EUROPEAN UNION
European Structural and Investing Funds
Operational Programme Research, Development and Education

MINISTRY OF EDUCATION, YOUTH AND SPORTS

Qualitative parameters of treated wastewaters, Czech and EU legislation

Lecture 1, Part 1

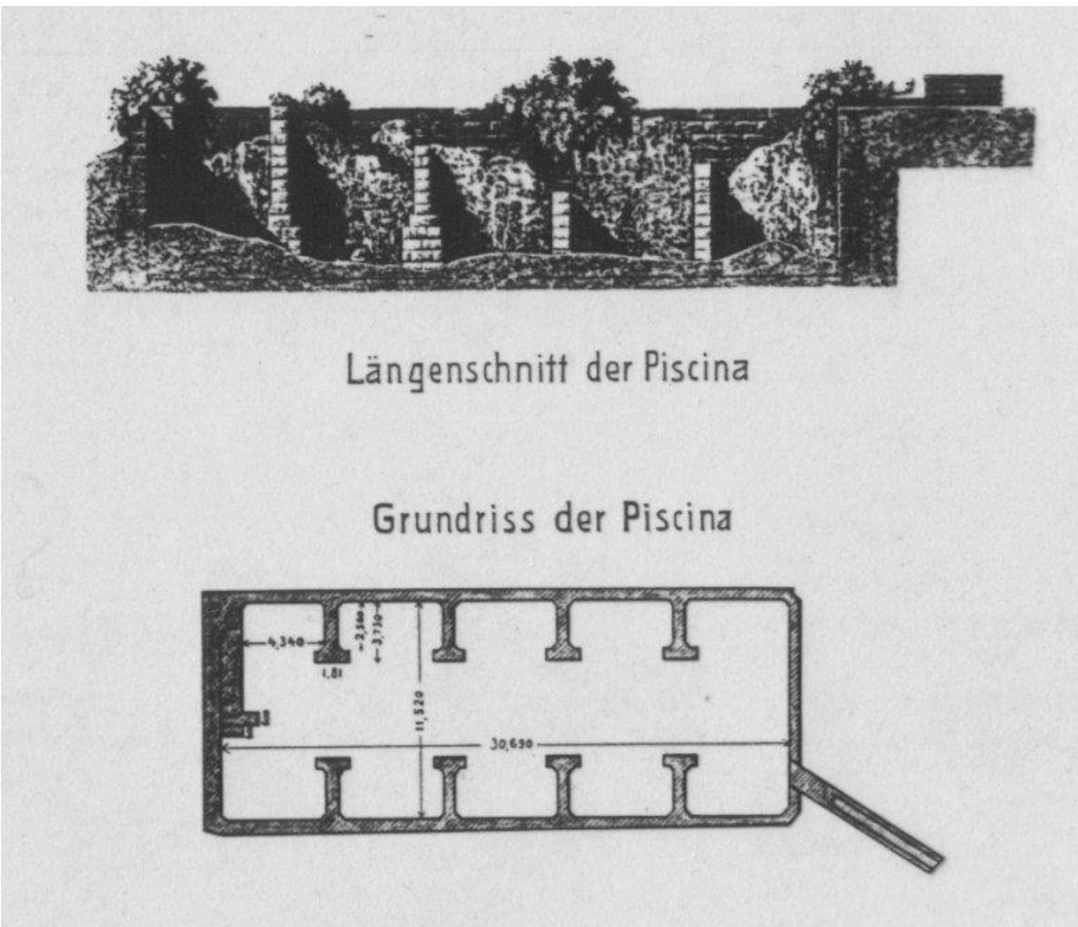
History of Sanitation and Wastewater Treatment

Historia Magistra Vitae

Sanitation of European Towns

- Beginnings in ancient Greek and Roman towns
- Centralized drinking water supply and sewage collection in Greek colonies in Asia Minor

Sanitation of European Towns



KIND OF

"SETTLING TANK" FROM

EPPIDAUROS REGION

Sanitation of European Towns

FAMOUS

“CLOACA MAXIMA” IN

ROME

- COMES FROM THE TIME OF ROMAN KINGS (DRAINAGE OF WETLANDS)
- COVERED UNDER EMPEROR AGUSTUS
- EMPEROR VESPASIAN:

CHARGES FOR PUBLIC TOILETS

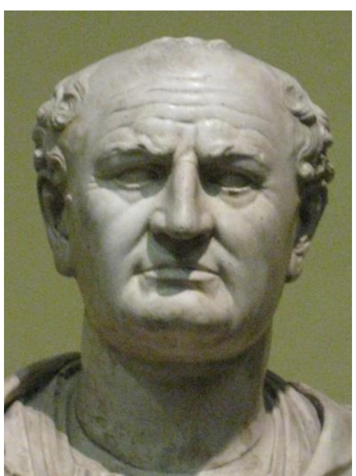
(PECUNIA NON OLET)

Cloaca Maxima

Cloaca Maxima

- Roman toilets

- Roman toilets and Jewish war



EMPEROR VESPASIAN: PECUNIA NON OLET

HISTORY OF SANITATION AND WASTEWATER TREATMENT IN EUROPEAN TOWNS

- Disastrous situation in Middle Ages
- Streets as public sewers
- Cleaning only before big church holidays
- Regular strikes of water-born diseases
- Flushing sewers in 16th/17th century
- Poor construction and performance
- Sometimes more problems than benefits

Europe under Emperor Charles IV

„Reich“ councils in Nuremberg

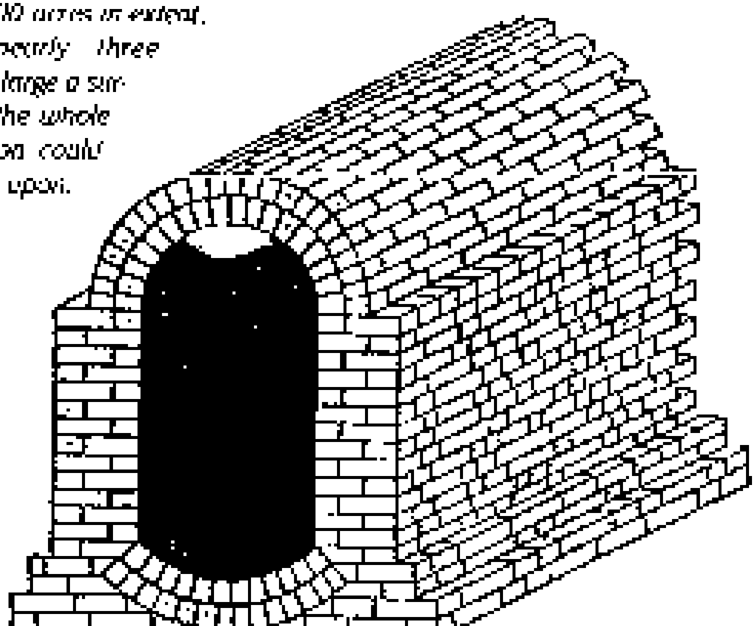
First urban rules

HISTORY OF SANITATION AND WASTEWATER TREATMENT IN EUROPEAN TOWNS

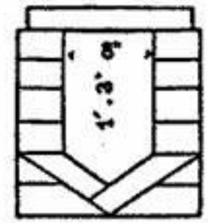
- The 2nd half of the 19th century: principles of sound sanitation of towns
- Gravity-flow sewers; combined systems
- Special sewer bricks, stone, cast iron
- Paris, London, Germany, Austro-Hungary
- Development of legislation – e.g. Royal Commission on Sewage Disposal in 1898

London, 1840s

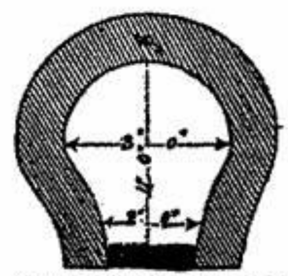
"Sometimes large sewers as well as large drains were filled nearly to the top with deposit. This cross-section shows the condition in which one of them was found. The space occupied by the ordinary run of the sewerage to be removed, and the shape of the bed which it had worn for itself, are shown near the crown of the arch. The whole evaporating surface of stagnant and pestilential matter beneath the houses and streets of the metropolis has been estimated to be equal to a canal 50 feet wide, 10 miles long, and above 6 feet deep, such as, if spread out 6 inches deep, would form a putrid swamp nearly 800 acres in extent, being nearly three times as large a surface as the whole population could be drawn upon.



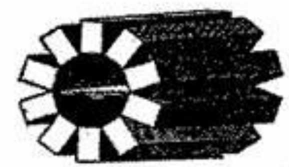
More early sewer designs



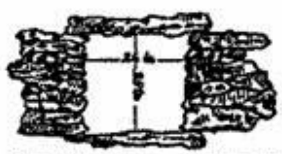
A "combined" conduit with V bottom led to better hydraulics at the bottom for "cleaning."



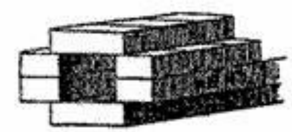
A covered "horseshoe" shape laid close to the surface and with no bottom allowed sewage to seep into the ground enroute.



A common form of construction of brick barrelled house drains.



The most common structure for draining cesspits.



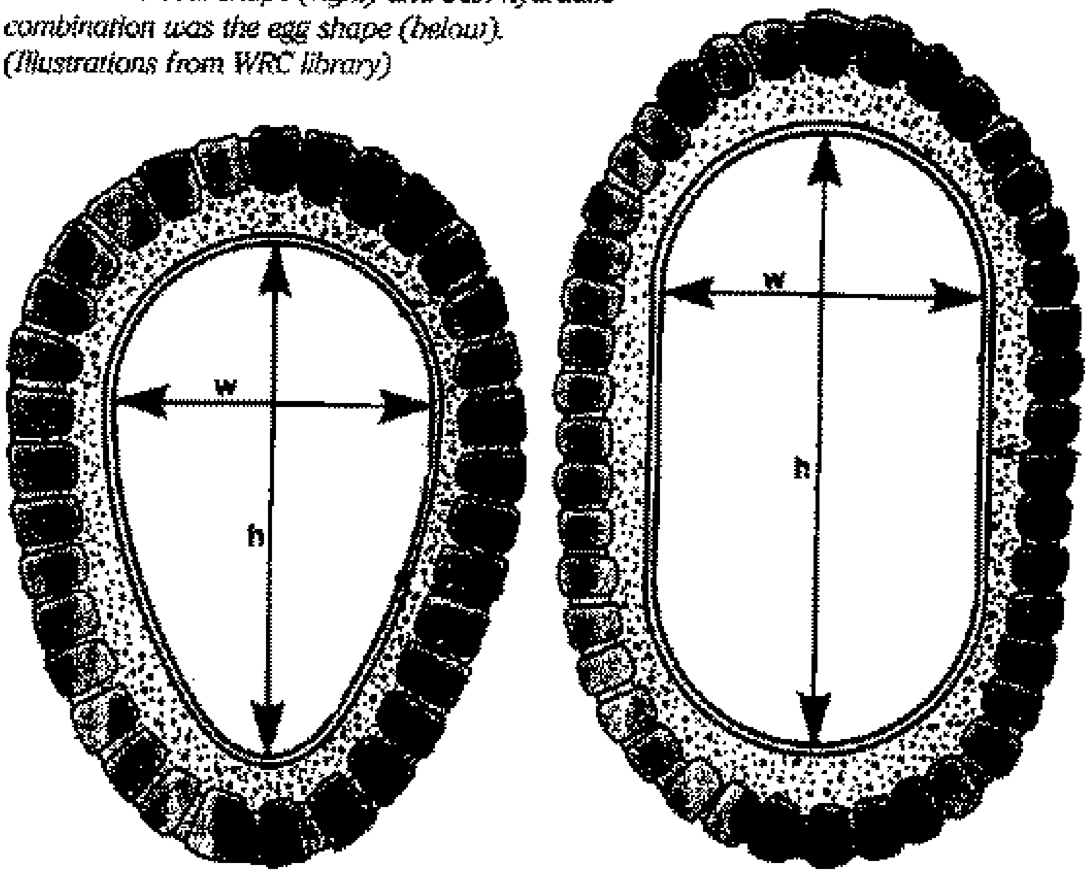
Flat brick house drains were generally put in without mortar at the bottom, so that much of the sewer refuse permeates the site of the house while the deposits ultimately choked up the drain.

DETAILS OF BRICK CONSTRUCTION

London, 1840s-1850s

OPTIMIZED SHAPES OF SEWERS FOR COMBINED SYSTEMS

Early sewer designs. Best "capacity" for combined use was the oval shape (right) and best hydraulic combination was the egg shape (below). (Illustrations from WRC library)



- London sewers did not solve the problem
- wastewater was brought directly into the river
- horrible smell from the river disturbed the Parliament sessions (hot summer 1858)
- this led to the idea that cholera is caused by the bad smell ("miasma")

HISTORY OF SANITATION AND WASTEWATER TREATMENT IN EUROPEAN TOWNS

London, *1850s*

At a demonstration of high pressure hoses, the fireman was directed to cascade the water down the side of a building to "cleanse the walls from urine stains and other filth."

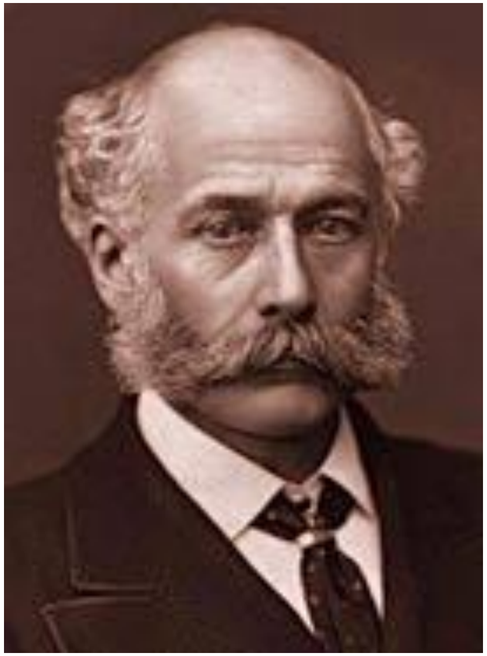
"Jet" cleaning of streets, buildings and sewers was a sensation with the public.

- fight with the smell
- "jet" cleaning of streets and buildings from urine and solid wastes
- clogging of sewers
- contamination of wells and drinking water reservoirs

London, ***1860s – 1870s***

Sir Joseph William Bazalgette found the solution – to bring sewage to the river downstream of the tide line

(to prevent sewage returning to the town)



One of sewage pumping stations

(Abbey Mills)

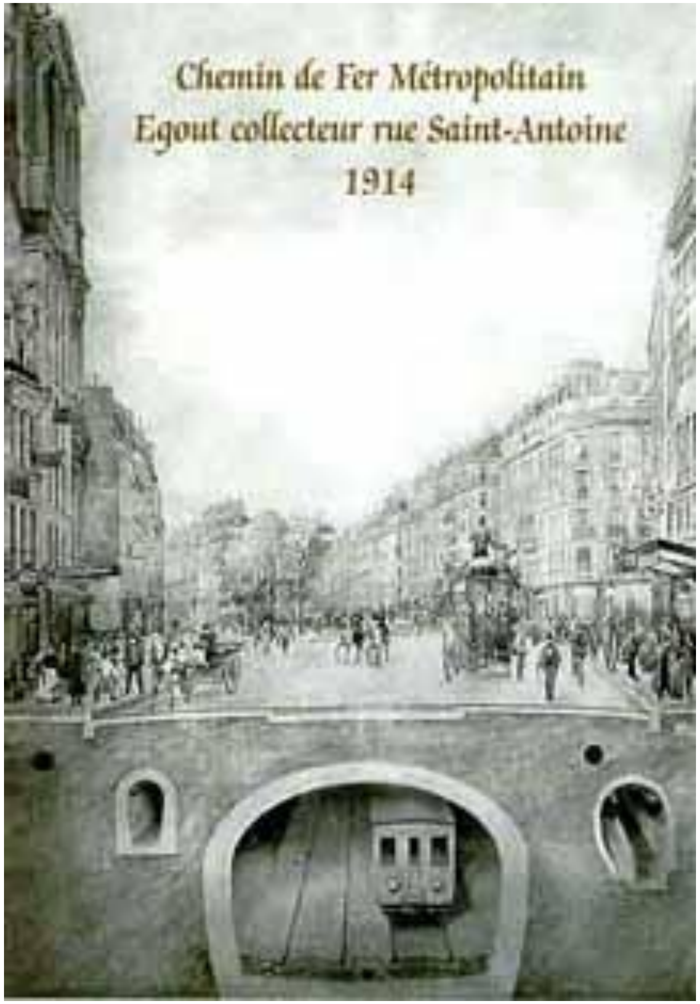
Cholera is a water-born disease

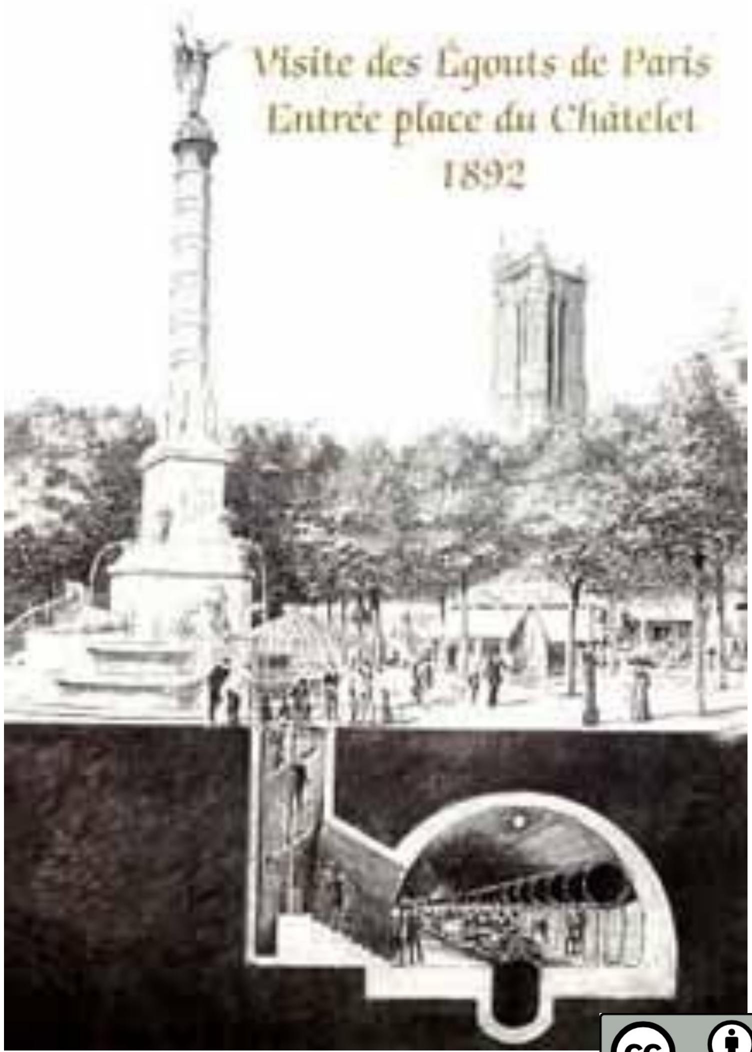
HISTORY OF SANITATION AND WASTEWATER TREATMENT IN EUROPEAN TOWNS

Paris of Victor Hugo

HISTORY OF SANITATION AND WASTEWATER TREATMENT IN EUROPEAN TOWNS

Paris of Victor Hugo



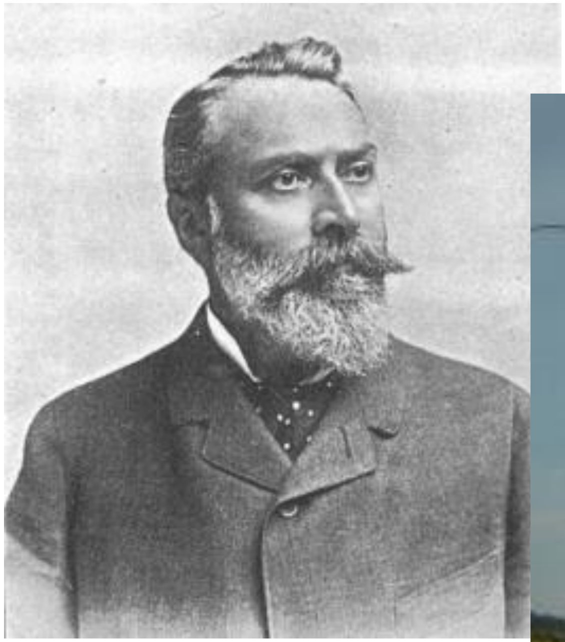


HISTORY OF SANITATION AND WASTEWATER TREATMENT IN EUROPEAN TOWNS

- Brick sewers
- Beginning of the 20^{th} century

HISTORY OF SANITATION AND WASTEWATER TREATMENT IN EUROPEAN TOWNS

- Sir William Heerlein Lindley 1854 – 1917
- First sewerage system with wastewater treatment on the Continent



Prague, 1906

HISTORY OF SANITATION AND WASTEWATER TREATMENT IN EUROPEAN TOWNS

- Sir William Heerlein Lindley 1854 – 1917

Prague, 1906

- First sewerage system with wastewater treatment on the Continent

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YOUTH AND SPORTS

Qualitative parameters of treated wastewaters, Czech and EU legislation
Lecture 1, Part 2
Legislation of European Union for Wastewater Treatment

COUNCIL DIRECTIVE
of May 21st, 1991
concerning urban waste water treatment

(as amended) (1)
(91/271/EEC)

Objective of the directive

Article 1

This Directive concerns the collection, treatment and discharge of urban waste water and the treatment and discharge of waste water from certain industrial sectors.

The objective of the Directive is to protect the environment from adverse effects of the above mentioned waste water discharges.

Basic definitions

For the purpose of this Directive:

1. 'urban waste water' means domestic waste water or the mixture of domestic waste water with industrial waste water and/or run-off rain water;

2. 'domestic waste water' means waste water from residential settlements and services which originates predominantly from the human metabolism and from household activities;

3. 'industrial waste water' means any waste water which is discharged from premises used for carrying on any trade or industry, other than domestic waste water and run-off rain water;

Basic definitions

For the purpose of this Directive:

4. 'agglomeration' means an area where the population and/or economic activities are sufficiently concentrated for urban waste water to be collected and conducted to an urban waste water treatment plant or to a final discharge point;

5. 'collecting system' means a system of conduits which collects and conducts urban waste water;

6. '1 p.e. (population equivalent)' means the organic biodegradable load having a five-day biochemical oxygen demand (BOD5) of 60 g of oxygen per day;

7. 'primary treatment' means treatment of urban waste water by a physical and/or chemical process

involving settlement of suspended solids, or other processes in which the BOD5 of the incoming waste

water is reduced by at least 20 % before discharge and the total suspended solids of the incoming waste water are reduced by at least 50 %;

8. 'secondary treatment' means treatment of urban waste water by a process generally involving

biological treatment with a secondary settlement or other process in which the requirements

established in Table 1 of Annex I are respected;

Basic definitions

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involving settlement of suspended solids, or other processes in which the BOD5 of the incoming waste

water is reduced by at least 20 % before discharge and the total suspended solids of the incoming waste water are reduced by at least 50 %;

Basic definitions

For the purpose of this Directive:

8. 'secondary treatment' means treatment of urban waste water by a process generally involving biological treatment with a secondary settlement or other processes in which the requirements established in Table 1 of Annex I are respected;

11. 'eutrophication' means the enrichment of water by nutrients, especially compounds of nitrogen and/or phosphorus, causing accelerated growth

of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms present in water and to the quality of the water concerned;

Sensitive areas

Article 5

1. For the purposes of Paragraph 2, Member States shall by 31 December 1993 identify sensitive areas according to the criteria laid down in Annex II.

2. Member States shall ensure that urban waste water entering collecting systems shall before discharge into sensitive areas be subject to more stringent treatment than that described in Article 4, by 31 December 1998 at the latest for all discharges from agglomerations of more than 10 000 p.e.

3. Discharges from urban waste water treatment plants described in paragraph 2 shall satisfy the relevant requirements of Annex IB.

4. Alternatively, requirements for individual plants set out in paragraphs 2 and 3 above need not apply in sensitive areas where it can be shown that the minimum percentage of reduction of the overall load entering all urban waste water treatment plants in that area is at least 75 % for total phosphorus and at least 75 % for total nitrogen.

