Biofilm & Fixed Biomass processes

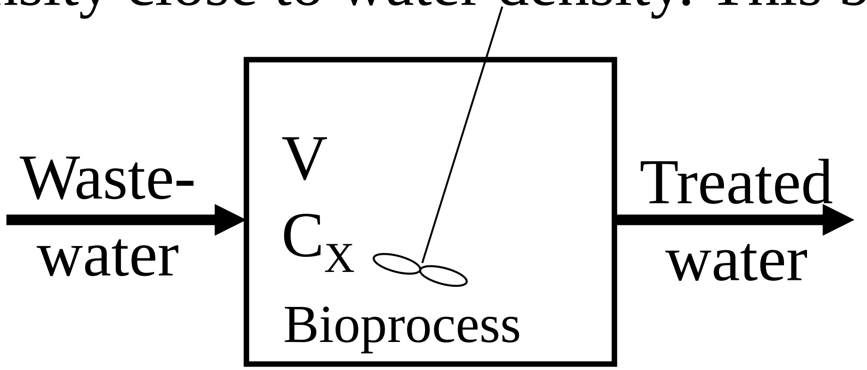
In Batch, Fed Batch, Chemostat and most of Activated Sludge WWTP (Activated Sludge), biomass consists of microorganisms in suspension in Completely Stirred Tank Reactor (CSTR)

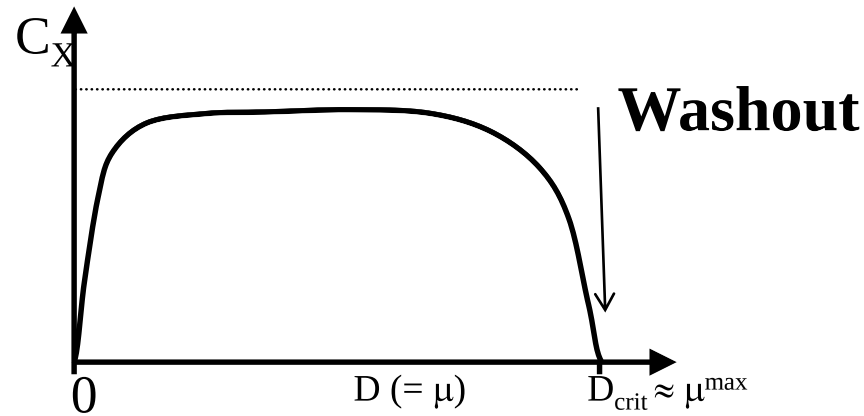
When biomass is not in suspension, we consider fixed biomass or biofilm bioprocesses!

→

Prevention of biomass washout (1)

In WWTP Activated Sludge basin, biomass stands in suspension in flocks where microorganisms are grouped in fluffy and cottony aggregates with density close to water density. This basin behaves like a chemostat CSTR.





When biomass is in suspension
→ **SRT = HRT**

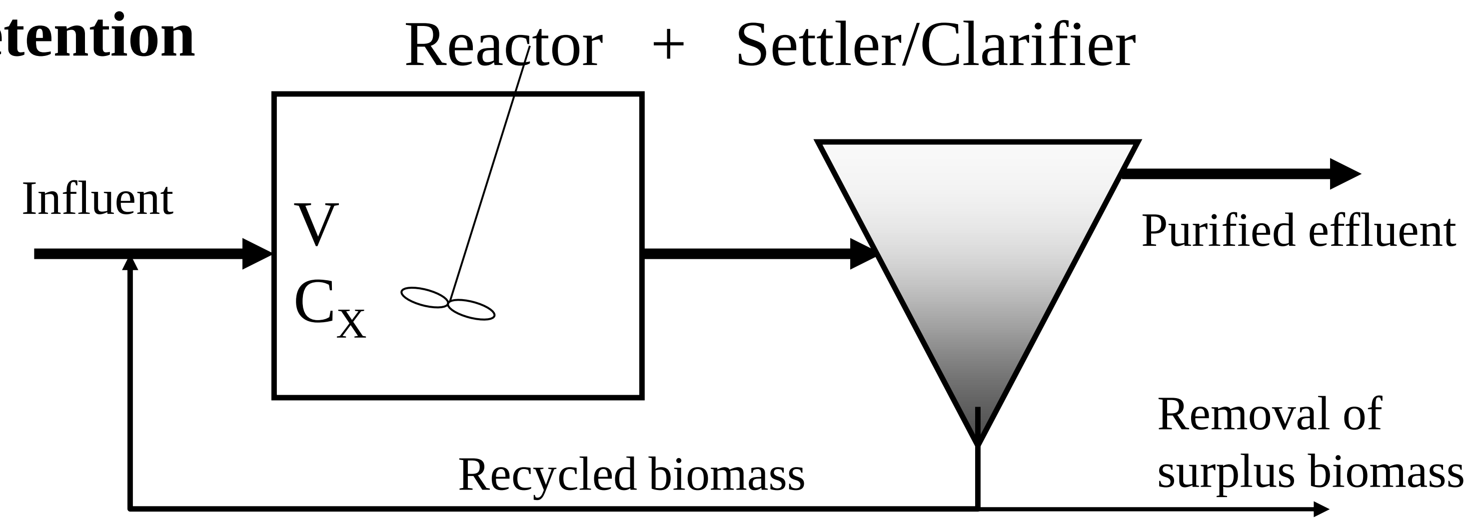
SRT Solids (biomass) Retention Time
HRT Hydraulic (Water) Retention Time
HRT = 1/D = V/ϕ_L $[m^3.(m^3.h^{-1})^{-1}] \equiv [h]$

Large influent flowrate with large hydraulic residence time (compatible with biomass growth rate μ = D dilution rate = 1/ SRT = 1/HRT) will require **very large reactor volume**…

Prevention of biomass washout (2)

In Activated Sludge WWTP, biomass (in suspension) washout is prevented by the mean of a **secondary settler (clarifier) WITH** activated sludge **recirculation.**

→ **Biomass retention**



Here, SRT can be controlled, thus HRT ≠ SRT

(Also called Sludge Age)

$$SRT = \frac{V.\,C_X}{removed \;\; biomass} \quad [m^3.kgC_X.m^{-3}.(kgC_X.d^{-1})^{-1}] \equiv [d]$$

Note: Settling in secondary clarifier is a natural way of Biomass/Effluent separation.

