Aalto University
School of Engineering

Biological treatment processes of water and waste
Lecture 5

WAT - E2180

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Lecture outline

Biological process applications

- Biofilm processes

- Algae processes

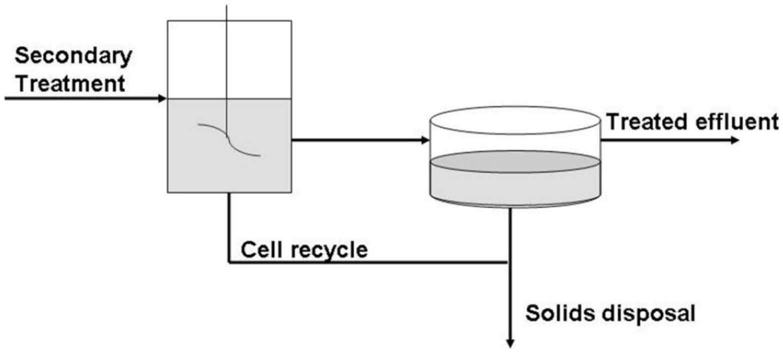
- Membrane bioreactors
- Aerobic granular sludge
- Microbial fuel cells

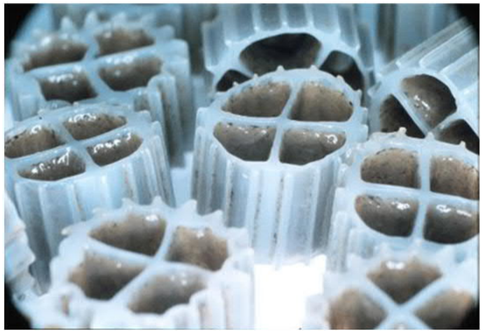
Biological processes Recap

How do the biological processes work?

Requirements for a process:

1) **Active microorganisms have to be concentrated within the system**
2) **Microorganisms need to be removed from the effluent before it leaves the system**





Principles of biological processes

Suspended growth	Biofilm processes
Activated sludge process, membrane bioreactor (MBR)	Moving bed bioreactor (MBBR), biological filters
Sludge is separated in a clarifier (or with a membrane)	No sludge recycle needed, because bacteria are fixed on the carrier material
Sludge recycle	

Most commonly only wastewater's own microbes are enriched in the process

Sometimes special kind of bacteria is added
Bioaugmentation is possible

Biofilm processes

Biofilm processes

- Biomass is growing on carriers
- Processes/Terms:

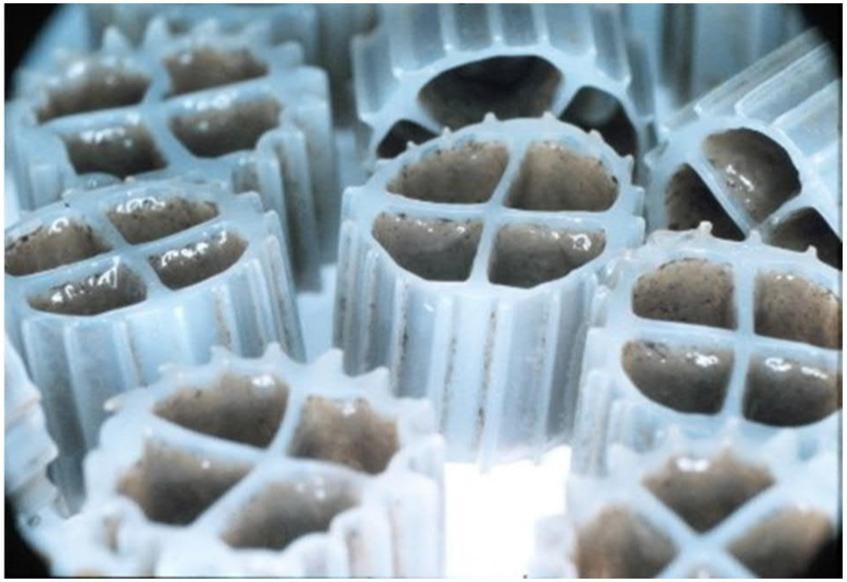
MBBR (Moving bed biofilm)

IFAS (Integrated fixed-film activated sludge) = MBBR with sludge recycling

Trickling filter

Biological filter

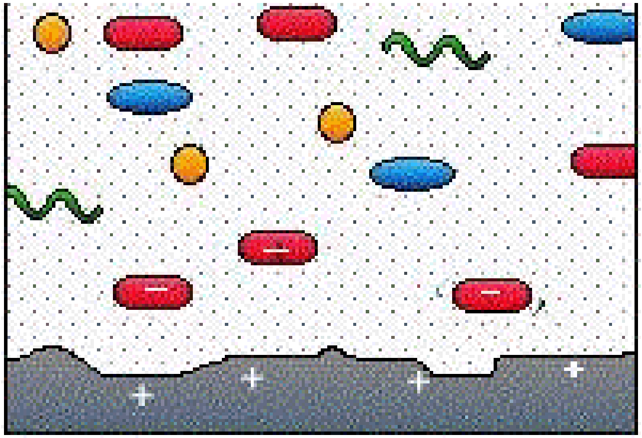
Biorotor



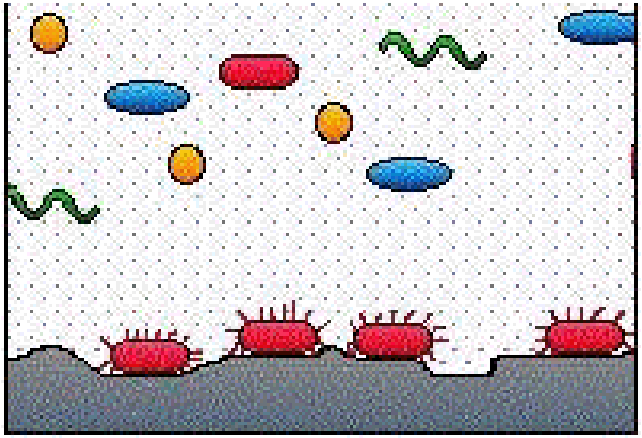
Biofilm

- On any kind of surface, microbes will attach and start to grow as long as there are water and nutrients available = biofilm grows