Sensitive areas

Article 6

1. For the purposes of Paragraph 2, Member States may by 31 December 1993 identify less sensitive areas according to the criteria laid down in Annex II.

2. Urban waste water discharges from agglomerations of between 10,000 and 150,000 p.e. into coastal waters and those from agglomerations of between 2,000 and 10,000 p.e. to estuaries situated in areas described in Paragraph 1 may be subjected to treatment less stringent than that prescribed in Article 4 providing that:

i) such discharges receive at least primary treatment as defined in Article 2(7) in conformity with the control procedures laid down in Annex ID,

ii) comprehensive studies indicate that such discharges will not adversely affect the environment.

Water reuse

Article 12

Treated waste water shall be reused whenever appropriate. Disposal routes shall minimize adverse effects on the environment.

Effluent sampling requirements

Type of samples

Flow-proportional or time-based 24-hour samples shall be collected at the same well-defined

point in the outlet and if necessary in the inlet of treatment plants in order to monitor compliance with the requirements for discharged waste water laid down in this Directive.

Effluent sampling requirements

Frequency of sampling

The minimum annual number of samples shall be determined according to the size of a treatment plant and be collected at regular intervals during the year:

– 2,000 to 9,999 p.e.:

12 samples during the first year, four samples in subsequent years, if it can be shown that the water during the first year complies with the provisions of the Directive; if one sample of the four fails, 12 samples must be taken in the year that follows.

Effluent sampling requirements

Frequency of sampling

The minimum annual number of samples shall be determined according to the size of a treatment plant and be collected at regular intervals during the year:

– 10,000 to 49,999 p.e.: 12 samples.

– 50,000 p.e. or over: 24 samples.

Effluent sampling requirements

Compliance with effluent standards

The treated waste water shall be assumed to conform to the relevant parameters if, for each relevant parameter considered individually, samples of the water show that it complies with the relevant parametric value in the following way:

(a) for the parameters specified in Table 1 and Article 2(7), the maximum number of samples which are allowed to fail the requirements, expressed in concentrations and/or percentage reductions in Table 1 and Article 2(7), is specified in Table 3;

Effluent sampling requirements

Compliance with effluent standards

The treated waste water shall be assumed to conform to the relevant parameters if, for each relevant parameter considered individually, samples of the water show that it complies with the relevant parametric value in the following way:

(b) for the parameters of Table 1 expressed in concentrations, the failing samples taken under normal operating conditions must not deviate from the parametric values by more than 100 %. For the parametric values in concentrations relating to total suspended solids, deviations of up to 150 % may be accepted;

Effluent sampling requirements

Compliance with effluent standards

The treated waste water shall be assumed to conform to the relevant parameters if, for each relevant parameter considered individually, samples of the water show that it complies with the relevant parametric value in the following way:

(c) for those parameters specified in Table 2, the annual mean of the samples for each parameter shall conform to the relevant parametric values.

Tabulka 1: Požadavky na vypouštění z čistíren městských odpadních vod podle článků 4 a 5 této směrnice. Použijí se buď hodnoty koncentrací nebo procenta úbytku.

Table 1: Requirements for discharges from urban waste water treatment plants subject to Articles 4 and 5 of the Directive. The values for concentration or for the percentage of reduction shall apply.

Ukazatele Parameters	Koncentrace Concentration	Minimální procento úbytku [1] Minimum percentage of reduction [1]	Referenční metoda stanovení Reference method of measurement
Biologická spotřeba kyslíku (BSK_5 při 20°C) bez nitrifikace [2] Biochemical oxygen demand (BOD_5 at 20°C) without nitrification [2]	25 mg O_2/l	70 – 90 40 dle čl. 4 odst. 2 under Article 4(2)	Homogenizovaný, nefiltrovaný a neslitý vzorek. Stanovení rozpuštěného kyslíku před a po pětidenní inkubaci při 20°C v naprosté tmě. Přídavek inhibitoru nitrifikace. Homogenized, unfiltered, undecanted sample. Determination of dissolved oxygen before and after five-day incubation at 20±1°C, in complete darkness. Addition of a nitrification inhibitor.
Chemická spotřeba kyslíku (CHSK) Chemical oxygen demand (COD)	125 mg O_2/l	75	Homogenizovaný, nefiltrovaný a neslitý vzorek. Dichroman draselný. Homogenized, unfiltered, undecanted sample. Potassium dichromat.

Nerozpuštěné látky Total suspended solids	35 mg/l [3] 35 mg/l dle čl. 4 odst. 2 (nad 10 000 EO) under Article 4(2) (more than 10 000 p.e.) 60mg/l dle čl. 4 odst. 2 (2 000-10 000 EO) under Article 4(2) (2 000-10 000 p.e.)	90 [3] 90 dle čl. 4 odst. 2 (nad 10 000 EO) under Article 4(2) (more than 10 000 p.e.) 70 dle čl. 4 odst. 2 (2 000-10 000 EO) under Article 4(2) (2 000-10 000 p.e.)	Filtrace reprezentativního vzorku membránovým filtrem 0,45 µm. Sušení při 105°C a zvážení. Filtering of a representative sample through a 0,45 µm filter membrane. Drying at 105°C and weighing. Odstředění representativního vzorku (po dobu nejméně pěti minut při středním zrychlení 2 800 - 3 200 g), sušení při 105°C a zvážení. Centrifuging of a representative sample (for at least five mins with mean acceleration of 2 800 to 3 200 g), drying at 105°C and weighing.

[1] Úbytek vztažený k zatížení na vtoku.
[2] Tento ukazatel lze nahradit jiným ukazatelem - celkovým obsahem organického uhlíku (TOC) nebo celkovou spotřebou kyslíku (TOD), pokud lze prokázat závislost mezi BSK_5 a náhradním ukazatelem.
[3] Tento požadavek je volitelný.

[1] Reduction in relation to the load of the influent.
[2] The parameter can be replaced by another parameter: total organic carbon (TOC) or total oxygen demand (TOD) if a relationship can be established between BOD_5 and the substitute parameter.
[3] This requirement is optional.

Rozbory odtoků z biologických dočišťovacích nádrží se provádějí ve filtrovaných vzorcích; koncentrace celkových nerozpuštěných látek však nesmí přesáhnout hodnotu 150 mg/l.

Analyses concerning discharges from lagooning shall be carried out on filtered samples; however, the concentration of total suspended solids in unfiltered water samples shall not exceed 150 mg/l.

Tabulka 2: Požadavky na vypouštění z čistíren městských odpadních vod v citlivých oblastí podléhajících eutrofizaci, vymezených podle přílohy IIA písm. a). Podle místní situace se může použít jeden nebo oba ukazatele. Lze uplatnit hodnoty pro koncentrace nebo procenta úbytku.

Table 2: Requirements for discharges from urban waste water treatment plants to sensitive areas which are subject to eutrophication as identified in Annex IIA(a). One or both parameters may be applied depending on the local situation. The values for concentration or for the percentage of reduction shall apply.

Ukazatele Parameters	Koncentrace Concentration	Minimální procento úbytku [1] Minimum percentage of reduction [1]	Referenční metoda stanovení Reference method of measurement
Celkový fosfor Total phosphorus	2 mg/l (10 000-100 000 EO) (10 000-100 000 p.e.) 1 mg/l (nad 100 000 EO) (more than 100 000 p.e.)	80	Molekulová absorpční spektrofotometrie Molecular absorption spectrophotometry
Celkový dusík [2] Total nitrogen [2]	15 mg/l (10 000-100 000 EO) [3] (10 000-100 000 p.e) [3] 10 mg/l (nad 100 000 EO.- p.e.) [3] (more than 100 000 p.e.) [3]	70-80	Molekulová absorpční spektrofotometrie Molecular absorption spectrophotometry

Comments to Table 2

1) Reduction in relation to the load of the influent.
2) Total nitrogen means: the sum of total Kjeldahl-nitrogen (organic and ammoniacal nitrogen), nitrate-nitrogen and nitrite-nitrogen.
3) These values for concentration are the annual means as referred to in Annex I, paragraph D4(c). However, the requirements for nitrogen may be checked using daily averages when it is proved, in accordance with Annex I, paragraph D1, that the same level of protection is obtained. In this case, the daily average must not exceed 20 mg/l of total nitrogen for all the samples when the temperature from the effluent in the biological reactor is above or equal to 12°C. The conditions concerning temperature can be replaced by limiting the time of operation to take into account the regional climatic conditions.

Tabulka 3 *Table 3*

Počet ročně odebíraných vzorků Series of samples taken in any year	Maximální přípustný počet nevyhovujících vzorků Maximum permitted number of samples which fail to conform
4-7	1
8-16	2
17-28	3
29-40	4
41-53	5
54-67	6
68-81	7
82-95	8
96-110	9
111-125	10
126-140	11
141-155	12
156-171	13
172-187	14
188-203	15
204-219	16
220-235	17
236-251	18
252-268	19
269-284	20
285-300	21
301-317	22
318-334	23
335-350	24
351-365	25

Annex II - Definition of areas

A. Sensitive areas

A water body must be identified as a sensitive area if it falls into one of the following groups:

(a) natural freshwater lakes, other freshwater bodies, estuaries and coastal waters which are found to be eutrophic or which in the near future may become eutrophic if a protective action is not taken.

(b) surface freshwaters intended for the abstraction of drinking water which could contain more than the concentration of nitrate laid down under the relevant provisions of Council Directive 75/440/EEC 1 of 16 June 1975.

DIRECTIVE 2000/60/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 October 2000 establishing a framework for Community action in the field of water policy

PURPOSE

The purpose of this Directive is to establish a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater which:

(a) **prevents** further deterioration and **protects** and **enhances** the **status of aquatic ecosystems** and, with regard to their water needs, terrestrial ecosystems and wetlands directly depending on the aquatic ecosystems;

(b) **promotes sustainable water use** based on a long-term protection of available water resources;

DIRECTIVE 2000/60/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 October 2000 establishing a framework for Community action in the field of water policy

PURPOSE

The purpose of this Directive is to establish a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater which:

(c) aims at enhanced protection and improvement of the aquatic environment, inter alia, through specific measures for **the progressive reduction of discharges, emissions and losses of priority substances** and the cessation or phasing-out of discharges, emissions and losses of the priority hazardous substances;

(d) ensures the progressive **reduction of pollution of groundwater** and prevents its further pollution, and

(e) contributes to mitigating the effects of **floods and droughts**

DIRECTIVE 2000/60/EC
Article 4 **Environmental objectives**

a) For surface waters

(i) Member States shall implement the necessary measures to prevent deterioration of the status of all bodies of surface water,

(ii) Member States shall protect, enhance and restore all bodies of surface water,

(iii) Member States shall protect and enhance all artificial and heavily modified bodies of water,

Specification of tasks in Annex II, section 1

DIRECTIVE 2000/60/EC
Article 4 **Environmental objectives**

a) <u>For groundwater</u>

(i) Member States shall implement the necessary measures to prevent or limit the input of pollutants into groundwater and to prevent the deterioration of the status of all bodies of groundwater

(ii) Member States shall protect, enhance and restore all bodies of groundwater, ensure a balance between abstraction and recharge of groundwater, with the aim of achieving good groundwater status at the latest 15 years after the date of entry into force of this Directive,

Specification of tasks in Annex II, section 2

DIRECTIVE 2000/60/EC

Article 8 **Monitoring of sensitive areas**

1. Member States shall ensure the establishment of programmes for the monitoring of water status in order to establish a coherent and comprehensive overview of water status within each river basin district:

- for protected areas the above programmes shall be supplemented by those specifications contained in Community legislation under which the individual protected areas have been established

DIRECTIVE 2000/60/EC

Article 10 **Combined approach for point and diffuse sources**

1. Member States shall ensure that all discharges into surface waters referred to in Paragraph 2 are controlled according to the combined approach set out in this Article.
2. Member States shall ensure the establishment and/or implementation of:

(a) the emission controls based on the **best available techniques**, or

(b) the relevant emission limit values, or

(c) in the case **of diffuse impacts,** the controls including, as appropriate, best environmental practices

DIRECTIVE 2000/60/EC
Article 13 **River basin management plans**

1. Member States shall ensure that a river basin management plan is produced for **each river basin district lying entirely within its territory.**

2. In the case of an **international river basin district** falling entirely within the Community, Member States shall ensure coordination with the aim of producing a single international river basin management plan. Where such an international river basin management plan is not produced, Member States shall produce river basin management plans covering at least those parts of the international river basin district falling within their territory to achieve the objectives of this Directive.

DIRECTIVE 2000/60/EC

Article 13 **River basin management plans**

3. In the case of an **international river basin** district extending beyond the boundaries of the Community, Member States shall endeavour to produce a single river basin management plan, and, where this is not possible, the plan shall at least cover the portion of the international river basin district lying within the territory of the Member State concerned.

4. The river basin management plan shall include the information detailed in Annex VII. (elements of river basin management plans)

Act No. 254/2001 Coll.: Water Act

Wastewater discharges can only take place on the basis of a permit:

§ 9

(1) Permits for water management are issued for a limited time. The permit for water management shall specify the purpose, scope, obligations and, where appropriate, the conditions under which such authorization is granted. The background for the issue of a groundwater permit is the expression of a person with professional competence unless, in exceptional cases, the water authority decides otherwise.

(2) The permit for discharge of wastewater can not be issued for a period longer than 10 years; in the case of discharges of wastewater with particularly dangerous substances or dangerous substances (according to Annex 1) for more than 4 years.

Act No. 254/2001 Coll.: Water Act

§ 32 Sensitive areas

(1) Sensitive areas are water bodies of surface water:

a) in which a high concentration of nutrients occurs or is expected to occur in the near future to an undesirable state of water quality,

b) which are used or are expected to be used as sources of drinking water in which the nitrate concentration exceeds 50 mg / l; or

c) in the light of the interests protected by that law, a higher degree of waste water treatment is required.

(2) Sensitive areas are defined by governmental regulation. The definition of sensitive areas is subject to review at regular intervals not exceeding four years.

(3) For sensitive areas and for the discharge of wastewater into surface waters affecting water quality in sensitive areas, the Government will set a permit for indicators of permissible wastewater pollution and their values.

Act No. 254/2001 Coll.: Water Act

§ 33 Vulnerable areas

1) Vulnerable areas are the territories with occurrence of

a) surface or groundwater, in particular, used or designated as drinking water sources in which the nitrate concentration exceeds or may reach the value of 50 mg / l; or

b) surface waters where, due to high concentrations of nitrates from agricultural sources, an undesirable deterioration in water quality occurs or may occur.

(2) Vulnerable areas are declared by governmental regulation. It regulates the use and storage of fertilizers and manure, crop rotation and anti-erosion measures (hereinafter referred to as the "action program"). The action program and the definition of vulnerable zones are subject to review and possible modifications at intervals not exceeding four years. The review shall be carried out on the basis of an evaluation of the effectiveness of the measures deriving from the adopted action program.

Act No. 254/2001 Coll.: Water Act

§ 38 Wastewater

(1) Wastewater is water used in residential, industrial, agricultural, healthcare and other buildings, installations or means of transport if it has a changed quality (composition or temperature) after use, as well as other water flowing from these buildings, equipment or vehicles that may endanger the quality of surface or groundwater. Wastewater is also leakage water from sludge ponds and landfills, with the exception of water that is reused for the organization's own use and water that flows into mine water.

(2) ……..

(3) Whoever discharges waste water into surface or underground waters shall be obliged to arrange for their disposal in accordance with the conditions laid down in the permit for their discharge. When establishing these conditions, the water authority is required to take into account the best available wastewater disposal technologies, which means the most efficient and advanced stage of development of the waste disposal or purification technology developed to the extent that it can be implemented under economically and technically acceptable conditions and at the same time as the most efficient for water protection. Whoever discharges the mine water into surface or underground waters pursuant to the Act on the Protection and Use of Mineral Resources1a) can do so only in the manner and under the conditions laid down by the Water Authority.

(4) Any person discharging wastewater into surface water or underground water shall, in accordance with the water authority's decision, measure the volume of discharged water and the extent of its pollution and report the results of these measurements to the water authority that issued the decision to the appropriate river basin manager and authorized expert. By this decision, the Water Authority determines the location and method of measuring the volume and pollution of discharged waste water and the frequency of submission of the results of these measurements. Sampling and analyzes to determine the level of pollution of discharged waste water may be carried out only by suitably qualified persons (hereinafter referred to as the "authorized laboratory").

Act No. 254/2001 Coll.: Water Act

§ 38 Wastewater

5) Those who dispose wastewater through a wastewater treatment plant intended for the treatment of wastewater to the capacity of 50 equivalents declared according to Article 15a, the essential part of which is a product designated CE, shall not be subject to the obligation under section 4. List and classification of CE marked products including permissible pollution is set by the Government.

(6) Any person who accumulates wastewater in a cesspool shall be obliged to ensure their disposal so as not to endanger the quality of the surface or groundwater and at the request of the Water Authority or the Czech Environmental Inspectorate to prove their disposal in accordance with this Act.

(7) Direct discharge of wastewater into groundwater is prohibited. The discharge od wastewater not containing hazardous wastes (§39, section 3) from individual buildings for housing, individual constructions for family recreation or from individual buildings providing accommodation services, arising predominantly as a product of human metabolism and activities in households through soil layers into underground waters, may be authorized only exceptionally on the basis of an expert's opinion on their impact on groundwater quality unless it is technically possible or with regard to interests protected by other legislation to be discharged into surface or public sewers.

(8) When permitting the discharge of wastewater into surface waters or underground waters, the water authority shall set the maximum permissible values and their pollution levels. When permitting the discharge of wastewater into surface water, it is bound by indicators that indicate water status in watercourses, environmental quality standards, indicators and values of permissible surface water pollution, indicators and permissible values for waste water pollution, and the conditions of the permit for wastewater discharge including the specifications of the best of the available wastewater disposal technologies and the conditions for their use, which the Government sets by regulation. When permitting the discharge of wastewater into underground waters, it shall be bound by indicators indicating the groundwater status in the relevant groundwater body, indicators and values of permissible groundwater contamination, indicators and permissible values of wastewater pollution, and the conditions for permitting discharge of wastewater into underground waters the Government shall determine by regulation.

(9) When permitting the discharge of waste water into the waters of the surface or underground water, the authority

a) takes into account the need to achieve or maintain good status of surface or groundwater and water-bound ecosystems; and

b) assesses the possibilities of limiting pollution at its source as well as limiting emissions into the environment as a whole and the possibility of re-use of wastewater.

Act No. 254/2001 Coll.: Water Act

§ 38 Wastewater

(10) Where required by the relevant river basin management plan or water protection or environmental quality objectives as set out in the directly applicable European Community legislation, the water authority shall set stricter permissible values for the indicators of waste water pollution than those set by the government decree under paragraph 8, and their permissible values. The values set by the government in this regulation must not be more stringent than those achievable using the best available technologies in the field of waste water disposal; the standards directly applicable to the European Communities shall not be affected. Similarly, this also applies in the case of pollution indicators and their values set by the Government Decree pursuant to § 31, 34 and 35.

(11) The Water Authority may, when permitting discharges of wastewater from industrial buildings and installations, impose disposal of wastewater from individual sub-assemblies or cooling water separately from other wastewater.

(12) The Water Authority may, in exceptional cases, allow the necessary time, in particular for putting the Waste Water Treatment Plant in service, for the trial operation, for the necessary repairs or modifications of the waste water disposal facilities and for the accidents of these facilities, and in cases where the wastewater will be discharged into the surface waters in a controlled manner while determining other conditions limiting the possibility of deterioration of the quality of surface waters, discharge of wastewaters with permissible values of indicators of wastewater pollution higher than the values established by the Government by the regulation pursuant to section 8 or pursuant to § 31.

(13) In case of doubt about the definition of wastewater, the water authority decides.

Governmental regulation 401/2015 Coll.

This Regulation

a) in accordance with the law of the European Union

1. Indicators indicating the status of surface water,
2. Indicators and values of permissible surface water pollution,
3. Indicators and values of permissible wastewater pollution,
4. Indicators and values of permitted wastewater pollution for sensitive areas and for the discharge of effluents into surface waters affecting water quality in sensitive areas,
5. Indicators and values of permissible pollution for surface water sources that are used or are expected to be used as sources of drinking water,
6. Indicators and values of permissible surface water pollution that are appropriate for the life and reproduction of native species of fish and other aquatic animals,
7. Indicators and values of permissible pollution of surface water used for bathing,
8. Environmental quality standards for priority substances and some other pollutants,
9. Requirements and conditions of the permit for discharge of wastewater into surface and sewerage water,
10. List of priority substances and priority hazardous substances,
11. Best available technologies in urban wastewater disposal and conditions of use,

b) defines sensitive areas in accordance with European Union law.

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European Structural and Investing Funds
Operational Programme Research,
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MINISTRY OF EDUCATION,
YOUTH AND SPORTS

2. BASIC PRINCIPLES OF BIOLOGICAL WASTEWATER TREATMENT

TERMINOLOGY OF BIOCHEMICAL PROCESSES

Substrate

is defined as the source of energy for living cells

light - **phototrophic** microorganisms
inorganic compounds - **chemolithotrophs (chemoautotrophs)**
organic compounds - **chemoorganotrophs**

Carbon source

for the synthesis of new biomass

inorganic carbon - **autotrophs**
+ light as the substrate - **photoautotrophs**
+ inorganic compounds as the substrate - **chemolithotrophs (chemoautotrophs)**
organic carbon - **chemoorganotrophs (chemoheterotrophs)**

External substrates/carbon sources

are present in the medium, before they can be utilized by cells, they should be transported to the cells´ interior - **exogenous** metabolism

Internal substrates/carbon sources

materials accumulated and/or stored in cells are metabolized - **endogenous** metabolism

Nutrients

In general microbiology, the term nutrients means **all chemical elements** which are utilized as building materials for cell synthesis.

In wastewater treatment terminology, **only N and P** are referred to as nutrients (nutrient removal systems = systems removing compounds of N and P).

In bacterial growth, elements like N, P and S - **macronutrients**,

Fe, Ca, Mg, K, Mo, Zn, Co,… - **micronutrients**.