Prevention of biomass washout (3)

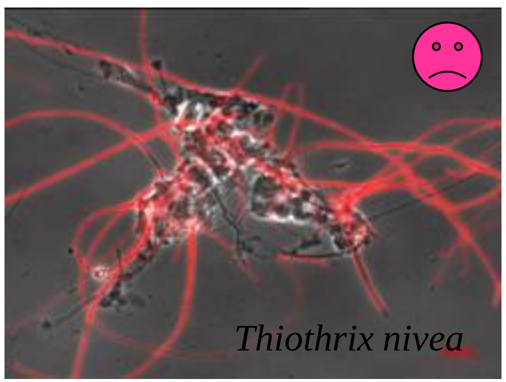
Settling is a natural property of Activated Sludge Biomass which occurs in settler or clarifier, allowing control of SRT independently of HRT…

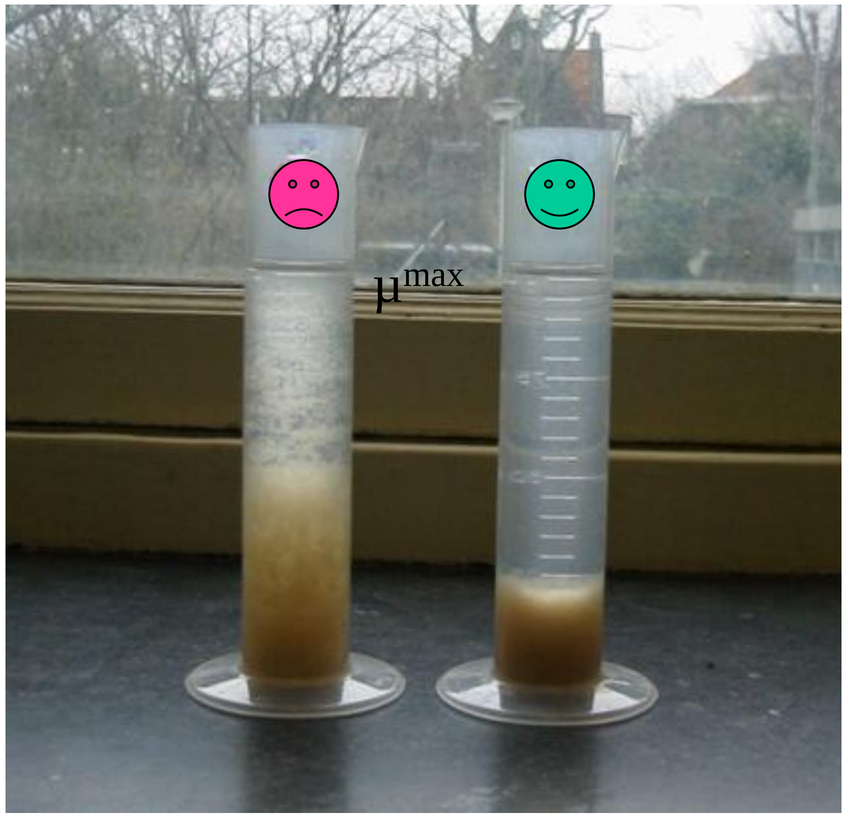
BUT … Settling can be problematic

Filamentous bacteria

↓

Poor sedimentation

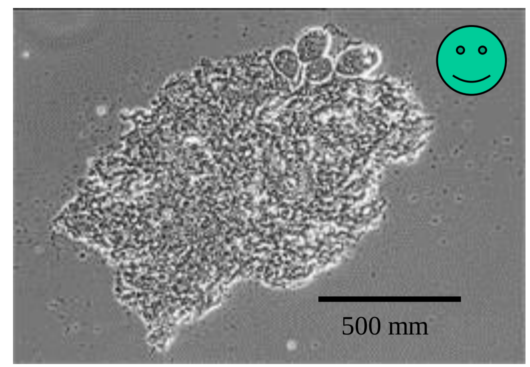




Floc-forming bacteria

↓

Better sedimentation



Prevention of biomass washout (4)

To prevent washout, dilution rate D must be smaller to maximum specific growth rate μ^{max} → SRT > $(\mu^{max})^{-1}$

Desired organism	**μ^{max} "order" (h^{-1})**	**SRT (h)**
aerobic heterotrophs	0.4	> 2.5
sulfate reducers	0.05	> 20
nitrifiers	0.02	> 50
methanogens	0.005	> 200

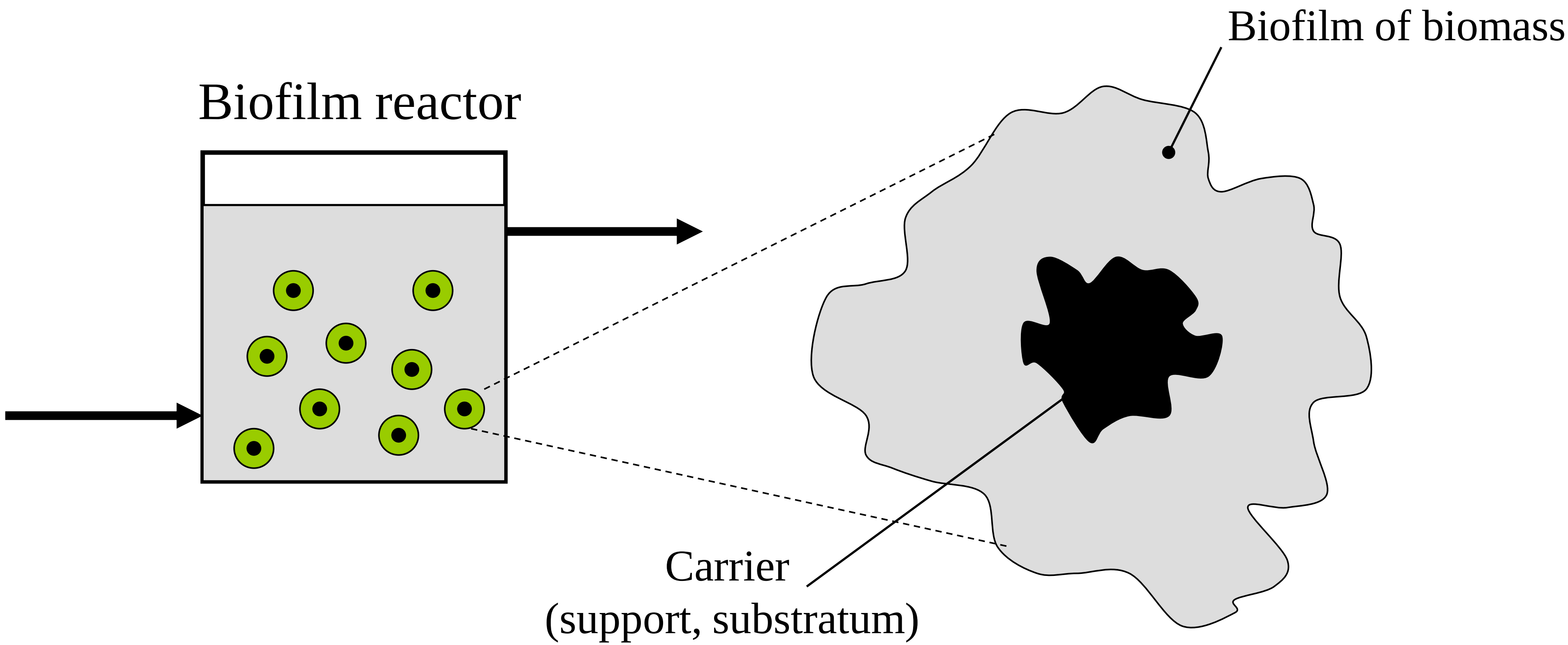
To satisfy large SRT despite of short HRT (reactor volume reduction), one can use:

1. **Biomass retention**: settler, membrane separation, centrifugation
2. **Biomass immobilization**: natural biomass fixation as biofilm on fixed or moving supports, and artificial immobilization.