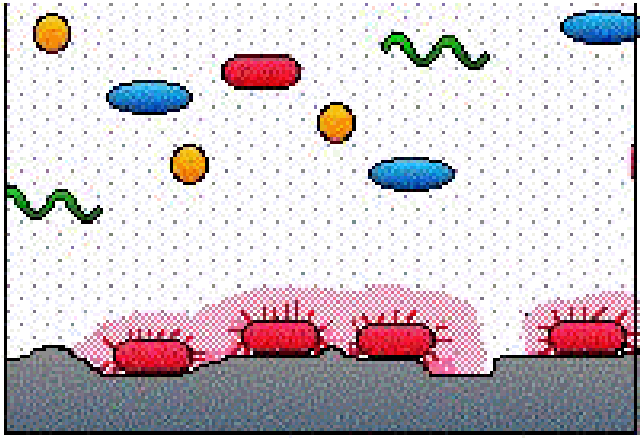
Biofilm



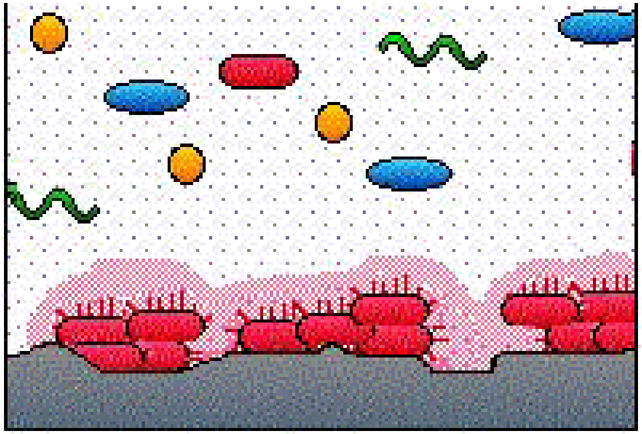
Biofilm



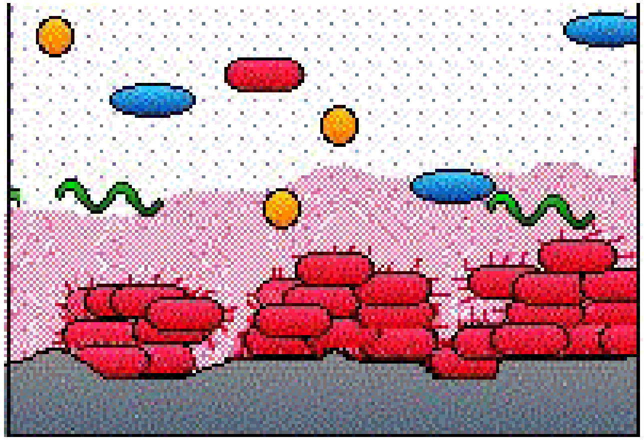
Biofilm



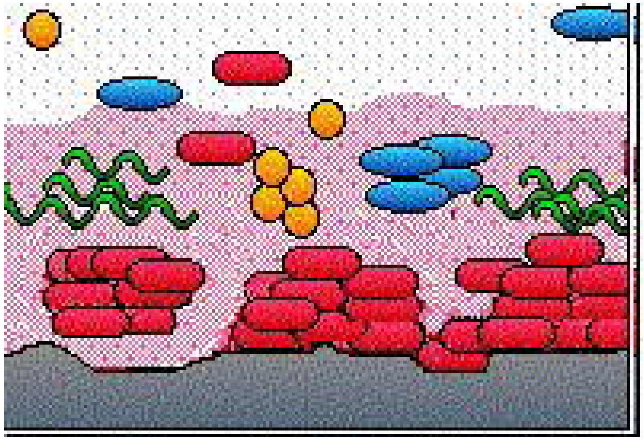
Biofilm



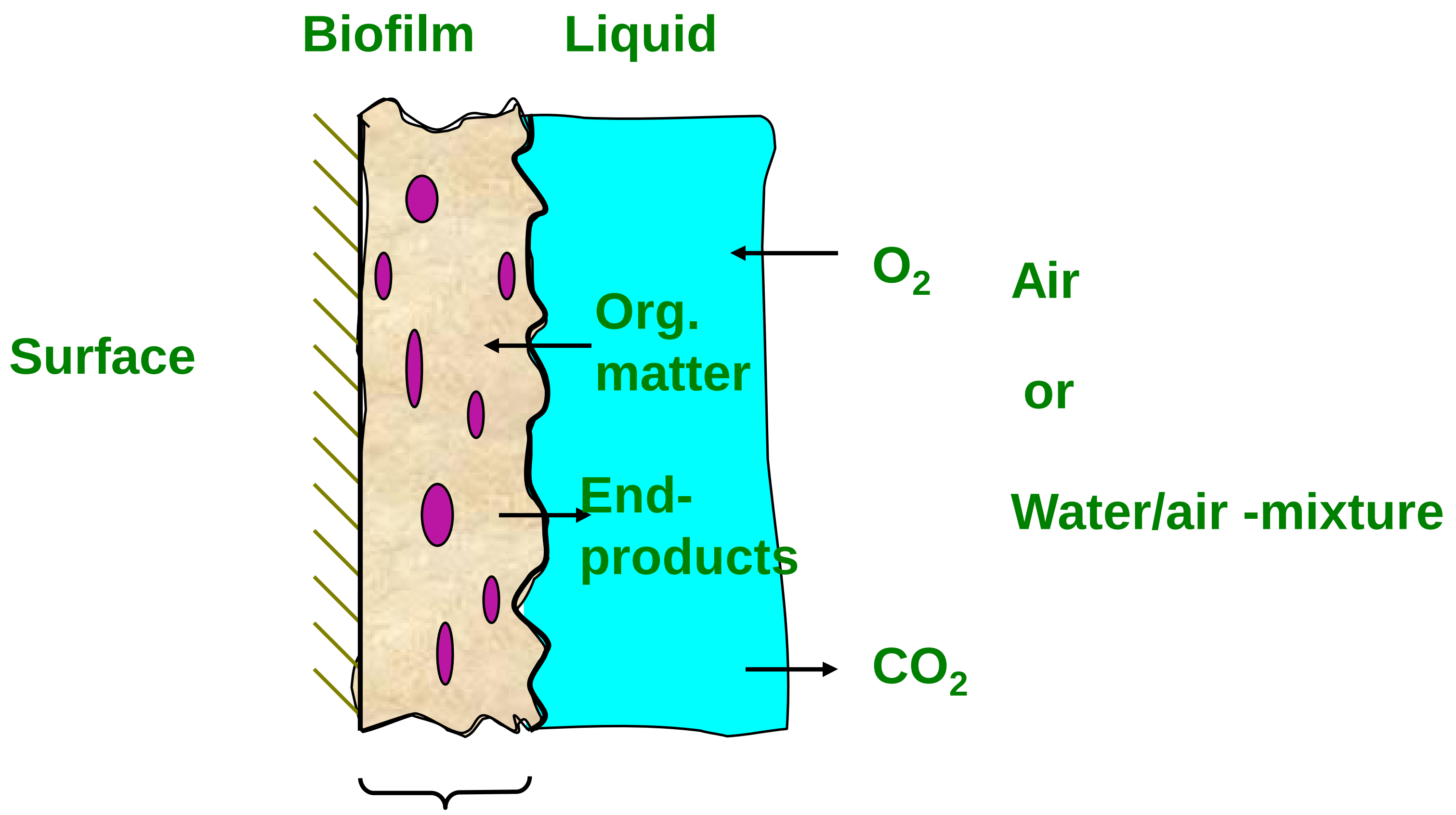
Biofilm



Biofilm



Structure of biofilm



- Efficient thickness appr. 100 µm

Structure of biofilm

Microbes are protected inside the biofilm

MBBR in large scale

Pictures: Odegaard 2014

MBBR

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

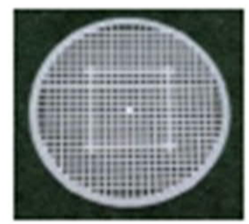
K1

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

K3

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

K5



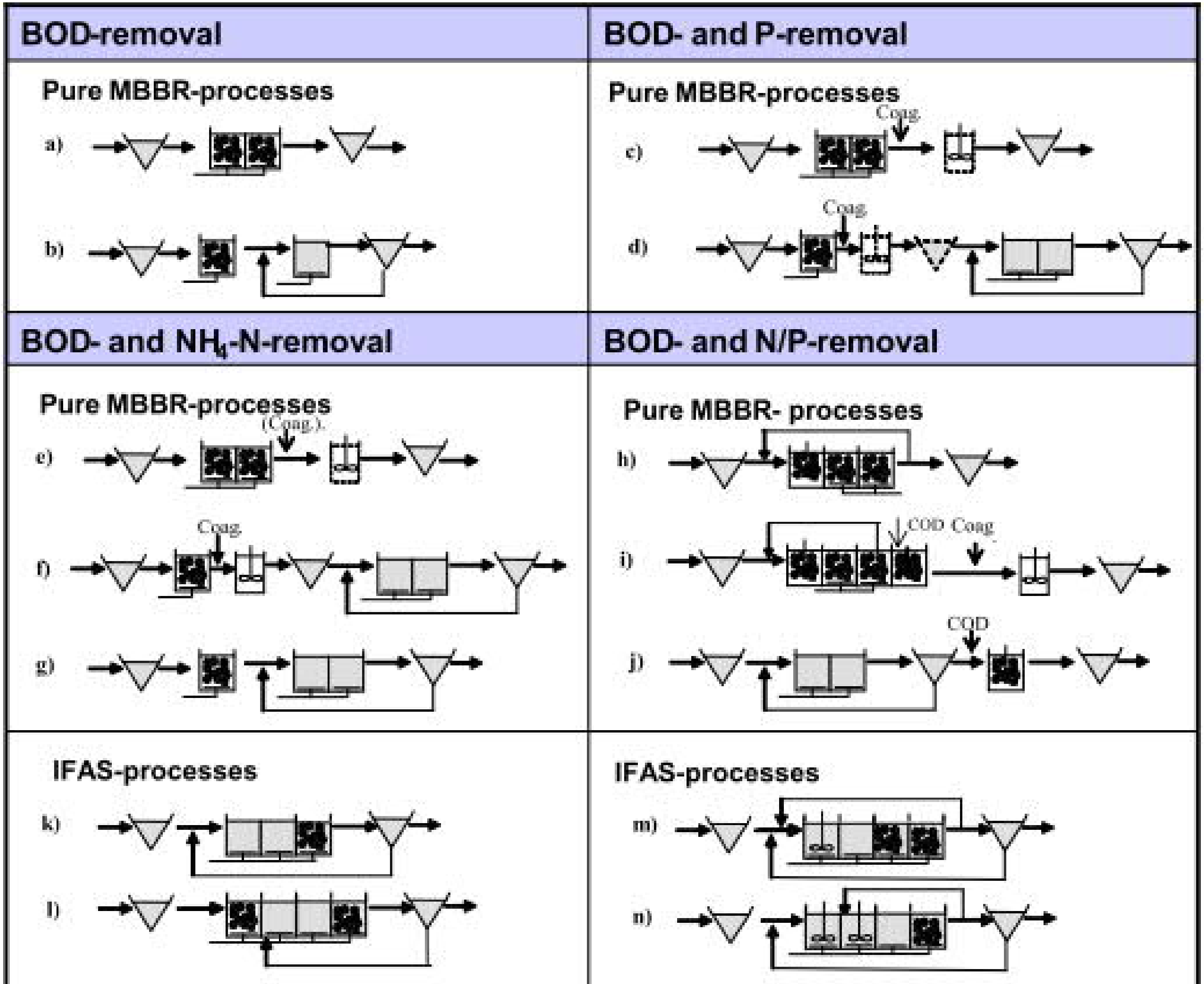
- 1200 m²/m³ bulk
- 48 x 2.2 mm diameter/depth

BiofilmChip M

Pictures: Odegaard 2014

MBBR – important parameters

- Different carrier have different surface areas
- Typically 500 – 800 m^2/m^3
- Reactors are not full of carriers - 40 – 60 % → specific max filling rate for each carrier
- The carriers have a density of a bit less 1 g/cm^3
- Carriers are mixed using air bubbles and mixers
- Aeration typically with course bubble aerators
- MBBR fans claim that oxygen transfer is improved by the carriers(?)

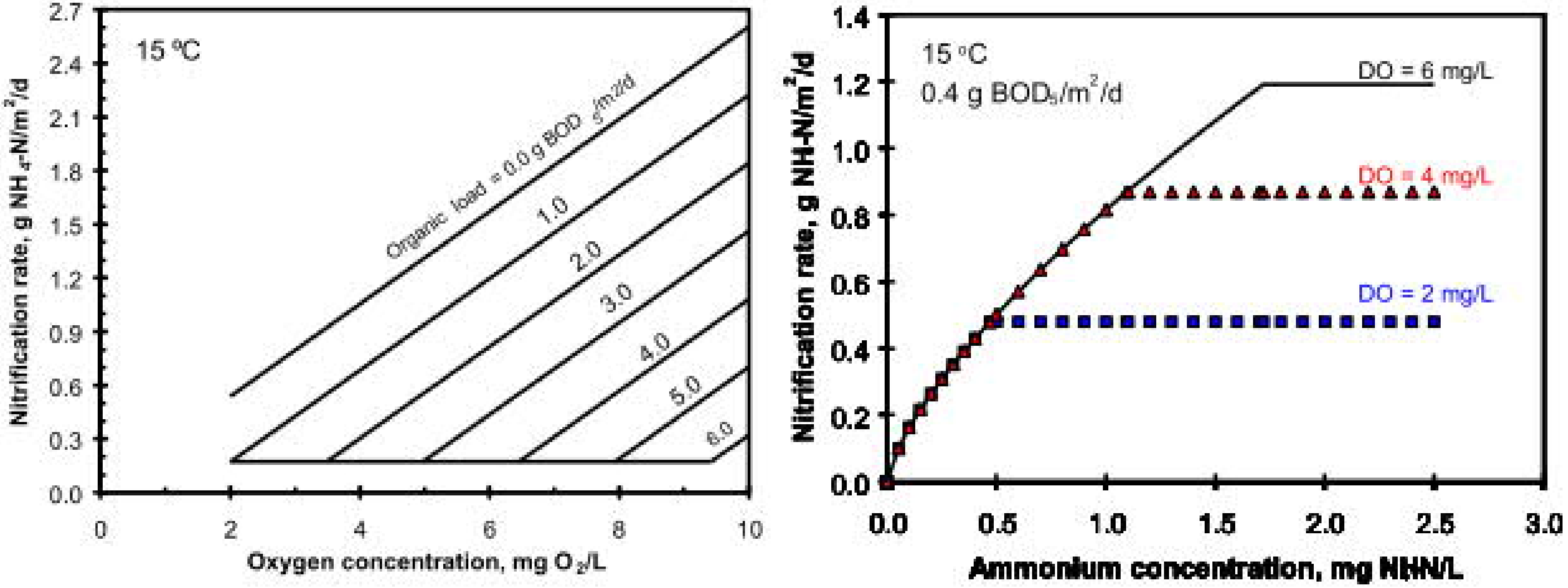


Figures: Odegaard 2014

Solid separation in MBBR

- **MBBR effluent typically contains 150-500 mgSS/l (>90 % of the biomass stays on the carriers)**
- **Typically two types of flocs: : large flocs (30 – 300 um) and very small particles (less than 1 um)**
- **Small particles require chemical flocculation**
- **Solid separation can be done with settling, flotation, sand filtration,…**

