Professor Navarro

M-tech course :
Biological water treatment of raw water meant for drinking water production

1. Quality of groundwater and surface water

Figure 1 illustrates the water cycle in town ; in this course, we will study biological treatment applied to drinking water production, not to waste water or sludge purification.
Raw water may be very polluted as shown in **figure 2**.
Biological treatment in drinking water production is rare (**figure 3**) but it issystematic in waste water purification.

2. Quality of drinking water

WHO (1998) has created five drinking water parameters categories (Guidelines for drinking water quality) : **figure 4**.

1. Bacteriological quality
2. Chemicals of health significance in drinking water
3. Chemicals not of health significance at concentrations normally found in drinking-water
4. Radioactive constituents of drinking-water
5. Substances and parameters in drinking water that may give rise to complaints from consumers

Among these chemicals and parameters, some can be removed by means of a biological treatment ; they can be either :
- dissolved substances (if they are suspended solutes, they can be separated from water by means of a simple clarification), or
- biodegradable chemicals :
  - source of carbon, nitrogen, phosphorus… : if the exploited microbes are heterotrophic, these matter are organic (glucose, urea, amino acids, phosphoproteins…), otherwise they are autotrophic (CO_2, N_2, NH_3, PO_4^{3-}, S…).
  - source of electron (i.e. source of energy - ATP) : these microbes get their energy from reduced matters oxidations : they are chemotrophic (on the contrary, some organisms get their energy from light and are phototrophic) ; if the source of electron is organic (glucose, CH_4…), they are called chemo-organotrophic, otherwise they are chemo-lithotrophic (NH_3, NO_2^-, S, S^{2-}…) ; these oxidations are coupled with reductions ; the whole reaction called oxidation-reduction generates ATP ; electrons must be accepted by a chemical called final electron acceptor ;

The undesirable chemical can be the final acceptor of electron in energetic metabolism : this oxidized chemical is reduced by the electrons issued from the oxidation of the source of electrons ; the whole biochemical process, called respiration (localized in a membrane and performed in a electron transport chain), can be either aerobic (O_2 is the final acceptor) or anaerobic (NO_3^-, CO_2, SO_4^{2-}, SO_3^{2-}…).
Most organisms which are heterotrophic are in the same time chemo-organotrophic : the source of carbon is also the source of electrons : they are called chemo-organo heterotrophic : all animals, bacteria like *Escherichia coli, Pseudomonas aeruginosa…*
Most organisms which are autotrophic are also chemio-lithotrophic : they are called chemo-litho autotrophic : only bacteria like *Nitrosomonas, Nitrobacter, Gallionella ferruginea, Leptothrix…*
In order to master the biological water treatment process, one should know the requirements of the exploited bacteria :
- is the undesirable substance the source or the acceptor of electrons, the source of carbon, of nitrogen…?
- is it an aerobic or an anaerobic metabolism ?
- is this metabolism sensible to temperature, pH, or to the presence of chemicals like metals, acids, organic matters…?

3. Origins and risks associated to undesirable substances meant to be remove by biological process : **figure 5**

4. The biological processes in water treatment : biofilm and microbial flocculation

Once the metabolism is performed, the exploited microbes must be separated from treated water ; there are two techniques : attached or suspended growth ; in drinking water production, as raw water is quiet clear, attached growth is the main technology : **figures 6 to 8**
All the exploited biochemical processes are existing reactions belonging to different matter cycles (C, N…).

4.1. Nitrogen substances

Two main chemicals are concerned : ammonia and nitrates ; their removal is an exploitation of some reactions existing in nitrogen cycle.

4.1.1. Nitrogen cycle : **figure 9**

Ammonia is removed by means of nitrification and nitrification thanks to denitrification.
Ammonia can be removed by means of chlorination, and nitrates by ion exchange.

4.1.2. Ammonia removal

4.1.2.1. Involved micro-organisms

Nitrosomonas and *Nitrobacter* are bacteria but possess intracellular membranes in which nitrification occurs : **figure 10**

4.1.2.2. Biochemistry of the process

They are chemo-litho autotrophic ; their source of electrons are respectively NH_3 and NO_2^-, oxygen is the final electron acceptor.
Nitritation performed by *Nitrosomonas* :
$2\ NH_3 + 3\ O_2 \longrightarrow 2\ NO_2^- + 2\ H_3O^+$
Nitratation performed by *Nitrobacter* :
$2NO_2^- + O_2 \longrightarrow 2NO_3^-$
Whole reaction of nitrification :
$NH_3 + 2O_2 \longrightarrow NO_3^- + H_3O^+$
A coherent caption is respected for figures describing processes : **figure 11**

4.1.2.3. Operating

Raw water containing ammonia is treated by as aerated biofilter colonized by an attached growth ; the biofilm contain the two types of bacteria ; treated water contains nitrates.
Once biofilter is clogged, it must be backwashed : **figure 12**

4.1.3. Nitrates removal

4.1.3.1. Involved micro-organisms

A lot of bacteria are able to remove nitrates : *Pseudomonas aeruginosa*, *Escherichia coli…*

4.1.3.2. Biochemistry of the process

The reaction is called denitrification ; it transforms nitrates in N_2 , and nitrates are the final electron acceptors. It is an anaerobic respiration ; the reaction is catalyzed by nitrate reductase. Nitrate is first reduced in nitrite and then the reduction continues until the state N_2.
The type of electron donor determinates the requirement of the bacteria :
- it can be an organic substance (ethanol, glucose, acetic acid…) : the bacteria are chemo-organo heterotrophic ; this matter must be present in raw water, together with nitrates. This type of heterotrophic denitrification is performed in all the waste water treatments (where organic matter , BOD, is present naturally) and the most current drinking water treatments (where organic matter is added)
- or a mineral chemical (S, S^{2-}, Fe^{2+}…) : bacteria are chemo-litho autotrophic ; in general, there is enough CO_2 in water to provide carbon ; this kind of denitrification is less efficient.
Oxygen inhibits denitrification (the oxidation of the donor is more exergonic and bacteria prefer aerobic respiration).

4.1.3.3. Operating

The biofilter is closed (anaerobic respiration) and :
- if it concerns heterotrophic denitrification, an organic matter is added in water (more often ethanol) : **figure 13**
- if it concerns autotrophic denitrification, the electron donor is already present in raw water.
Some very rare processes purify ground water (**figure 14**), or need the addition of the donor of electrons (H_2 for example) ; **figure 15**
Finally, some processes allow to remove both nitrates and ammonia in water : anaerobic denitrification must be the first step : **figure 16**

4.2. Iron and manganese

4.2.1. Involved micro-organisms

In the stalk of *Gallionella ferruginea,* ferric ions are precipitated. The stalk allows the bacterium to fix on surfaces : **figure 17**
Leptothrix concentrates oxides of manganese in its sheath. It can adopt two forms : filamentous or single, flagellated and mobile : **figure 18**

4.2.2. Biochemistry of the process

Ferrous iron Fe^{2+} and manganese ion Mn^{2+} are the electron donors : these bacteria are chemo-litho autotrophic, aerobic :

$Fe^{2+} + e^- \longrightarrow Fe^{3+}$

and $Fe^{3+} + 3\ OH^- \longrightarrow Fe(OH)_{3\ p}$

$Mn^{4+} + 2e^- \longrightarrow Mn^{2+}$

and $Mn^{2+} + 2\ O_2^{2-} \longrightarrow MnO_{2\ p}$

The two oxidations don't occur in the same area of pH- oxidation – reduction potential : **figure 19.**

4.2.3. Operating of biological removal of iron

The biofilter is aerated, no need to add the donor of electrons…: **figure 20**
The biological oxidation is quite difficult to master because chemical oxidation occurs too ; this oxidation gives rise to precipitates less compact than those issued from biological oxidation.

4.2.4. Operating of biological removal of iron and manganese

Iron removal must be performed before manganese removal because it needs less oxygen : **figure 21**

4.3. Dissolved organic carbon

4.3.1. Involved micro-organisms

All the aerobic heterotrophic organisms can participate to DOC oxidation.

4.3.2. Biochemistry of the process

DOC is source of carbon and electron ; the reaction is the oxidation of organic matter in CO_2 and water.
Different pathways can be used :
- to oxidize **organic matter** in glyceraldehyde 3-P : glycolysis, pentose phosphate pathway or Entner Doudoroff pathway
- then oxidation continues in the tricarboylic acid cycle : it gives rise to $\mathbf{CO_2}$, partially oxidized chemicals (organic acids…) and reduced compounds whose oxidation with $\mathbf{O_2}$ occurs in a membrane and generates $\mathbf{H_2O}$ and **energy** (ATP). It is an aerobic respiration.

Oxygenic photosynthesis generates O_2.
All these metabolisms exist in the carbon cycle : **figure 22**
The microorganisms carrying out these metabolisms, participate to a food chain : **figures 23 and 24**

4.3.3. Operating

There are two kinds of biofiltration :
- slow filtration (5 m^3 / d) : **figure 25**
- or , if DOC is refractory to biodegradation, an intermediary oxidation precedes the biofiltration and allows to transform RDOC in BDOC : **figure 26**

Conclusion : **figure 27** summarises the different biological processes applied to drinking water production.