Prevention of biomass washout (5)

1) Natural Biomass immobilization = Biofilm

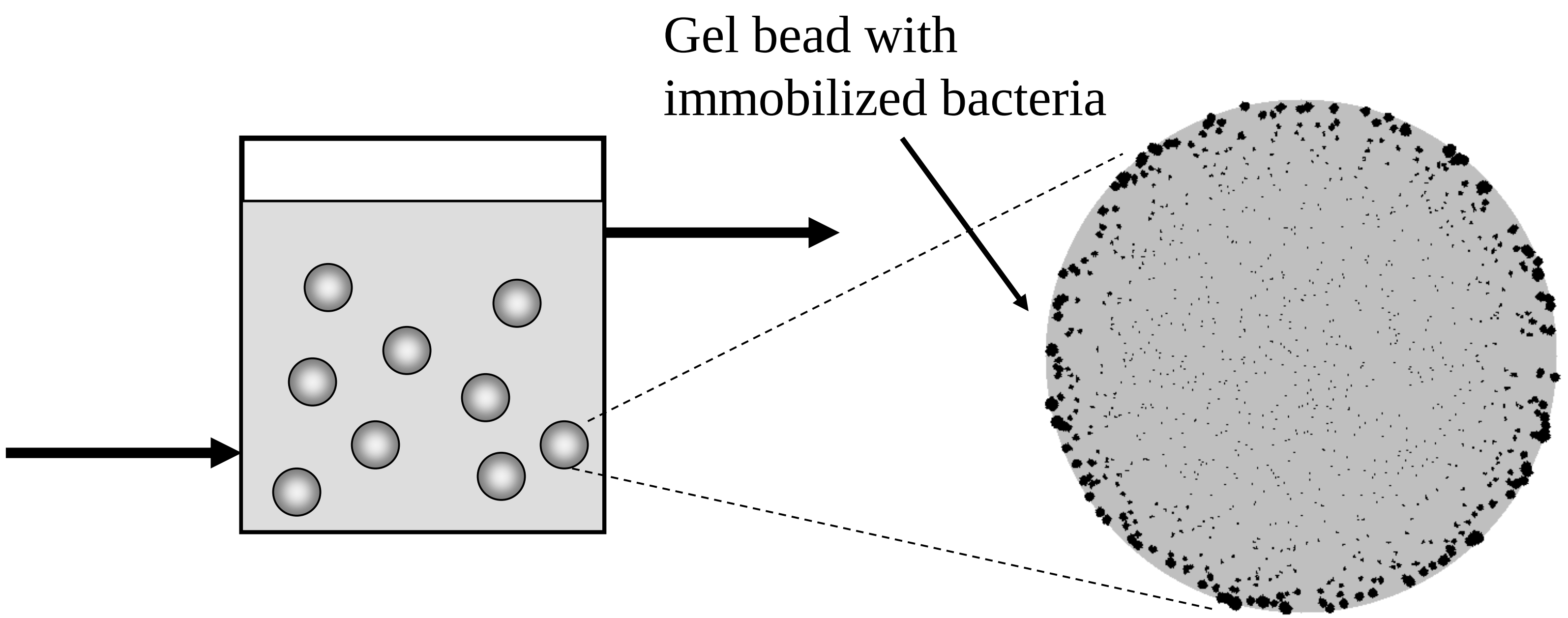
Naturally biomass grows on mobile or fixed supports (carriers), to form biofilm



Prevention of biomass washout (6)

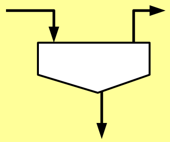
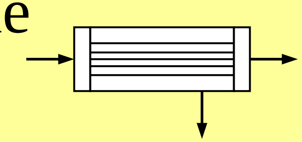
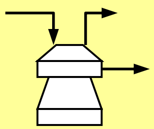
2) Artificial Biomass immobilization

Artificial biomass immobilization consists of entrapping microorganisms in an artificial non suspended matrix (typically agar gel beads). This is an efficient, but expensive, mean of immobilization.



Prevention of biomass washout (7)

Comparison of biomass retention techniques …

Technique	Solid retention time (hours)	Biomass concentration (kg VSS/m^3)
Settler 	~ 25	5
Membrane module 	∞	20
Centrifuge 	∞	30
Biofilm	~ 500	40

Where are the biofilms? Everywhere

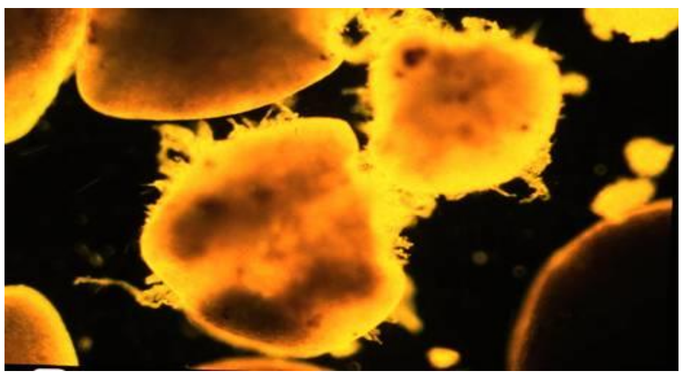
Medical Biofims on:

Contact lens

Tooth

Catheter

Biofilms in WWTP



In air lift granular bed reactor

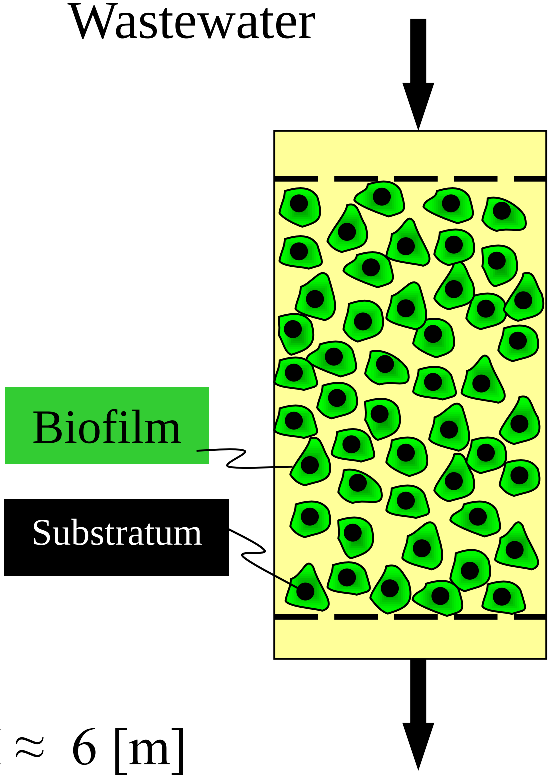
On reactor baffle

Biofilm process bioreactors (1)