Nitrification in MBBR



- Kuvat: Odegaard 2014

Denitrification in MBBR

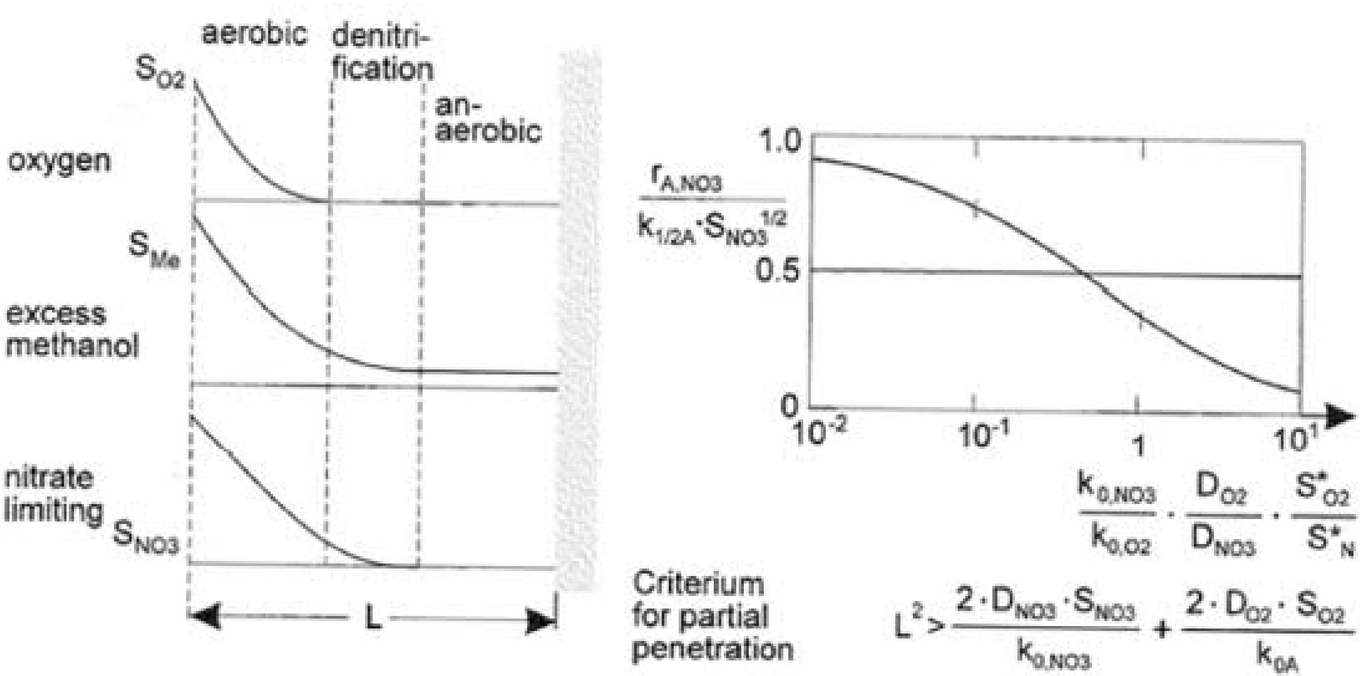
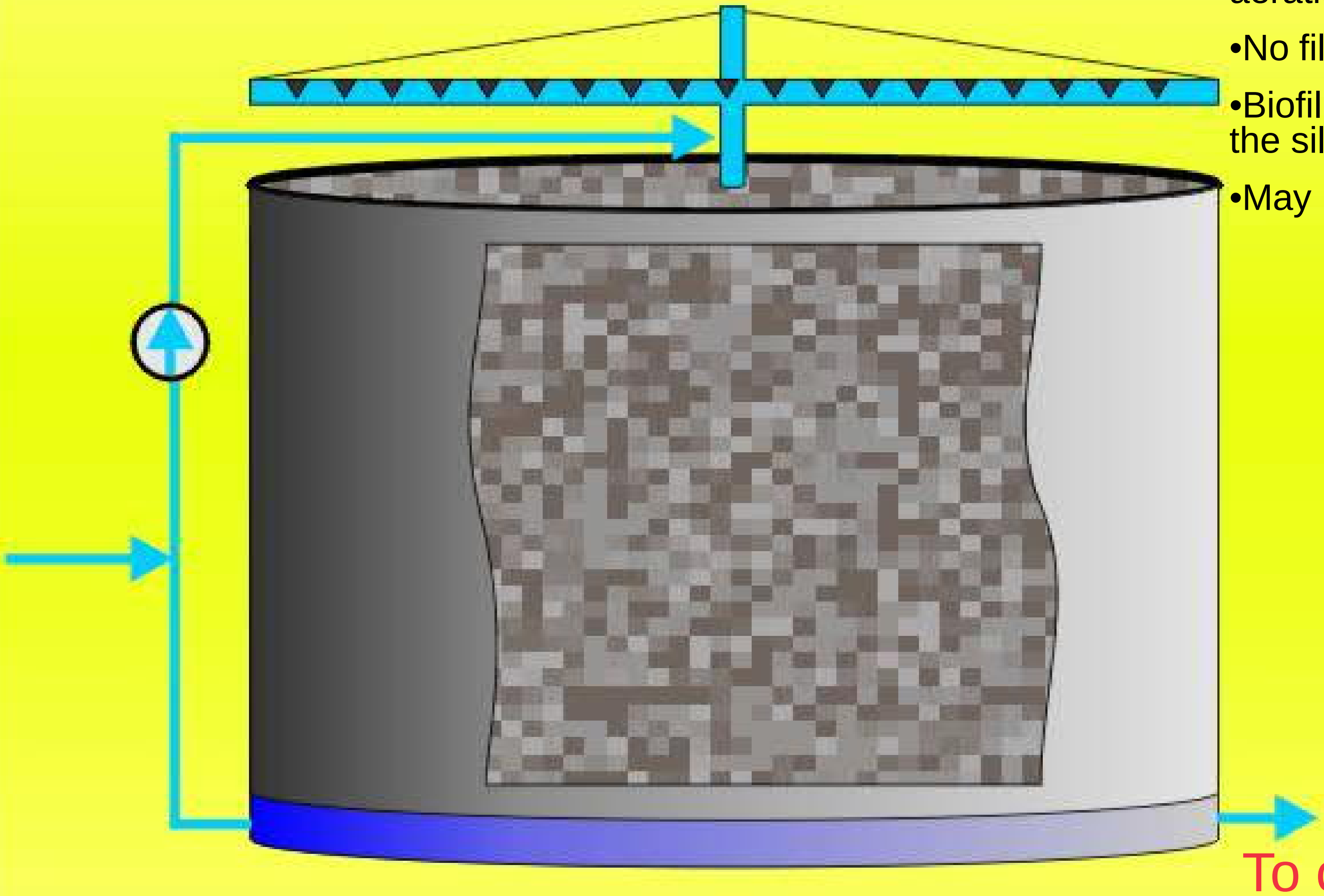


Figure 7.5. The figure shows how denitrification may occur in spite of aerobic conditions in the free water. Nitrate diffuses through the aerobic part of the biofilm and is denitrified in the anoxic zone. To the right the reduced denitrification rate is shown compared with denitrification without oxygen.

Trickling filter



- •Water recycle=> no aeration
- •No filtration effect
- •Biofilm growing on the silter material
- •May be clogged