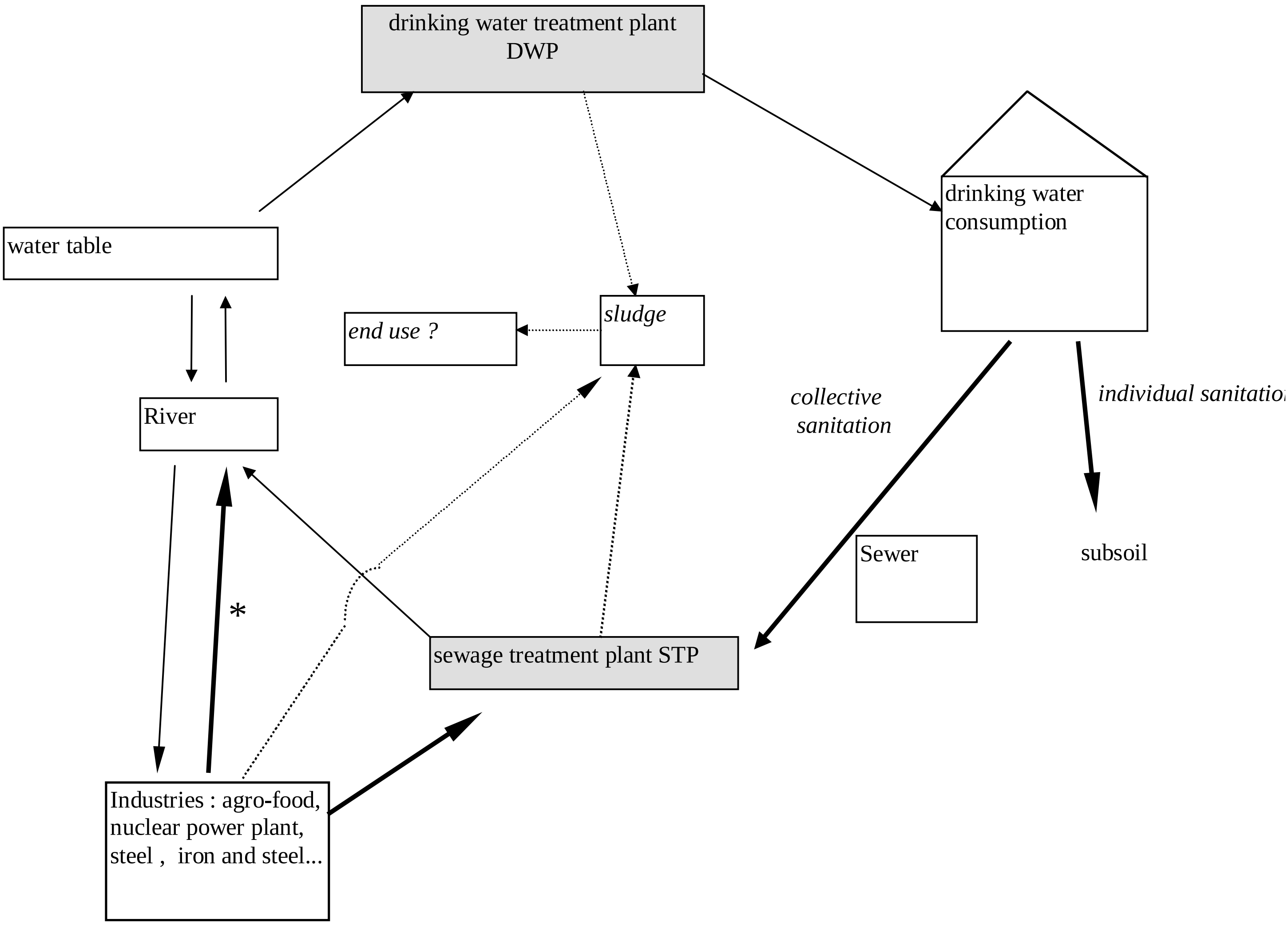


Figure 1 : Water cycle in town

Caption :

raw water for DWP or industries

municipal and industrial waste water ;* the necessity to treat industrial waste water depends on its quality and the regulation

sludge

Bacteriological analysis	Unit	Value	Regulation
Total coliforms	/ 100mL	> 200	-
Thermoduric coliforms	/100mL	> 200	20,000
Streptococci (*Enterococcus faecalis*)	/100mL	> 200	10,000
E.coli		4	-
Physico-chemical analysis	**Unit**	**Value**	**Regulation**
Temperature	°C	13	25
Aspect	cloudy and yellowish		
pH at 20°C		6.75	-
conductivity	µS.cm^{-1} at 20°C	540	-
Turbidity	NTU	390	200
Nitrates	mg NO_3^- / L	67.1	50
Nitrites	mg NO_2^- / L	0.09	-
Ammonium	mg NH_4^+ / L	< 0.05	4
Permanganate value	mg O_2 / L	2.2	10
Hardness	mg $CaCO_3$/ L	323	-

Conclusion : Very hard water containing nitrites and which nitrate concentration is superior to 50 mg / L. Very bad raw water bacteriological quality.

Notes :

* Regulation : European Economic Community (75/440/EEC) concerning raw water quality meant to drinking water production
* (-) means that the regulation doesn't indicate any information concerning this parameter though it was analysed.

Figure 2 : Example of raw water quality meant to drinking water production

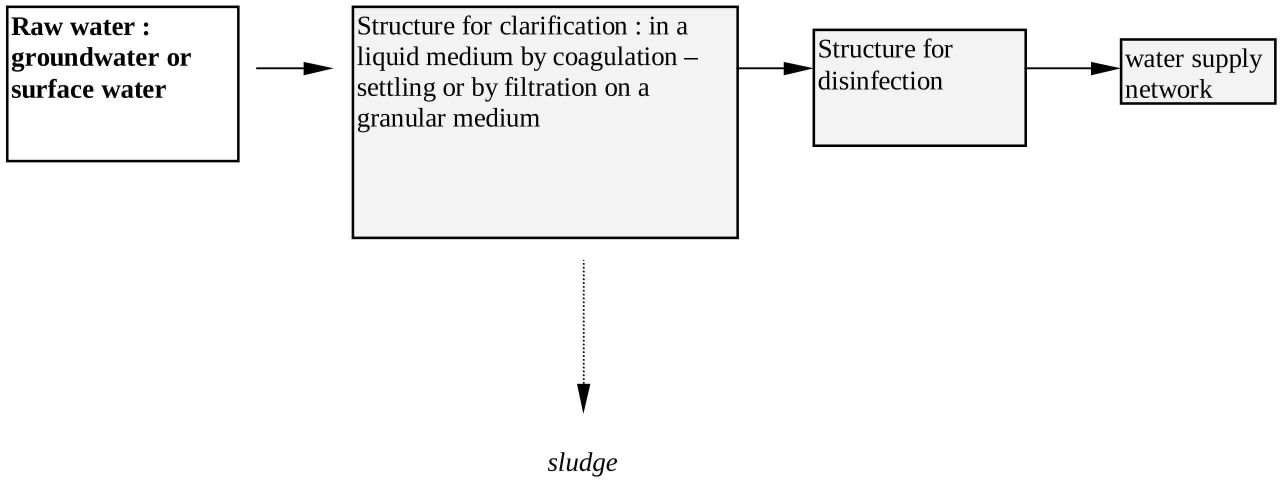


Figure 3 : Example of a drinking water production process

Parameters	**units**	**WHO recommendation**
1. Bacteriological quality		
Total coliform bacteria	/ 100 mL	0
E.coli or Fecal or thermotolerant coliforms	/ 100 mL	0
Enterococcus faecalis (fecal streptococci)	/ 100 mL	0
Sulphite reducing *Clostridium*	/ 20 mL	0
2. Chemicals of health significance in drinking-water		
2.1. Inorganic constituents		
antimony	mg / L	0.005
arsenic	mg / L	0.01
barium	mg / L	0.7
Beryllium	mg / L	NAD : No Adequate Date to permit recommendation of a health-based guideline value
Boron	mg / L	0.5
Cadmium	mg / L	0.003
Chromium	mg / L	0.05
Copper	mg / L	2
Cyanide	mg / L	0.07
Fluoride	mg / L	1.5
Lead	mg / L	0.01
Manganese	mg / L	0.5
Mercury (total)	mg / L	0.001
Molybdenum	mg / L	0.07
Nickel	mg / L	0.02
Nitrate	**mg / L**	**50**
Nitrite	**mg / L**	**3**
Selenium	mg / L	0.01
Uranium	mg / L	0.002
2.2. Organic constituents		
2.2.1. Chlorinated alkanes		
Carbon tetrachloride	µg / L	2
Dichloromethane	µg / L	20
1,1-dichloroethane	µg / L	NAD
1,2-dichloroethane	µg / L	30
1,1,1-trichloroethane	µg / L	2,000
2.2.2. Chlorinated ethenes		
Vinyl chloride	µg / L	5
1,1-dichloroethene	µg / L	30
1,2-dichloroethene	µg / L	50
Trichloroethene	µg / L	70
Tetrachloroethene	µg / L	40
2.2.3. Aromatic hydrocarbons		
Benzene	µg / L	10
Toluene	µg / L	700
Xylenes	µg / L	500
Ethylbenzene	µg / L	300
Styrene	µg / L	20
Benzo[a]pyrene	µg / L	0.7

Parameters	units	WHO recommendation
2.2.4. Chlorinated benzenes		
Monochlorobenzene	µg / L	300
1,2-dichlorobenzene	µg / L	1,000
1,3-dichlorobenzene	µg / L	NAD
1,4 dichlorobenzene	µg / L	300
Trichlorobenzene (total)	µg / L	20
2.2.5. Miscellaneous		
Di((2-ethylhexyl)phtalate	µg / L	8
Adipate	µg / L	80
Acrylamide	µg / L	0.5
Epychlorohydrin	µg / L	0.4
Hexachlorobutadiene	µg / L	0.6
EDTA	µg / L	600
Nitrilotriacetic acid	µg / L	200
Dialkyltins	µg / L	NAD
Tributyltin oxide	µg / L	2
Microcystin-LR	µg / L	1
2.3. Pesticides		
Alachlor	µg / L	20
Aldicarb	µg / L	10
Aldrin/dieldrin	µg / L	0.03
Atrazin	µg / L	2
Bentazone	µg / L	300
Carbofuran	µg / L	7
Chlordane	µg / L	0.2
Chlorotoluron	µg / L	30
Cyanazine	µg / L	0.6
DDT	µg / L	2
1,2-dibromo-3-chloropropane	µg / L	1
1,2-dibromoethane	µg / L	0.4 – 15
2,4-dichlorophenoxyacetic acid (2,4-D)	µg / L	30
1,2-dichloropropane (1,2-DCP)	µg / L	40
1,3-dichloropropane	µg / L	NAD
1,3-dichloropropene	µg / L	20
Diquat	µg / L	10
Heptachlor and heptachlor epoxide	µg / L	0.03
Hexachlorobenzene	µg / L	1
Isoproturon	µg / L	9
Lindane	µg / L	2
MCPA	µg / L	2
Methoxychlor	µg / L	20
Metolachlor	µg / L	10
Molinate	µg / L	6
Pendimethalin	µg / L	20
Pentachlorophenol	µg / L	9
Permethrin	µg / L	20
Propanil	µg / L	20
Pyridate	µg / L	100
Simazine	µg / L	2
Terbutylazine (TBA)	µg / L	7
Trifuralin	µg / L	20
Chlorophenoxy herbicides other than 2,4-D and MCPA		
2,4-DB	µg / L	90
Dichlorprop	µg / L	100