Fixed biofilm → Trickling filter

Also called fixed bed, where biofilm grows on non mobile carriers…

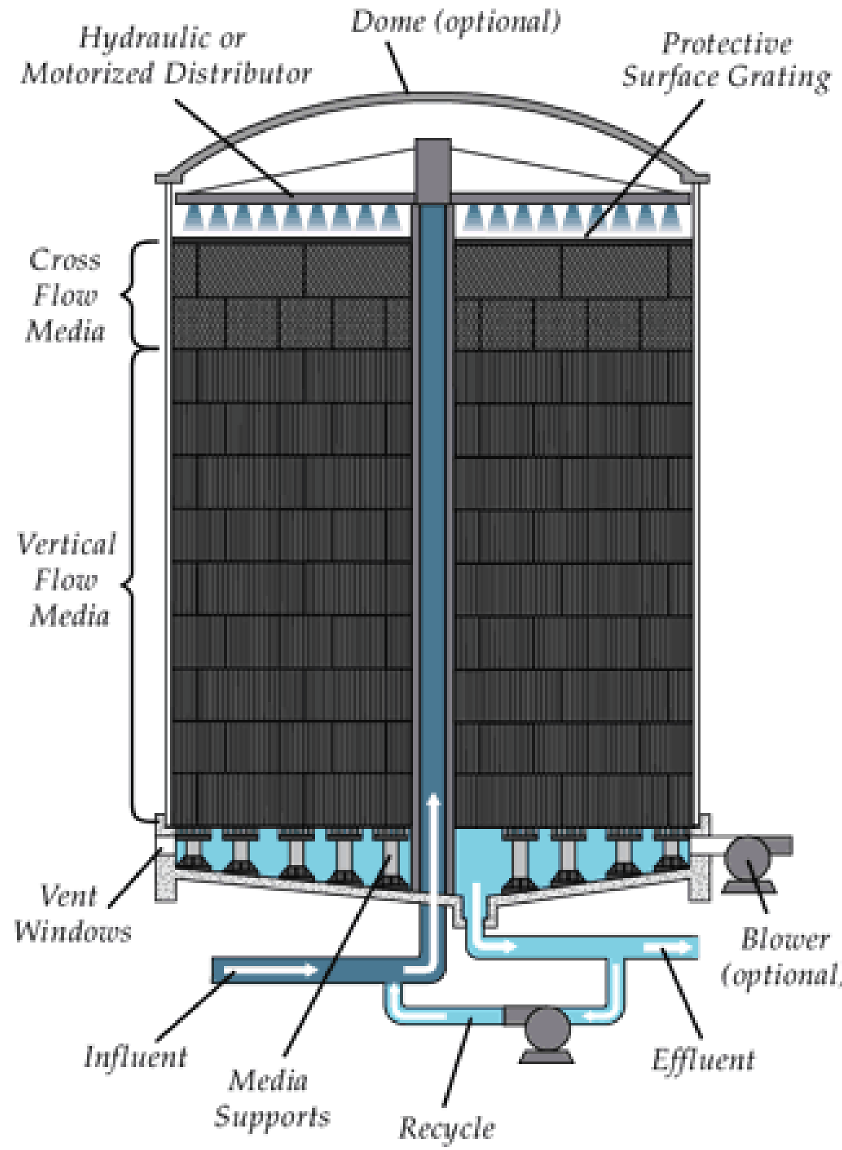
Wastewater



$H \approx 6$ [m]

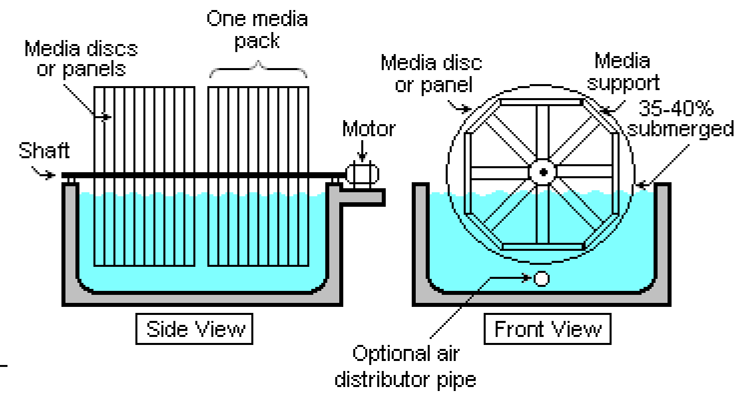
$A_v \approx 200$ [$m^2.m^{-3}$]

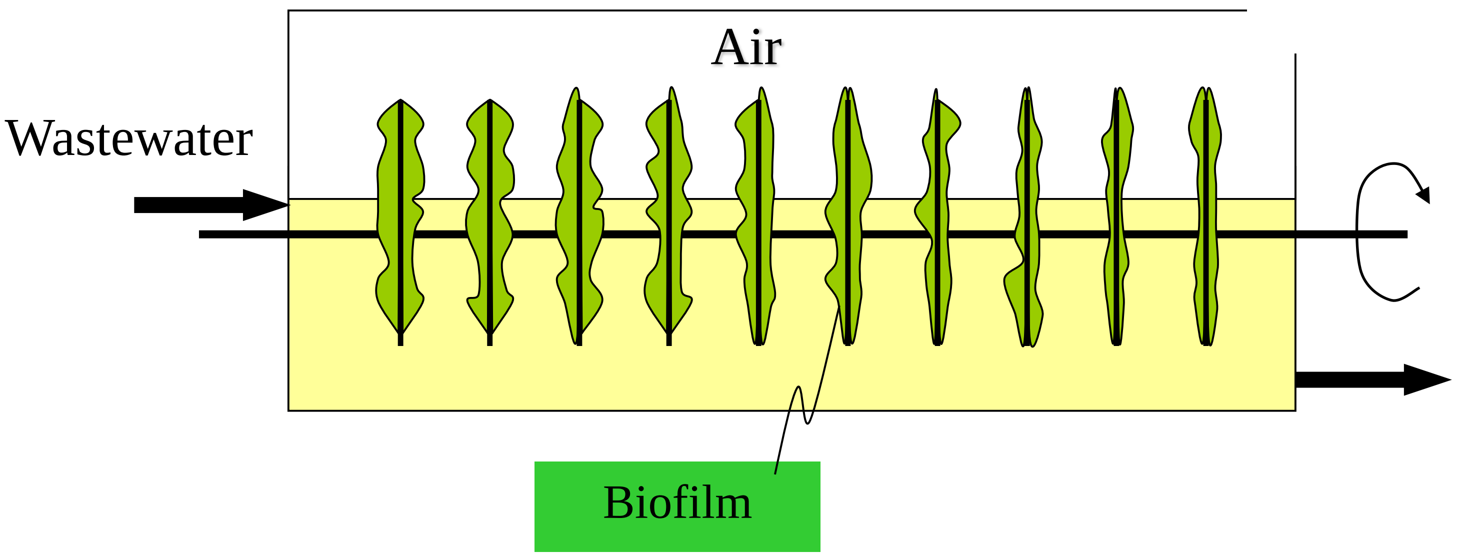
High clogging risk !