<u>Cultivation conditions</u>

Modern terminology for cultivation conditions is based on different electron acceptors which participate in individual biochemical reactions.

oxic

- dissolved molecular oxygen O_2

anoxic

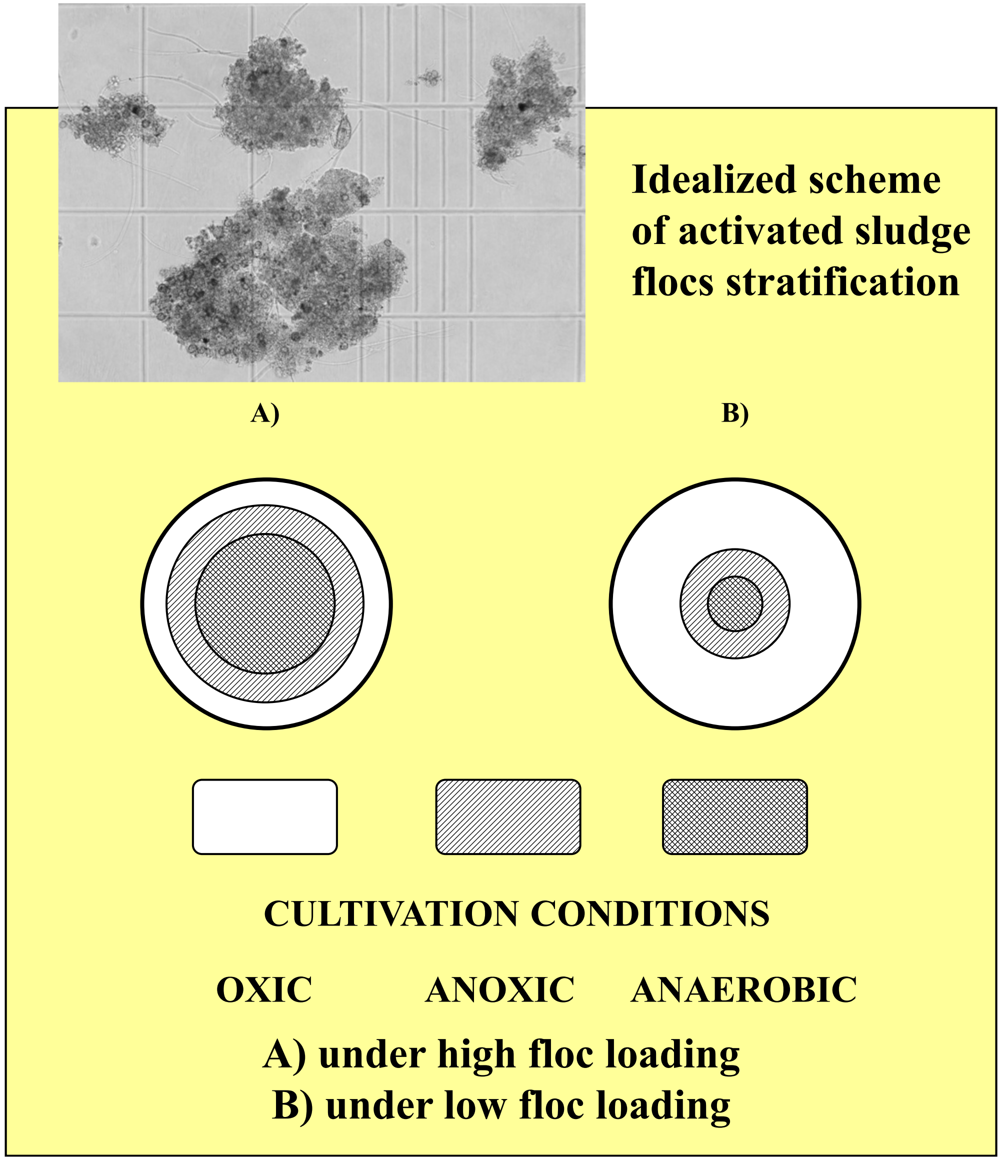
- nitrogen at oxidation stage +5 or +3 (less frequently)

$N\text{-}NO_3^-$, $N\text{-}NO_2^-$

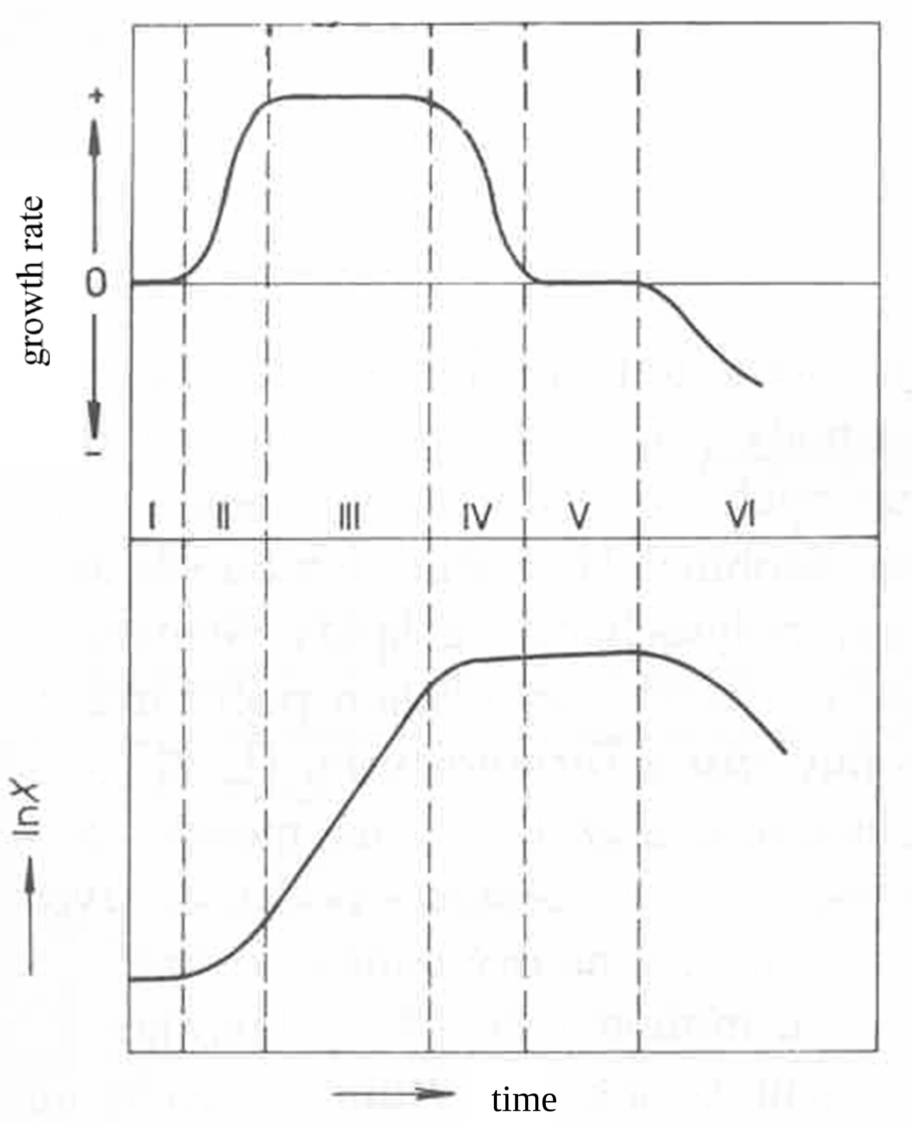
anaerobic

- electrons can be transferred from the organic substrate to organic compounds, sulphate sulphur

ORP - oxidation-reduction potential



GROWTH CURVE



I	lag phase
II	accelerated growth phase
III	exponential growth phase
IV	declining growth phase
V	stationary phase
VI	death phase

Growth rate in the exponential phase (of batch cultivation):

$$\frac{dX}{dt} = \mu \cdot X \quad \Longrightarrow \quad \boldsymbol{X = X_0 \cdot e^{\mu t}}$$

X_0 is the biomass concentration $[M \cdot L^{-3}]$ at $t = 0$
μ is the specific growth rate $[T^{-1}]$

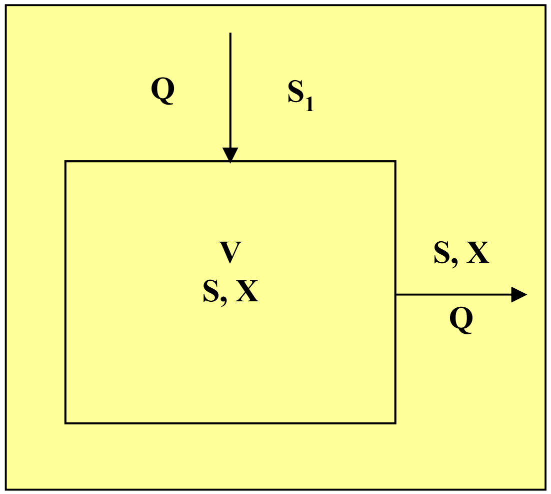
The value of the growth rate depends on the substrate concentration (S) according to the **Monod equation:**

$$\mu = \mu_{\max} \cdot \frac{S}{K_S + S}$$

μ_{max} is the maximum value of the growth rate at infinite substrate concentration $[T^{-1}]$
K_S is the half-velocity (half-saturation) constant $[M \cdot L^{-3}]$
- its numerical value is equal to substrate concentration S at which $\mu = ½\ \mu_{max}$

The growth curve can only be observed in batch cultivation systems.

Continuous cultivation systems without biomass recycle
(not used in wastewater treatment): chemostat



$$\frac{dX}{dt} = \mu \cdot X - b \cdot X - D \cdot X$$

b - specific decay rate [T^{-1}]
D = Q/V - cells dilution rate [T^{-1}].

Steady state conditions: $\mu = b + D$

PRINCIPLES OF BIOLOGICAL WASTEWATER TREATMENT

in biological reactors by means of microorganisms (mixed culture, biomass)

<u>Classification of biological reactors:</u>

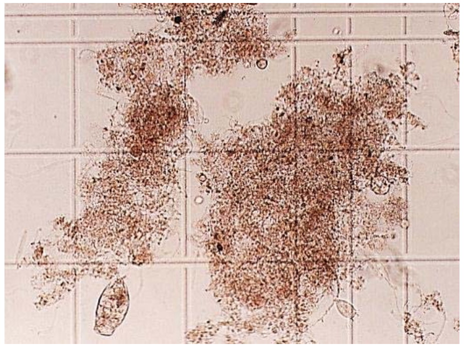
1. cultivation of biomass **in suspension = activated sludge**

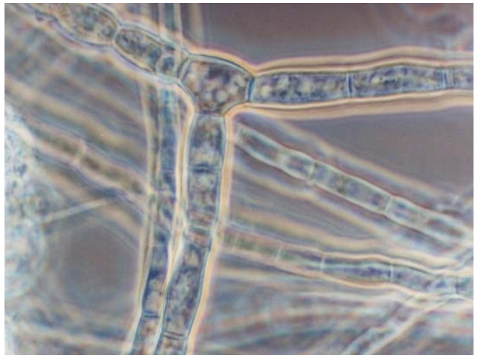
2. cultivation **of attached** biomass on biomass carriers = **biofilms**

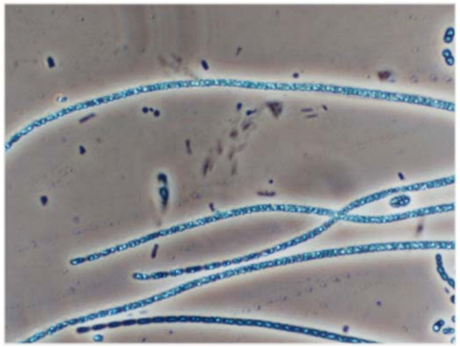
3. reactors with **combined biomass cultivations**

MICROBIAL COMPOSITION OF ACTIVATED SLUDGE

1. Decomposers (95 %)
- responsible for biochemical degradation of polluting substances in wastewaters
- bacteria (95 %), microscopic fungi, colorless cyanophyta,…







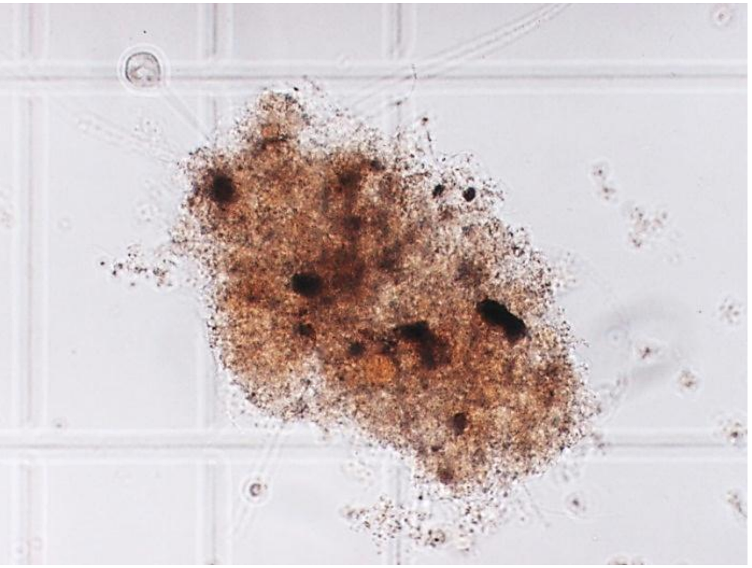
2. Consumers (5 %)
- utilize bacterial and other microbial cells as substrates
- activated sludge microfauna - protozoa and metazoa

Bacteria in activated sludge - basic physiological groups

• **<u>oxic organotrophic bacteria</u>**

energy source + required carbon form: organic compounds

electron acceptor: O_2, products: CO_2 + H_2O + biomass



• **<u>anoxic organotrophic bacteria (80 – 90 %)</u>**

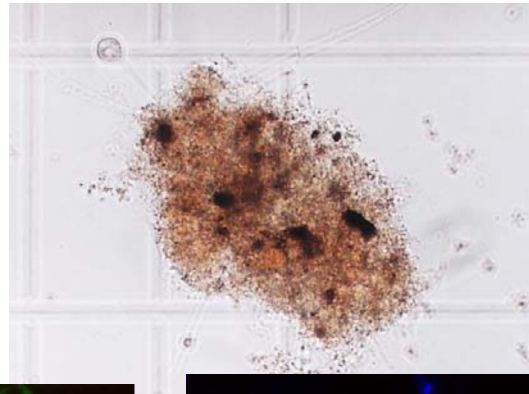
energy source + required carbon form:
organic compounds

electron acceptor: $N\text{-}NO_3^-$ ($N\text{-}NO_2^-$)

denitrifying bacteria: $N\text{-}NO_3^- \longrightarrow N_2$

• **<u>chemolithotrophic bacteria (1 – 3 %)</u>**

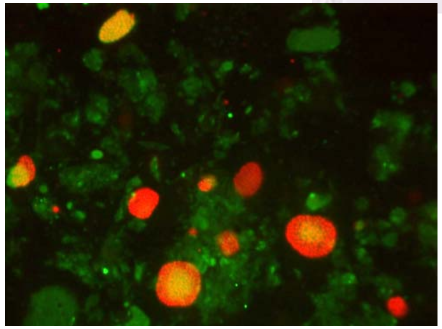
energy source: oxic oxidation of inorganic compounds
required carbon form: inorganic compounds

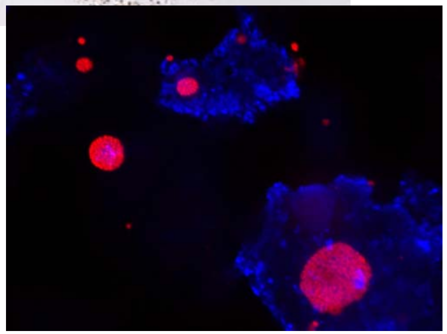


nitrifying bacteria:

N-NH_4^+ ➡ N-NO_2^- ➡ N-NO_3^-

slow growing, very sensitive (O_2, pH, temperature, sludge age, wastewater composition - inhibition/toxicity)

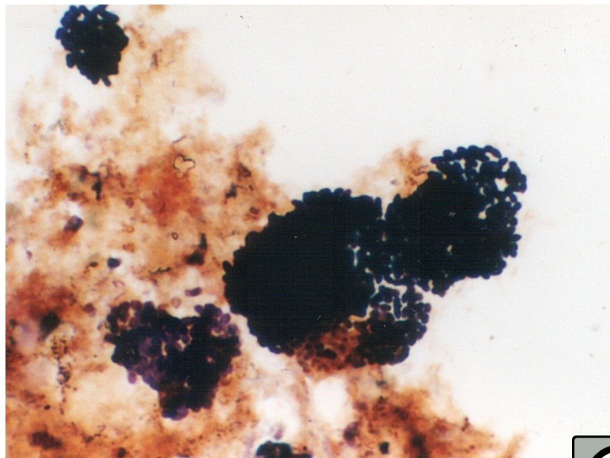




• **<u>polyphosphate accumulating organisms (PAOs)</u>**

energy source: polyphosphates (PP), organic storage products (OSP)
required carbon form: organic compounds

- activated sludge is alternately exposed to anaerobic and oxic conditions
- Neisser staining



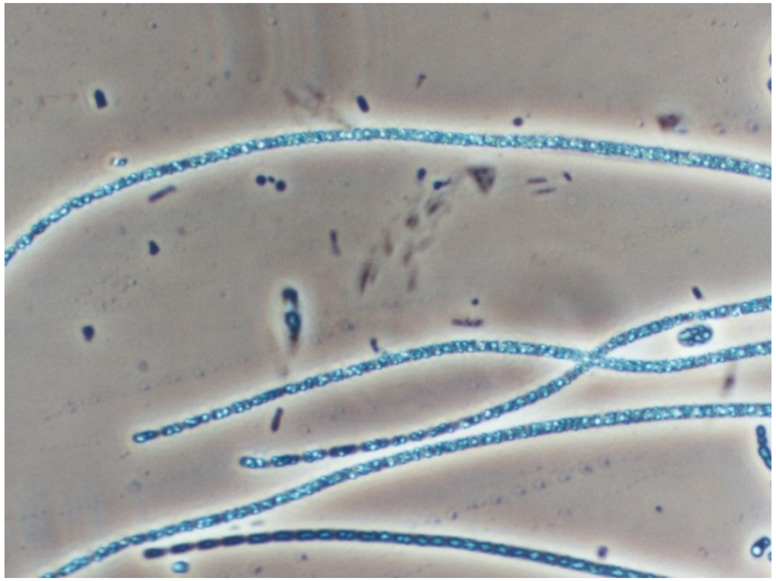
• **microorganisms of sulphur cycle**

- sulphate-reducing bacteria

organotrophic microorganisms reducing sulphate sulphur into S^0/S^{2-} under anaerobic conditions (strict anaerobes???)
required carbon form: organic compounds

- sulphide/sulphur-oxidizing bacteria

required carbon form: inorganic compounds



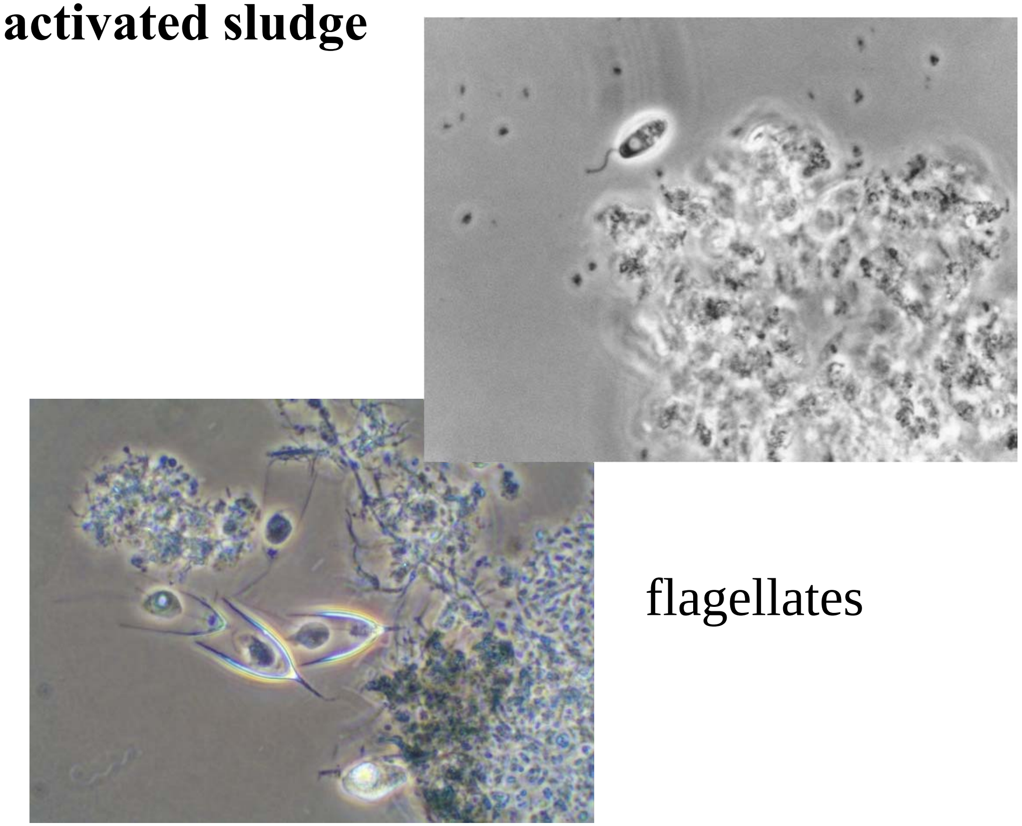
Microfauna of activated sludge

Protozoa

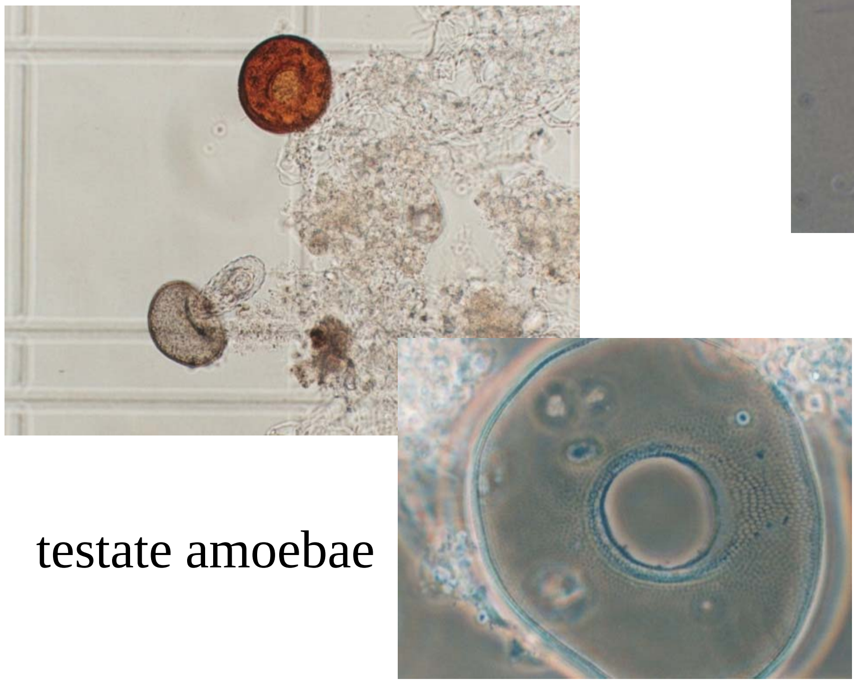
Flagellates

Rhizopods

- testate amoebae, amoebae



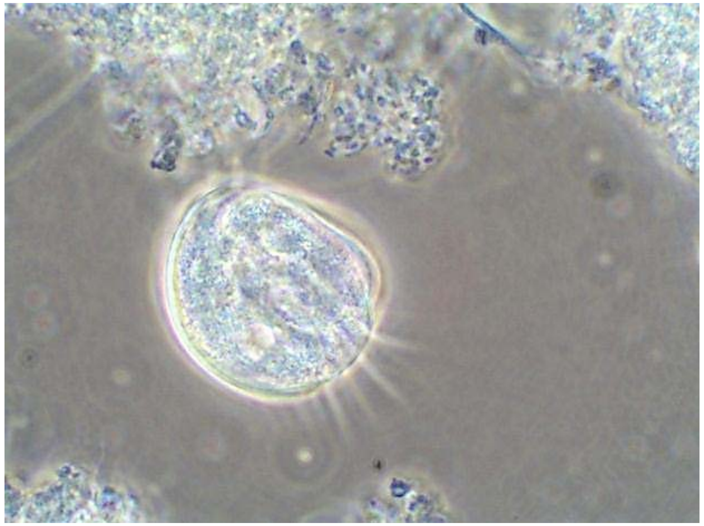
flagellates



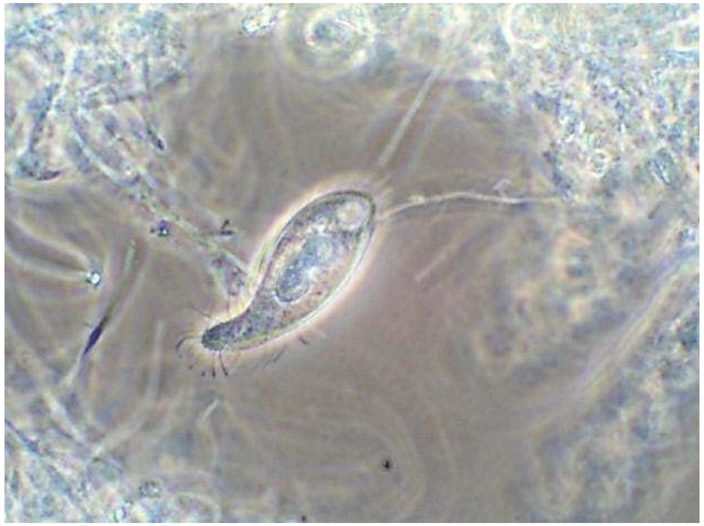
testate amoebae

amoeba

Ciliates

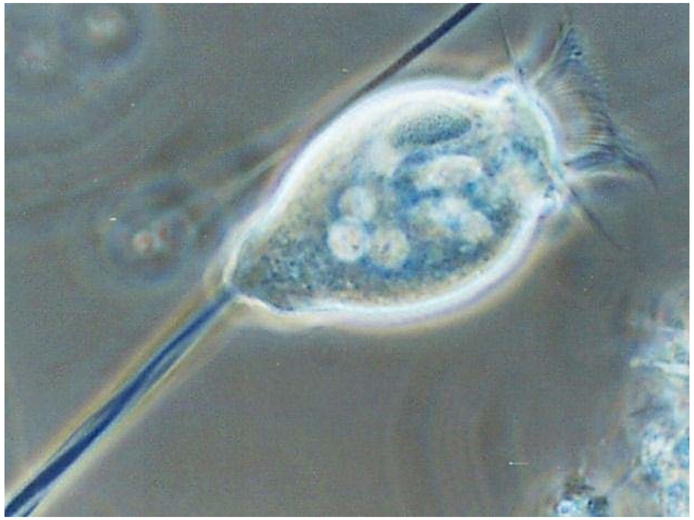


- crawling



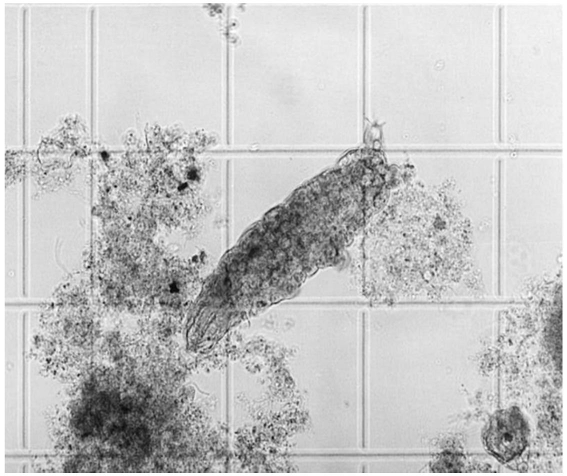
- free swimming

- attached (stalked)