Parameters	units	WHO recommendation
Fenoprop	µg / L	9
MCPB	µg / L	NAD
Mecoprop	µg / L	10
2,4,5-T	µg / L	9
2.4. Disinfectants and disinfectants by-products		
2.4.1. Disinfectants		
Monochloramine	mg / L	3
Di- and trichloramine	mg / L	NAD
Chlorine	mg / L	5
Chlorine dioxide	mg / L	
Iodine	mg / L	NAD
2.4.2. Disinfectants by-products		
Bromate	µg / L	25
Chlorate	µg / L	NAD
Chlorite	µg / L	200
2.4.3. Chlorophenols		
2-chlorophenol	µg / L	NAD
2,4-dichlorophenol	µg / L	NAD
2,4,6-trichlorophenol	µg / L	200
Formaldehyde	µg / L	900
MX	µg / L	NAD
Trihalomethanes	µg / L	1
Bromoform	µg / L	100
Dibromochloromethane	µg / L	100
Bromodichloromethane	µg / L	60
Chloroform	µg / L	200
2.4.4. Chlorinated acetic acids		
Monochloroacetic acid	µg / L	NAD
Dichloroacetic acid	µg / L	50
Trichloroacetic acid	µg / L	100
Chloral hydrate (trichloroacetaldehyde)	µg / L	10
Chloroacetone	µg / L	NAD
Halogenated acetonitril	µg / L	NAD
Dichloroacetonitrile	µg / L	90
Dibromoacetonitrile	µg / L	100
Bromochloroacetonitrile	µg / L	NAD
Trichloroacetonitrile	µg / L	1
Cyanogen chloride (as CN)	µg / L	70
chloropicrin	µg / L	NAD
3. Chemicals not of health significance at concentrations normally found in drinking-water		
Asbestos	U	
Fluranthene	U	
Glyphosatsilver	U	
Tin	U	
silver	U	
4. Radioactive constituents of drinking-water		
alpha activity	Bq/L	0.1
beta activity	Bq/L	1
5. Substances and parameters in drinking water that may give rise to complaints from consumers		
5.1. Physical parameters		
Colour	mg/L Pt-Co	15
Taste and odour		
Temperature		

Parameters	units	WHO recommendation
Turbidity	NTU	5
5.2. Inorganic constituents		
Aluminium	mg / L	0.2
Ammonia	**mg / L**	**1.5**
Chloride	mg / L	250
Copper	mg / L	1
Hardness	ppm $CaCO_3$	500
Hydrogen sulphide	mg / L	0.05
Iron	**mg / L**	**0.3**
Manganese	**mg / L**	**0.1**
Dissolved oxygen		
pH		6.5-8.5
Sodium	mg / L	200
Sulphate	mg / L	250
Total dissolved solids	mg / L	1,000
zinc	mg / L	3
5.3. Organic constituents		
Toluene	µg / L	24-170
Xylene	µg / L	20-1,800
Ethylbenzene	µg / L	2-200
Styrene	µg / L	4-2,600
Monochlorobenzene	µg / L	10-120
1,2-dichlorobenzene	µg / L	1-10
1,4-trichlorobenzene	µg / L	0.3-30
Synthetic detergents	µg / L	5-50
5.4. Disinfectants and disinfectants by-products		
Chlorine	µg / L	600-1,000
Chlorophenols		
2-chlorophenol	µg / L	0.1-10
2,4-dichlorophenol	µg / L	0.3-40
2,4,6-trichlorophenol	µg / L	2-300

Figure 4 : Regulation governing the quality of drinking water : WHO recommendation (Geneva 1986) ; parameters meant to biological removal are written in **large bold type**.

Undesirable compound C	**Origin**	**Toxicity or inconvenient**
DOC : humic acids, pesticides, hydrocarbon…	natural pollution	precursors of carcinogenic halogen compounds if raw water is chlorinated (preoxidation)
NH_3 / NH_4^+	organic pollution	Chlorine consumption and bacterial multiplication in drinking water network
NO_3^-	Fertiliser or MWW outlet	methaemoglobinaemia and carcinogenic nitrosamin(d)es
Fe^{2+}	natural	Chlorine consumption, degradation of the network , taste and colour (rust)
Mn^{2+}	natural	Like iron (black colour)

Figure 5 : Origins and risks associated to the presence of undesirable chemicals in raw water meant to biological water treatment process

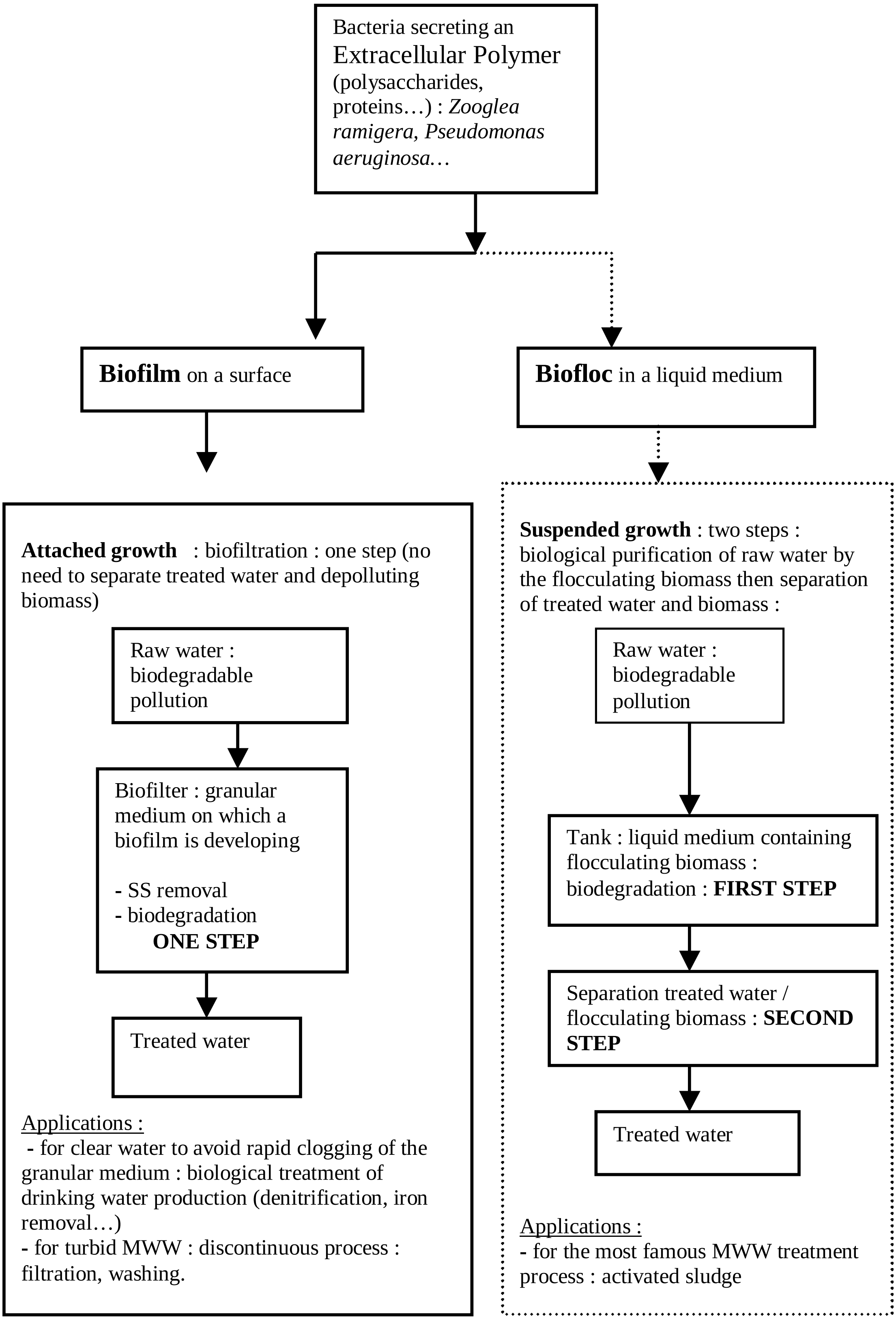


Figure 6 : Attached and suspended growth in water treatment

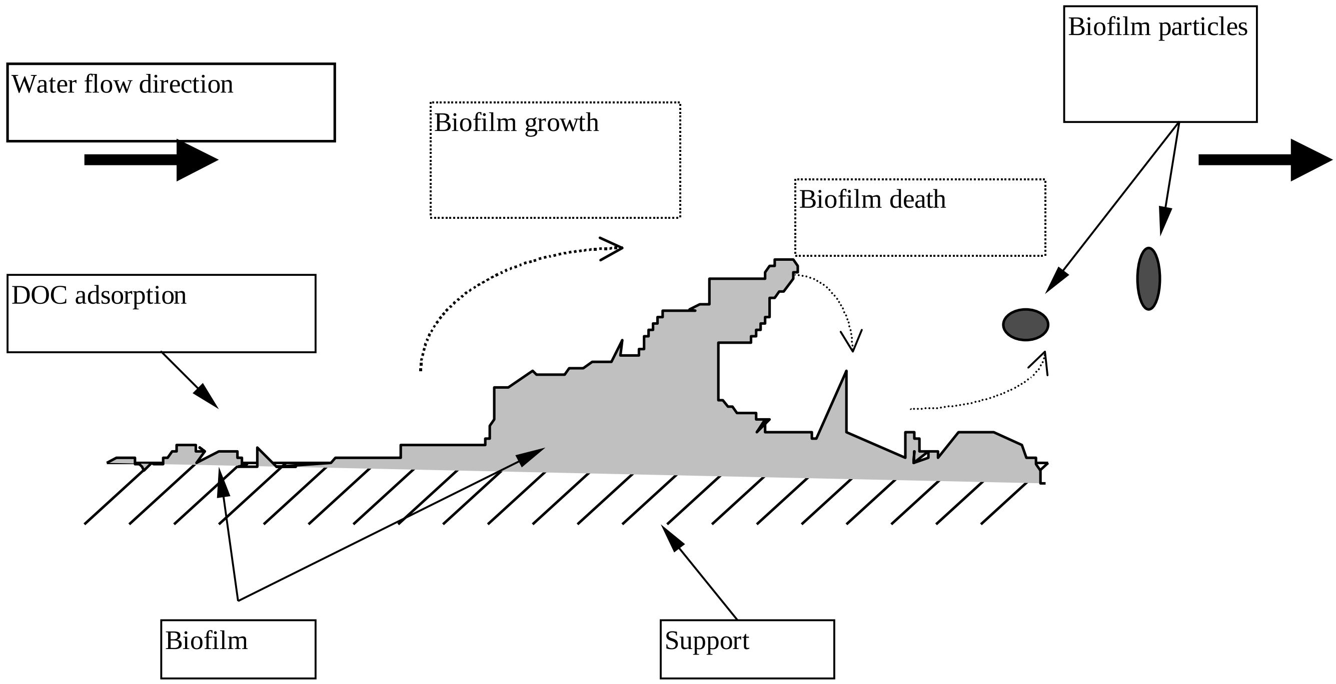


Figure 7 : Sketch of a biofilm (Maul A., Vagost D., Block J.C., 1989)