Biofilm process bioreactors (2)

Fixed biofilm → Rotating disk





$H \approx 2$ [m]

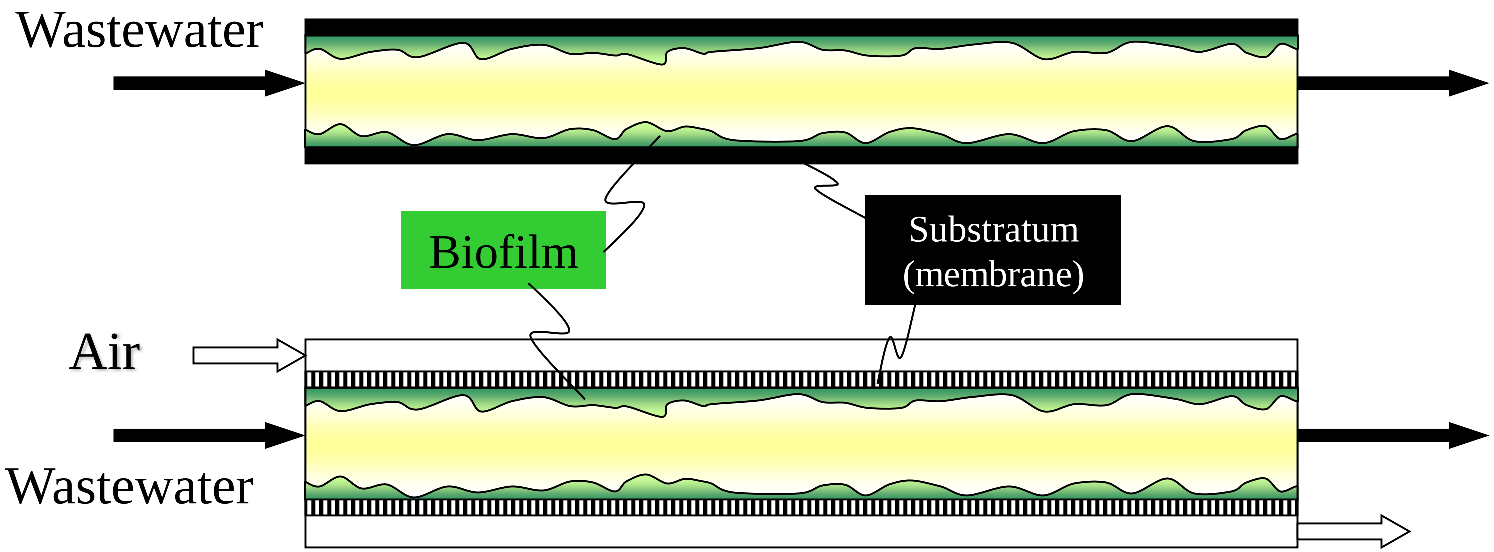
$A_v \approx 200$ [$m^2.m^{-3}$]

Less clogging risk…

Good settling efficiency…

Biofilm process bioreactors (3)

Fixed biofilm → Membrane reactors



$H \approx 1$ [m]

$A_V \approx 1000$ [$m^2.m^{-3}$]

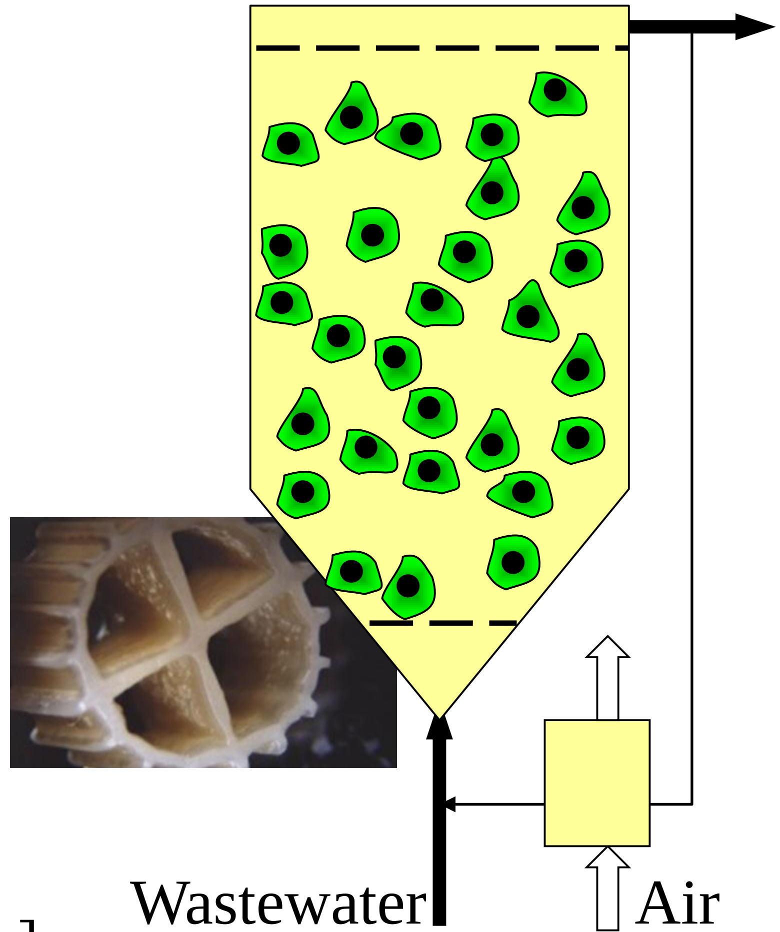
Clogging risk!

Biofilm process bioreactors (4)

<u>Moving biofilm → Fluidized bed</u>

In fluidized bed bioreactors, biofilm grown on carriers are maintained in suspension by fluid velocity against gravity. In case of aerobic bioprocess, O_2 requirement is provided by mean of an external aerator.

Washout by overflow of carriers is the risk.



$H \approx 20$ [m]

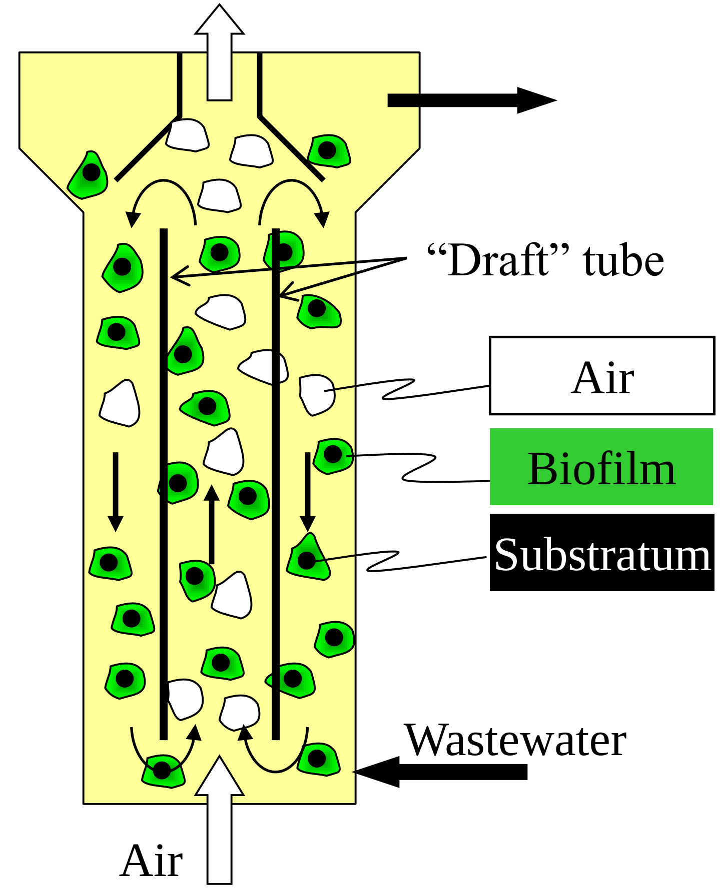
$A_v \approx 1200$ [$m^2.m^{-3}$]

Biofilm process bioreactors (5)

Moving biofilm → Air lift bioreactor

Also called "bubble column" when no draft tube is present. These fluidized bed bioreactors, biofilm grown on carriers are mixed along the column by aeration flowrate. In air lift bioreactor, an hydraulic recirculation is generated by the draft tube.