Metazoa
Rotifers
Tardigrades
Nematodes
Bristle worms

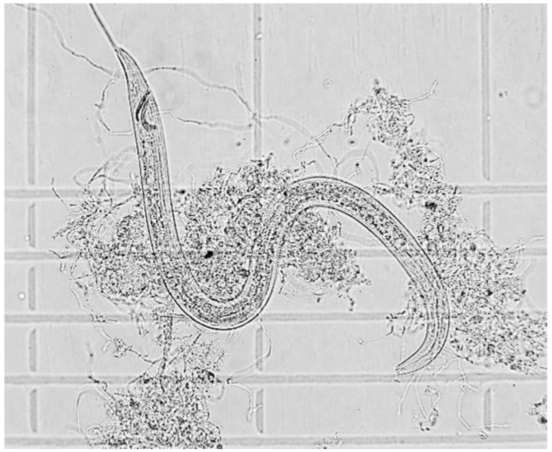
tardigrade
(water bear)



rotifer

worm

nematode



activated sludge
acarid

BASIC WAYS OF ACTIVATED SLUDGE CULTIVATIONS

Basic arrangements of activated sludge systems:

- **batch**
- **semicontinuous (fill-and-draw)**
- **continuous**

  ideal systems

  - piston-flow systems

  - ideally mixed systems

  real systems

  - plug-flow systems

  - completely mixed systems

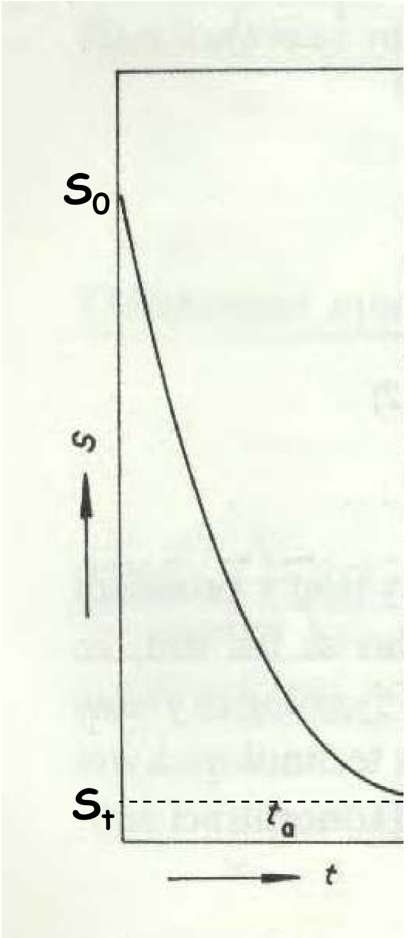
<u>Batch systems</u>

Activated sludge (biomass) is mixed with wastewater (substrate).

During the operation:

- decrease of substrate concentration from S_0 to S_t (substrate removal)
- increase of biomass concentration from X_0 to X_t (accumulation, storage or cell multiplication)

Microorganisms are exposed to <u>variable substrate concentrations.</u>

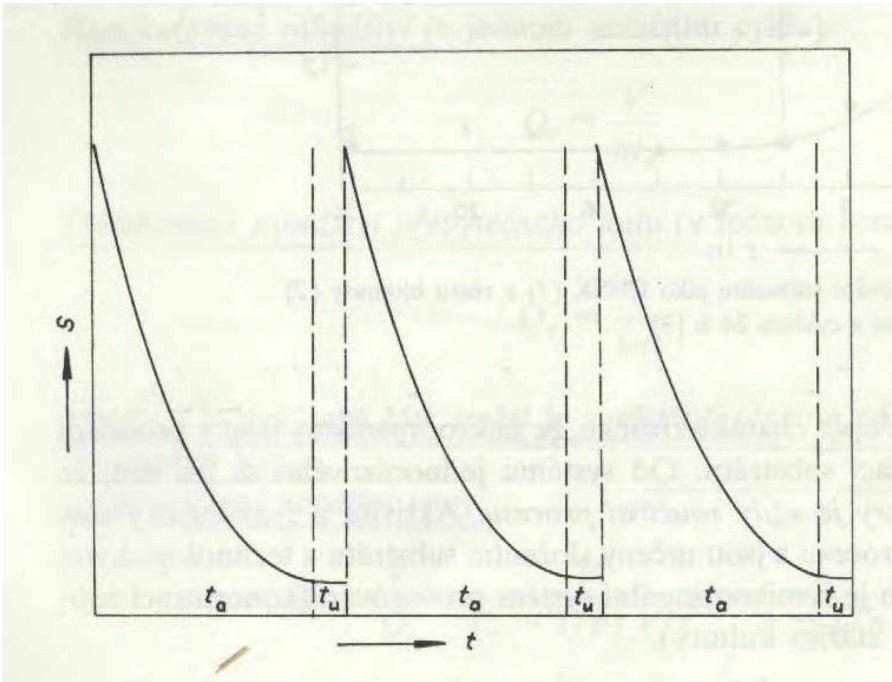


Cultivation is not repeated with the same biomass in the next batch - not applicable for practical purposes (but highly suitable for lab-scale measurements).

Semicontinuous systems
(fill-and-draw reactors)

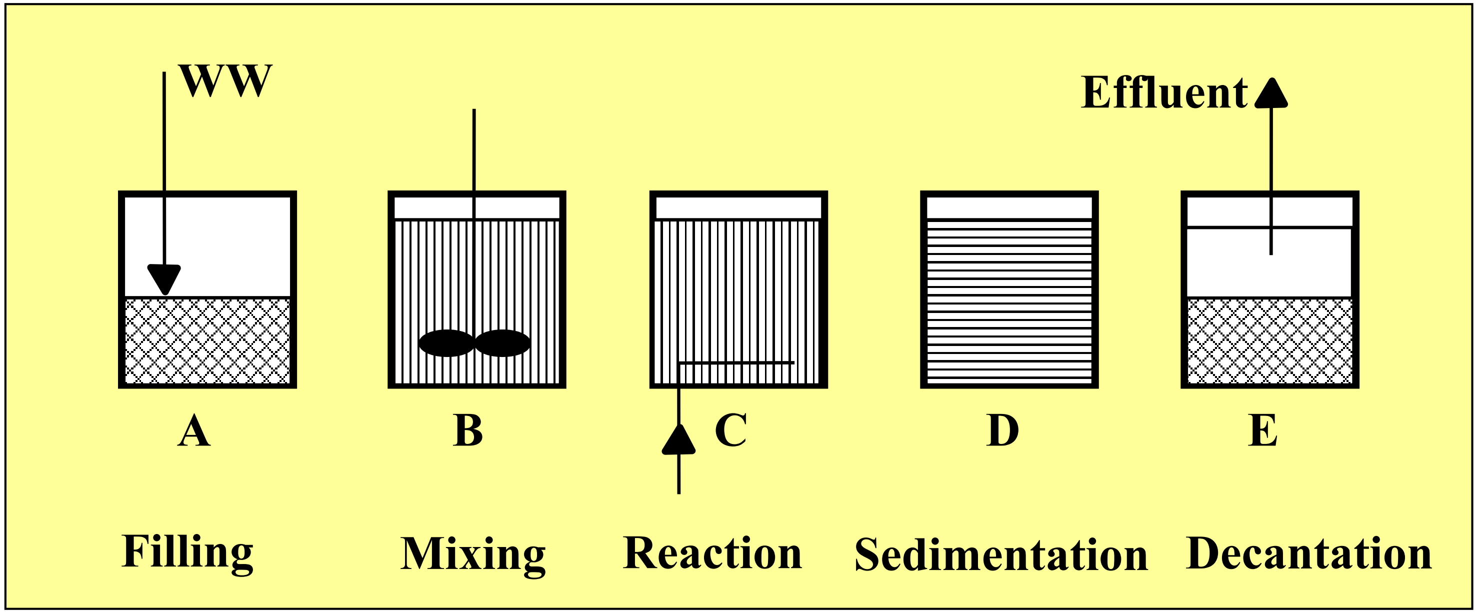
The substrate concentration profiles during the subsequent cycles are similar to those in batch tests, but repeated with the same biomass.

Microorganisms are exposed to variable substrate concentrations.

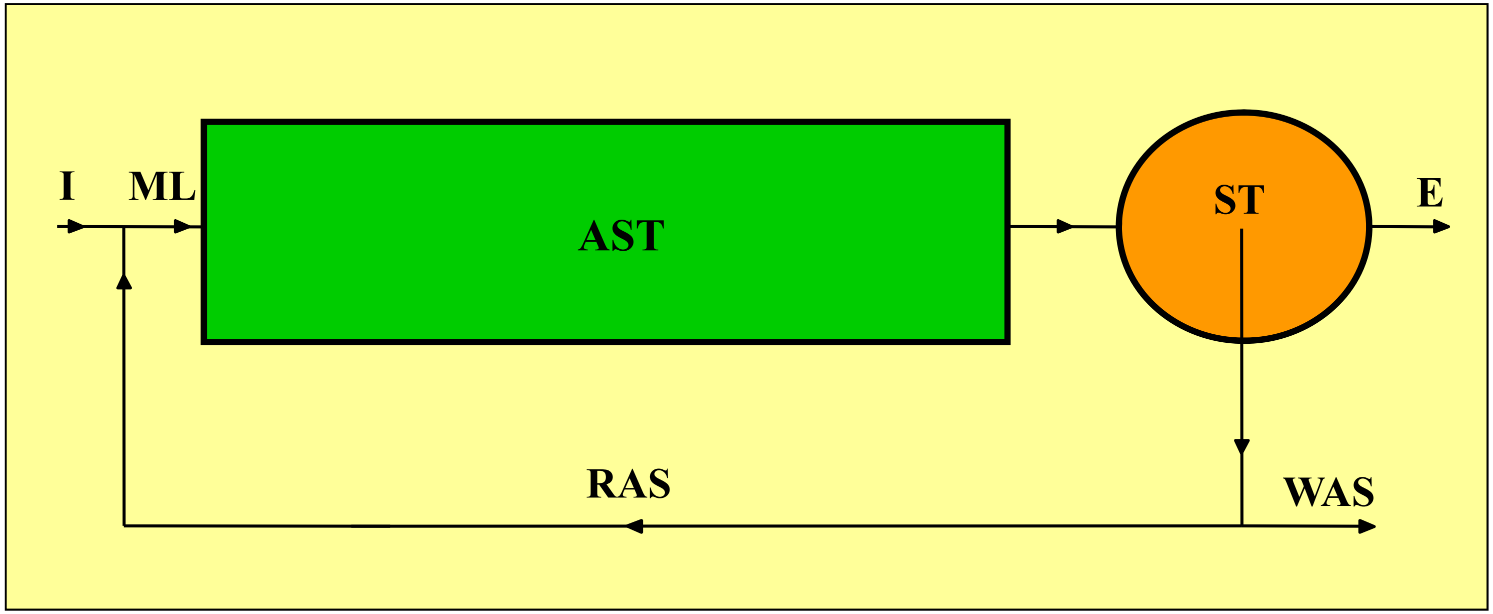


Used in experimental studies for simulating ideal continuous piston-flow reactors.

Full-scale applications - sequencing batch reactors (SBRs)



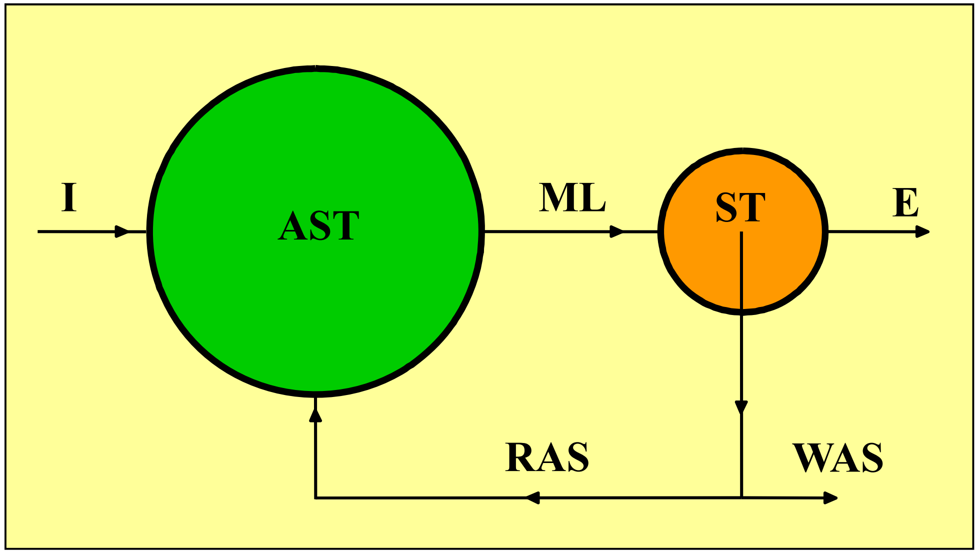
Continuous plug-flow systems



I - influent, E - effluent, ML - mixed liquor, AST - activated sludge tank, ST - settling tank, RAS - return activated sludge, WAS - waste activated sludge

- RAS is mixed with treated WW and this mixture is introduced into the reaction volume
- microorganisms of activated sludge are cultivated in the environment with the substrate gradient between the concentration values of raw WW and the system effluent

Continuous completely mixed systems



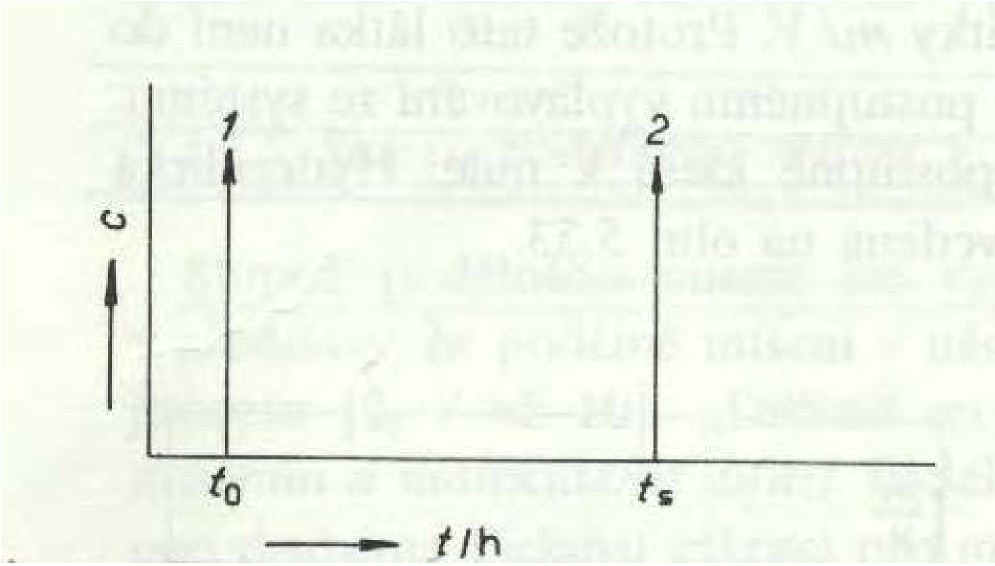
I - influent
E - effluent
ML - mixed liquor
AST - activated sludge tank
ST - settling tank
RAS - return activated sludge
WAS - waste activated sludge

- RAS is mixed with the mixed liquor in the reactor and not with the WW under treatment
- homogeneity of substrate and biomass concentrations from the inlet to the outlet
- substrate concentration in the reactor is the same as in the effluent
- microorganisms are not exposed to higher concentrations than those of the effluent

Hydraulic regime - tracer tests

Characteristics of tracer compounds:
- not hazardous to the environment or health
- determinable at low concentrations
- not affecting hydraulic chracteristics
- reasonably priced

Tracer compounds:
- dyes (Rhodamine B)
- inorganic salts
- radioisotopes of biogenic elements (less frequently)

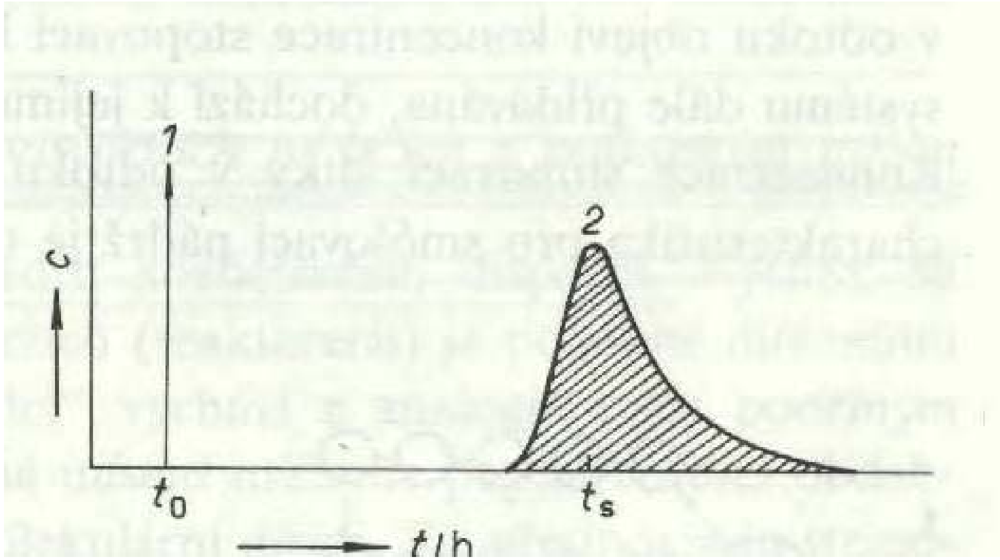


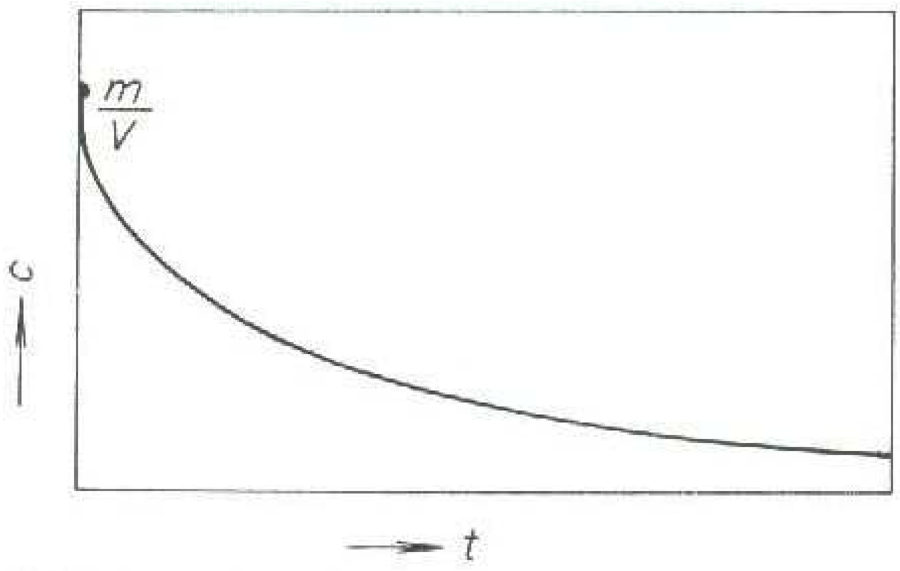
Ideal piston-flow systems

• no longitudinal mixing

Plug-flow systems

• can be simulated by a cascade of high numbers of individual completely mixed reactors





Hydraulic regime of **ideally mixed systems**

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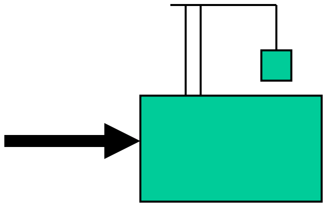
3. TECHNOLOGICAL SCHEME OF MUNICIPAL WWTPs: MECHANICAL WASTEWATER TREATMENT

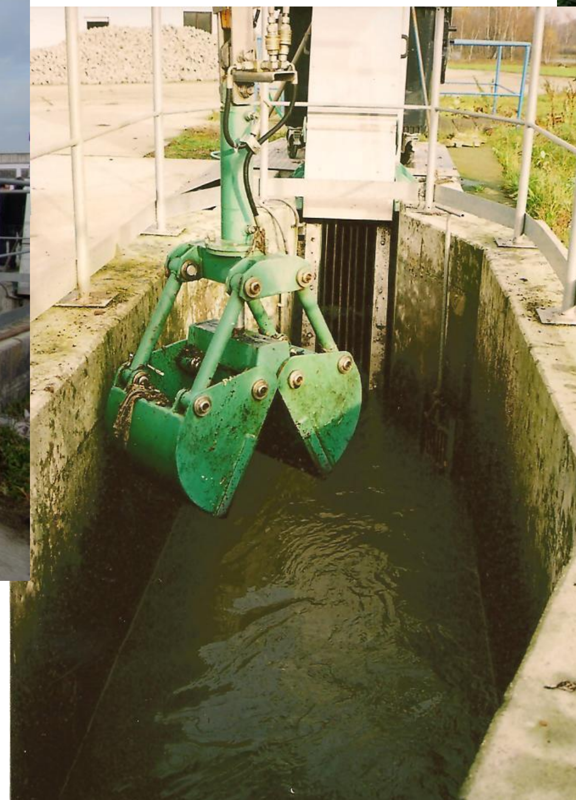
MECHANICAL WASTEWATER (PRE)TREATMENT (PRIMARY TREATMENT)

Stone/gravel trap

stone/gravel trap



- protection from the coarsest particles
- stones, gravel, trash, bricks or their parts
- removal of stone by crane/excavator