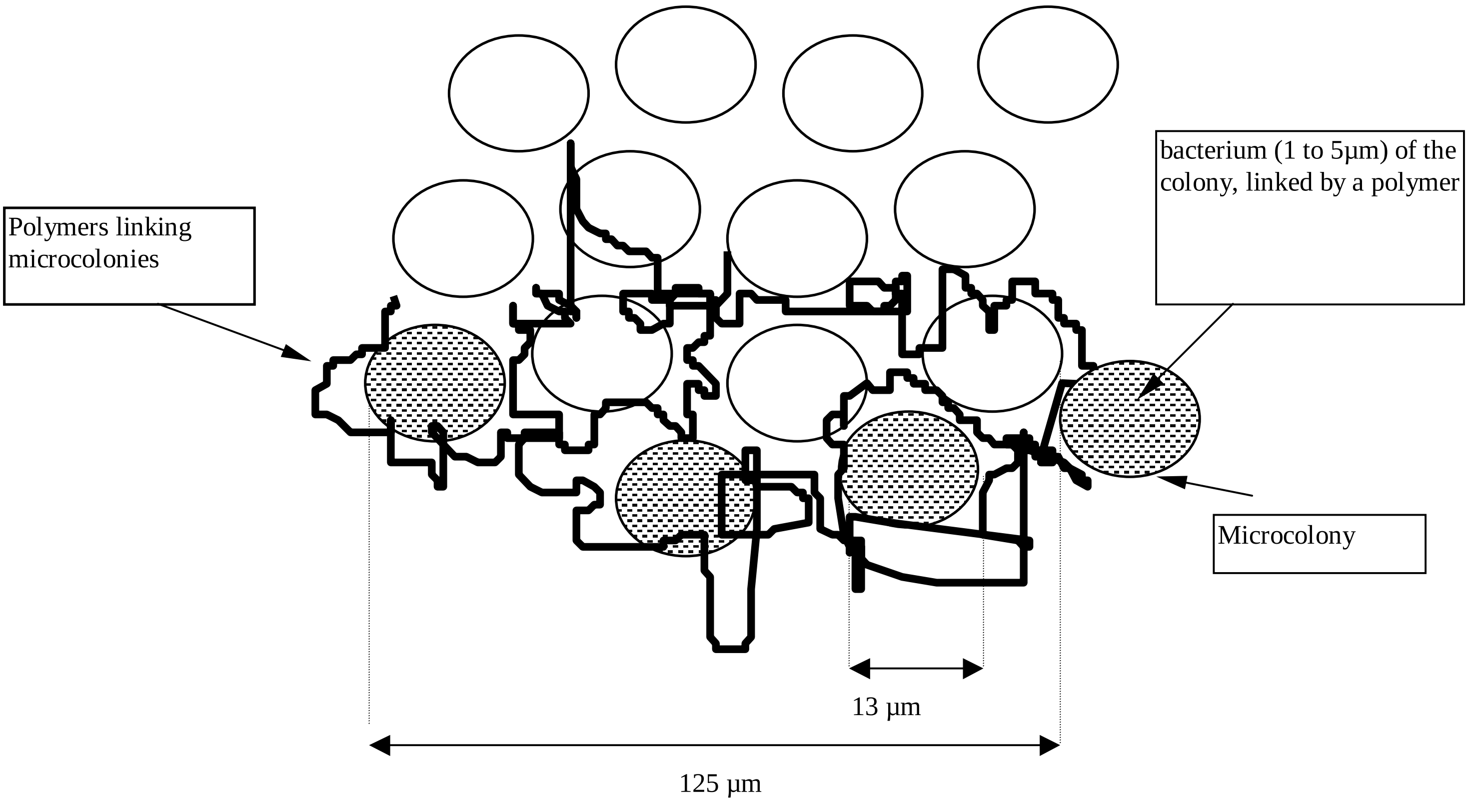


Figure 8 : Model of structure microbial floc in activated sludge

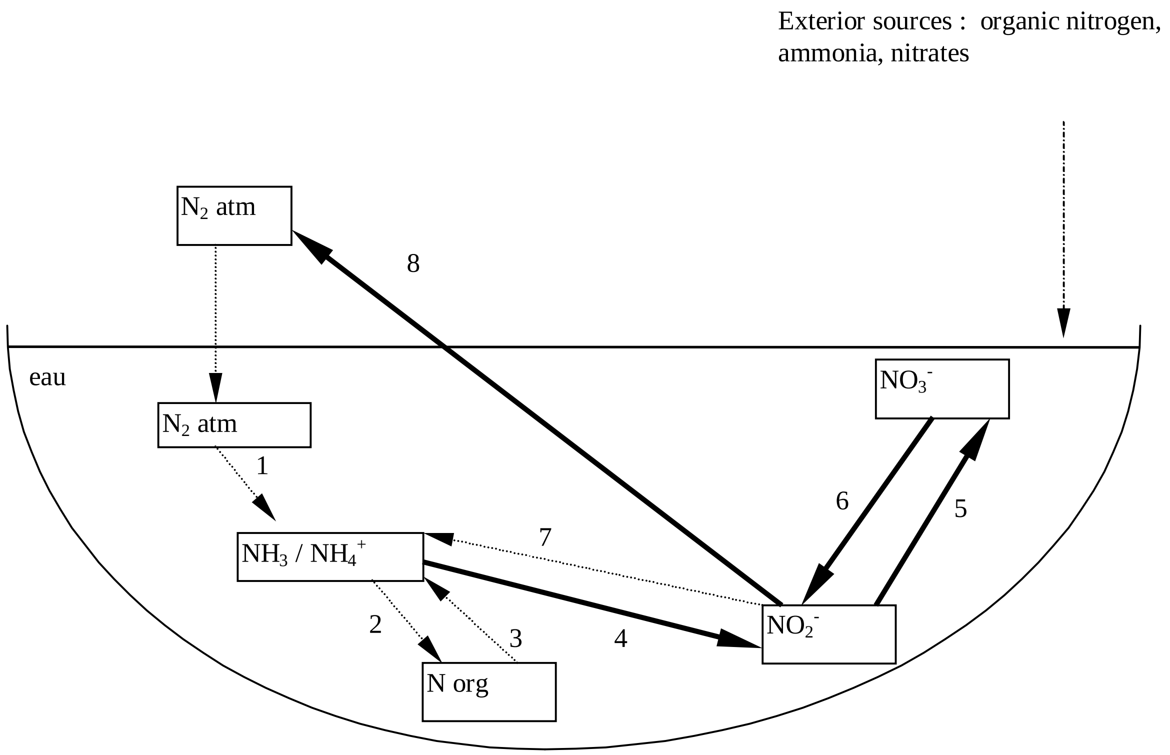


Figure 9 : the nitrogen cycle in an aquatic medium

Caption :

a) Biochemical reaction :

1 : Nitrogen **fixation** : $N_2 + 8H^+ + 8e^- + 16\ ATP \longrightarrow 2\ NH_3 + H_2 + 16\ (ADP + P_i)$; catalysed reaction by a symbiotic bacteria nitrogenase [*Rhizobium* – leguminous association, actinomycetes – angiosperm plants, cyanobacteria (*Anaboena*) - aquatic bracken] or a free bacteria [photosynthetic (cyanobacteria, green bacteria) or heterotroph as enterobacteria, *Clostridium*, *Methanococcus*].

2 : **assimilation of ammonia** (glutamate dehydrogenase or glutamate synthase / glutamine synthetase pathways, depending on the available ammonia concentration $[NH_4^+]$)

3 : **ammonification**

4 : **nitritation** : $\mathbf{NH_4^+} + ½\ O_2 \longrightarrow \mathbf{NO_2^-} + H_2O + 2H^+$; bacteria CLA Ae : *Nitrosomonas*

5 : **nitratation** : $\mathbf{NO_2^-} + ½\ O_2 \longrightarrow \mathbf{NO_3^-}$: bacteria CLA Ae : *Nitrobacter*

4 + 5 : **nitrification** : here, the nitrogened compound is source of energy (electron donor)

6 + 7 : reduction of nitrates in ammonia : $\mathbf{NO_3^-} + 8\ e^- + 10H^+ \longrightarrow \mathbf{NH_4^+} + 3\ H_2O$

2 pathways :

☛ **assimilatory reduction** (6 catalysed by Nitrate Reductase B) followed by the incorporation of nitrogen in organic acids by transamination s to give amino acids

☛or **dissimilatory reduction (**6 catalysed by la Nitrate Reductase A) ; it is called the DNRA pathway : dissimilatory nitrate reduction to ammonia

6 + 8 : dissimilatory reduction of nitrates (NRA) until N_2 : **denitrification** : here the nitrates are final electron acceptor

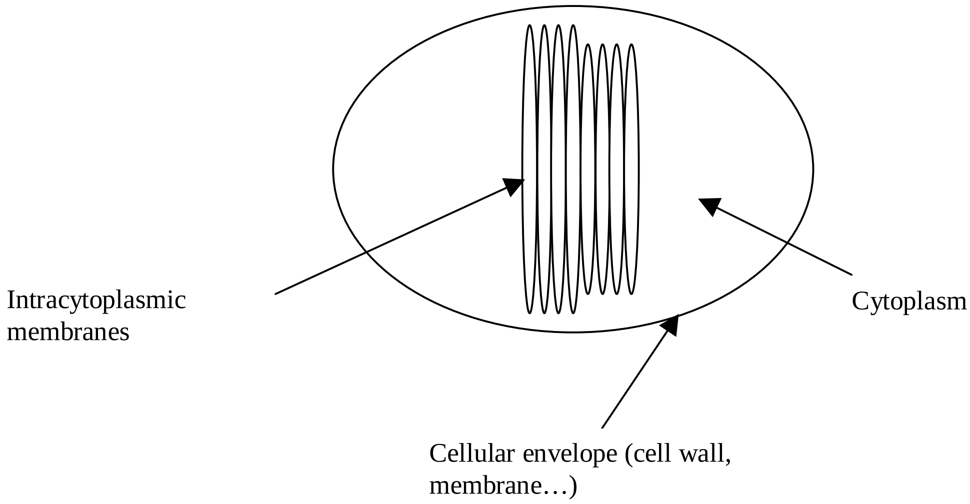
$2\ \mathbf{NO_3^-} + 12\ H^+ + 10e^- \longrightarrow 6\ H_2O + \mathbf{N_2}$: bacteria CLA or COH depending on the kind of electron donor

The choice between dissimilatory reduction of nitrates until N_2 or NH_4^+ depends on the concentration of ammonia in the medium

b) Water treatment applications:

⟶ running reaction in nitrogen removal in wastewater purification and raw water meant to drinking water production (mainly nitrification and denitrification)

┈➤ minor importance reactions in water treatment



<u>Figure 10 : Sketch of a nitrifying bacteria</u> (CLA Ae : *Nitrosomonas* or *Nitrobacter*…) ; although they are prokaryotes , their cytoplasm contains membranes in which electron transport occurs

Figure 11 : General caption for the description of the processes

structure for treatment

Raw or treated water

: Water flow

: sludge, backwash water, products of reaction

: reagent addition

MO : micro-organisms
DOC : dissolved organic carbon
Nutritional types :
C : chemotrophic
P : phototrophic
O : organotrophic
L : lithotrophic
H : heterotrophic
A : autotrophic
A : aerobic
An : anaerobic