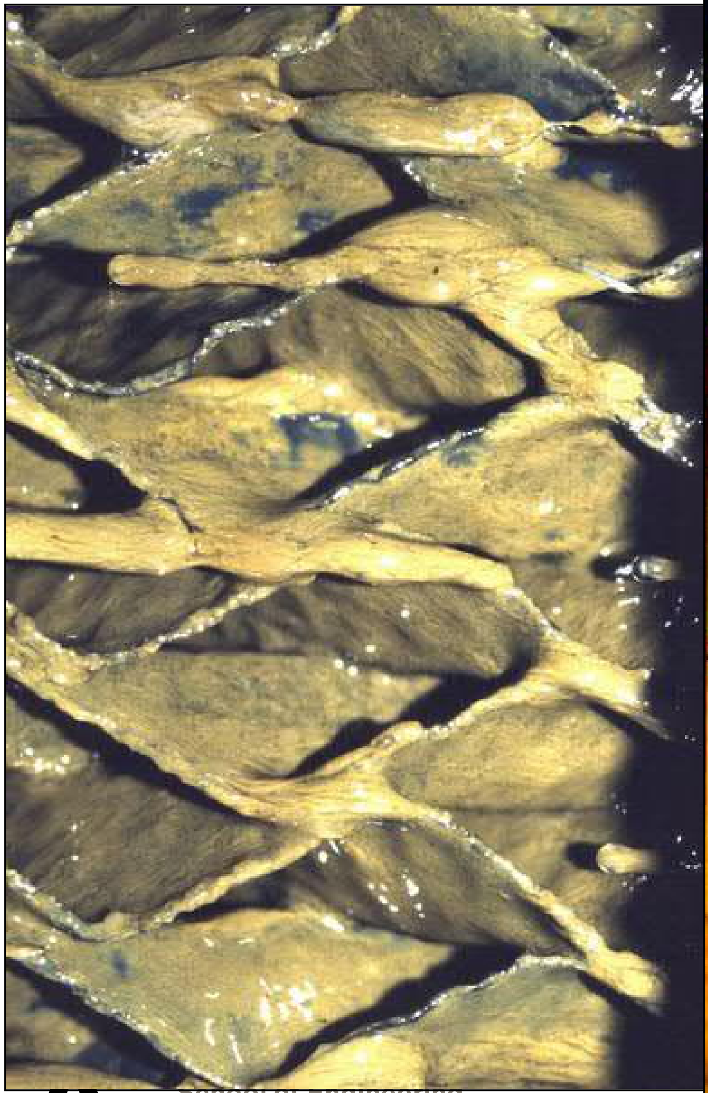
Trickling filter

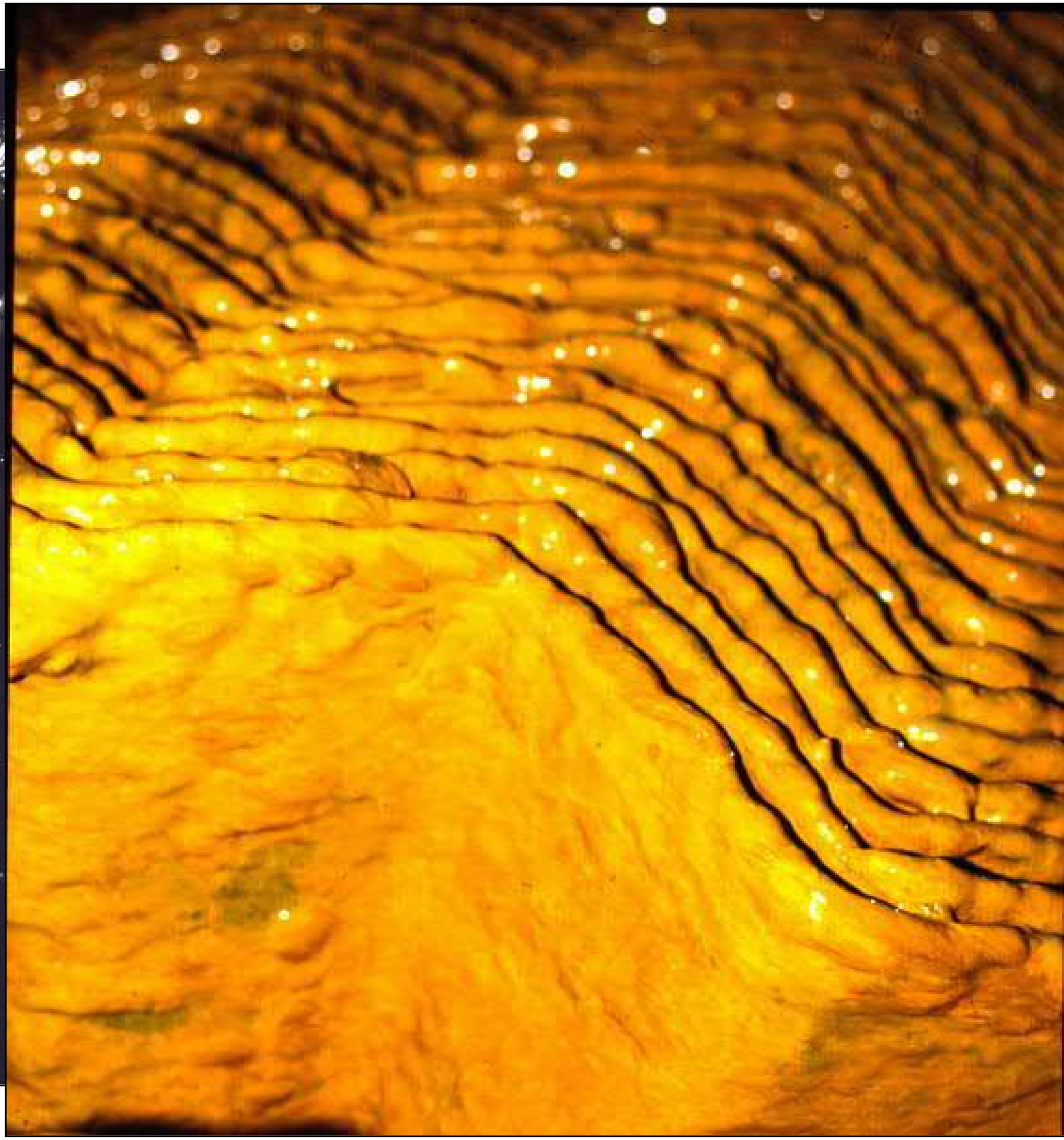
Finnish Ufox-carrier

Trickling filter Metallostroi, St. Petersburg

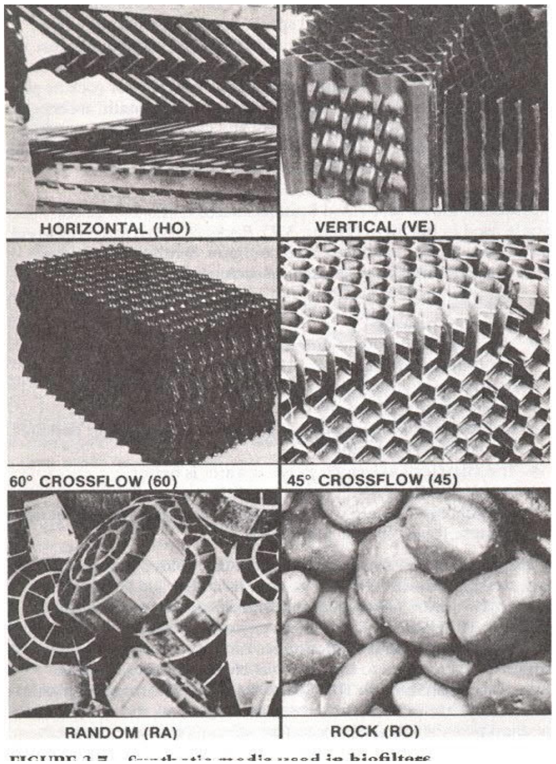
Biorotor

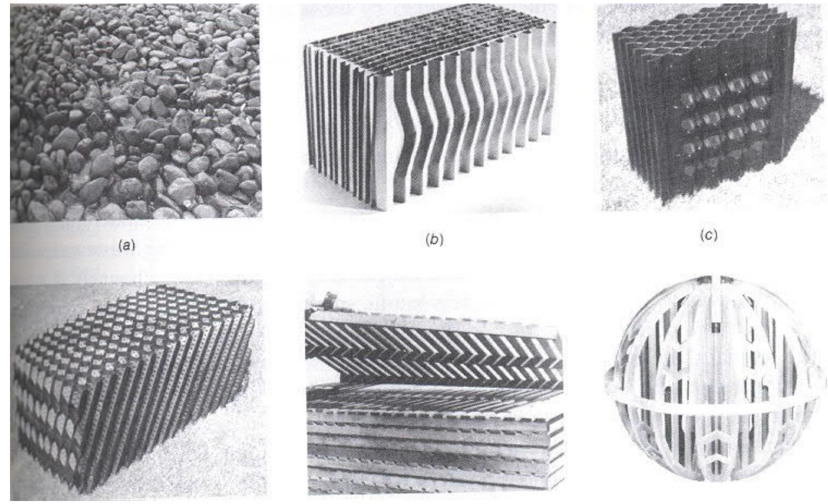
Biorotor





Examples of different carrier material





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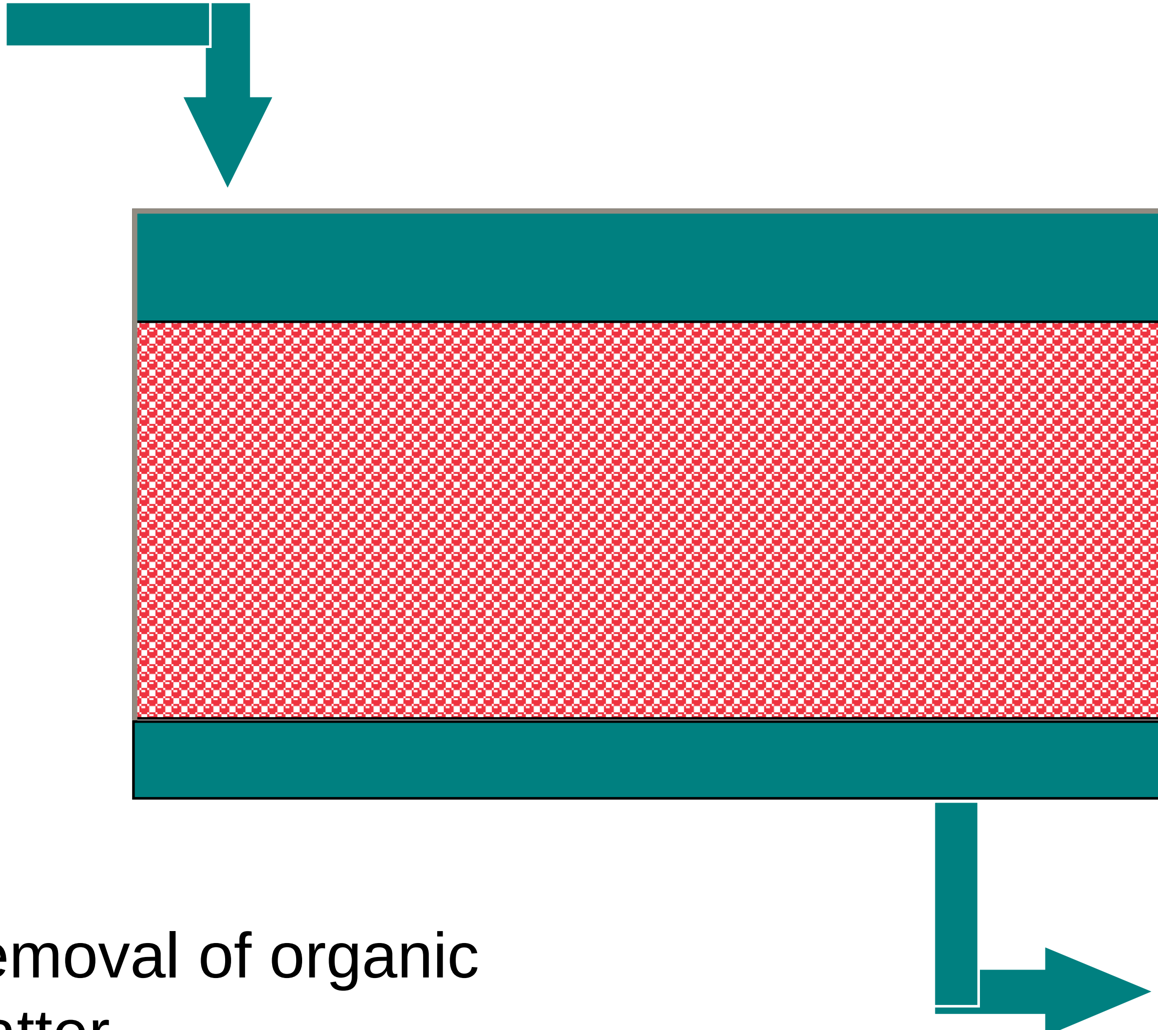
Biological filter

- Biological treatment + physical filtration
- Removal of BOD, SS, P, nitrification, denitrification
- Often the last process step (tertiary)
  - Can be also used as the main process
- Filter material e.g.. sand, grit, small balls of polystyrene
- Filter is back-washed
  - Washwater 2 – 5 % of the treated wastewater
  - The quantity of biofilm can be controlled (unlike in trickling filter)