Stone/gravel removal process

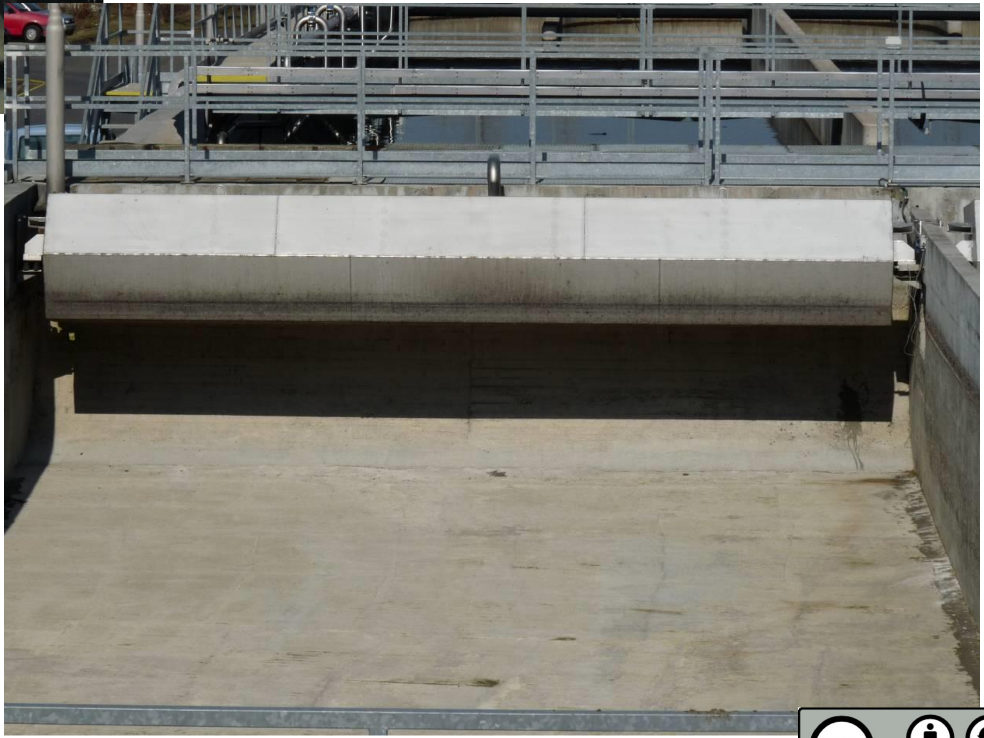
Influent to plants

Storm overflow

- hydraulic overloading prevention
- storm water tank or receiving water body

Storm overflow

Storm overflow in big plants



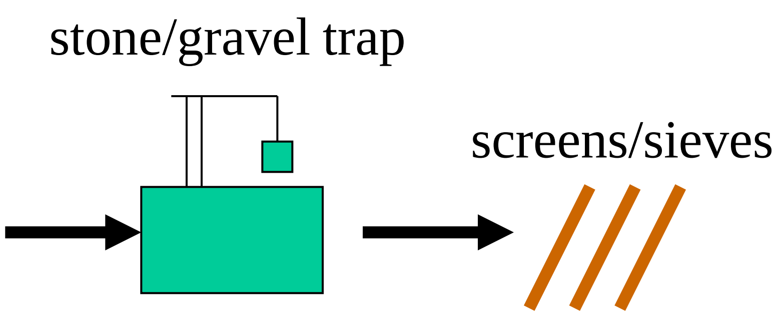
Storm water tanks

Pumping, lifting

- wastewater can flow by gravity

Screw pumps

Screens and sieves



- main purpose is to remove all large objects that are deposited in the sewer systems, such as rags, sticks, condoms, sanitary towels, cans, plastics, food particles, etc.
- most commonly done with manual or automated mechanically raked screens
- these large particles are freely dispersed in the stream of wastewater coming to a plant
- this type of waste is removed because it can damage the sensitive equipment at WWTPs (pumps, valves, aerators,…)

Types of screens

- coarse: 25 – 100 mm
- medium: 15 – 25 mm
- fine: less than 10 mm

Coarse and medium screens

- screens consist of vertical or inclined steel bars spaced at equal intervals across a channel through which the wastewater flows

Coarse and medium screens

Fine screens

Types of screens

- fixed frame screens
- step screens

Conventional bar screens

Fine step screens

Types of screens

- manual or mechanical removal of screenings
- specific production of screenings:

2 – 3 l/PE per year for coarse screens

5 – 10 l/PE per year for fine screens

Screenings

Screenings (coarse screens)

Screenings (fine screens)

- volume of produced screenings can be reduced by dewatering (piston or screw presses)

Dewatering of screenings

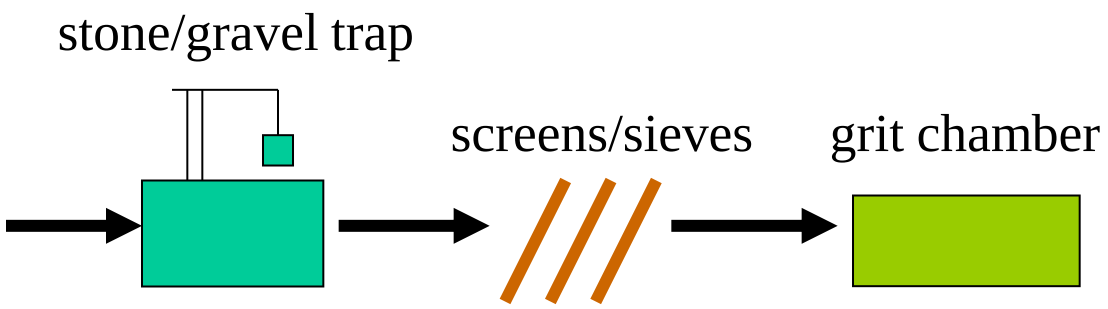
Dewatering of screenings

- deposition at municipal solid waste landfills
- mixing with municipal refuse and burning at municipal incinerators

Rotating sieves

- smaller WWTPs (sometimes comminutors or grinders are applied)

Grit chamber (sand trap)



- grit removal prevents unnecessary abrasion and wear of mechanical equipment, grit deposition in pipelines and channels and accumulation of grit in anaerobic digesters and biological reactors

Types of grit chambers

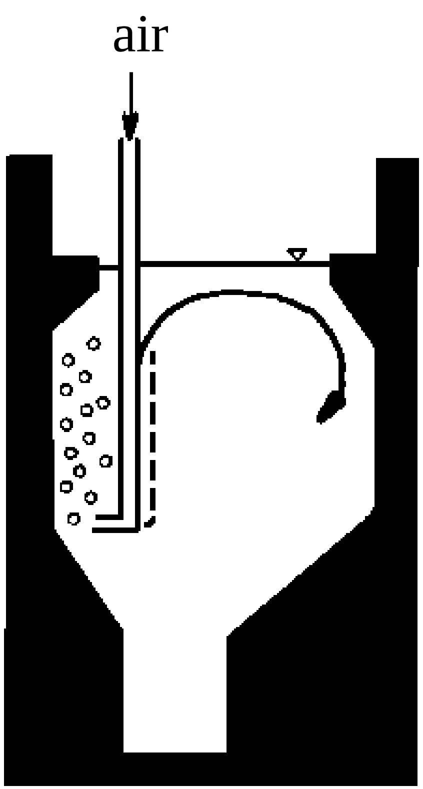
- aerated grit chambers
- vortex sand trap (smaller installations)

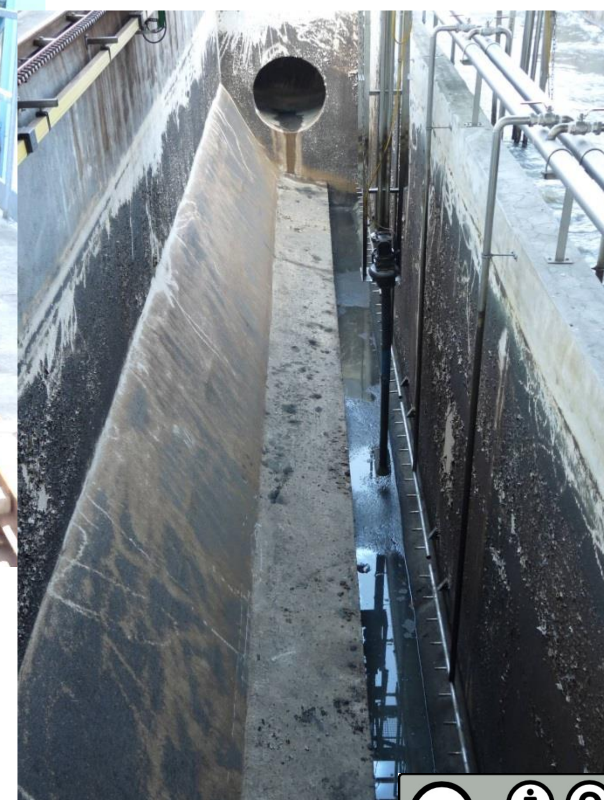
Aerated grit chambers

Vortex sand trap

Aerated grit chambers

- air introduced along one side near the bottom causes a spiral-roll velocity pattern perpendicular to the flow through the tank
- heavier particles with their corresponding higher settling velocities drop to the bottom while the roll suspends the lighter organic particles, which are eventually carried out of the tank





<u>Vortex grit removal</u>

- system relies on a mechanically induced vortex to capture grit solids in the center hopper of a circular tank
- combination of paddles, inlet baffles and inlet flow produces a spiraling, doughnut-shaped flow pattern that tends to lift lighter organic particles and settle the grit

- specific production of sand:

  5 – 10 l/PE per year

Air lift pumps

Odour control

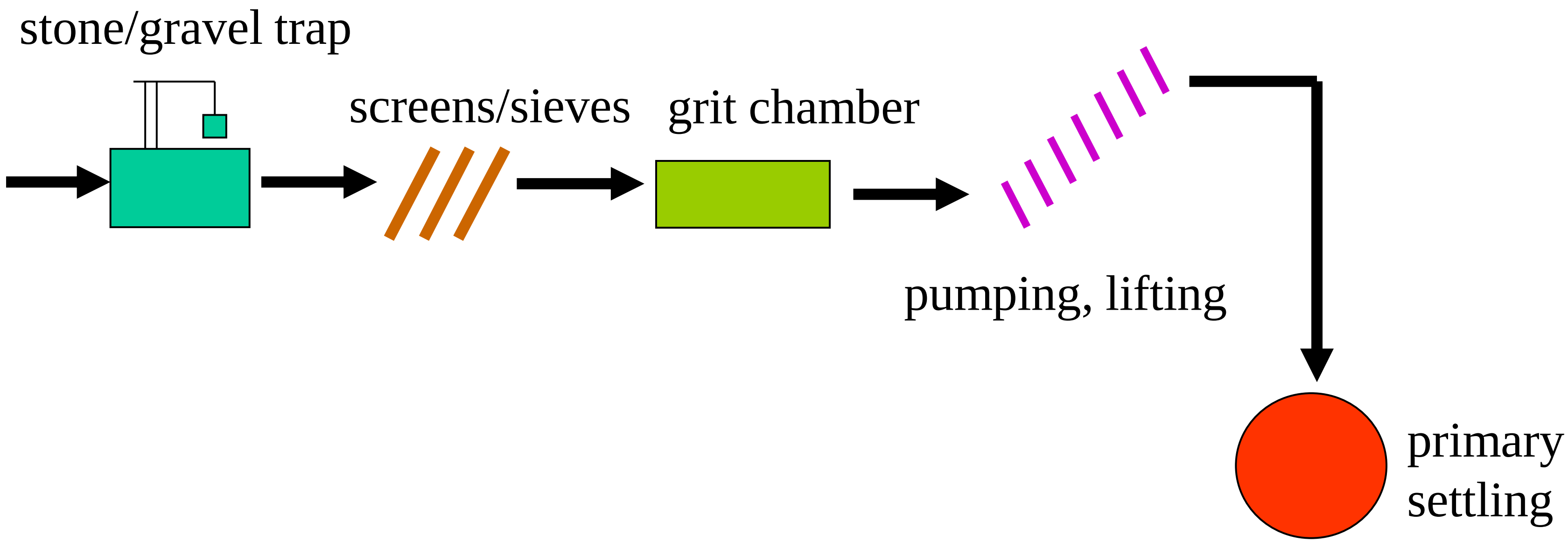
Sand washing (grit classifier)

- removal of organic material; organic material reenters the flow stream for further treatment
- grit is moved to a garbage dumpster to be picked up by a waste hauler and disposed at a landfill

Combined sand and grease trap

Jalousie slats

Settling - primary sedimentation



- removal of settleable organic particles and floating material (grease)
- most common form of primary treatment is quiescent settling with skimming, collection and removal of settled primary sludge, floating debris and grease
- preaeration or mechanical flocculation, often with chemical addition, can be used to enhance the primary settling
- primary settling is used in almost all larger WWTPs, but it can be omitted in smaller plants

Types of primary settling tanks

- rectangular tanks with horizontal flow
- circular tanks with radial flow

Basic technological parameters

Mean residence time

$\Theta = V_S \cdot \eta / Q$ [h]

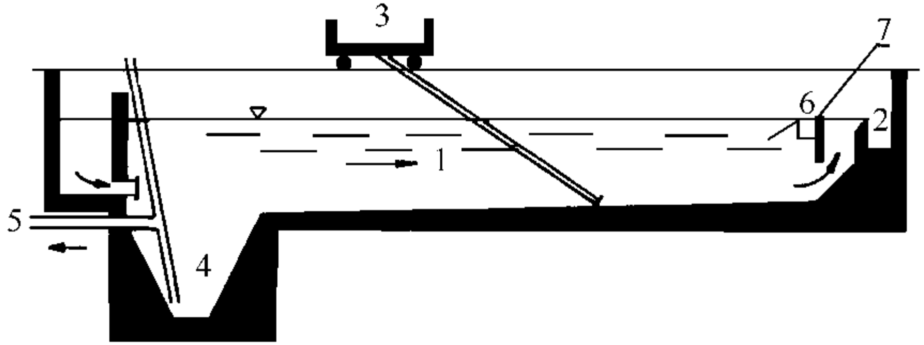
Surface overflow rate

$v_A = Q/A_h$ [$m^3/(m^2 \cdot h)$]

where V_S is the volume of the settling zone
η is the hydraulic efficiency of the primary settling tank
A_h is the surface area of the tank

Primary settling	Θ [h]	v_A [$m^3/(m^2 \cdot h)$]
biofilter system	2.0 – 4.0	0.7 – 1.4
activated sludge process	1.0 – 3.0	1.0 – 2.8

Rectangular tanks with horizontal flow



1 - settling zone
2 - effluent weir
3 - travelling bridge
4 - settled primary sludge
5 - sludge removal
6 - scum/floating material launder
7 - baffle

- width 5 – 10 m
- length up to 40 m
- depth 2 – 2.5 m

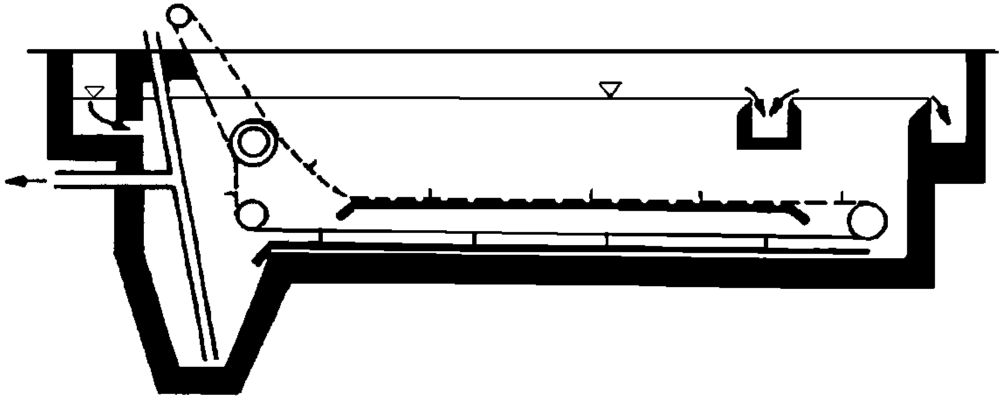
<u>Inlet parts</u>

- inlets should be designed to dissipate the inlet port velocity, distribute the flow and solids equally across the cross-sectional area of the tank and prevent short circuiting in the settling tank

Sludge scraping and surface skimming

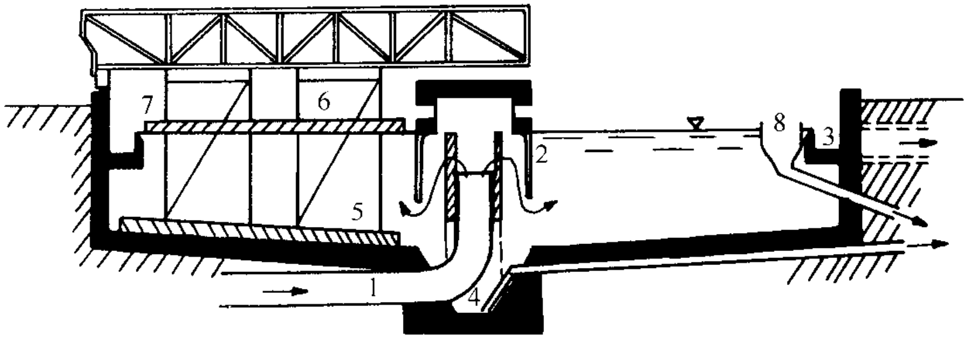
- settled primary sludge is scraped into a hopper where it is removed by gravity or pumping
- hopper is located at the inlet end of the tank to minimize the travel time of particles to the hopper

Travelling bridge



Chain-and-flight collector

Circular tanks with radial flow



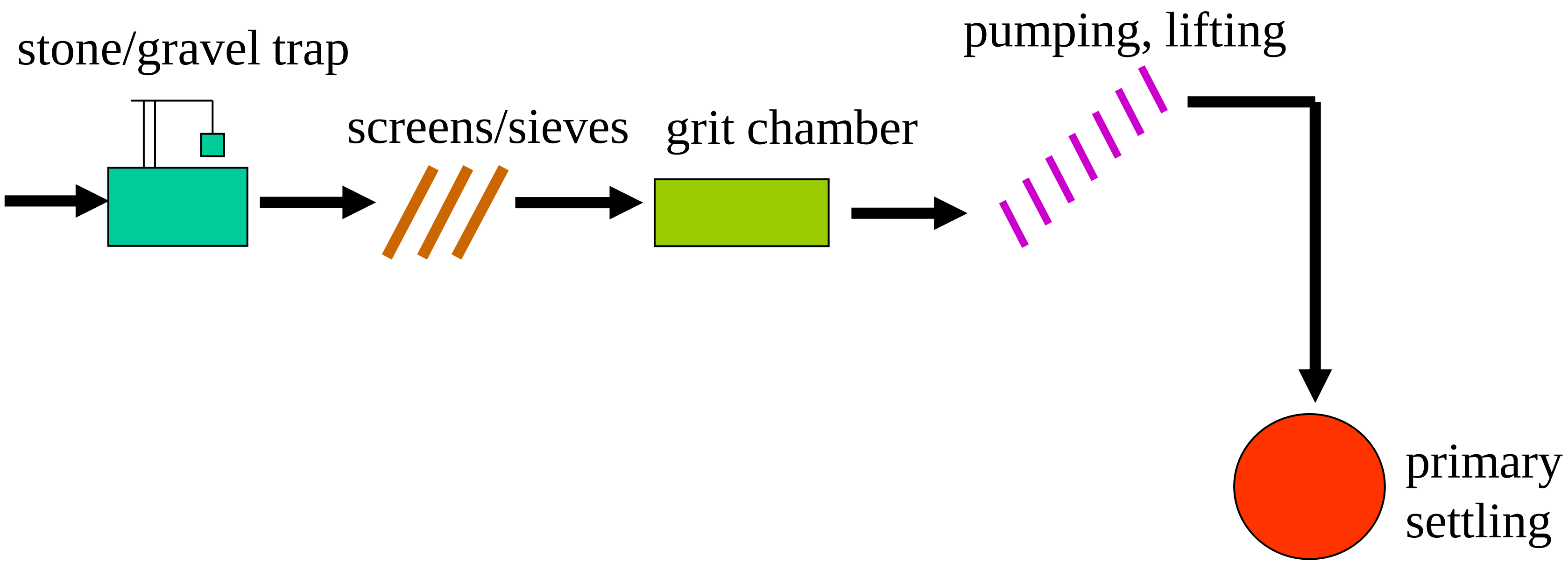
1 - inlet pipe
2 - influent/distribution well
3 - effluent launder
4 - settled primary sludge
5 - sludge scraping
6, 7 - surface skimming
8 - scum/floating material box

- diameter up to 50 m
- depth 2.5 – 3 m

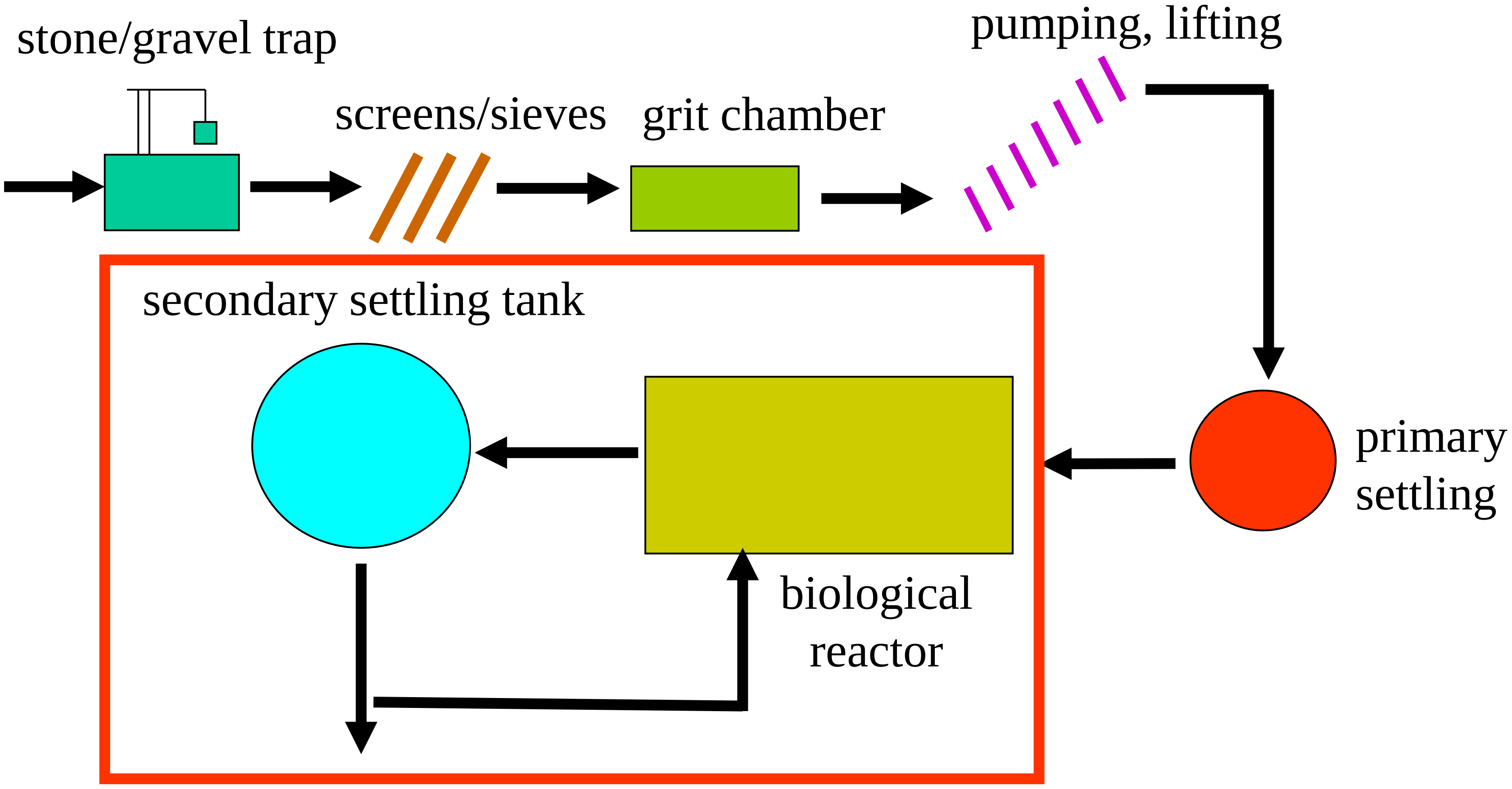
Scum box for floating material

Effluent weir

MECHANICAL WASTEWATER TREATMENT (PRIMARY TREATMENT)



BIOLOGICAL WASTEWATER TREATMENT (SECONDARY TREATMENT)



BIOLOGICAL WASTEWATER TREATMENT (SECONDARY TREATMENT)