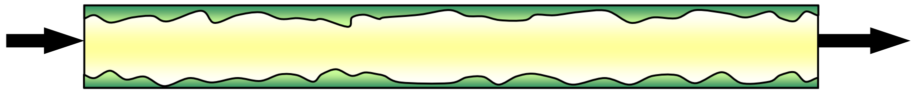
Overflow washout of carriers is the risk.



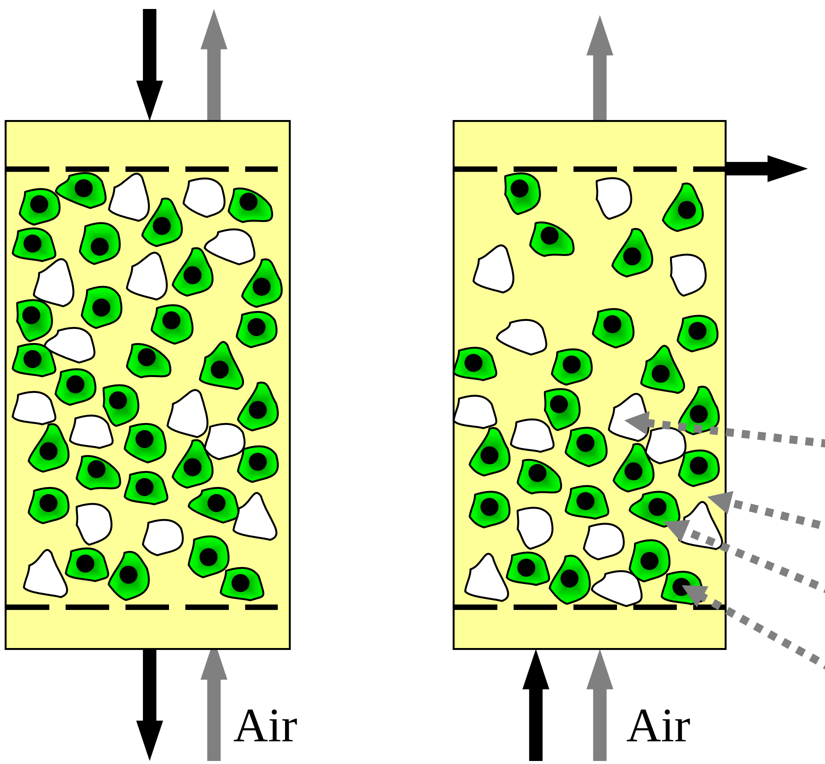
$H \approx 20$ [m]

$A_v \approx 3000$ [$m^2.m^{-3}$]

Basic types of biofilm reactors



Membrane bioreactors
(Fixed biofilm)



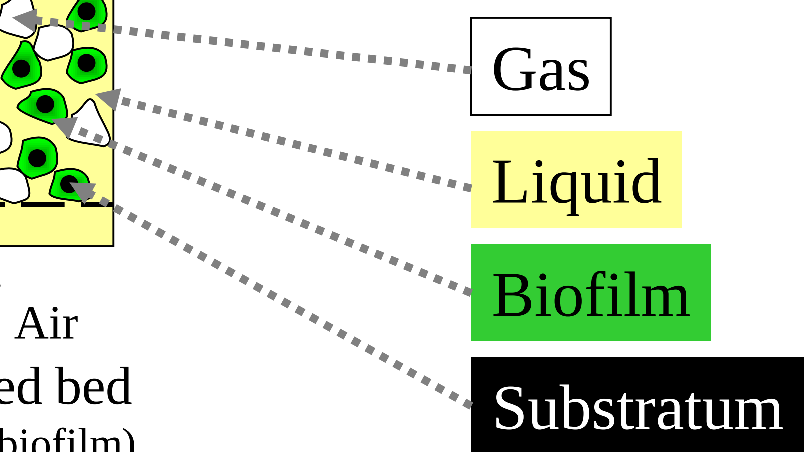
Fixed bed
(Fixed biofilm)

Fluidized bed
(Moving biofilm)

There are many types of biofilm reactors depending of **carrier type, shape and nature**, if there are **mobile or fixed**, and if aeration flux is **concurrent** or **countercurrent** to hydraulic flux…

In many case, general characteristic of biofilms reactors, but they are:

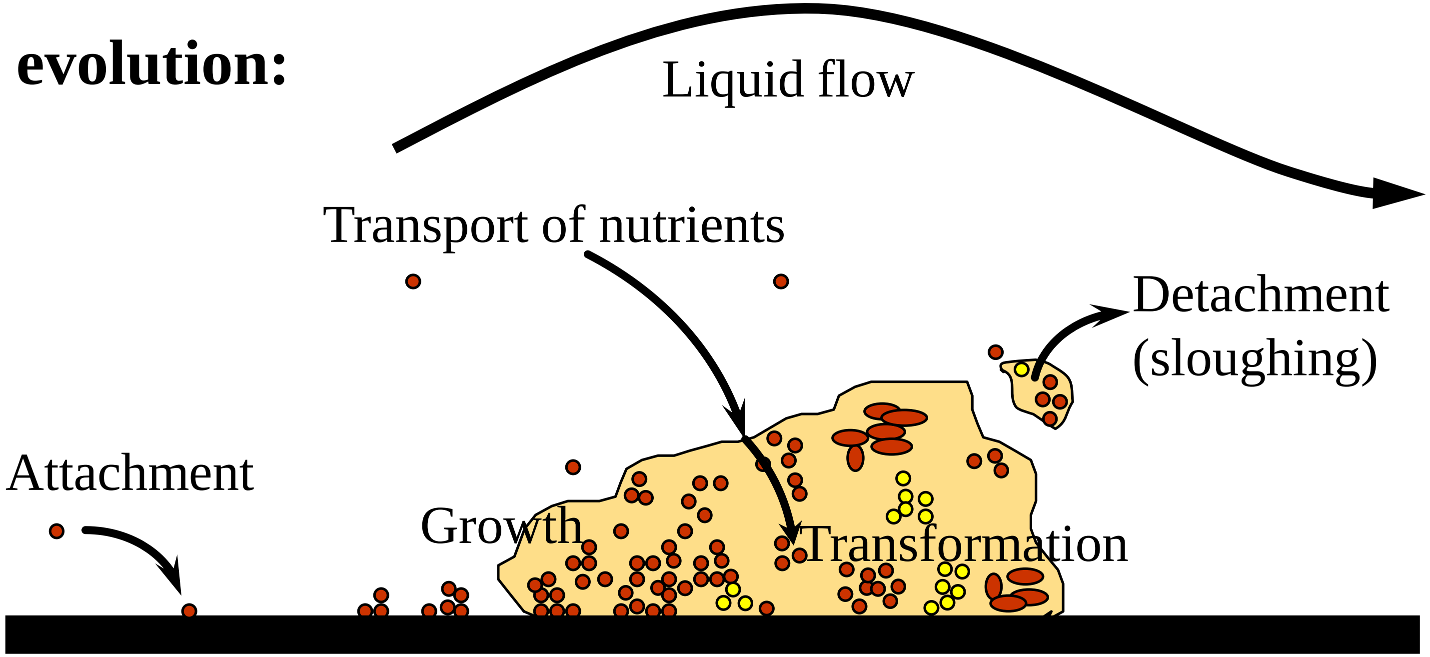
→ **MULTIPHASIC Bioreactors**…



Biofilm formation

Biofilm biosystem are “not simple” biomass of fixed microorganisms on carriers, surrounded by suspended biomass and gas bubbles in the bulk liquid phase… Biofilm formation and evolution is high **complex multiphasic (bio)processes**, with **complex interactions** within and among the different phases.

Biofilm evolution:



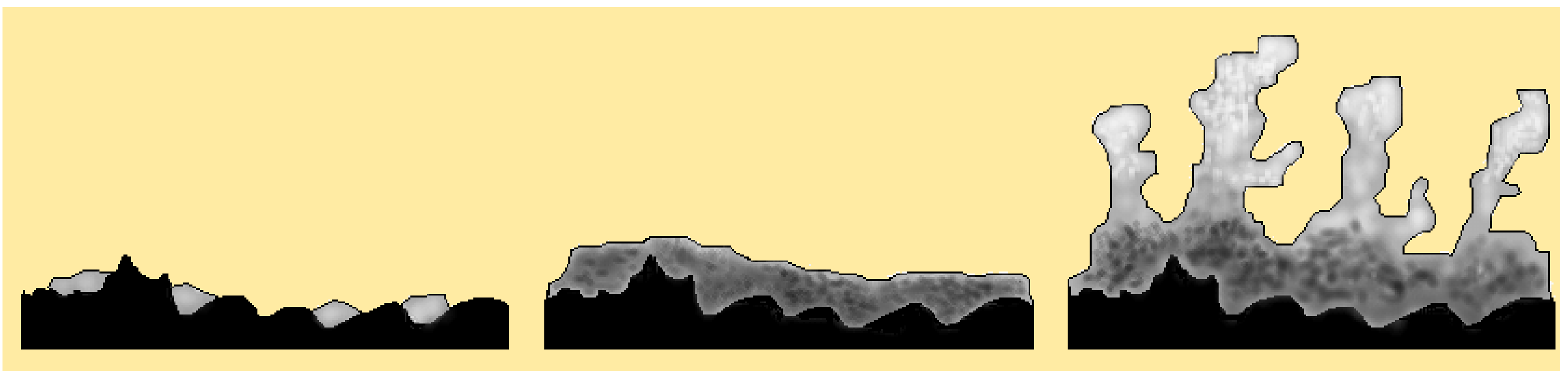
Biofilm geometrical heterogeneity (1)

Geometrical heterogeneity of biofilm is due to:

1. **Growth** behavior which is determined by bulk medium (**substrate diffusion**)
2. **Shear stresses** which is determined by hydraulic characteristics (**biofilm detachment**)

Shear forces intensity decrease

→ lower detachment rate!



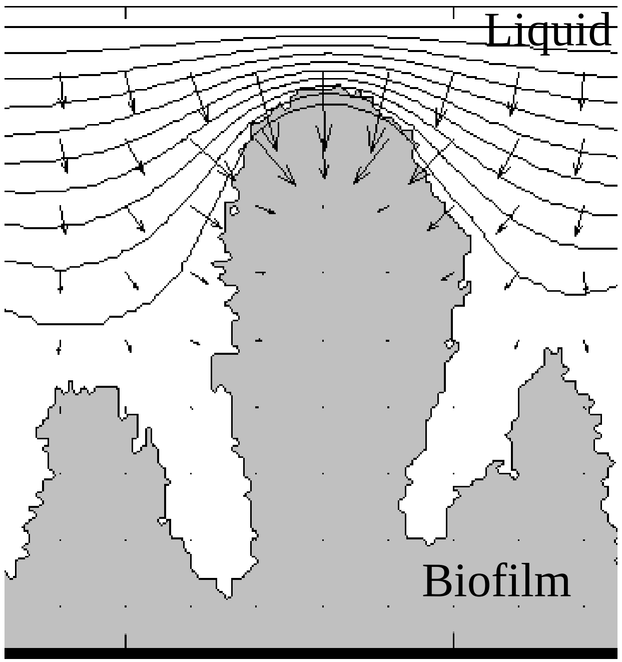
Picioreanu, Van Loosdrecht, Heijnen (2001) *Biotech Bioeng* 72(2), 205

Biofilm geometrical heterogeneity (2)

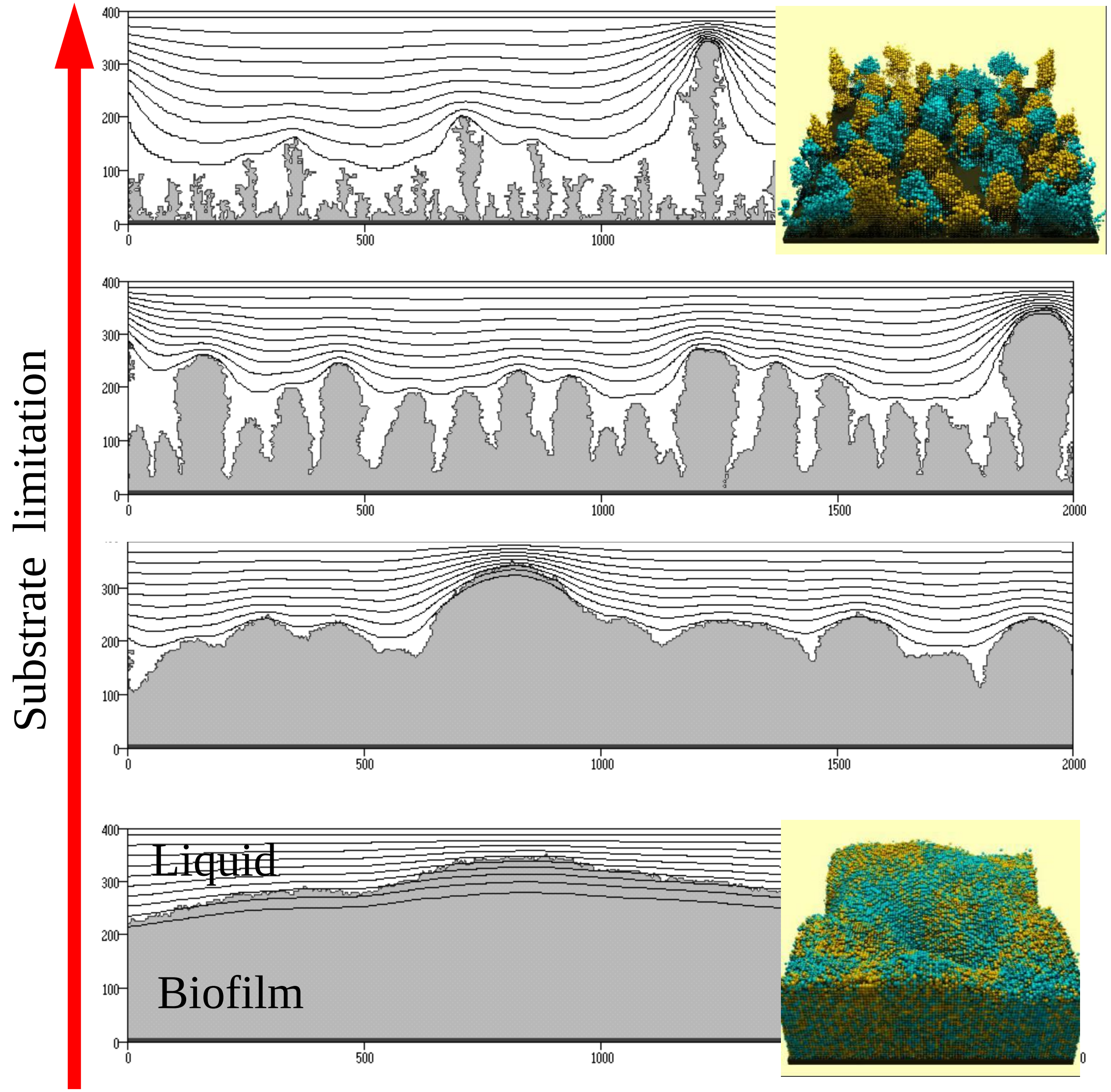
Diffusion - Reaction - Growth biofilm model