Biological filter down-flow

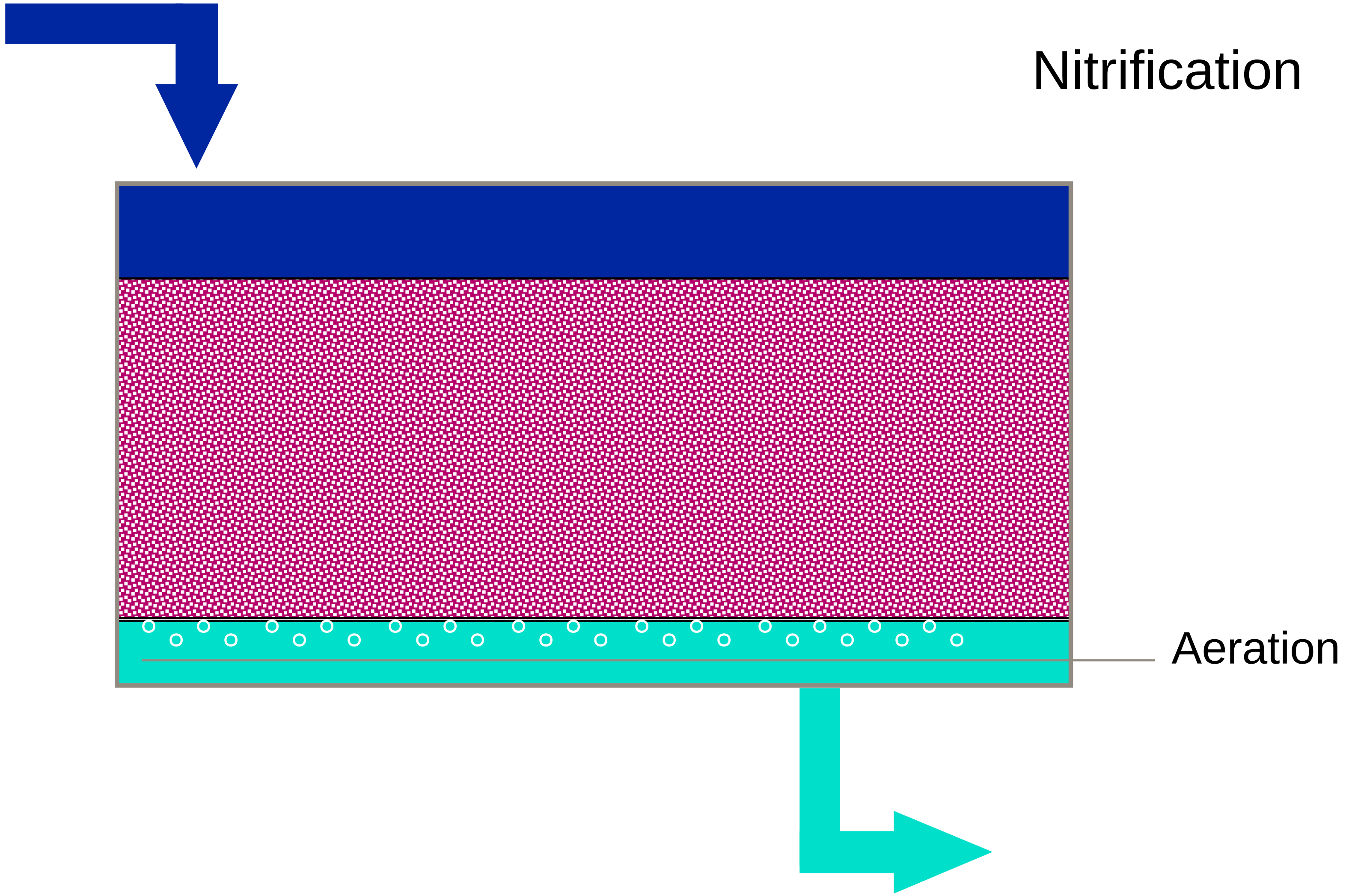


Removal of organic matter

Biological filter

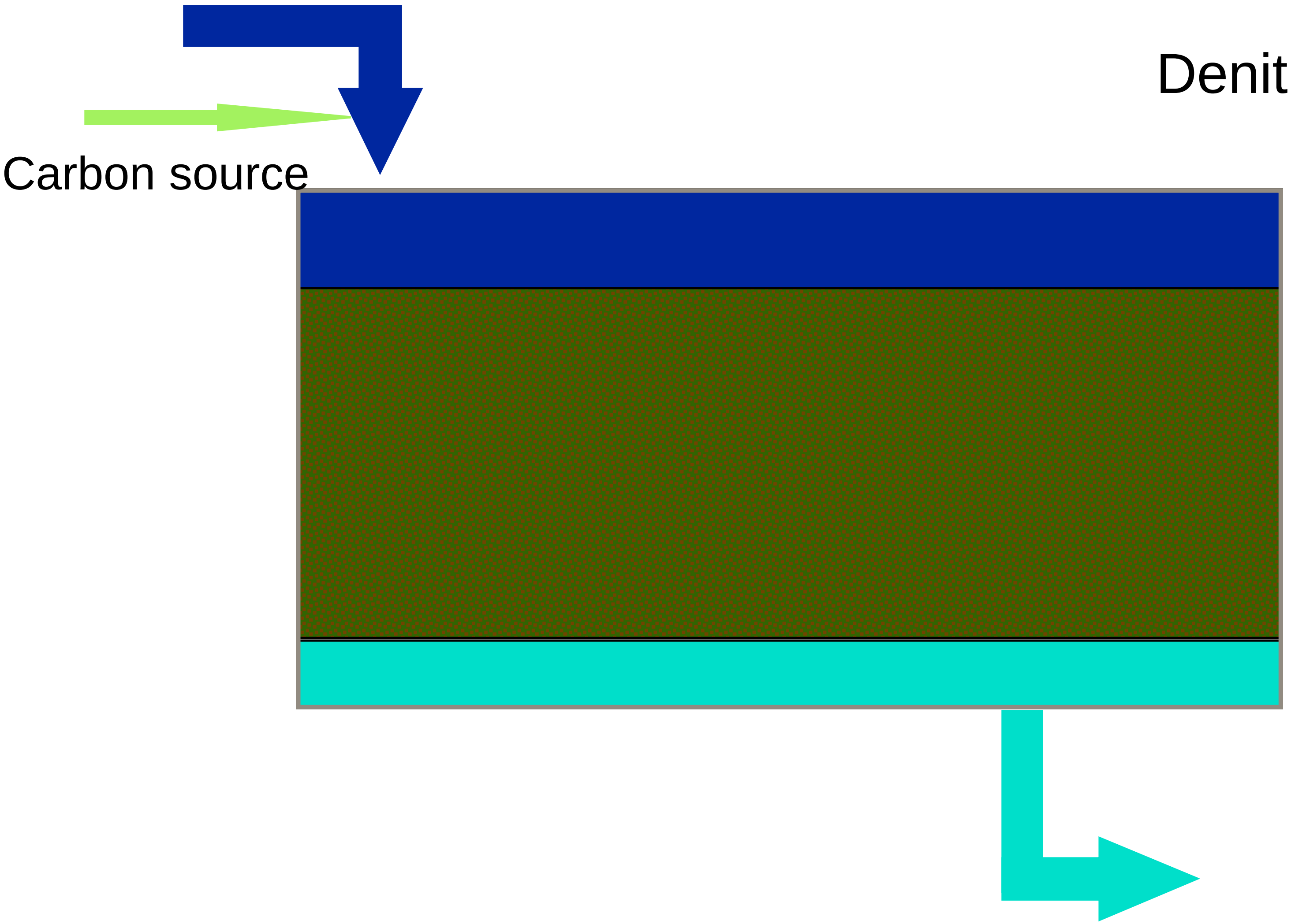
down-flow

Nitrification



Biological filter down-flow

Denitrification

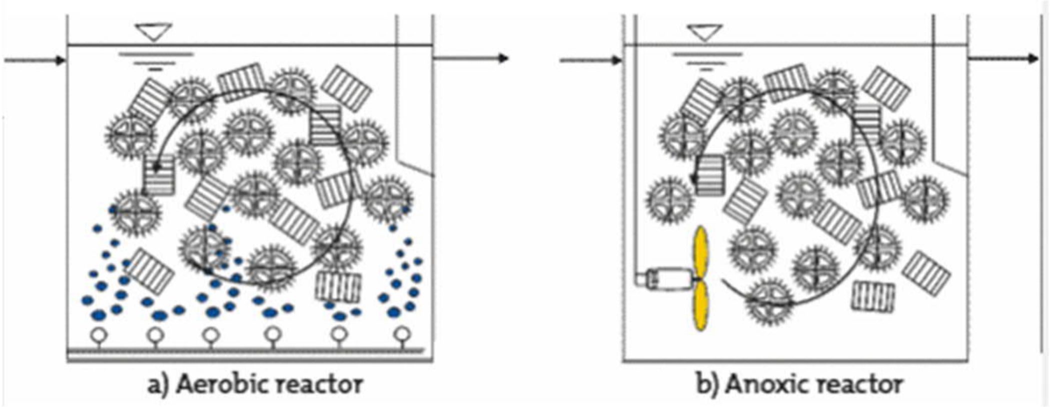


GROUP DISCUSSION: WHY MBBR?

What are the benefits of MBBR?

Any possible drawbacks?

Group discussion (15 min)



BREAK

Membrane bioreactors

Typical MBR process

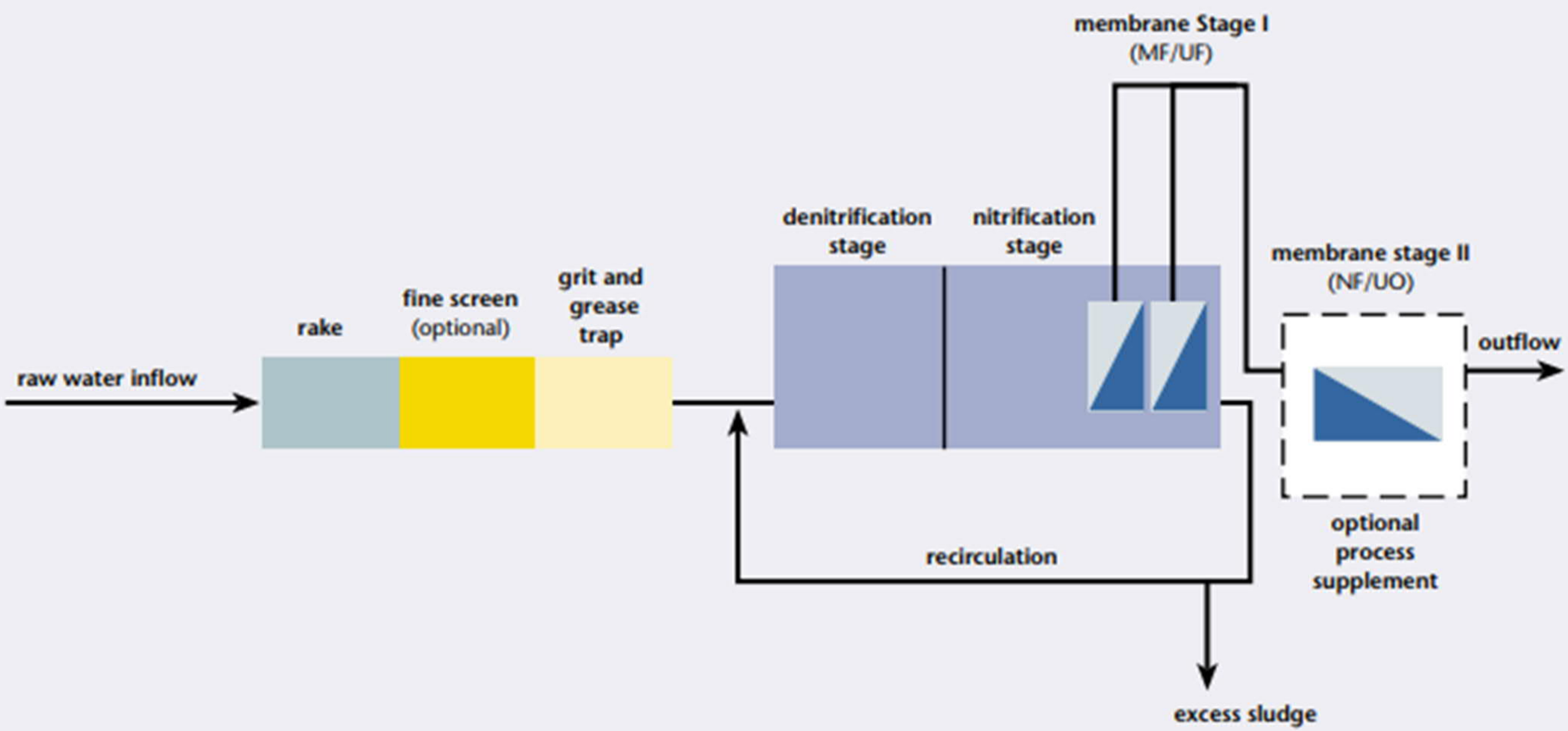


Figure 6. Typical MBR process scheme (Friedrich et al. 2003, p. 65).

