versus temperature

McQuarrie and Thomas (2009)

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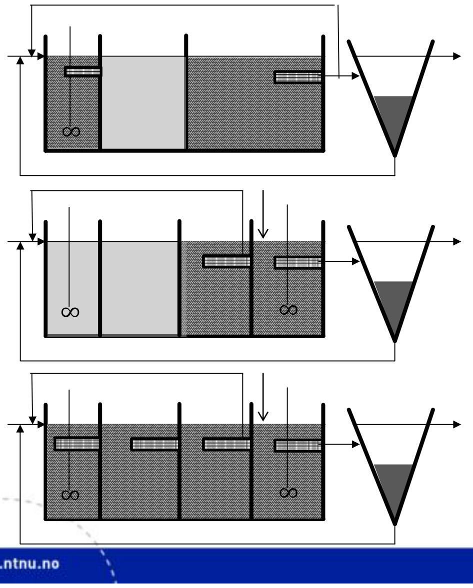
Denitrification in MBBR-based IFAS plants



- IFAS in Pre-DN - Not very common
- IFAS in post-DN – Quite possible
- Higher DN-rate in pre-anoxic reactor because more carbon seems to be left after short SRT_{susp} nitrification
- Post-anoxic IFAS reactor efficient
- IFAS may, in principle, be used in all reactors

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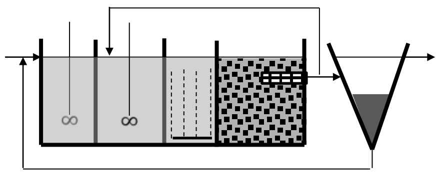
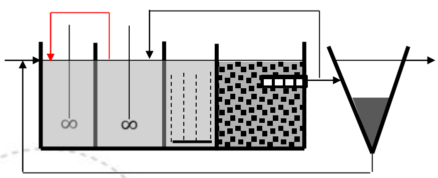
Biological P-removal in MBBR-based IFAS plants



Onnis-Hayden et al (2011) – Broomfield WWTP study:

- More EBPR activity in suspended biomass
  - 20-30 % in mixed liquor biomass
  - 3-8 % in biofilm media biomass
- N-removing and P-removing populations prefer conflicting SRT's,
  - hence they should be decoupled – allowing for separate SRT control



Bio-P may profit by using IFAS with UCT design because:

- The EBPR biomass is mixed with little nitrification biomass
- Nitrification is better promoted since most of the nitrification biomass will not pass the anaerobic stage

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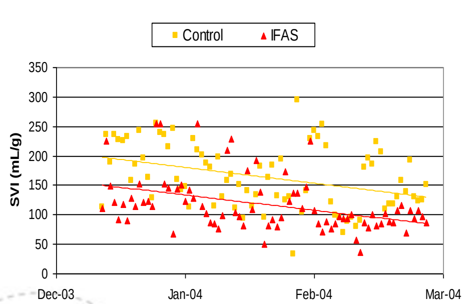
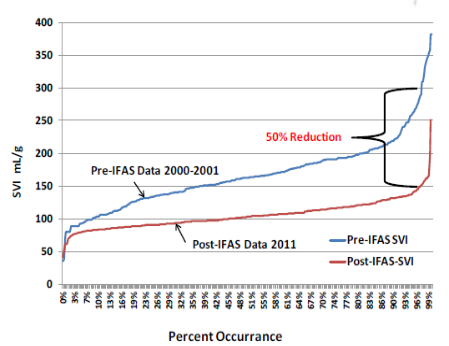
Biomass separation in IFAS

IFAS generally seems to improve settleability

Comparison on SVI in two parallel lines at Lakeview WWTP, Ontario, Canada , (Briggs, 2009)



Pre- and post IFAS SVI at Field's Point WWTP, Providence, RI, USA (Wilson et al., 2012)



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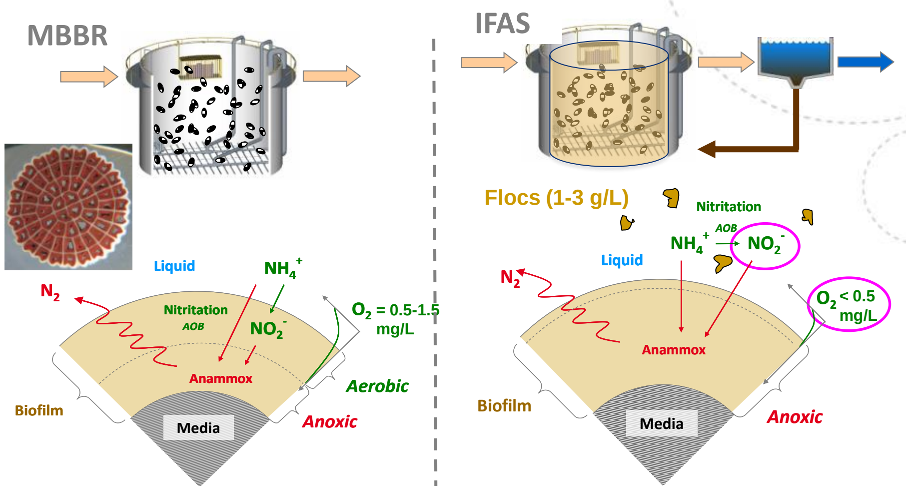
Anammox in IFAS (Christensson et al, 2013)