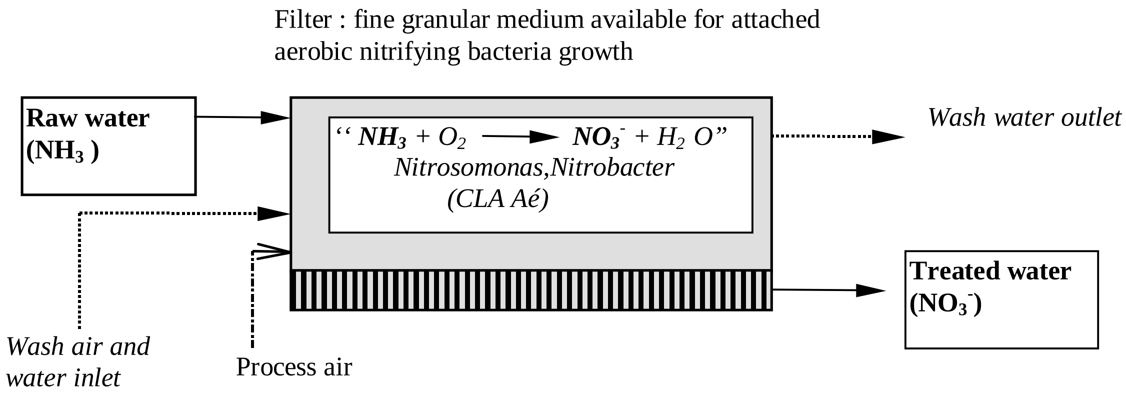


Figure 12 : sketch of a structure of biological removal of ammonia in raw water meant to drinking water production (non equilibrated reaction)

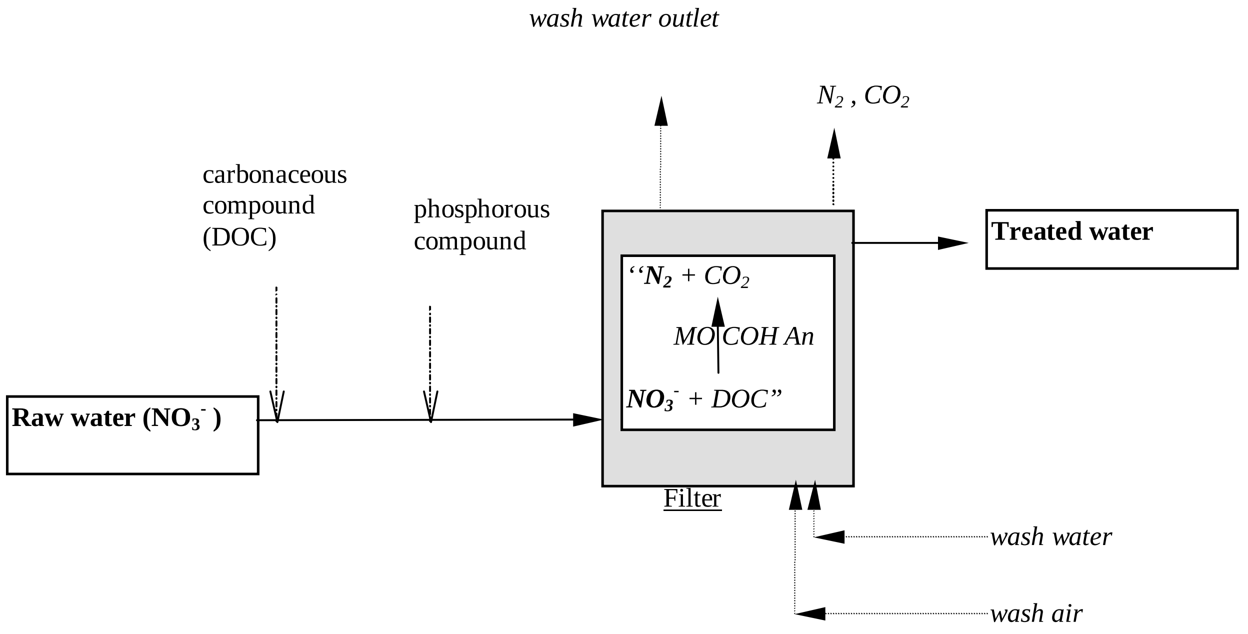


Figure 13 : Sketch of a structure of heterotrophic denitrification of raw water meant to drinking water production

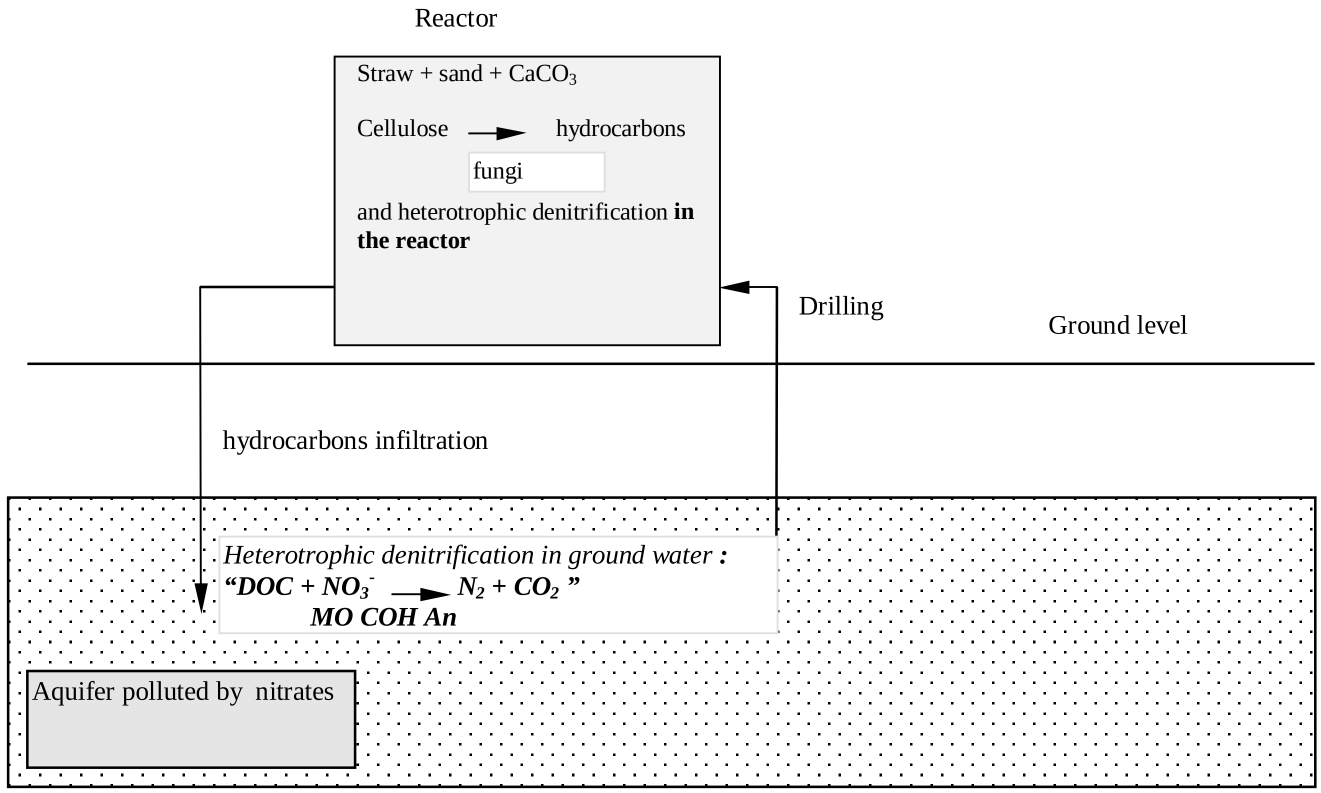


Figure 14 : Sketch of an *in situ* structure of heterotrophic denitrification of raw water meant to drinking water production

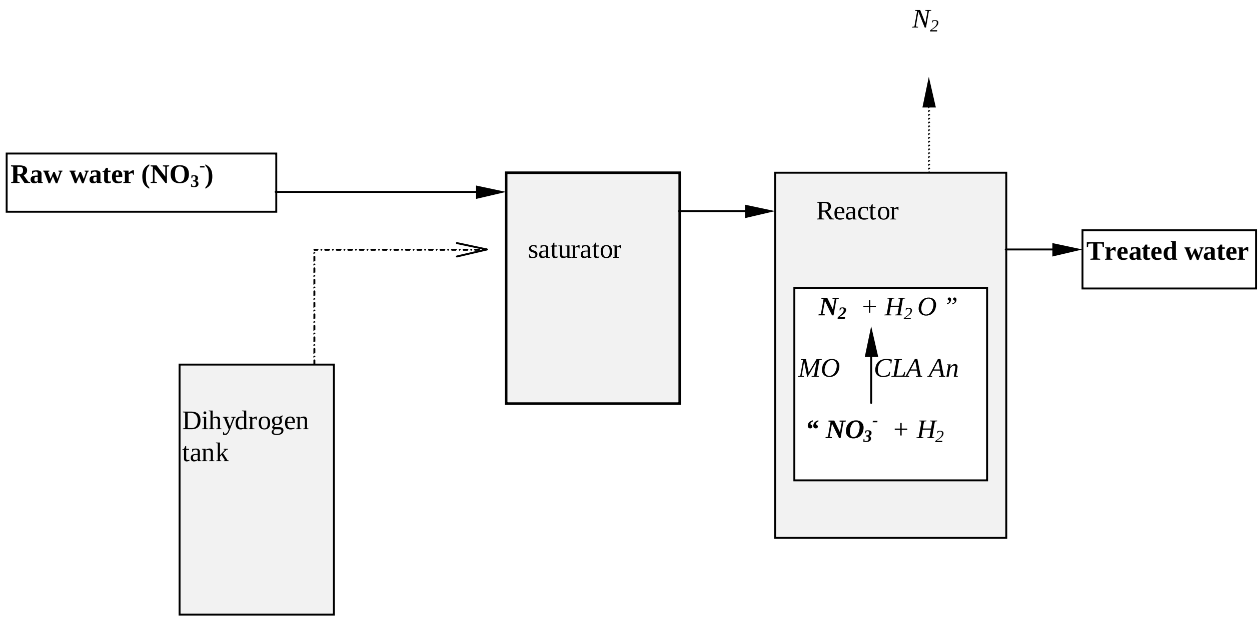


Figure 15 : Sketch of a structure of autotrophic denitrification of raw water meant to drinking water production