Membrane bioreactor MBR

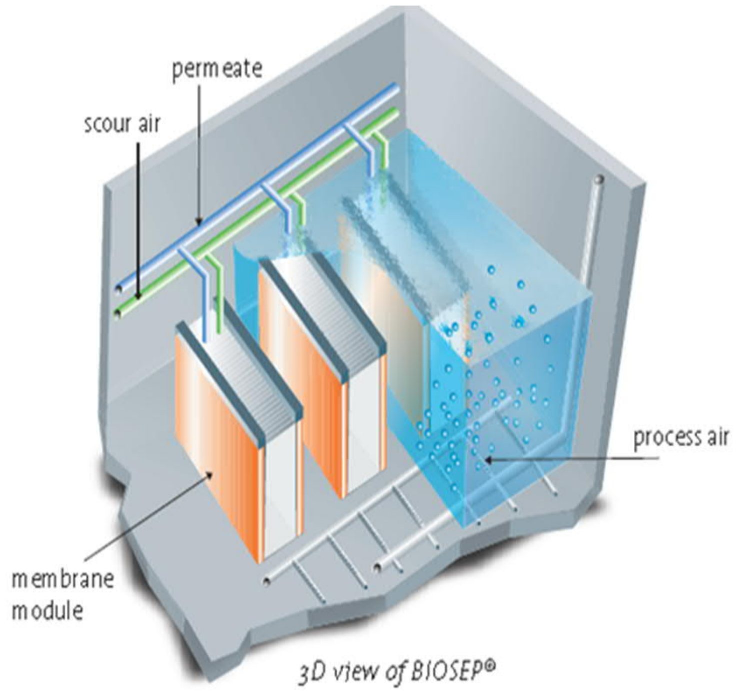
Membranes are submerged either in the aeration basin or in the separate basin

High sludge concentration

Very good treatment results

Still high costs of energy and chemicals

Compact because sludge concentration can be high



Membrane bioreactor performance

Membrane bioreactor's performance is often described with the following equation:

$$J = \frac{Q}{A}$$

where:

J = permeate flux [L/(m^2*h)], or [m/s]

Q = permeate flow [m^3/h]

A = area of membrane [m^2].

Trans-membrane pressure (TMP) is usually used as the driving force to push the liquid through a membrane. The MBR can be driven by varying permeate flux (J) while keeping the TMP constant, or by varying TMP while keeping J constant.

Under laminar conditions, the following equation applies to a permeate flux for pure solvent:

$$J = \frac{\Delta P}{\eta_p R_t} \qquad (6)$$

where:

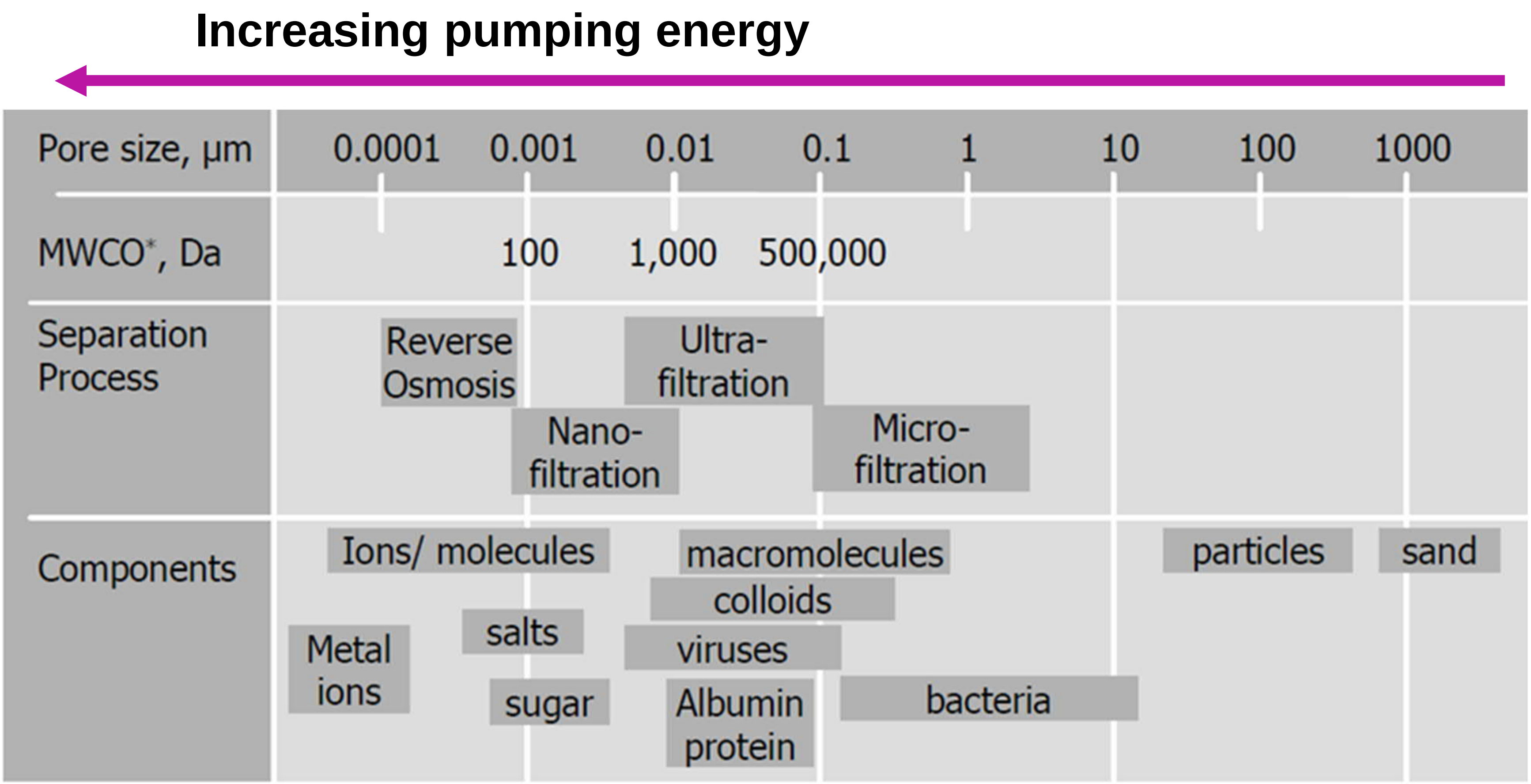
J = permeate flux [L/m^2*h], or [m/s]

ΔP = trans membrane pressure [Pa], or [bar]

η_p = permeate dynamic viscosity [Pa * s]

R_t = total filtration resistance [m^{-1}].

Membrane separation



*MWCO = Molecular Weight Cut Off

Membrane fouling

Membrane fouling is classified to:

- **reversible**
- **irreversible and**
- **irrecoverable fouling.**

Reversible fouling occurs when suspended solids, colloids and gels in mixed liquor create a cake layer, which accumulates to membranes. Reversible fouling can be minimized or prevented completely with low flux combined with high CFV and/or high air flows. To periodically remove reversible fouling, backwashing and relaxation are performed

Irreversible fouling occurs when dissolved and some colloidal matter are absorbed inside pores. This matter accumulates over time and constricts the pores or blocks them completely. Irreversible fouling cannot be cleaned by mechanical cleaning methods, but chemical cleaning can be done.

Irrecoverable fouling generates over long time and cannot be removed by mechanical and chemical cleaning methods.

KA Woffelsbach

Aerobic granular sludge

History of granules

- 1970s Anaerobic granules
- 1990s Research on aerobic granular sludge begins
- 2005 – first full-scale plant (industrial plant)
- 2009 – first full-scale plant treating municipal sludge
- 2020 – about 40 full-scale plant around the world

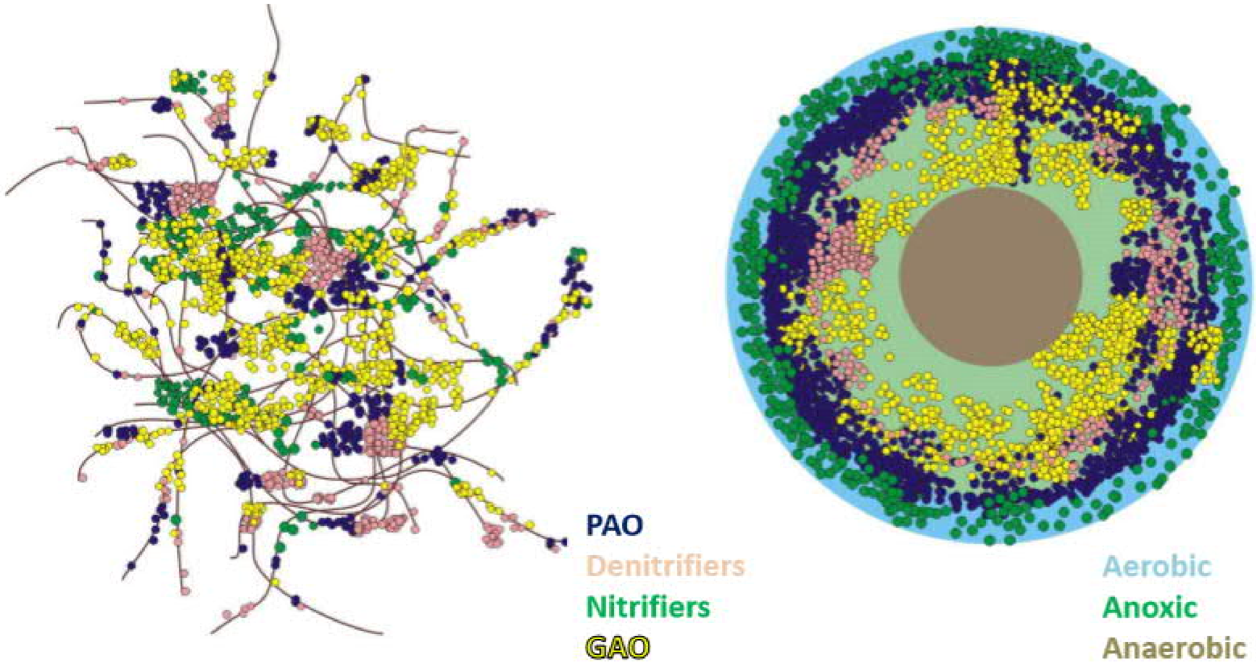
Picture: Nereda

Definitions on AGS

"Aerobic granular activated sludge is to be understood as aggregates of microbial origin, which do not coagulate under reduced hydrodynamic shear, and which subsequently settle significantly faster than activated sludge flocs."