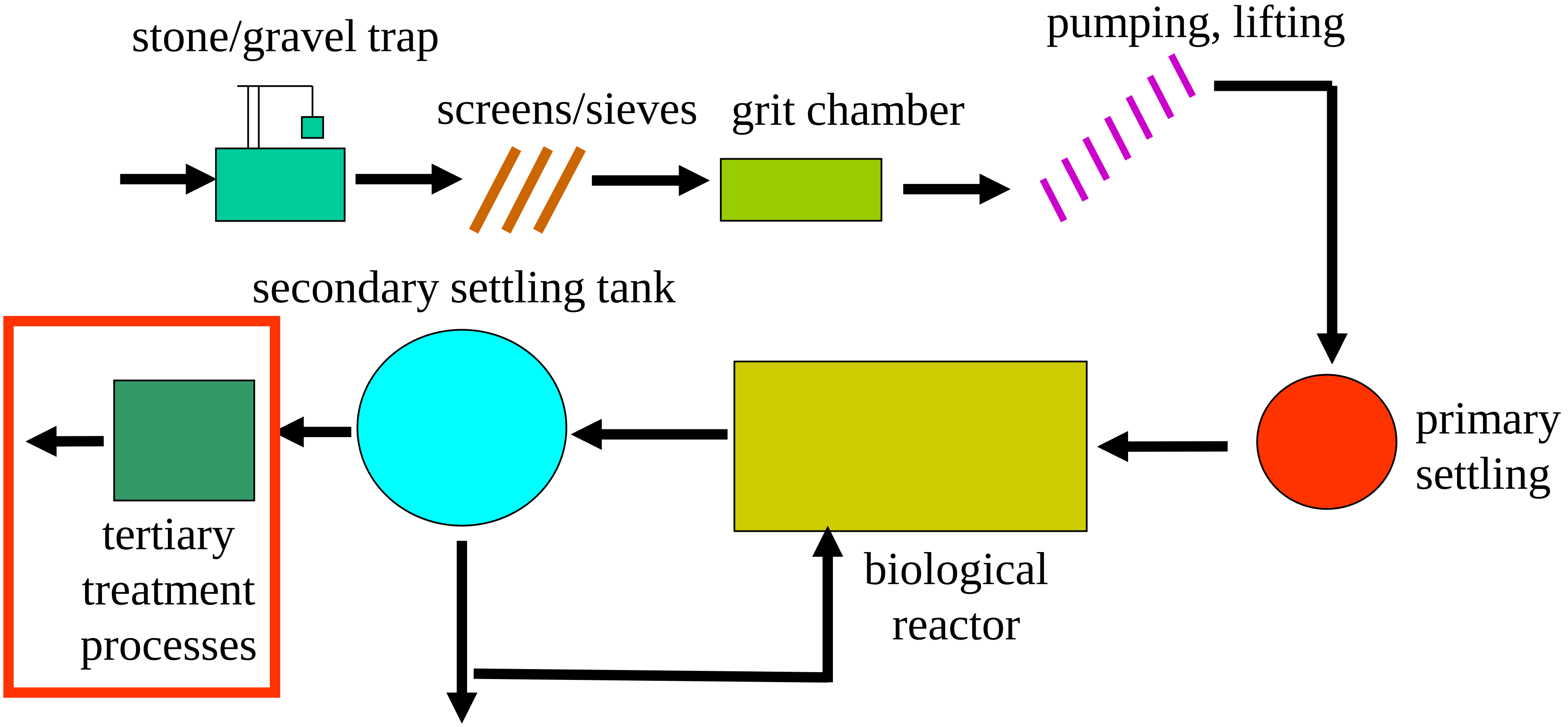
Biological reactor

- wastewater treatment by means of microorganisms (lecture 2)
- removal of C_{org}, N and P compounds (lectures 4 – 8)
- activated sludge process and biofilm processes (lecture 11)

Secondary settling tank

- activated sludge separation (lectures 9 – 10)
- secondary settling tank (lecture 12)

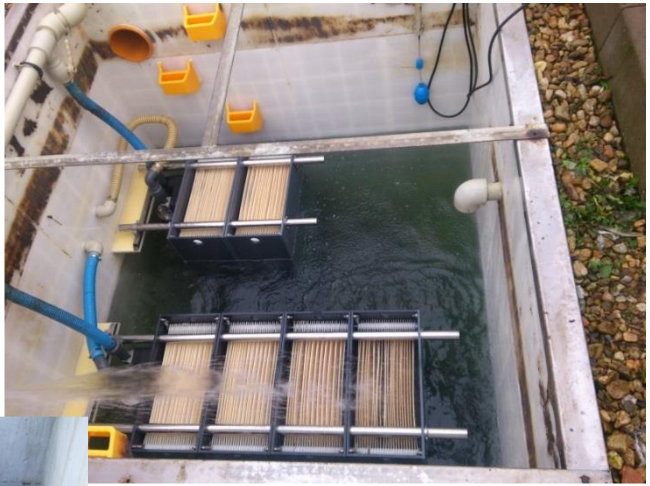
TERTIARY WASTEWATER TREATMENT



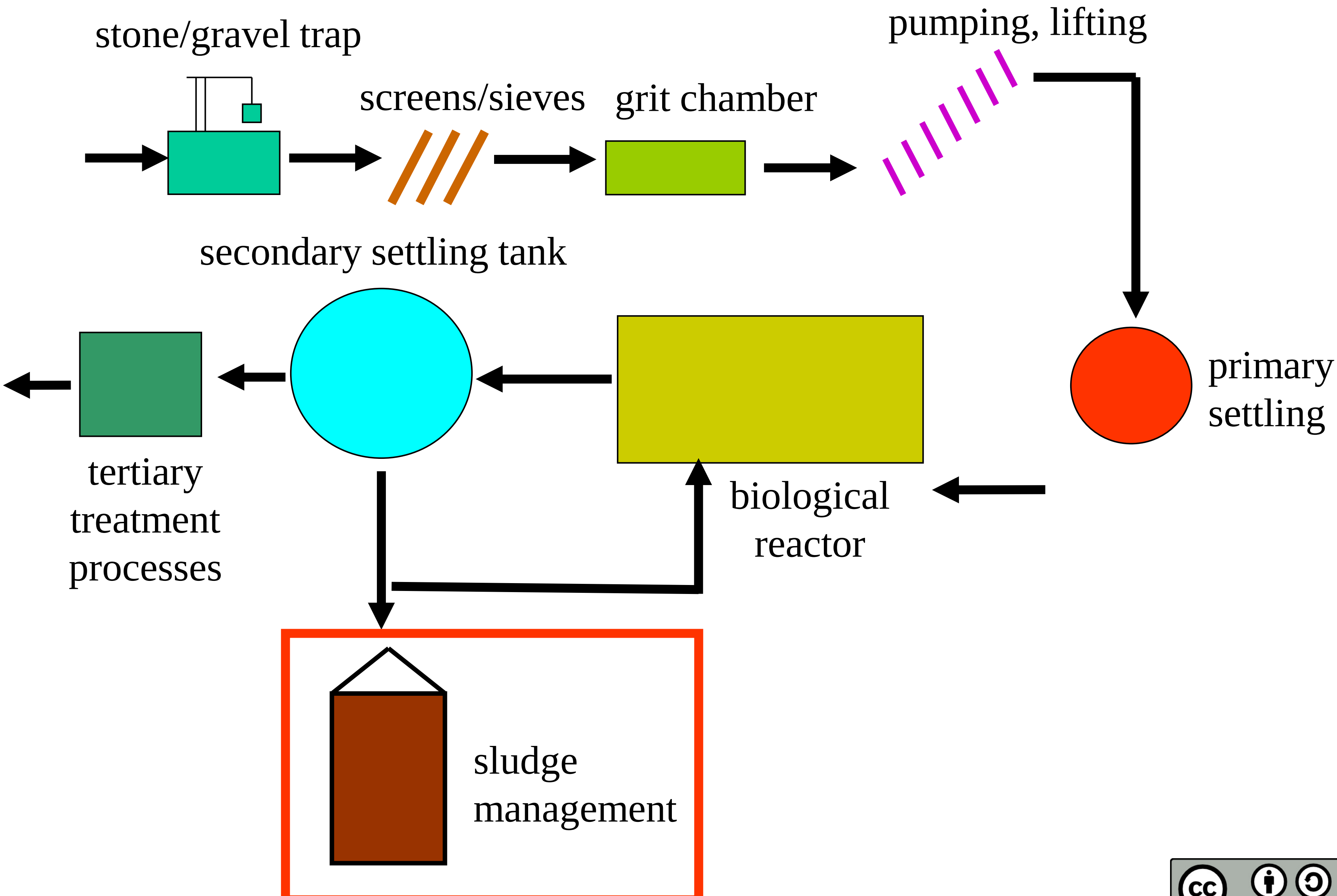
TERTIARY WASTEWATER TREATMENT

Tertiary treatment processes

- biological lagoons, filtration through microsieves, coagulation and/or precipitation, sand filtration, disinfection, membrane filtration… (lecture 14)



SLUDGE MANAGEMENT



SLUDGE MANAGEMENT

Sludge management processes

- sludge digestion, biogas production, sludge dewatering….

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Biochemical principles of organic compounds removal, nitrogen and phosphorus removal

Lecture 4

Main purposes of biological wastewater treatment

- **Remove organics (COD, BOD, TSS) at higher levels than primary treatment**
- **Remove nutrients (N & P)**
- **Remove bacteria at higher levels than primary treatment**

Additional purposes of biological wastewater treatment

("tertiary treatment" in terms of Directive 91/271/EEC)

- Remove individual organics / priority organic pollutants + emerging pollutants (PPCPs)
- Remove toxic metals
- Prepare wastewater for effluent reuse
- Etc., etc.,…!!

Removal of organic pollution

- principles of organic carbon removal
- balanced and unbalanced growth
- kinetics of bacterial growth and decay and organic substrate removal
- basic composition of microbial consortia used for organic carbon removal

Overall process “reaction”

CHONP + O_2 + microorganisms → more biomass + end products

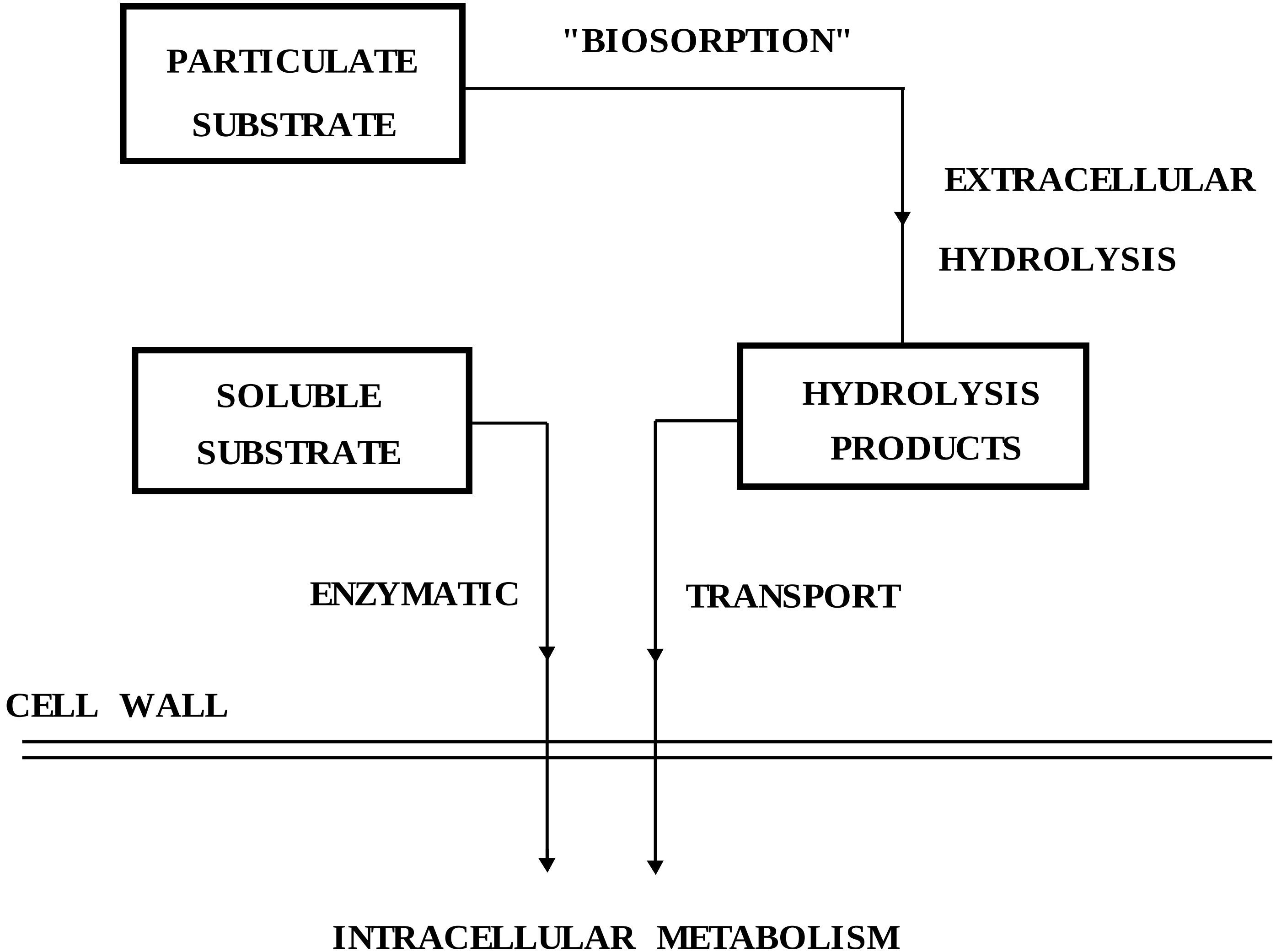
CHNOP = wastewater
O_2 = oxygen
microorganisms = mixed liquor
more biomass = WAS, effluent TSS
end products = CO_2, BOD, NH_3, NO_3, PO_4,……

Overall process

- **Microorganisms grow on wastewater components to produce more microorganisms and end products**
- **Wastewater: source of organic (inorganic) carbon and energy for the growth of microorganisms:**
  - ***chemolithotrophic***
  - ***organotrophic***

Bacterial kinetics and selection

REMOVAL OF ORGANIC POLLUTION



(KATABOLISM and ANABOLISM)

Bacterial kinetics and selection

GROWTH OF ORGANOTROPHS

Specific growth rate μ

$$\mu = dX / X\,dt$$

SUBSTRATE (ORG. CARBON)

- ENERGY
- CELL GROWTH
  - SYNTHESIS OF ATP, etc
  - FORMATION OF STORAGE PRODUCTS
  - CELL MULTIPLICATION (NEW CELLS)

DEPENDS ON

S_0 / X_0

PRACTICAL APPROACH:

GROWTH ≈ INCREASE IN BIOMASS WEIGHT

Define growth rate (μ)

Growth rate is a fractional rate of increase of microorganism mass, *i.e.* mass of sludge formed/mass of sludge in system

$$\frac{\Delta X}{\Delta t . X} = \mu, \quad d^{-1}$$

Bacterial kinetics and selection

BIOMASS „DECAY“

- **SIMULTANEOUS ENDOGENOUS METABOLISM**
  - **INTERNAL STORAGE PRODUCTS EXPLOITATION**
  - **CELL BIOMASS (AUTOLYSIS)**

specific decay rate

- **CELL DEATH**

$$b = -\, dX / X\, dt$$

- **PREDATION**
  - **OFTEN SELECTIVE**

Define decay rate (b)

Decay rate is a fractional rate of decrease of microorganism mass, *i.e.* mass of sludge decayed/mass of sludge in system

$$\frac{-\Delta X}{\Delta t . X} = b, \quad d^{-1}$$

Bacterial kinetics and selection

Growth and Decay

NET GROWTH RATE

$$\mu_{net} = \mu - b$$

Since decay goes on all the time, it "subtracts" from the rate at which sludge grows, so:

- **Net growth rate = Growth rate – Decay rate**

Conversion of substrate into biomass

The amount of sludge formed when activated sludge grows on particular wastewater is a constant called the "Yield" (Y), where:

$$Y = \frac{\text{mass of sludge formed}}{\text{mass of substrate removed}}$$

Conversion of substrate into biomass

$$X_t - X_0 = Y_{obs}\ (S_0 - S_t) = -\,Y_{obs}\ (S_t - S_0)$$

$$dX / dt = (\mu - b)\ X$$

$$dX/dt = -\ Y\ dS/dt$$

$$-dS / dt = \mu\ X / Y$$

$$-\,dX / dS = Y_{obs} = [(\mu - b)/\ \mu\ ]\ Y = \mu_{net}/Y$$

Y_{obs} = *yield coefficient for sludge age > 0*

Bacterial kinetics and selection

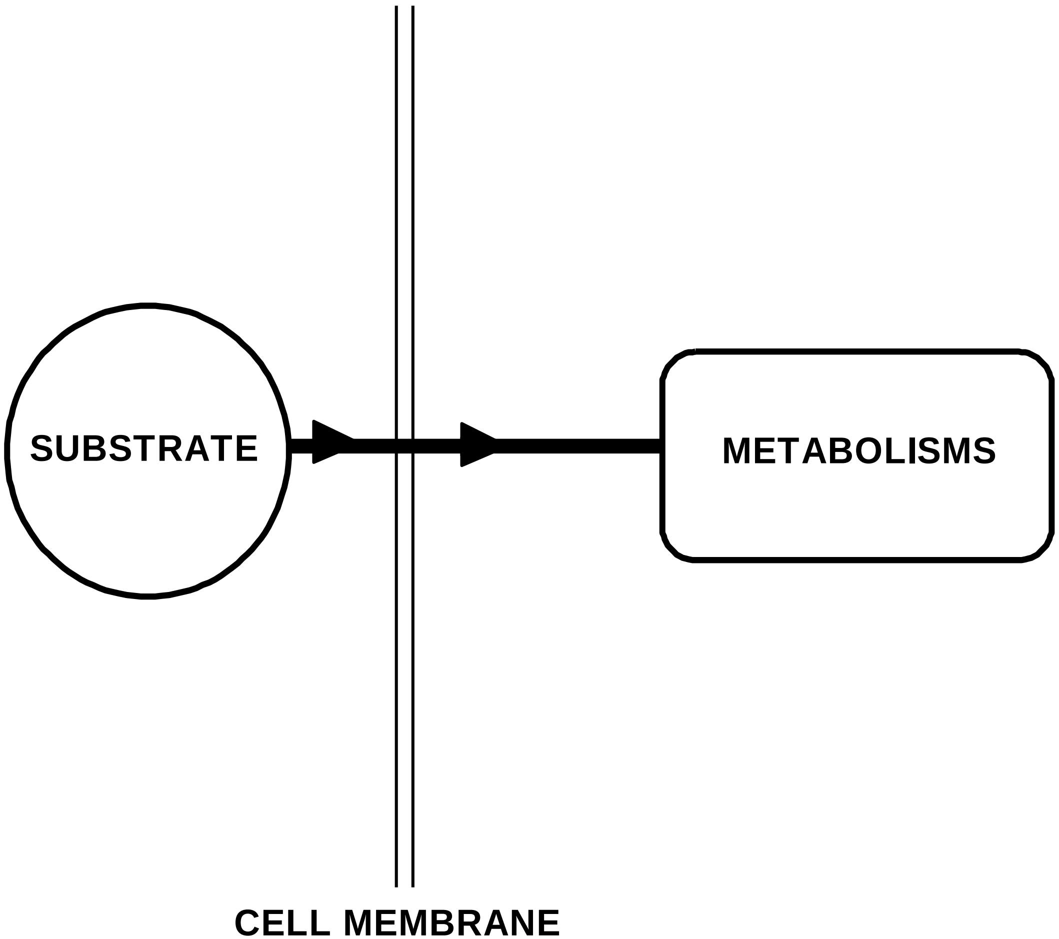
REMOVAL OF ORGANIC POLLUTION

Two types of growth according to the relationship between the rate of substrate transport and the rate of substrate use (metabolism)

- **BALANCED GROWTH**
- **UNBALANCED GROWTH**

Bacterial kinetics and selection

KINETIC SELECTION - BALANCED GROWTH



RATE OF TRANSPORT = RATE OF METABOLISM

= SLOW

Bacterial kinetics and selection

KINETIC SELECTION

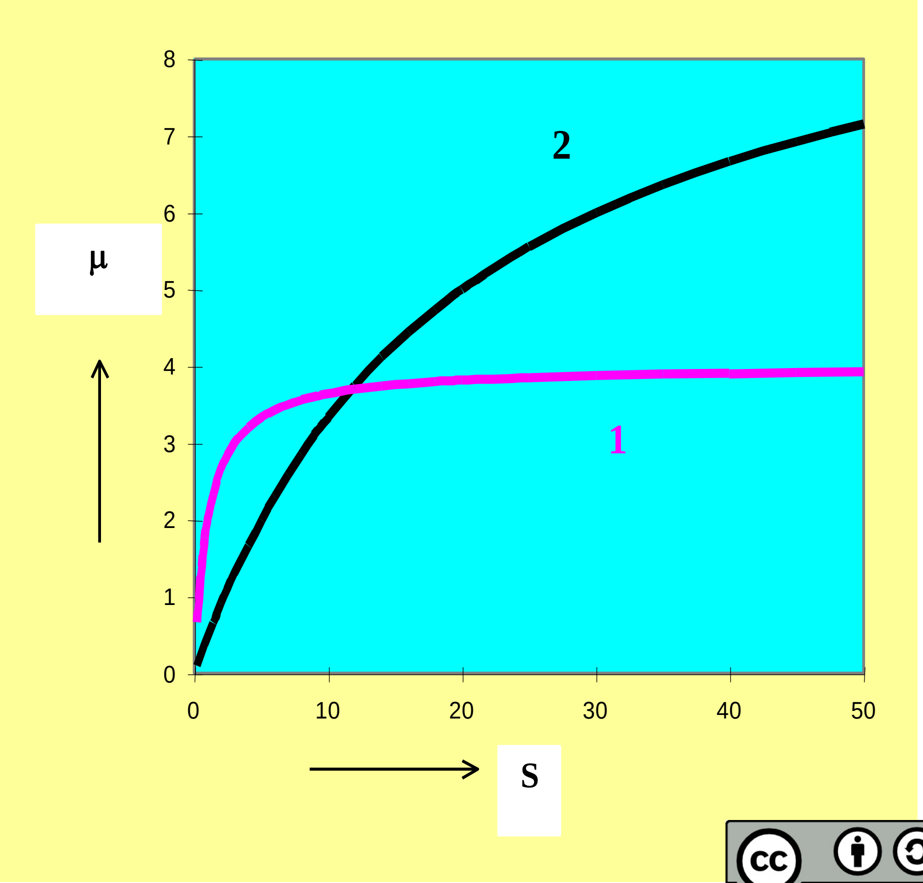
1) “BALANCED GROWTH”

- μ_{MAX} and K_S strategy

$$\mu = \mu_{MAX} \frac{S}{S + K_S}$$

1) K_S STRATEGY

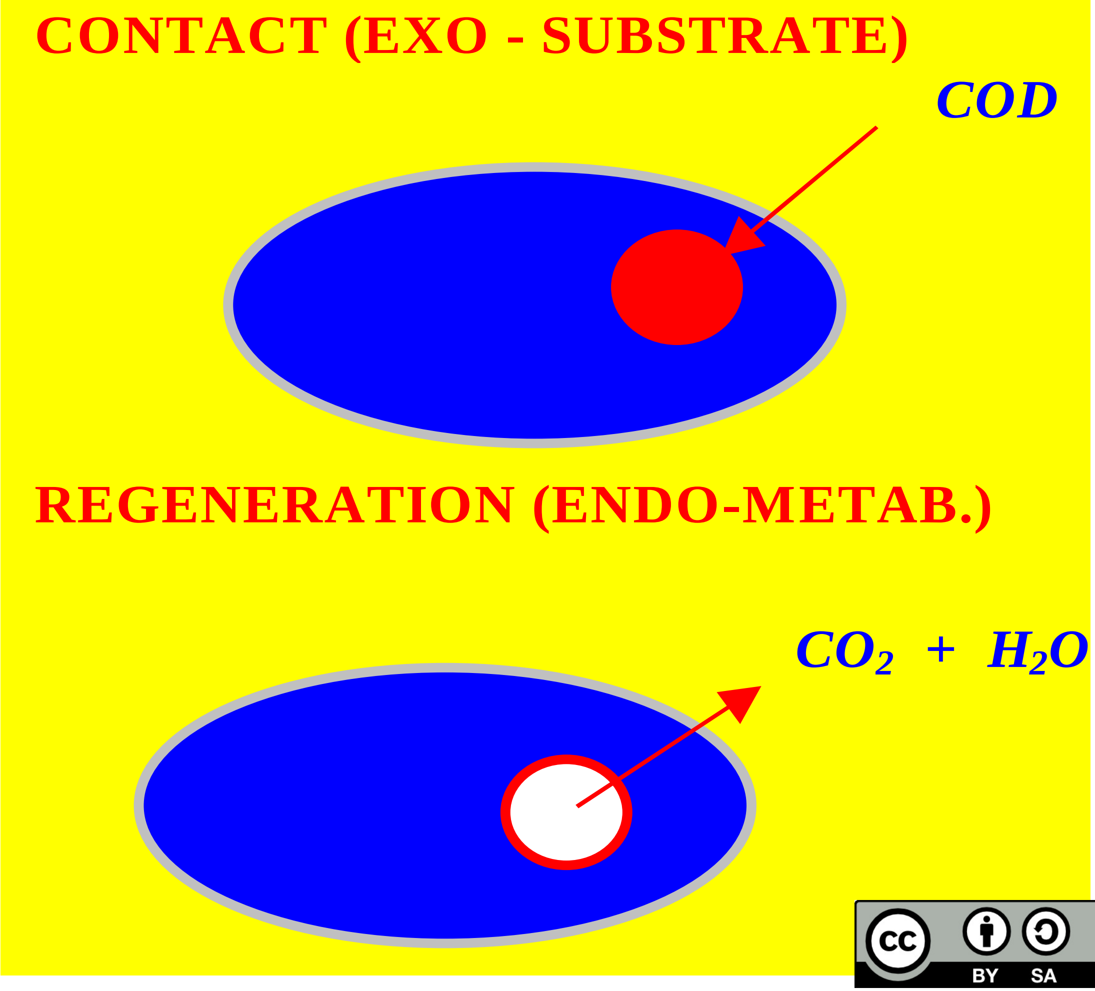
2) μ_{MAX} STRATEGY



Bacterial kinetics and selection

KINETIC SELECTION

2) “UNBALANCED GROWTH”