AOB in biofilm = NO_2^- limitation

AOB in flocs = less NO_2^- limitation

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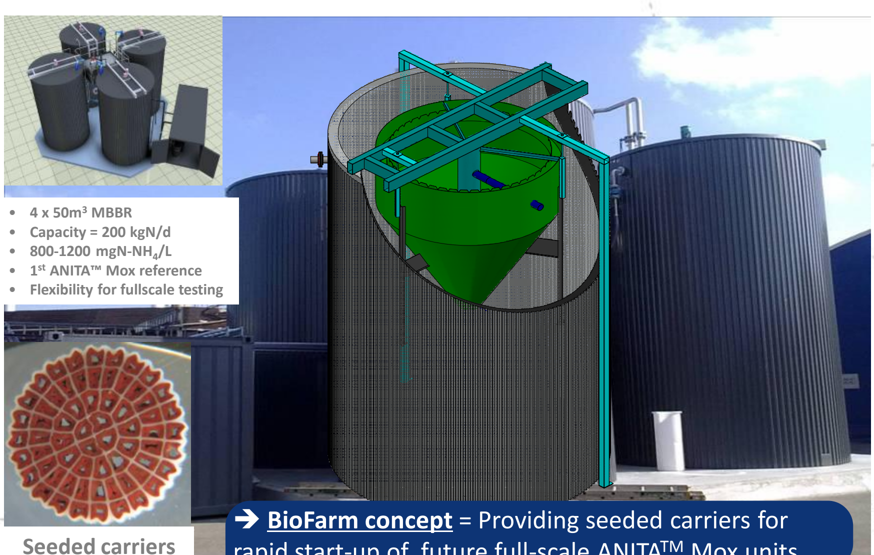
ANITA™ Mox – Sjölunda WWTP, Malmö (Sweden)



- 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

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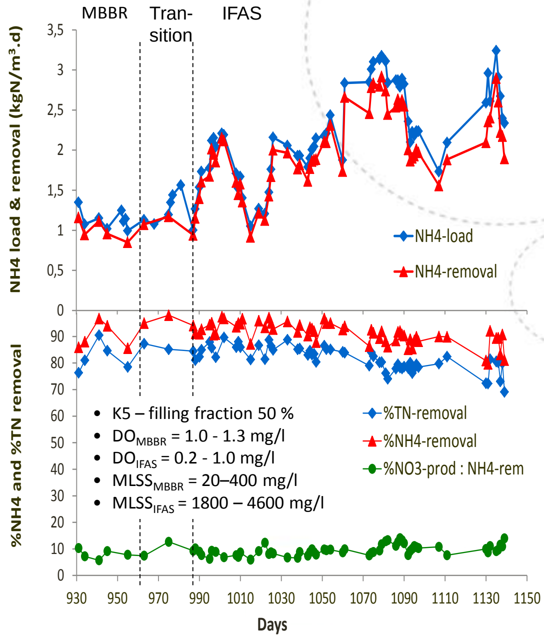
Full-scale test results ANITA™Mox , Sjölunda WWTP (Christensson et al, 2013)

- Very high N-removal rate up to 3 kg NH_4-N/m^3·d (7.5 g NH_4-N/m^2·d)
- 2.5-3 times higher than in pure MBBR design
- Energy consumption : 1.2 kWh/kg NH_4-N removed



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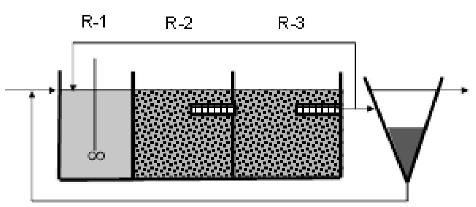
Design of IFAS systems



SF_{Nit} = aerobic suspended solids retention time / calculated nitrifier minimum SRT

Four design criteria are recognized to be important to IFAS system design:

1. The ammonia flux ($J_{F,NH3-N}$),
2. The biofilm area
3. The bulk liquid DO concentration (S_{O2}),
4. The bulk liquid ammonia concentration (S_N)

McQuarrie et al (2010) introduced a fifth design parameter :

5. The Nitrification Safety Factor ($SF_{Nit.}$),

This fifth design parameter characterizes the capability of nitrifiers to grow and reproduce in the suspended biomass independently of the biofilm.