- **True microbial biomass**
- **Minimum particle diameter of ~ 0.2 mm**
- **AGS SVI5 is equal to SVI30 of typical activated sludge**

Stucture of granules

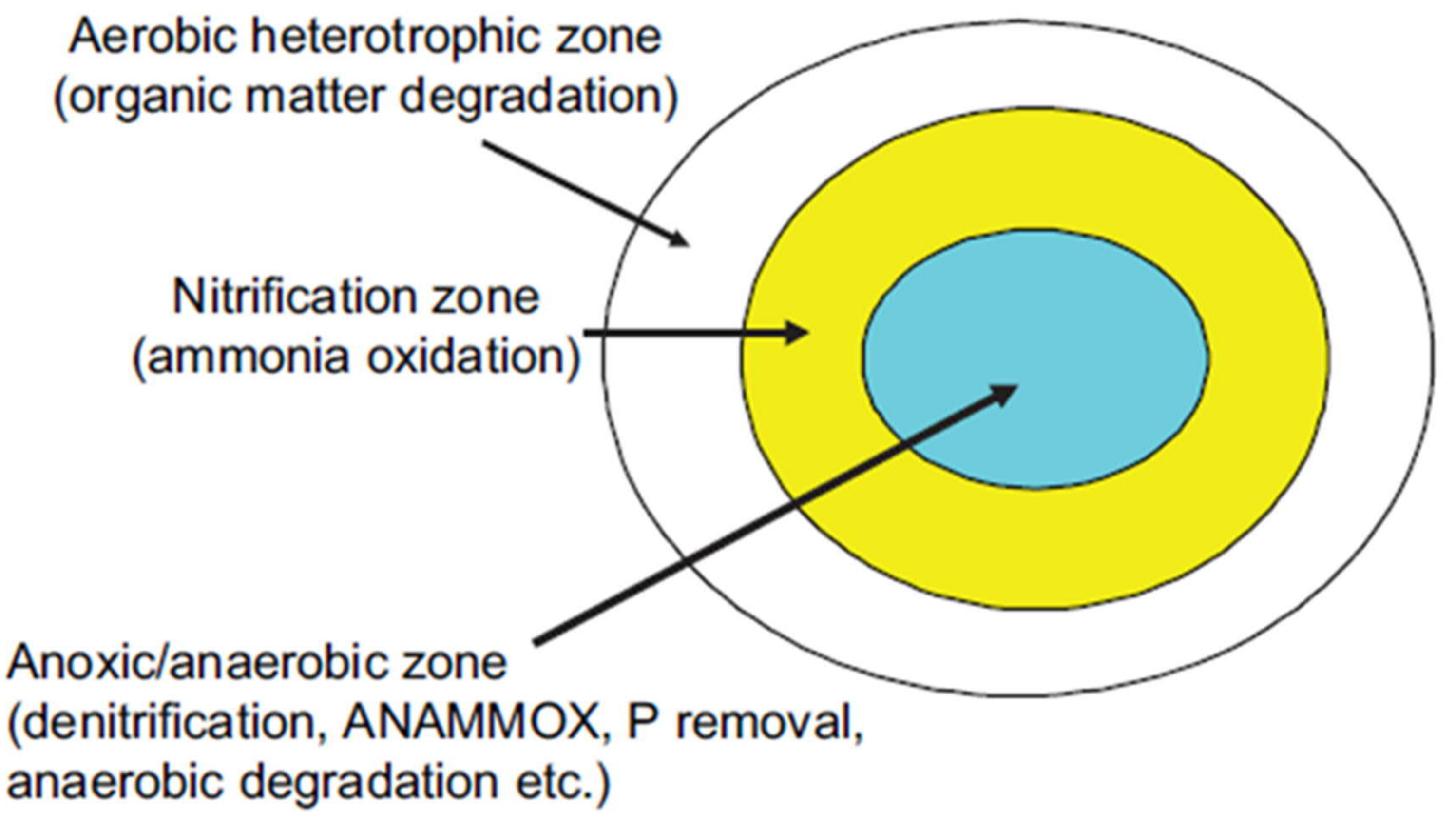


Conventional Activated Sludge
Mixed Microbial Community

Aerobic Granular Sludge
Layered Microbial Community

Source: engineersjournal.com

Microbial processes in granules



Selection in AGS

Hydraulic Selection

- **Selective wasting**
- **Wash out smaller particles**
- **Dense granules settle faster than CAS**
- **Decrease settling time**

(CAS = conventional activated sludge)

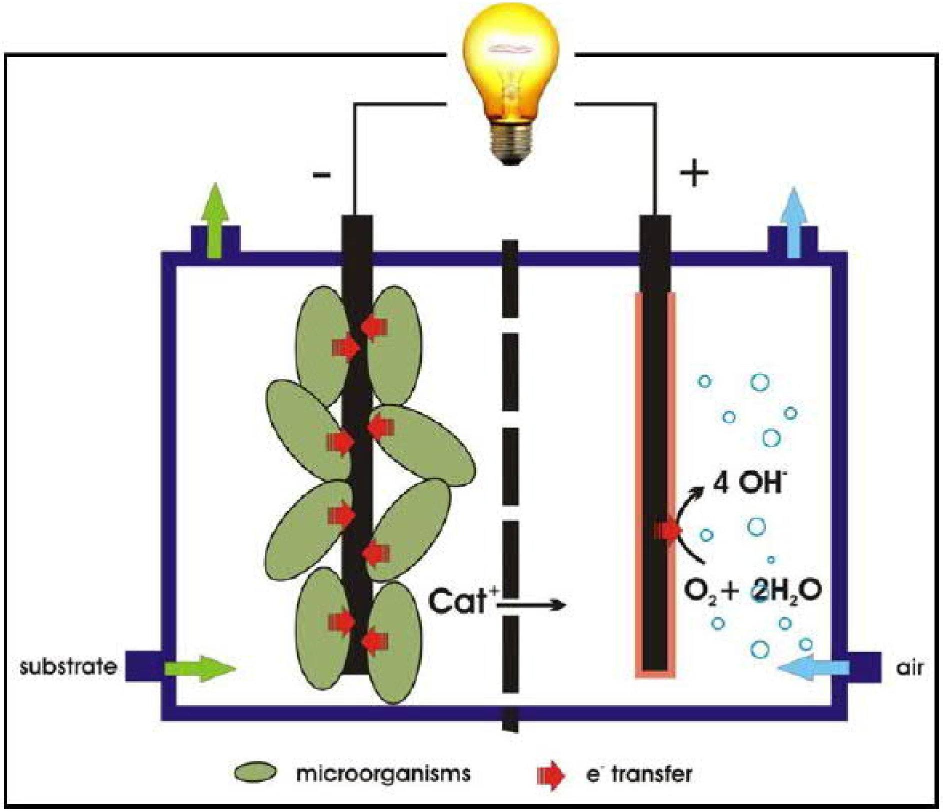
Biology selection

- **PAOs form EPS**
- **EPS is the chemical backbone of the granule**
- **Dense bacterial gathering allow rapid settling**

(PAO = phosphorus accumulating organisms; EPS = extracellular polymer substances)

Microbial fuel cells

Working principle of a microbial fuel cell



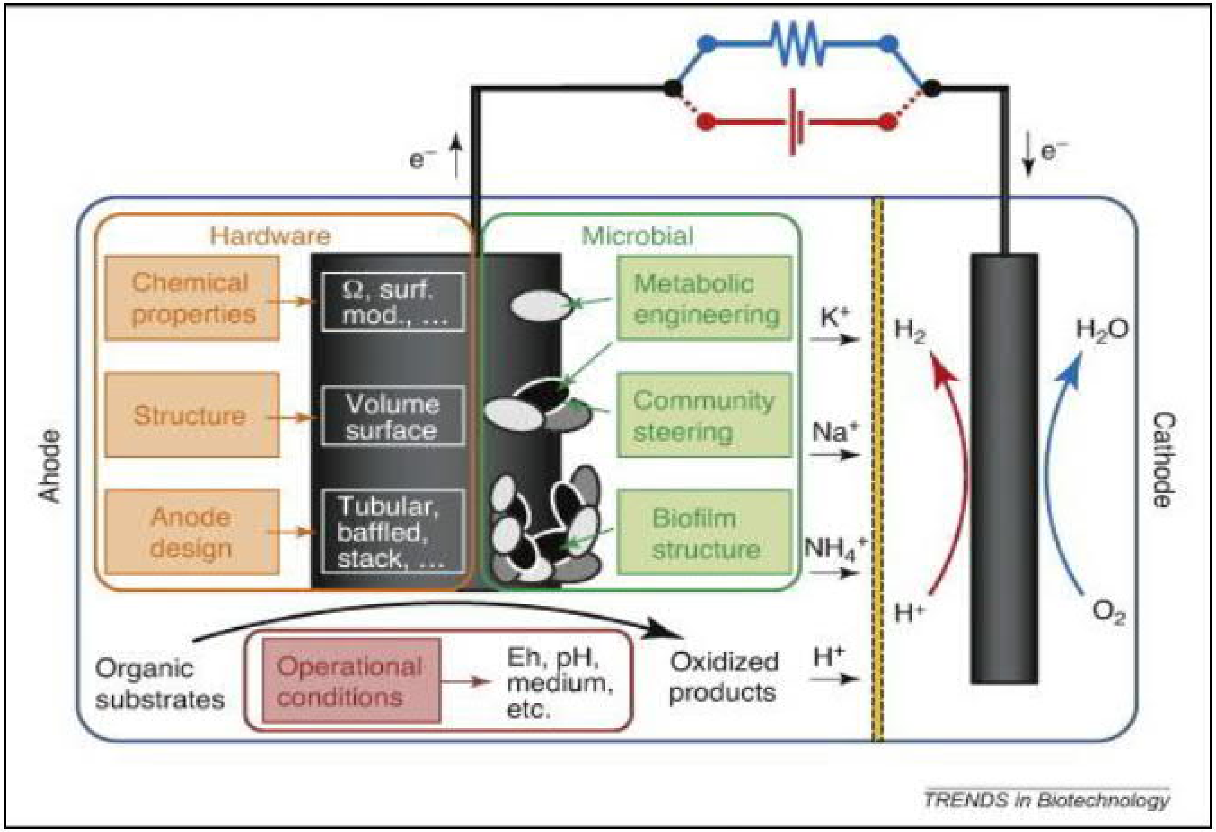
Oxidation:

Acetate (CH_3-COO-) + $2H_2O \rightleftharpoons$
$2CO_2 + 8e^- + 7H^+$

:Reduction

$2O_2 + 8e^- + 4H_2O \rightleftharpoons 8OH^-$

What are design and engineering criteria?