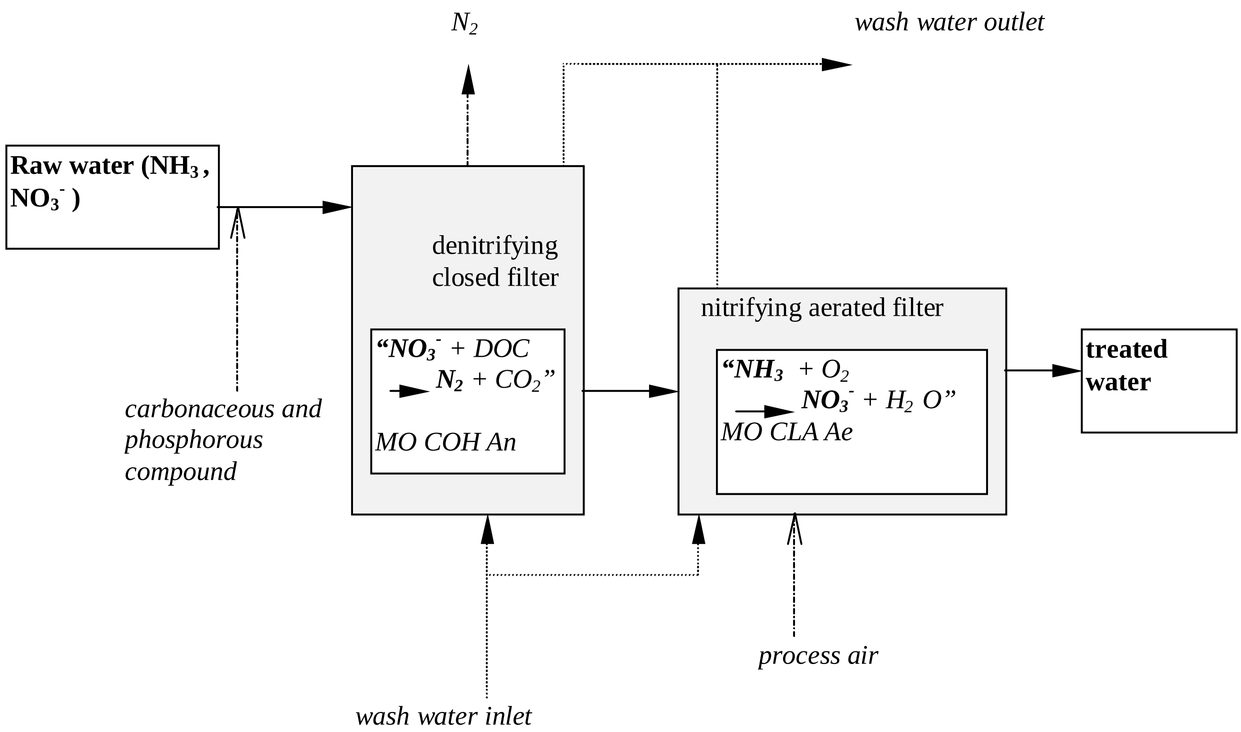


Figure 16 : Sketch of a structure of biological treatment of raw water containing both nitrates and ammonia and meant to drinking water production (non equilibrated reaction)

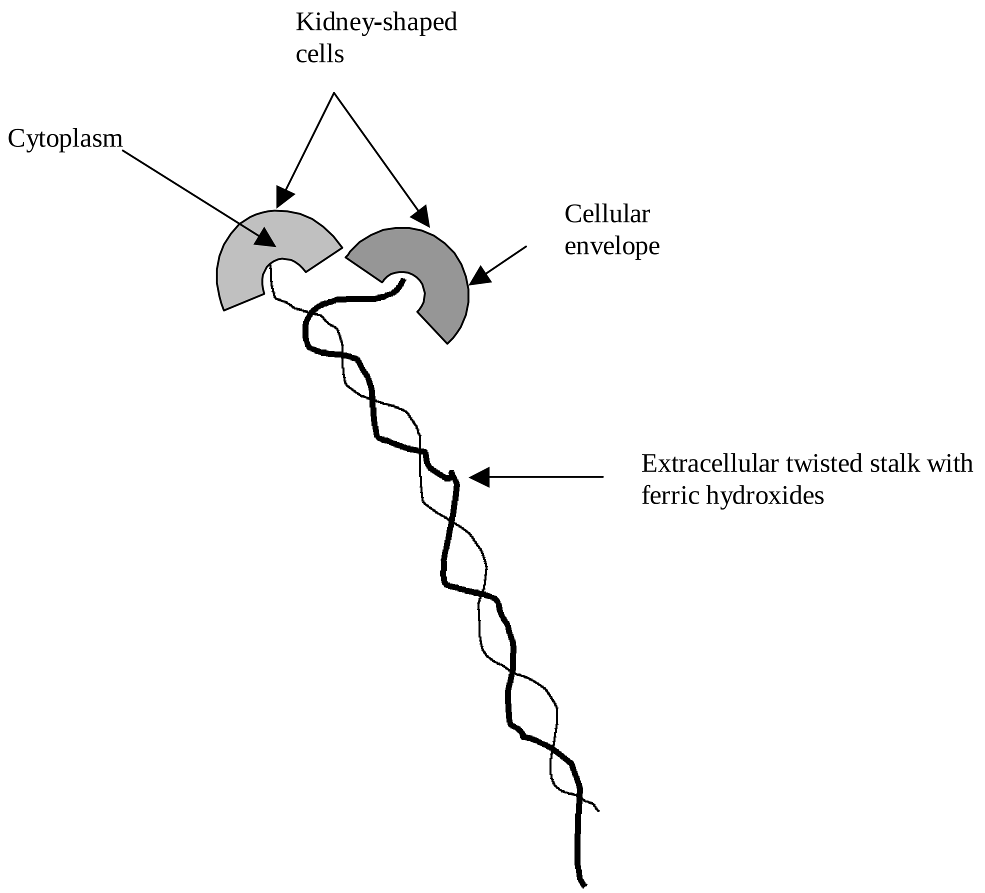


Figure 17 : Sketch of two bacteria *Gallionella Ferruginea* (CLA Ae) responsible of water iron removal

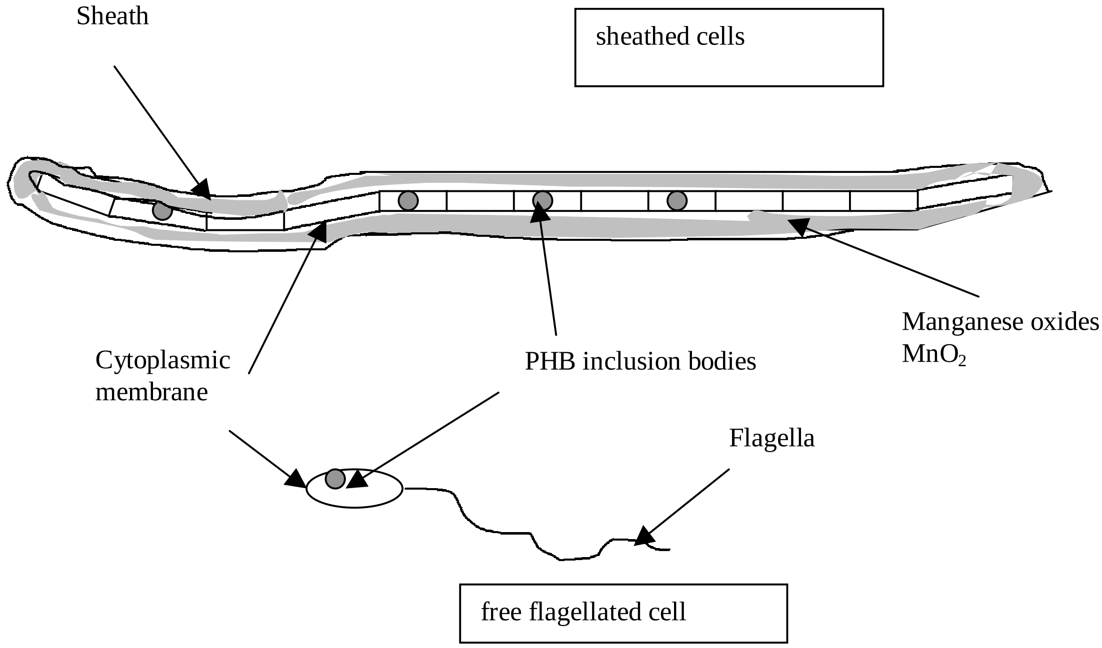


Figure 18 : Sketch of *Leptohrix* : sheathed bacteria including a lot of cells ,and free flagellated form ; CLA Ae, responsible for manganese removal in water

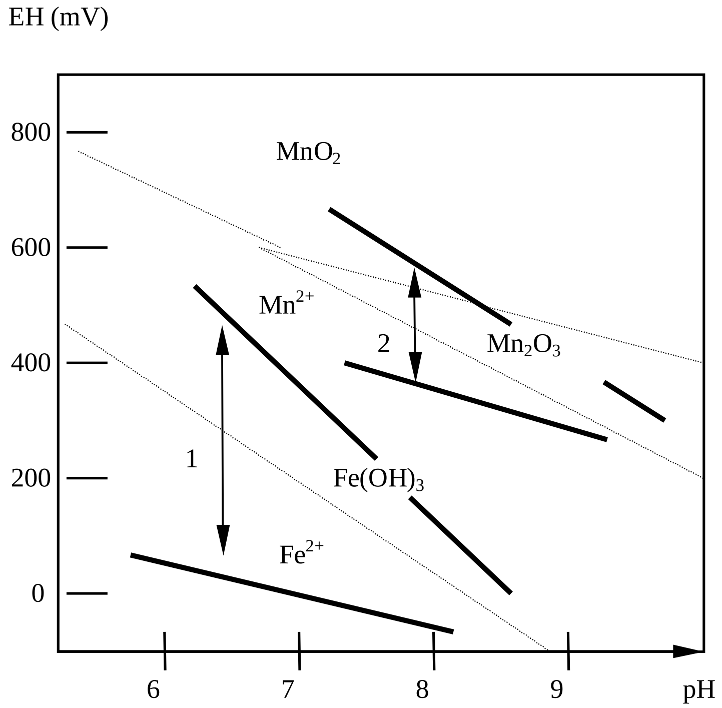


Figure 19 : Oxidation-reduction potential versus pH diagram of iron and manganese