Four approaches for IFAS system design as proposed by McQuarrie et al. (2010)

Design approach	$SF_{Nitrification}$	Effluent ammonia target, mg NH_3-N/L	Install media in reactor?		Parameter for determining ($J_{F, NH3-N}$).	
			R-2	R-3	R-2	R-3
A	0.5 to 1.0	< 2.0	Yes	No	S_{O2}[2]	-
B	0.5 to 1.0	< 1.0	Yes	Yes	S_{O2}	S_N
C	1.0 to 1.5	< 1.0	Yes	Option[1]	S_{O2}	S_N
D	1.5 to 2.0	< 1.0	Option[1]	No	S_{O2}	.

[1] Plastic carriers added to reactor to increase reliability against system perturbations
[2] Contribution of nitrification achieved by suspended growth component of the IFAS system is ignored

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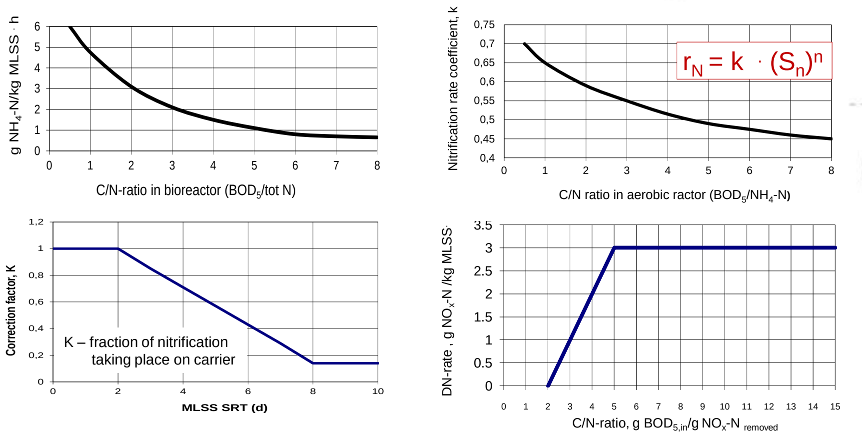
Design of IFAS systems

Empirical design methods – example Ødegaard (2008)



Mathematical modelling design methods

Mathematical models are available, that combine AS- and BF-models. They require, however, special modelling skills to be used correctly.

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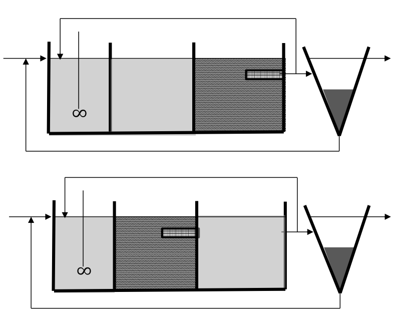
Compartment partition



Placing the media in an early stage may have several advantages:

- **C_{NH4} is highest in early stages** favoring the nitrification capacity of the attached biomass
- **DO may be reduced in the last compartment** (less DO return) since C_{NH4} here is low
- **Low intensity of mixing in last compartment** improves flocculation
- **"Seeding"** of nitrifiers from attached to suspended biomass is favored

		Trapani et al, 2012
DO/Temp.	mg O_2 L^{-1} / aver. °C	5.00 /13.8
SRT	d	3.4
Biofilm nitrification rate (10°C)	g NH_4-N·$m^{-2}d^{-1}$ (g NO_x-N·$m^{-2}d^{-1}$)	0.92 (1.02)
Biofilm biomass nitrification rate (10°C)	mg NH_4-N·g VSS^{-1} h^{-1}	2.37
Typical susp. biomass nitrific. rate (10°C)	mg NH_4-N·g VSS^{-1} h^{-1}	1-2
Suspended biomass nitrification rate (10°C)	mg NH_4-N·g VSS^{-1} h^{-1}	2.80

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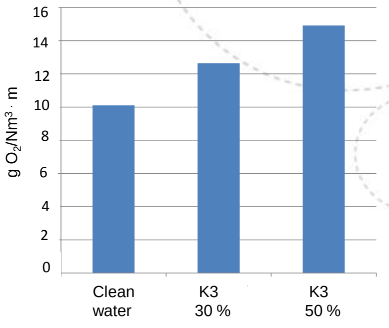
Oxygen transfer

- 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



- Mamaroneck wastewater treatment plant, Westchester County, New York Full scale clean water oxygen transfer test when using a **medium** bubble aeration system (with 55 % K3 carriers) :

SOTR : 13 g $O_2/Nm^3 \cdot m$

Christensson, 2013

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Approach velocity and sieve design