(2D Results)

Vector field of substrate diffusion flux



Picioreanu, Van Loosdrecht, Heijnen (1998)
Biotech Bioeng 58(1), 101



Biofilm or Not biofilm ?

Biomass in bioreactor is present either in form of **suspended biomass** or in the form of **biofilm**. Biofilm growth will be favored according spatial microenvironment pressure (dilution-washout). If dilution rate is greater specific growth rate, suspended biomass will be washed out and only biofilm will grow on available substrate.

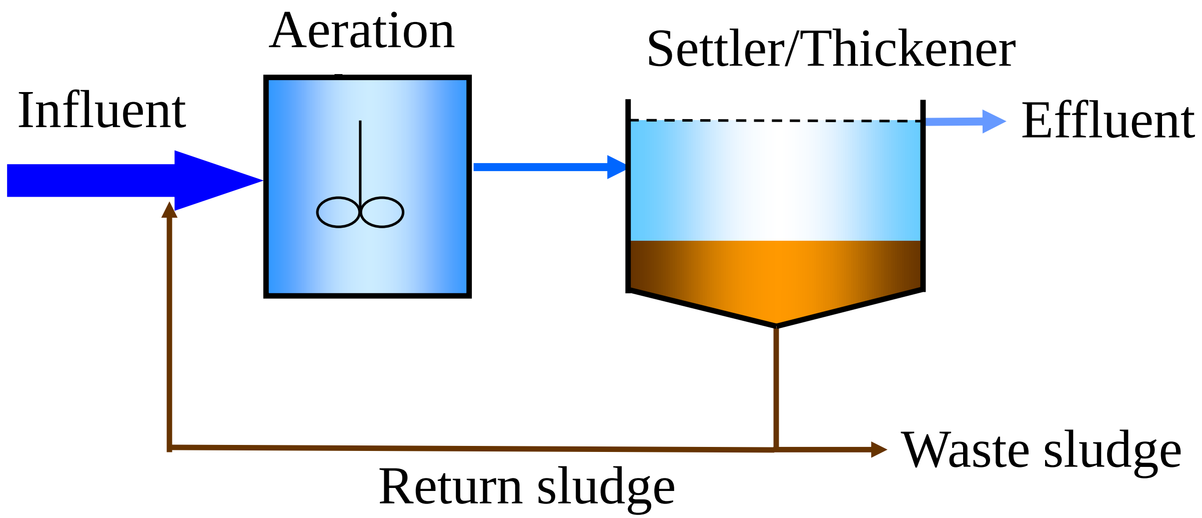
- If $D < \mu_{max}$ then Suspended cells growth is favored
- If $D > \mu_{max}$ then Biofilm growth is favored

Suspended biomass or biofilm growth is the result of the balance between: Dilution-washout / Biomass growth rate / Biofilm detachment

In fact:

1. Even if $D < \mu_{max}$ where suspended biomass is favored, little biofilm growth occurs naturally
2. If biofilm growth is favored with $D > \mu_{max}$, suspended biomass is still present due biofilm detachment

Conventional Activated Sludge WWTP



Disadvantages:

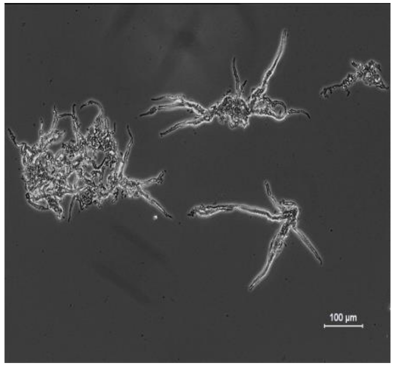
- Large area requirement
- High production of surplus biomass
- Relatively low volumetric conversion capacity

  ≈ 0.5 [kgCOD.m^{-3}.d^{-1}], for activated sludge vs conventional

  biofilm systems ≈ 2 [kgCOD.m^{-3}.d^{-1}]
- Load or toxic choc sensitivity
- Settling efficiency sensitivity

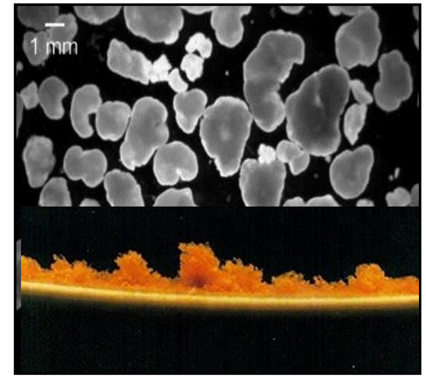
From conventional AS WWTP to biofilm bioprocesses

From biomass
in flocks



Fixed biomass
in granules/biofilm

→



From conventional Activated Sludge bioprocess → Biofilm reactors:
- Fixed or moving bed
- or granular bioreactor

Advantages & Benefits

- **Higher biomass** concentration
- **Higher volumetric conversion capac**ity
- **Less sludge** is produced
- **High settling velocity**
- Load and toxic **choc resistance**
  C, N and P removal (in same reactor/granule)

<u>One major drawback?</u>
Transport/Transfer in compact biofilm is more difficult than for suspended biomass or Activated Sludge…

Mass transfer in biofilm systems
Transport processes in a three-phase (Gas/Liquid/Solid) biofilm system