Caption :
1 : field for iron bacteria
2 : field for manganese bacteria

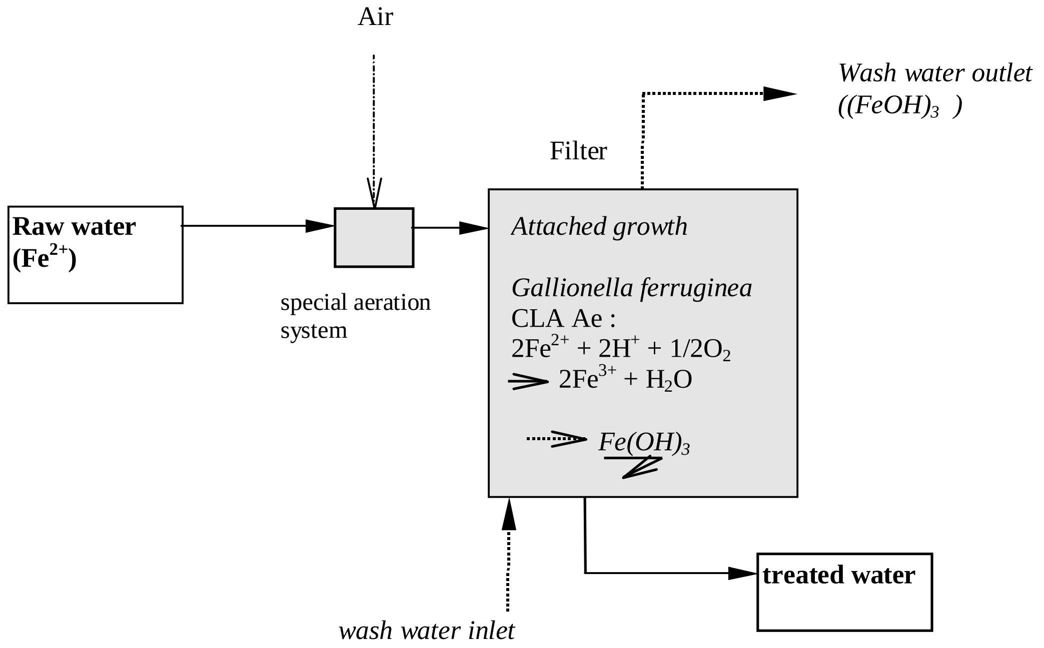
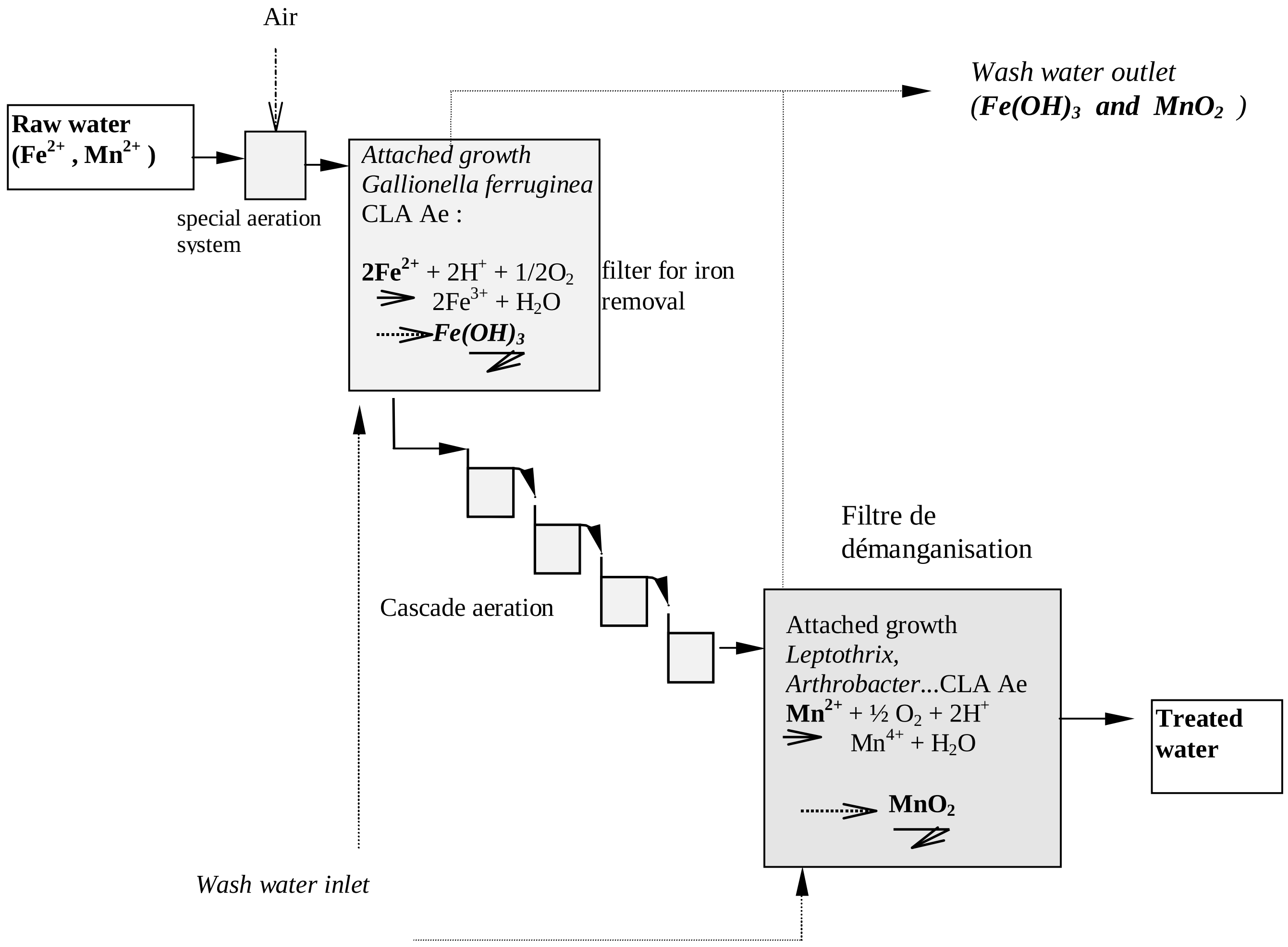


Figure 20 : Sketch of a structure of biological removal of iron in raw water meant to drinking water production



<u>Figure 21 : Flow sheet of a structure of biological removal of iron and manganese in raw water meant to drinking water production</u>

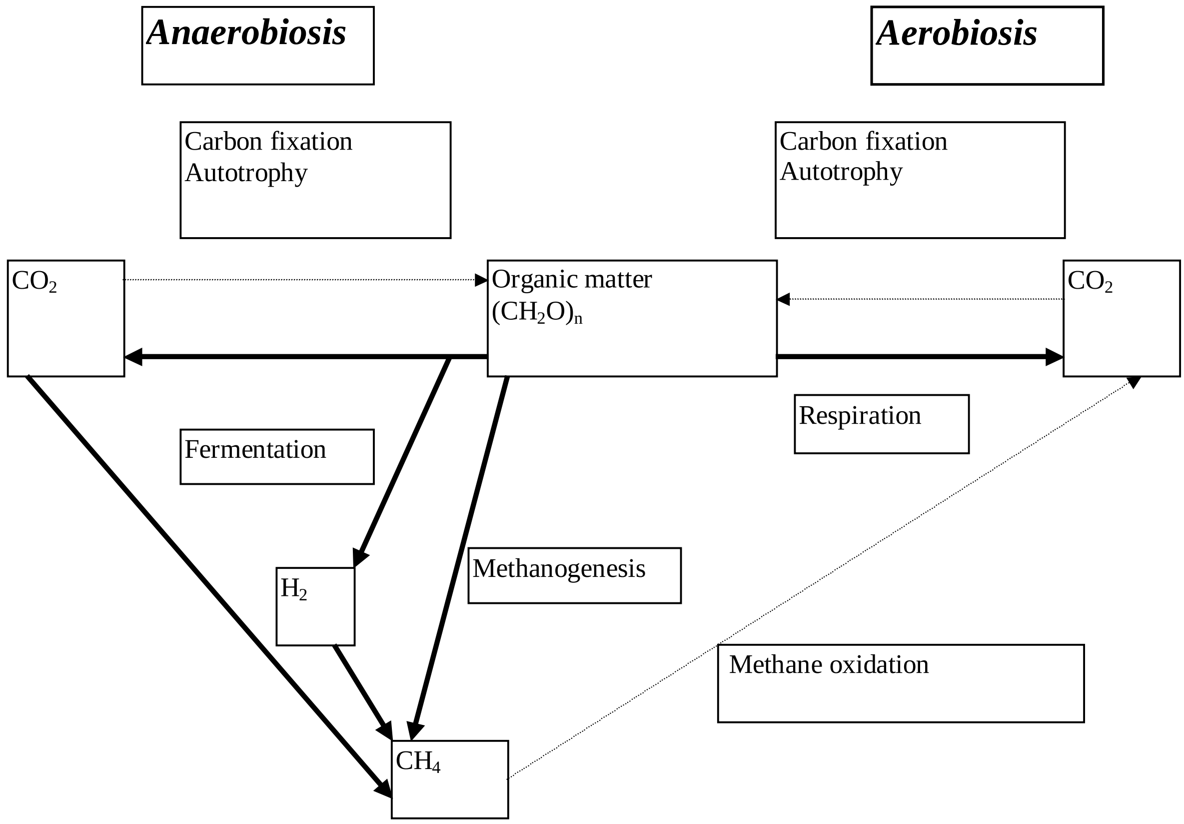


Figure 22 : Carbon cycle

Caption :

: running reaction in wastewater and sludge biological treatment

: non running reaction

Notes :

* all these biochemical reaction are running in lagooning process , including photosynthesis