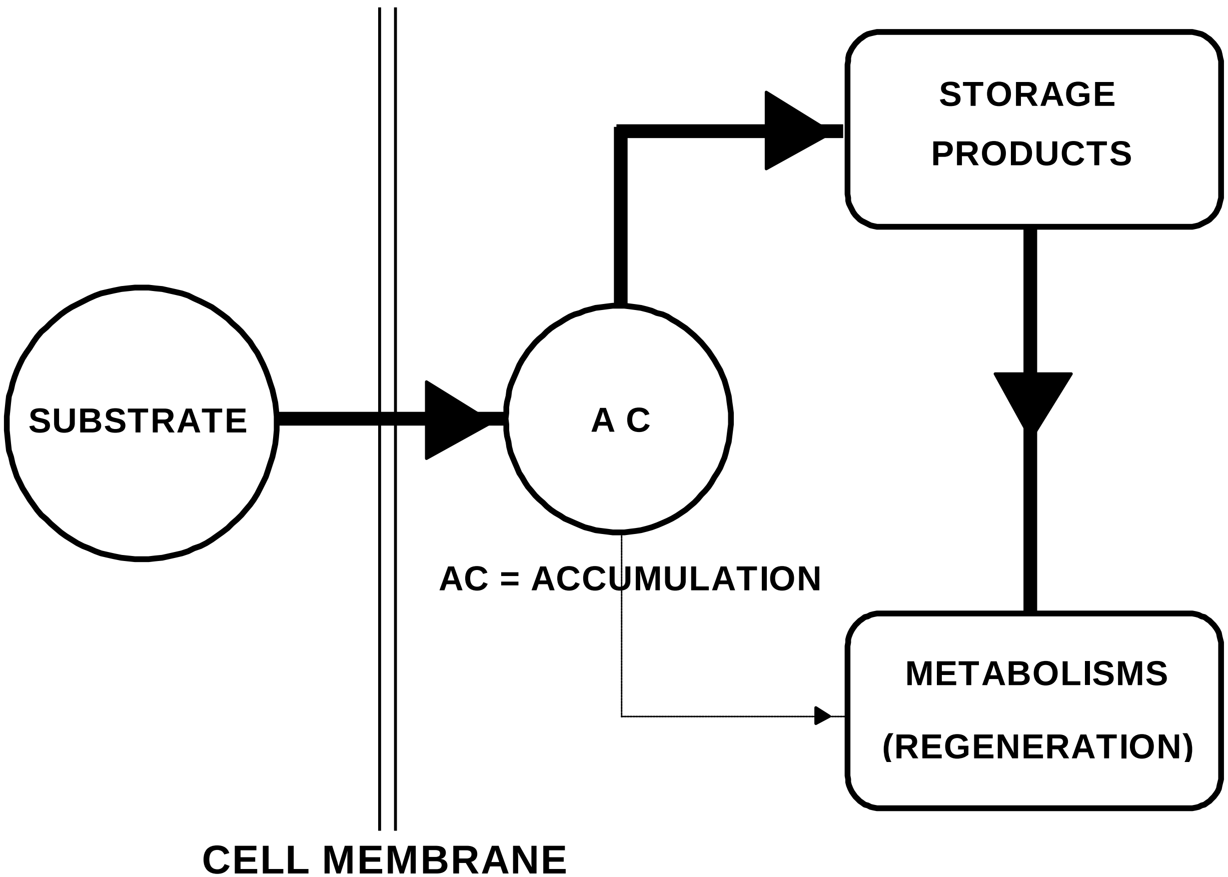


ACTIVATED SLUDGE

SYSTEM WITH SUBSTRATE CONCENTRATION GRADIENT

Bacterial kinetics and selection

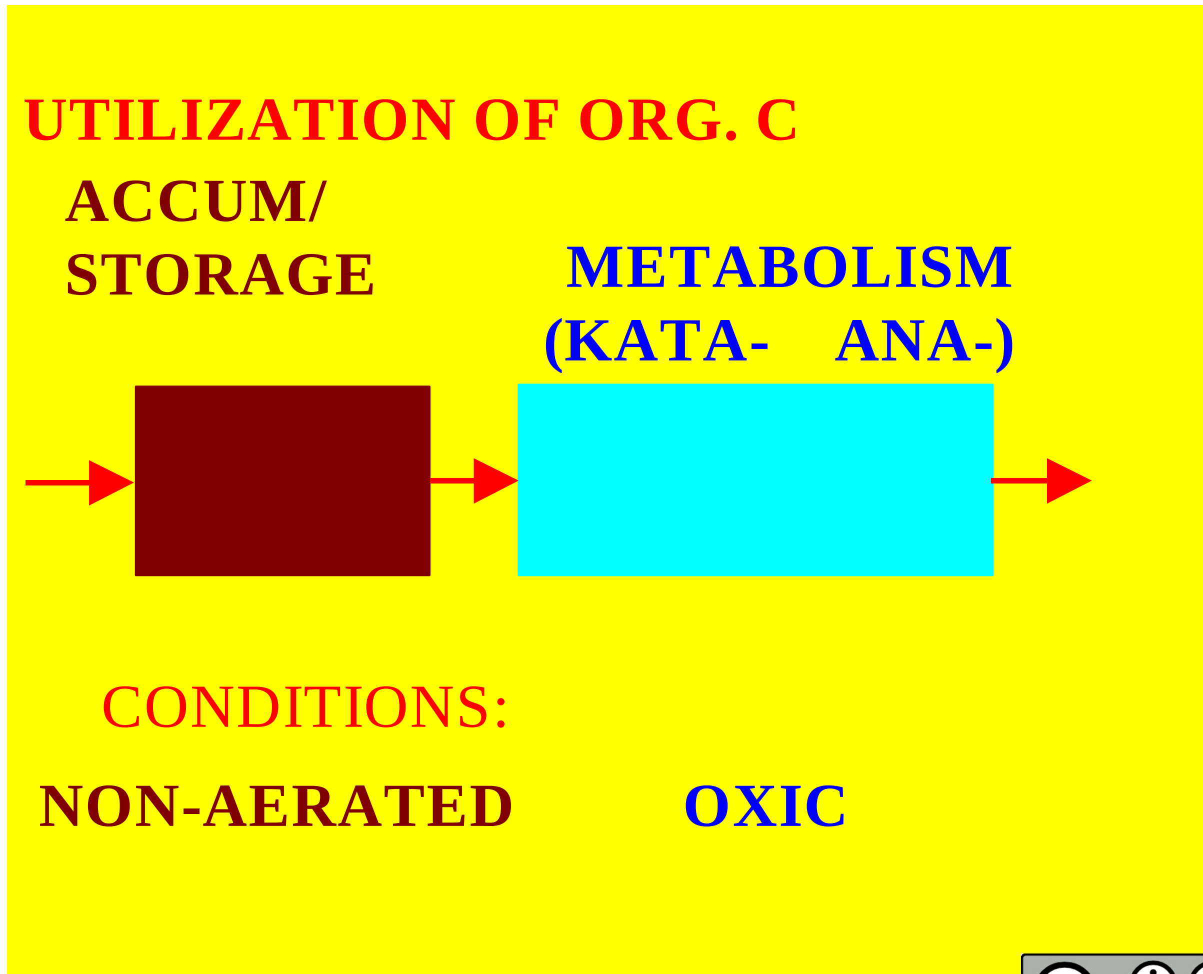
KINETIC SELECTION - UNBALANCED GROWTH



RATE OF TRANSPORT = RATE OF ACCUMULATION/ /STORAGE = FAST

Bacterial kinetics and selection

METABOLIC
SELECTION



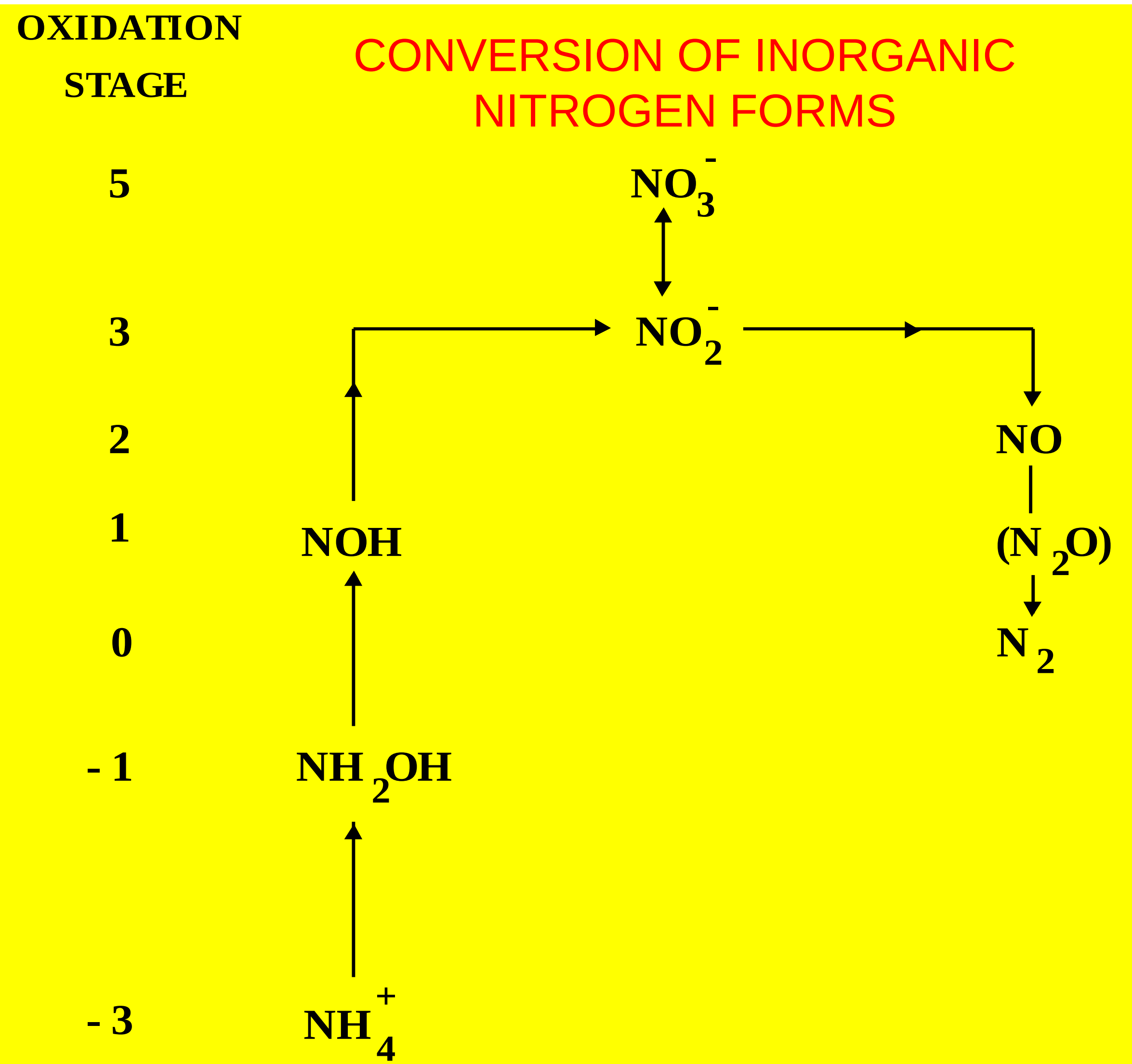
Bacterial kinetics and selection

OXIC / ANOXIC CONDITIONS

The result of the selection depends on the ability to use nitrate nitrogen as an electron acceptor under anoxic conditions (i.e., to denitrify)

Bacterial kinetics and selection

OXIC / ANOXIC CONDITIONS



NITRIFICATION:

N donor of 8 electrons

DENITRIFICATION:

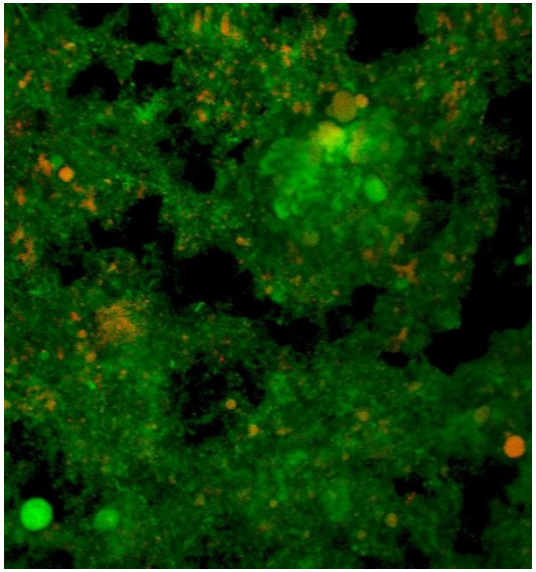
N acceptor of 5 electrons

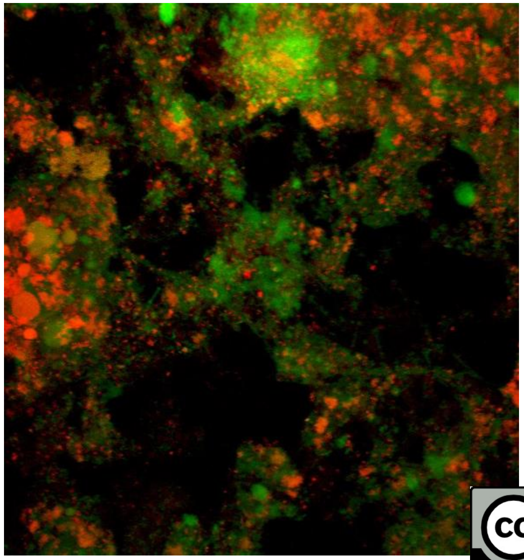
(1 N = 5/4 O_2)

(1 g N = 2.86 g O_2)

Nitrification

- **Definition: the stepwise oxidation of ammonia (NH_4^+) to nitrite (NO_2^-) and then nitrate (NO_3^-) by oxygen (O_2) performed by two groups of slow-growing "nitrifying bacteria"- the ammonia oxidizers (AOB) and the nitrite oxidizers (NOB)**





Denitrification

Definition:

The reduction of nitrite (NO_2^-) and nitrate (NO_3^-) to nitrogen gas (N_2) by organic matter (BOD, degradable COD) under anoxic (no oxygen) conditions.

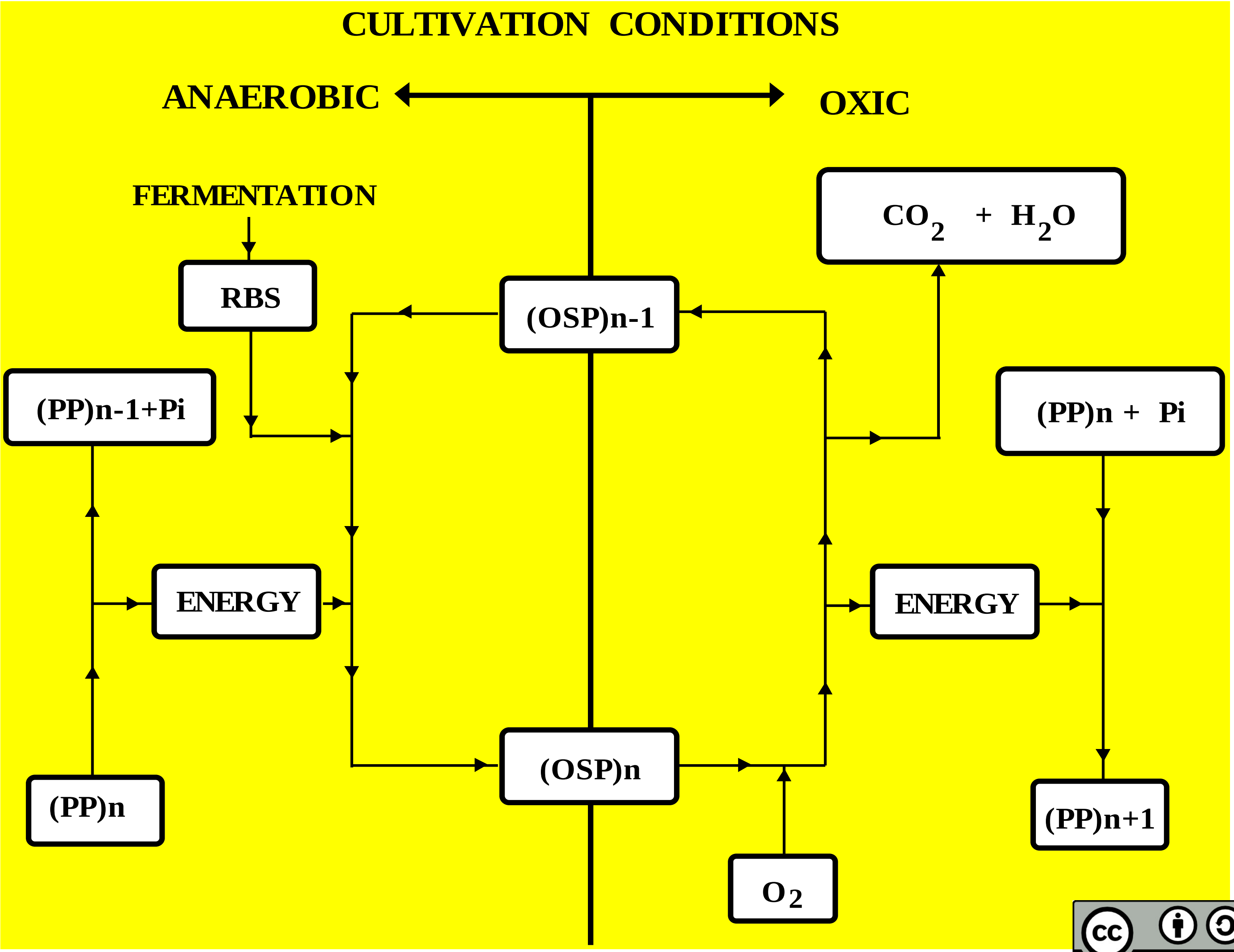
Bacterial kinetics and selection

OXIC / ANAEROBIC CONDITIONS

The result of the selection depends on the ability to use an alternative source of energy under anaerobic conditions (i.e., principle of EBPR)

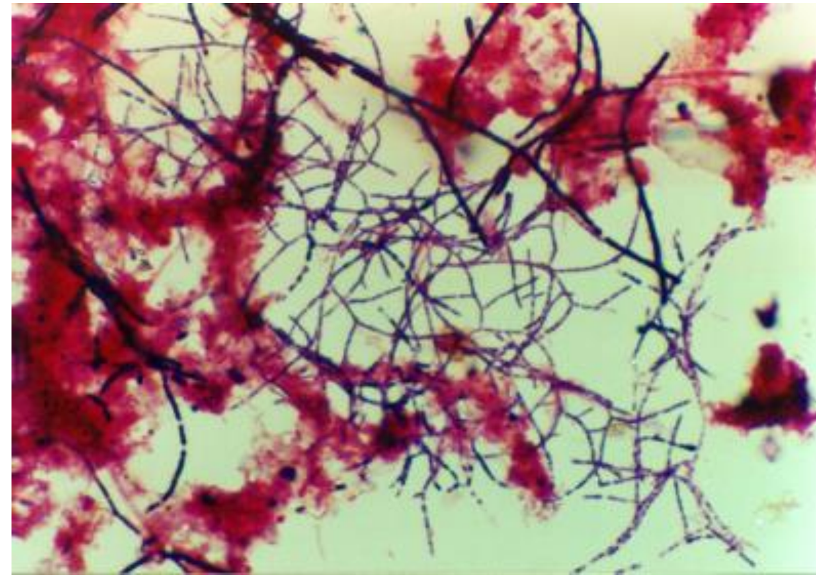
Bacterial kinetics and selection

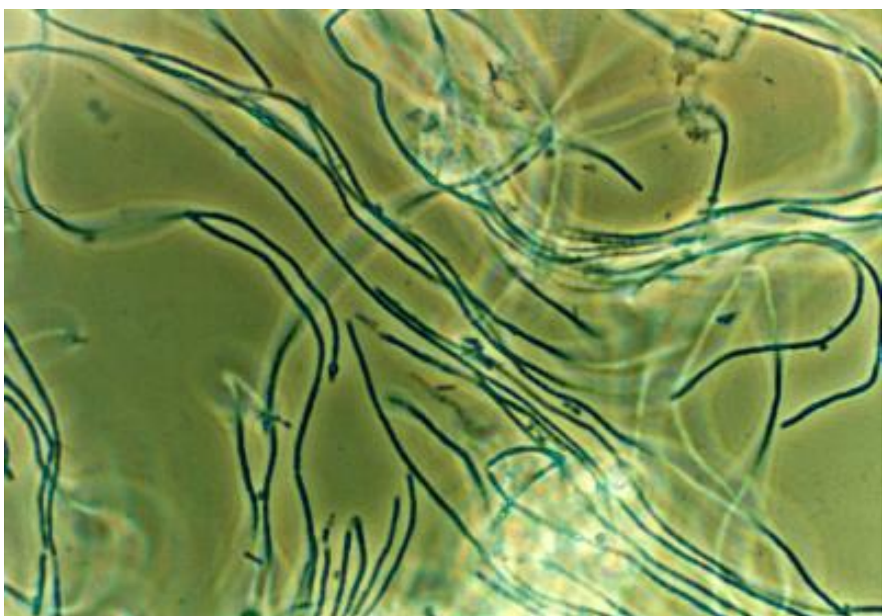
OXIC / ANAEROBIC CONDITIONS - principle of EBPR



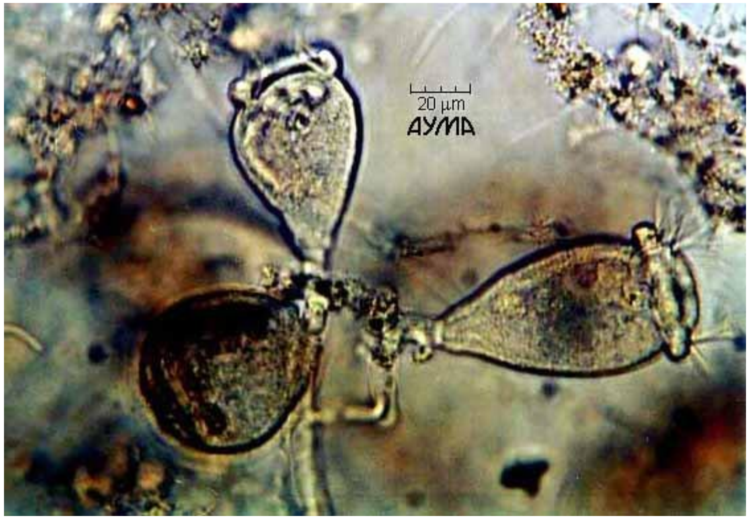
Basic composition of microbial consortia used for biological wastewater treatment