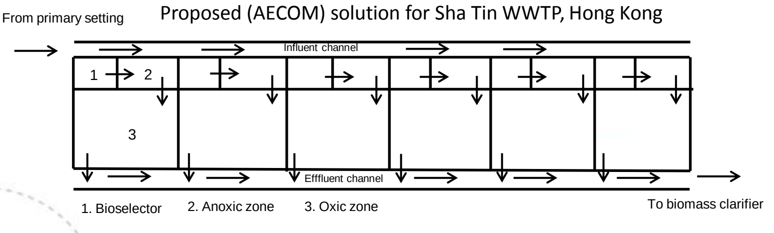
Upgrading of long narrow AS –tanks:

Oxford WWTP, UK

Recommended sieve velocities:

- Aerated sieve: 50-60 m/h
- Approach velocity: < 30 m/h at peak flow at a length/width-ratio of 1.0 decreasing linearly to 15 m/h at a length/width-ratio of 3.0.

Proposed (AECOM) solution for Sha Tin WWTP, Hong Kong



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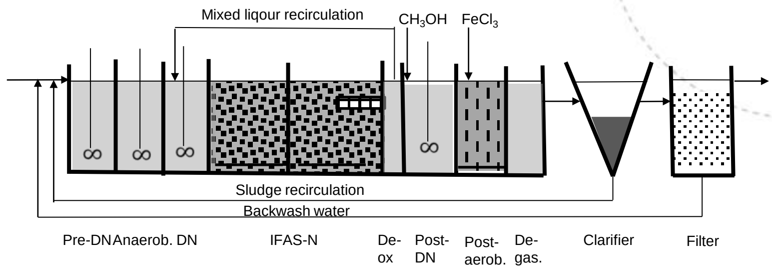
Example Marquette-Lez-Lille, France

(Veolia, 2013)



Before

Today

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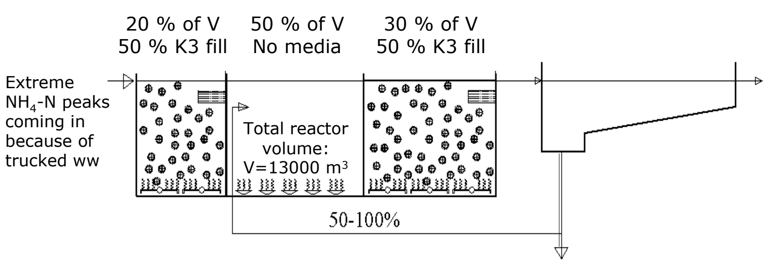
Example: Sharjah WWTP, UAE

Combining high-rate MBBR and IFAS for upgrading



Tasl

Convert a secondary treatment AS plant into a fully nitrifying plant at a double load - without bioreactor volume expansion

Parameter	Results performance tests			
	Nov 2008- Jan 2009		April 2010-May 2010	
	mg/l	% rem	mg/l	% rem
BOD_5	7,5	97,3	6,4	97,6
NH_4 – N (TKN)	4,7	92,9	0,92	97,0 (98,3)

Conclusions

1. IFAS is very compact compared to AS and is especially suitable when upgrading for nitrification/N-removal
2. Nitrification in IFAS is essentially independent of SRT ($SRT_{ae.,susp}$ may be ≤ 2d)
3. Nitrification activity is 3-4 times higher in the attached biomass than in the suspended biomass (at: T <15 ^{o}C, SRT < 3 d, $C/N_{incoming}$: 3-4, DO: 3-5 mg/l)
4. The lower the temperature, the higher is the fraction of the total nitrification that is taking place in the biofilm
5. Recommended DO_{design} : 4-6 mg/l at peak load
6. High oxygen transfer caused by carrier presence : 12-14 g $O_2/Nm^3 \cdot m$ (medium bubble at filling fractions > 50 %)
7. IFAS may also be used in anoxic and anaerobic reactors, but benefits are lower than in aerobic reactors
8. Design knowledge is not at the same level as AS design
9. IFAS operation seems to be more robust than that of AS

Acknowledgements

I would like to acknowledge:

- Magnus Christensson, AnoxKaldnes, Sweden
- Kim Helleøj Sørensen, WABAG, Switzerland

for being my co-authors for the Hybrid Systems chapter in the Activated Sludge 100 years book (IWA Publishing) and:

- James P. McQuarrie, Metro Wastewater Reclamation District, Denver, Colorado, USA,
- Joshua P. Boltz, CH2M HILL, Tampa, Florida, USA,
- Chandler Johnson, World Water Works, Oklahoma City, Oklahoma, USA,
- Mark Steichen, Black and Veatch, Kansas City, Missouri, USA,
- Daniele di Trapani, Università degli Studi di Palermo, Italy
- Bjørn Rusten, Aquateam, Norway

for their valuable support and comments during the preparation of that chapter

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