** the organic carbon removal in drinking water production process is completed by heterotrophy

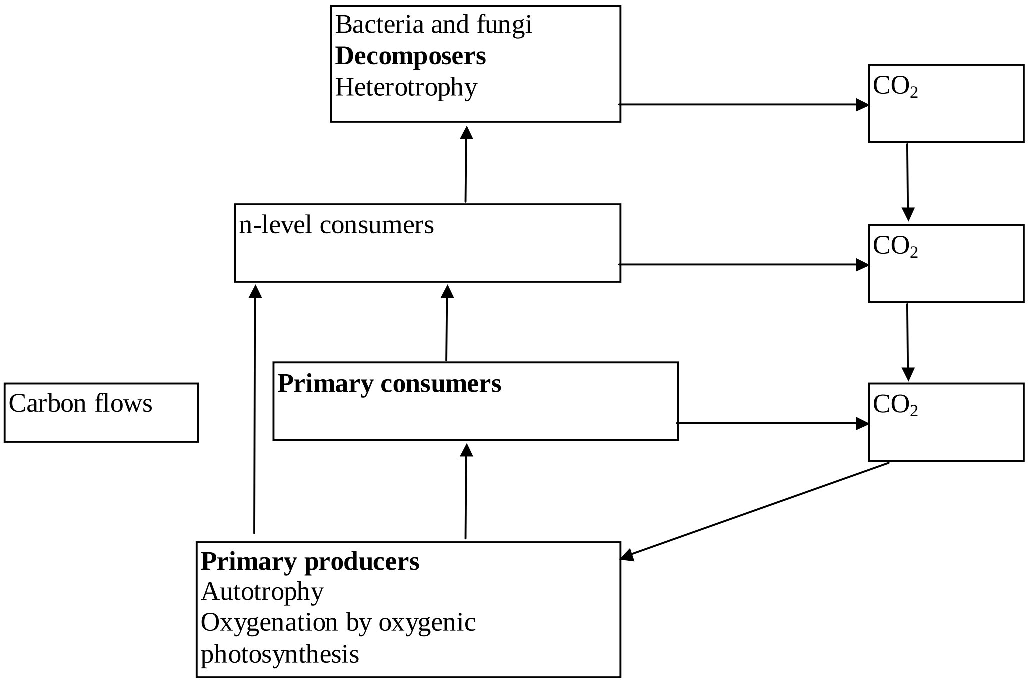


Figure 23 : Sketch of a food chain

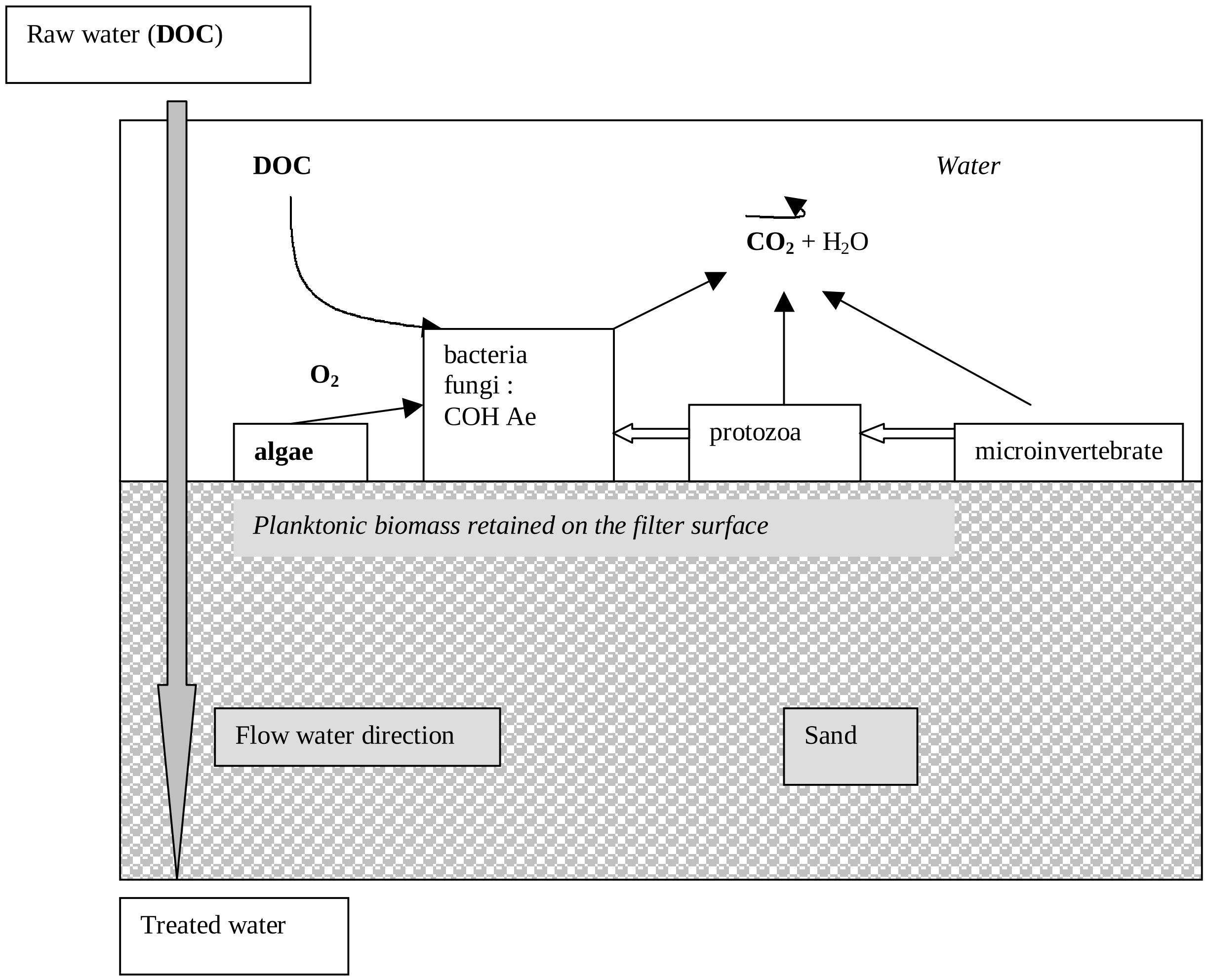


Figure 24 : Sketch of a food chain in a slow filter
Caption : ⟹ predation direction

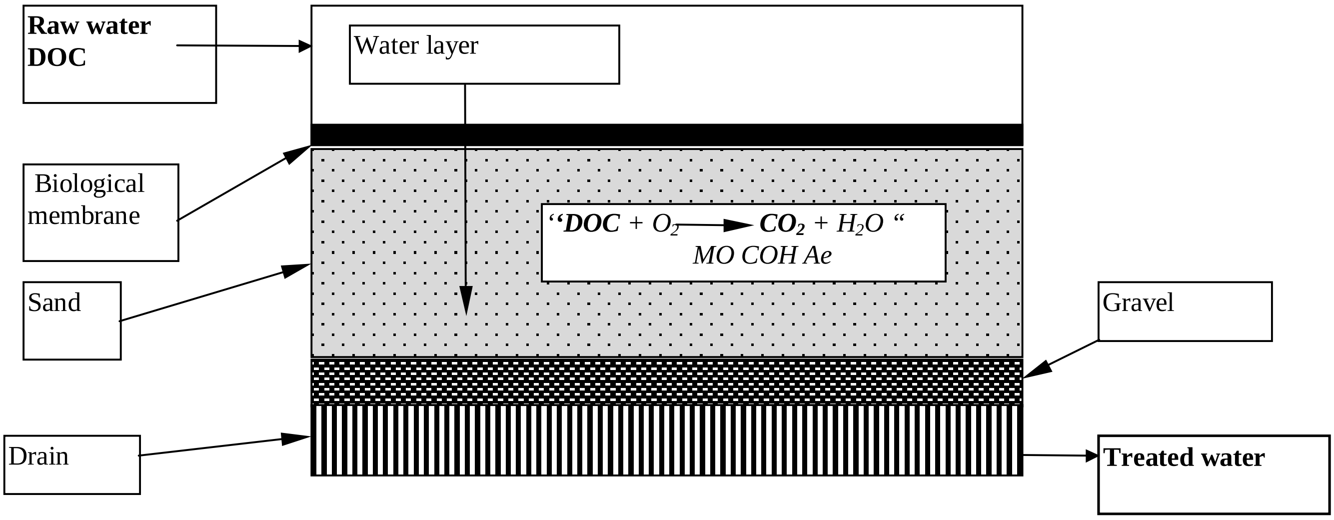
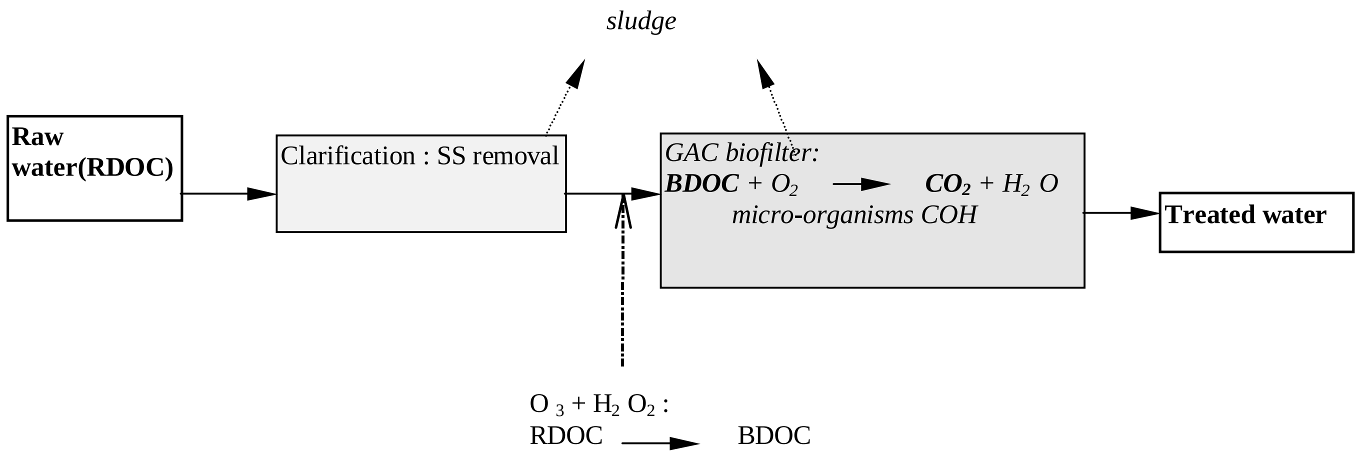


Figure 25 : sketch of a slow filter
(non equilibrated reaction)



Caption :
RDOC : refractory (pesticide, humic acids...)
BDOC : biodegradable DOC (organic acids...)
SS : suspended solids
GAC : granular activated carbon

Figure 26 : Sketch of a structure to remove RDOC by oxidant/biofilter coupling; non equilibrated reaction carried out by COH micro-organisms

Undesirable compound C	Origin	MAC raw water	MAC Drinking water (WHO or EEC)	Toxicity or inconvenient	Physical removal	Involved micro-organism	Trophic type	Role of C in the metabolism Product of reaction (☞)	Condition for the treatment	Advantage or inconvenient par rapport in relation to physical treatment
DOC : humic acids, pesticides, hydrocarbon…	natural pollution	- 5µg/l 1µg/l	 0.5µg/l 0.2µg/l	precursors of carcinogenic halogen compounds	adsorption on GAC	miscellaneous	COH Ae	Source of electrons and C ☞ CO_2	oxygenation	*only efficient process *no undesirable by-product
NH_3 / NH_4^+	organic pollution	4 mg/l	0.5mg/l	Chlorine consumption and bacterial multiplication	Chlorination	Nitrosomonas and Nitrobacter	CLA Ae	Source of electrons ☞ NO_3^-	oxygenation and not much organic matter	no undesirable by-product
NO_3^-	Fertilizer or MWW outlet	50mg/l	50mg/l	methaemoglobi--naemia and carcinogenic nitrosamin(d)es	Ion exchange, membrane process	Miscellaneous :enterobacteria, Pseudomonas	COH An or CLA An	final acceptor of electrons ☞N_2	anoxia and presence of organic matter if COH	Generates less by-products
Fe^{2+}	natural	2 mg/l	0.2mg/l	Chlorine consumption, degradation of the network , taste and colour (rust)	chemical oxidation (O_3…)	* Gallionella, Leptothrix, Sphaerotilus, Pseudomonas	CLA Ae	Source of electrons ☞Fe^{3+} , $Fe(OH)_3$ ↓	Gentle oxygenation	Very adhering precipitate (biofilm)
Mn^{2+}	natural	1 mg/l	0.05mg/l	Like iron (black colour)	Like iron	Leptothrix	CLA Ae	Source of electrons ☞Mn^{4+} , MnO_2 ↓	oxygenation and no ammonia	Like iron

Conclusion and summary : Figure 27 : Biological treatment of raw water meant to drinking water production

* some bacteria are specific of iron or manganese, others can oxidise both; many are mixotrophic