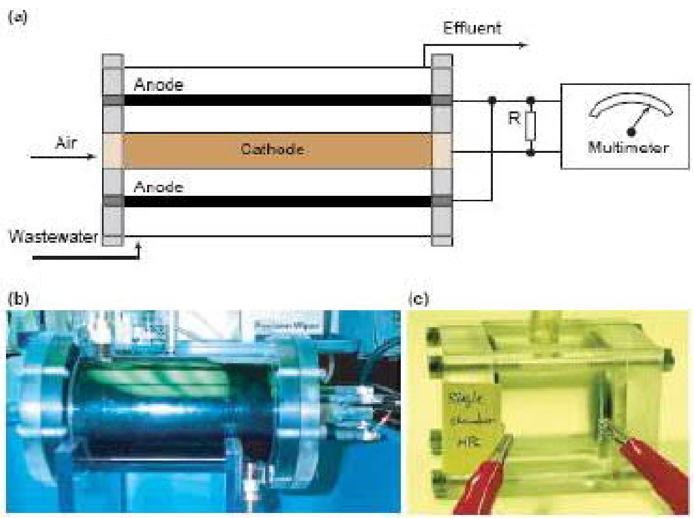
Pham, T. H., Aelterman, P. and Verstraete, W. (2009), Trends in Biotechnology, 27, 3: 168-178.

MFC design configurations for wastewater treatment

Most initial MFCs:
Plate designs

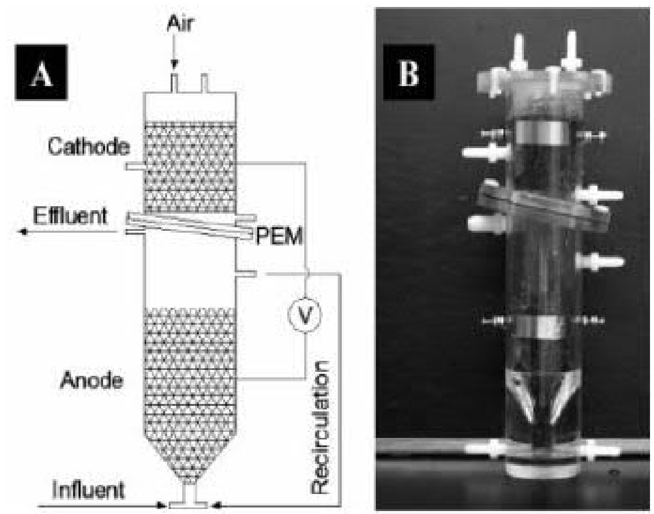
Tubular MFC designs

(Rabaey, K. & Verstraete, W. (2005). Trends Biotechnol. 23, 291-298.)

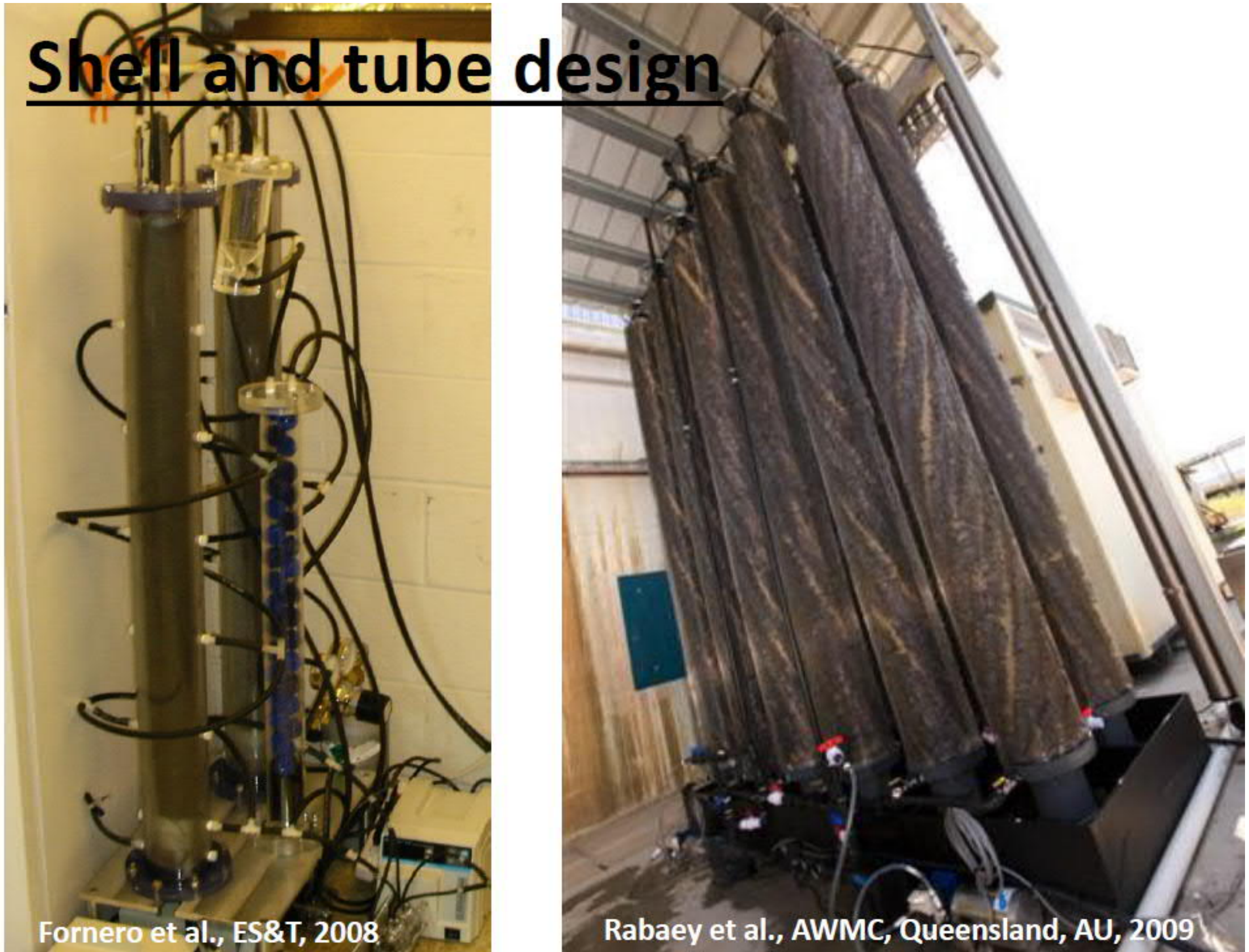


Upflow MFC designs

(He, Z., Minteer, S. D. & Angenent, L. T. (2005). Environ. Sci. Technol. 39, 5262-5267.)

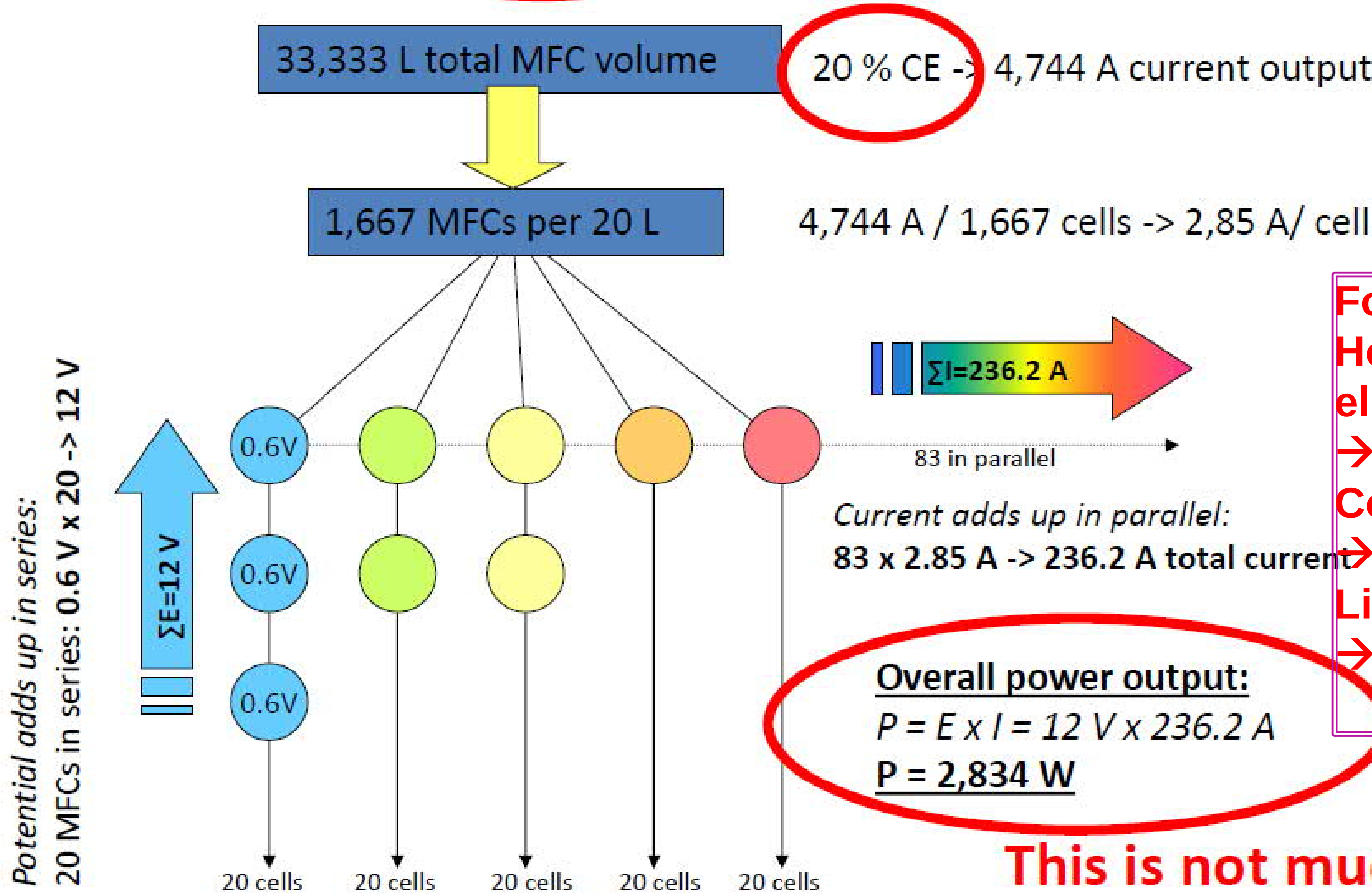


Some larger scale studies



Designs for a higher voltage/power output

100,000 L/ d wastewater @ 2,000 mg/L BOD and 85% BOD removal efficiency, 8 h HRT



For comparison:
Households electronics
→ 1,8 kWh/d
Cooking&dishes
→ 1,5 kWh/d
Lights
→ 1,3 kWh/d

This is not much!!

33

Reading material

Biofilms (Biological WWT)

Chapters:

17.1.

18.1-18.2

18.4

MBR

13.1. – 13.3.