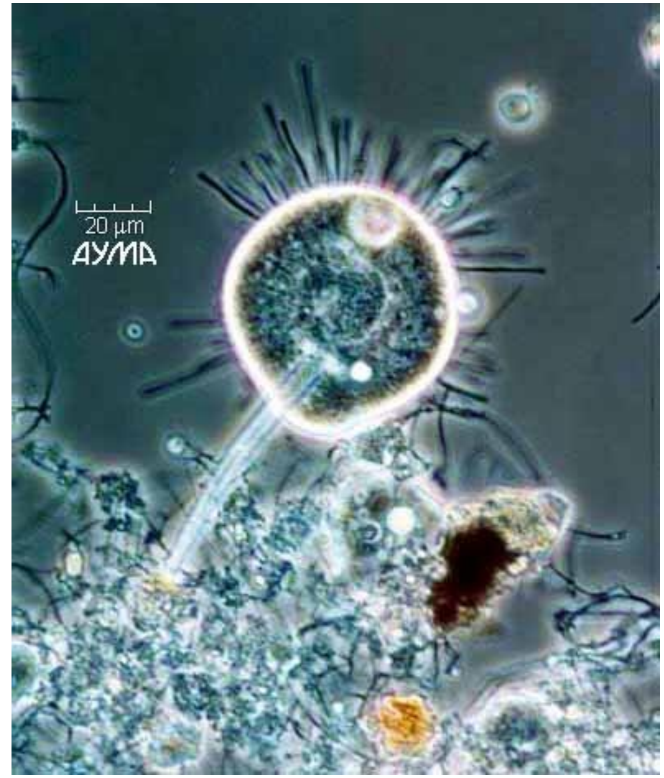
- more than 95 % of total biomass: organotrophic bacteria
- bacteria producing extracellular polymers (glycocalyx)
- formation of activated sludge flocs or biofilms
- important morphological group: filamentous bacteria or cyanobacteria






10 µm
AYMA


20 µm
AYMA


20 µm
AYMA


20 µm
AYMA


20 µm
AYMA

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Activated sludge process:

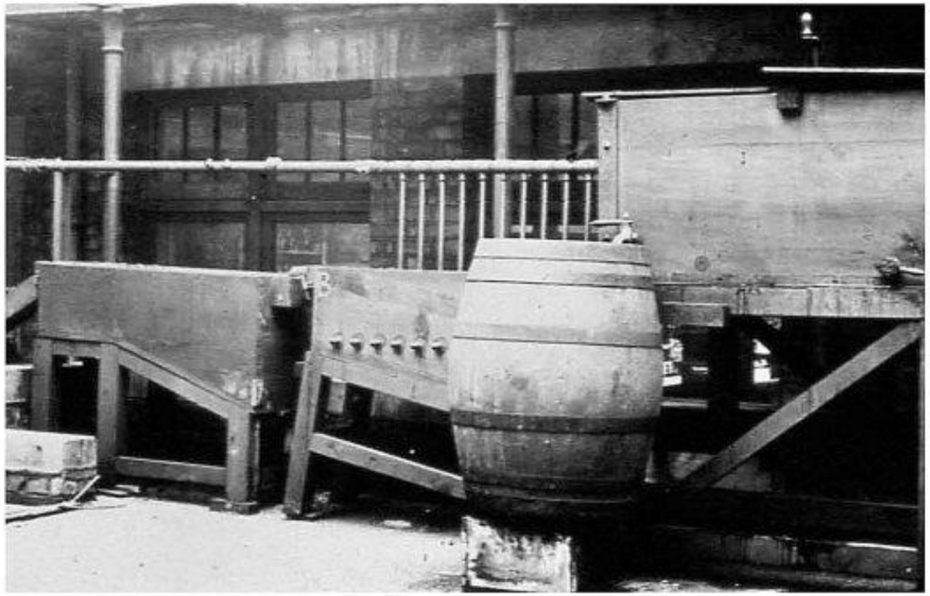
i) Principles, technological parameters
ii) Technological modifications, conventional and batch systems, sludge regeneration
Lecture 5

Activated sludge process - 1914

Founding fathers: Ardern and L

Activated sludge process 1913/1915

Manchester pilot plant, 14 Febr, 1914



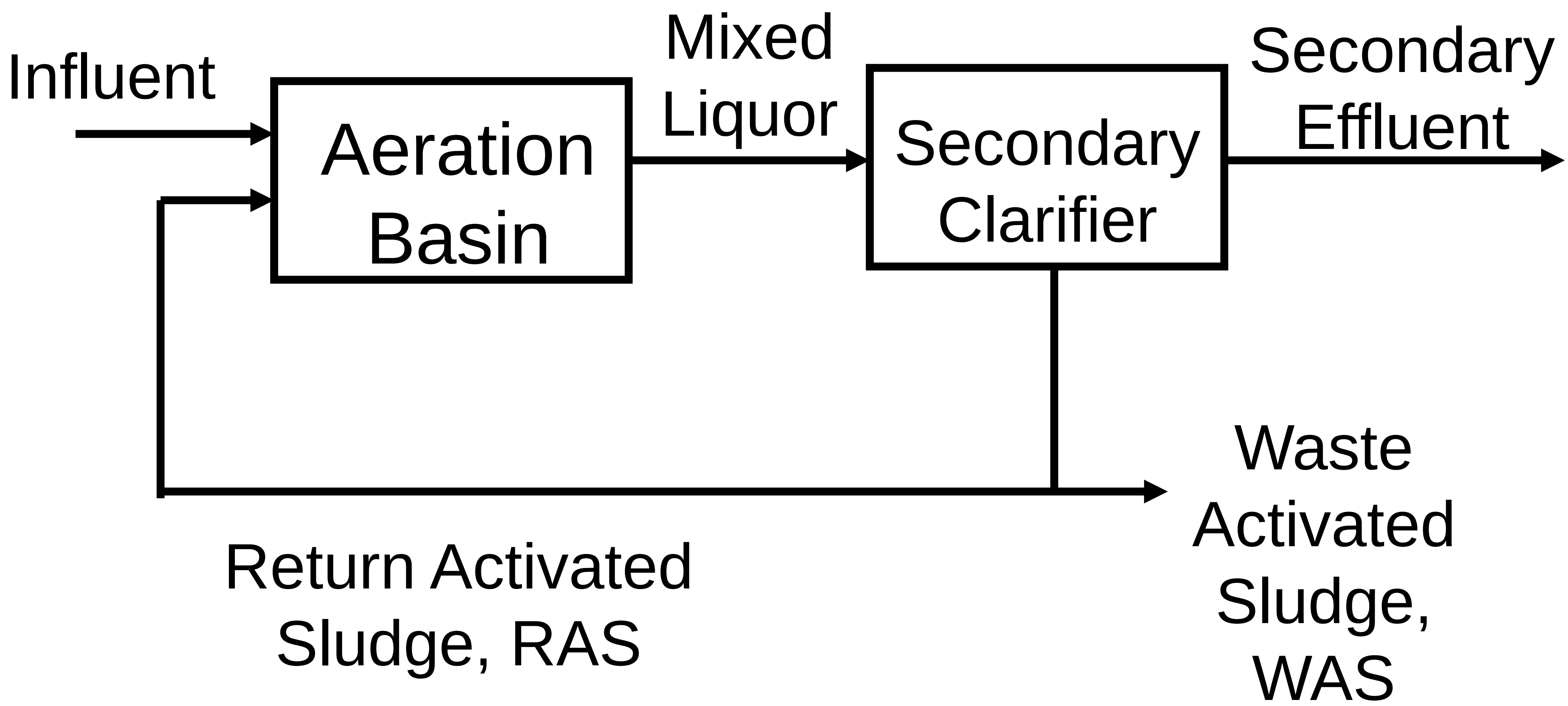
experimental plant

aeration tank

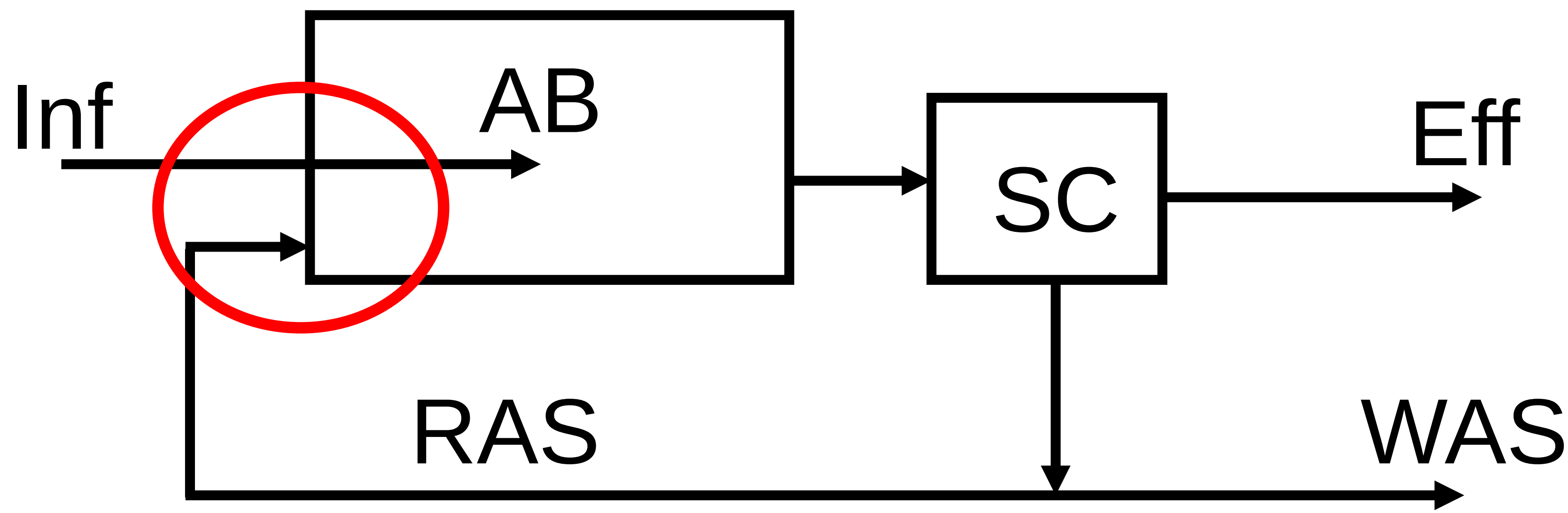
Basic activated sludge process configurations

- Continuous flow with gravity clarifier
- Continuous flow with membrane (MBR)
- Sequencing batch reactor (SBR)

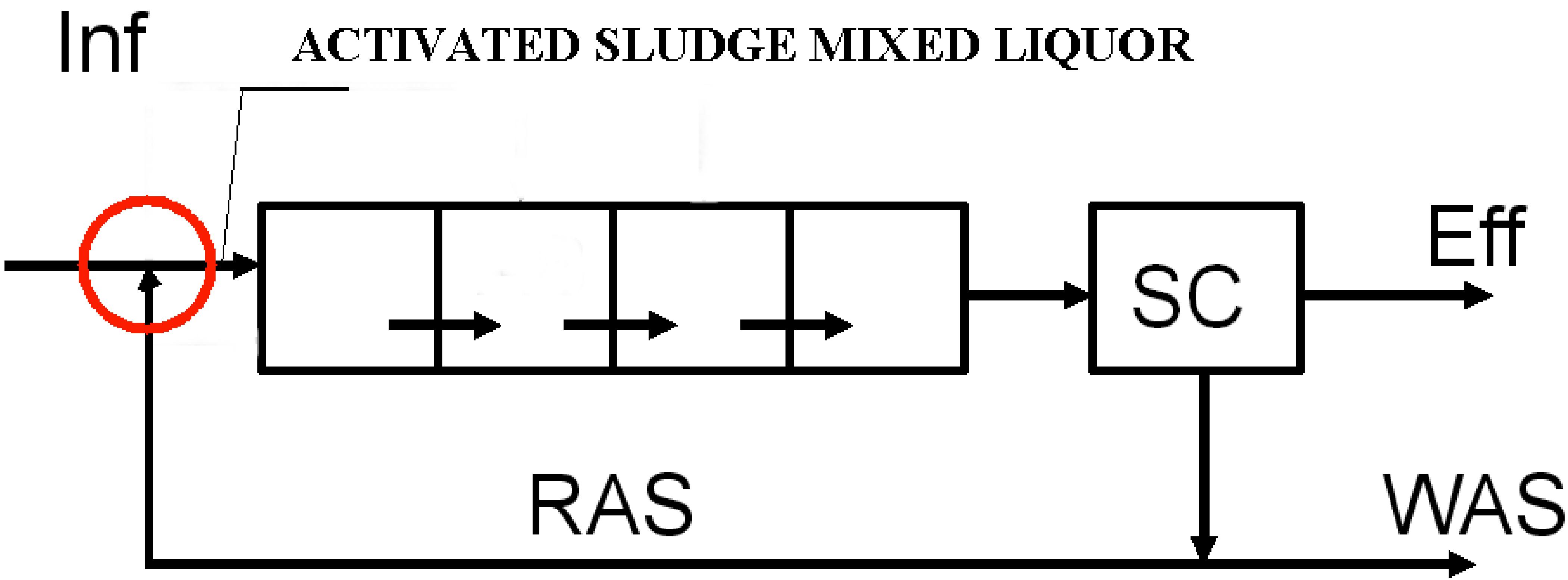
Continuous flow with gravity clarifier



Completely mixed activated sludge (CMAS)



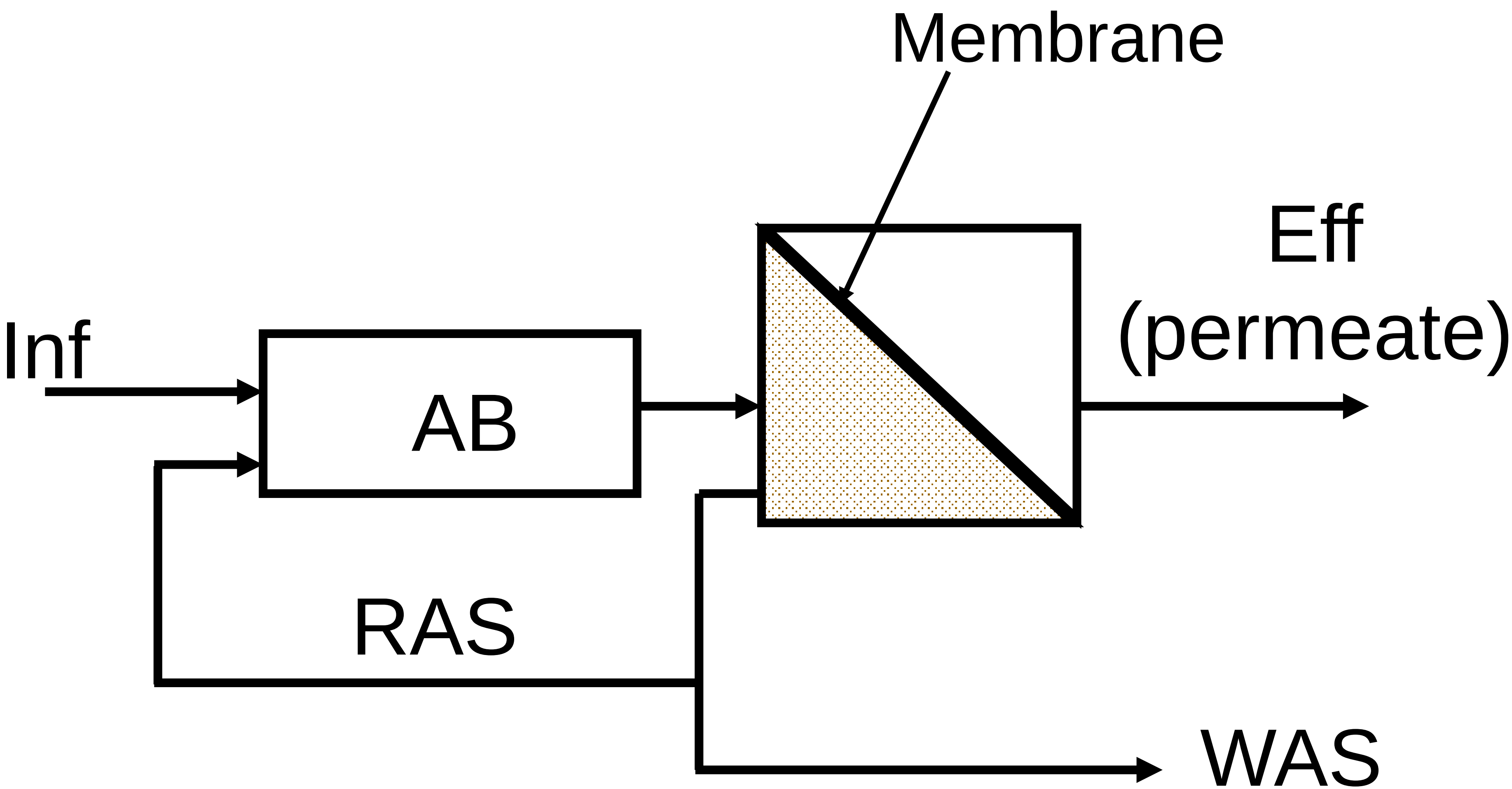
Compartmentalized plug-flow activated sludge system



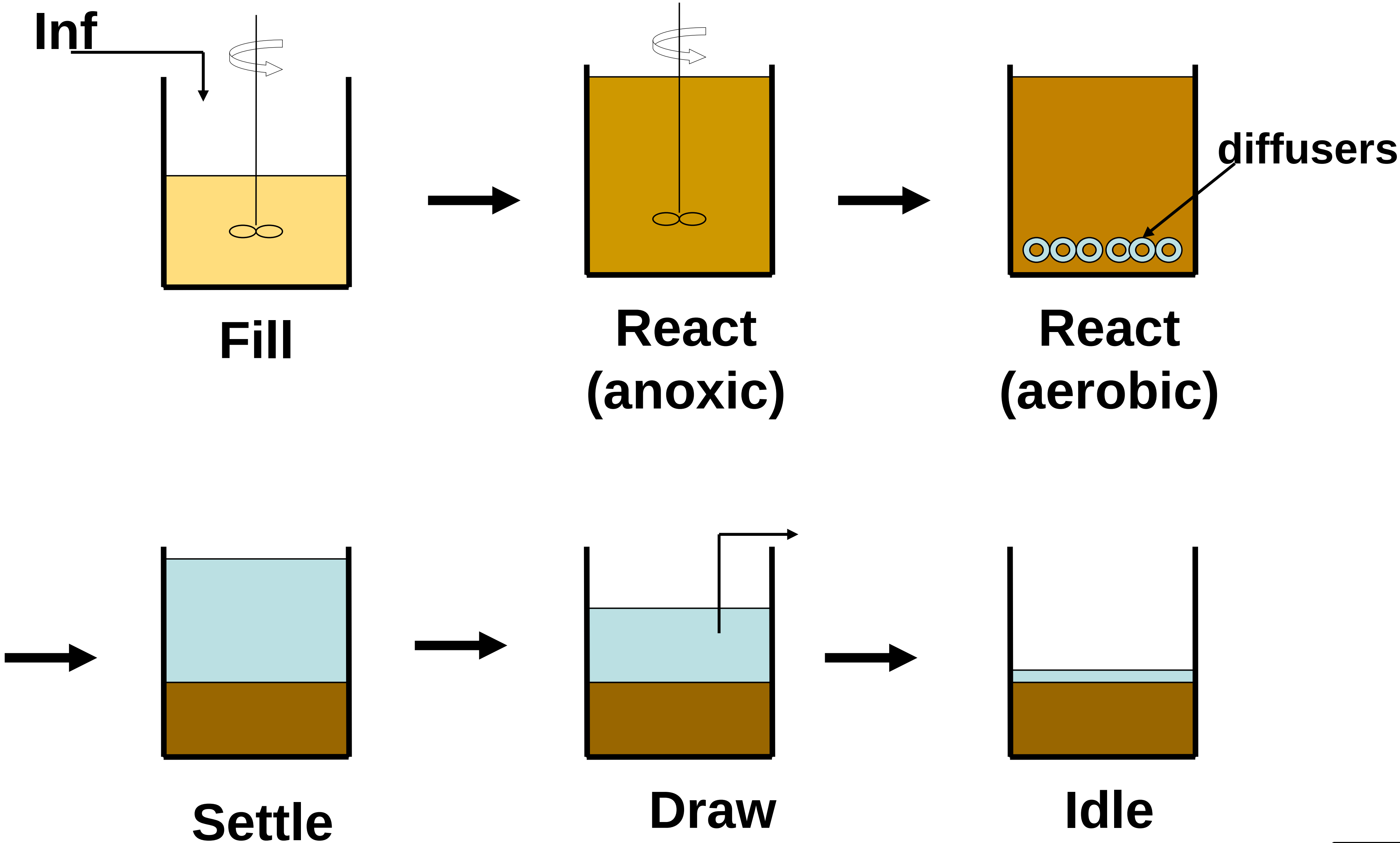
Compartmentalized plug-flow activated sludge system

Examples of compartmentalized systems

Continuous flow with membrane (MBR)



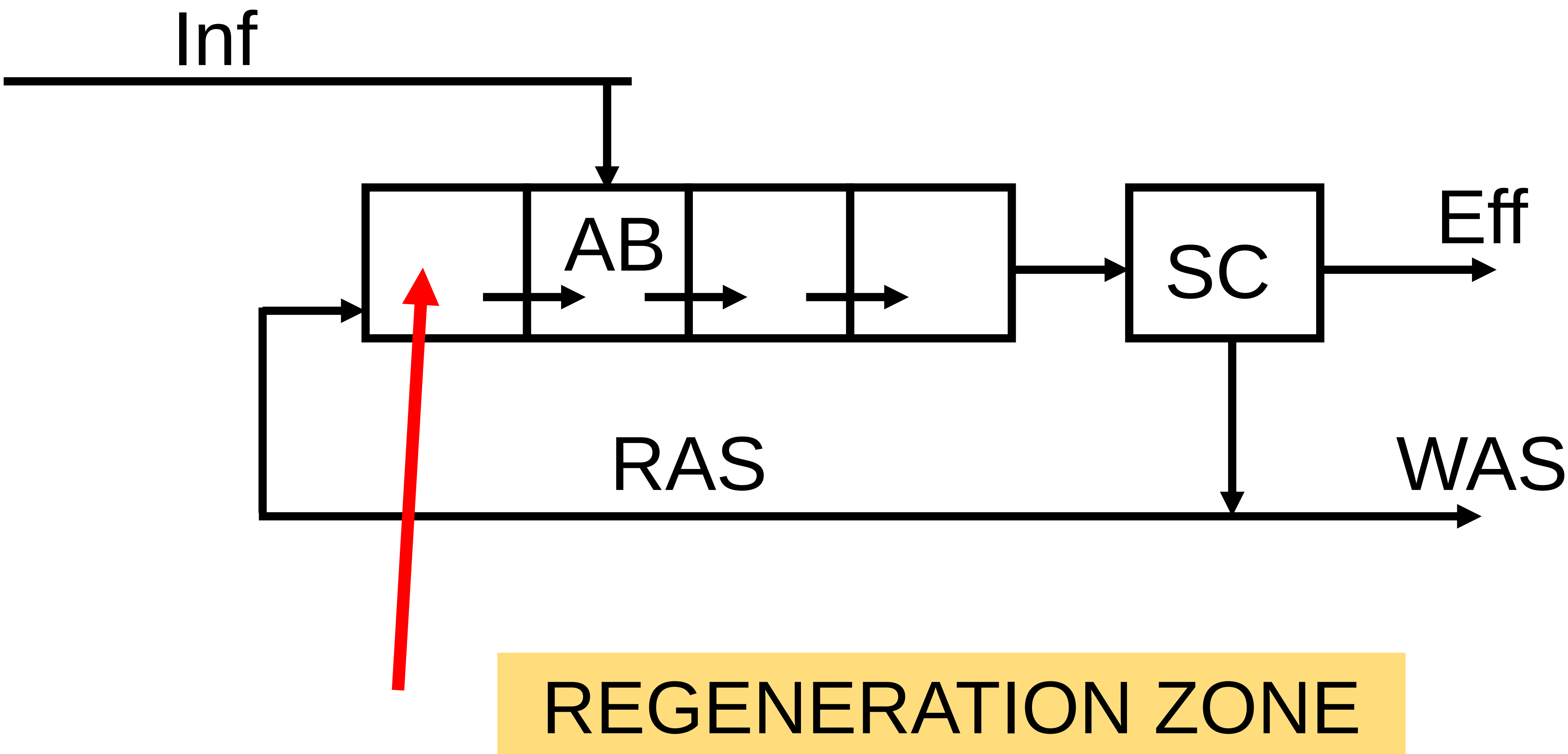
Sequencing batch reactor



Individual phases of SBR working cycle

Common process flow schemes

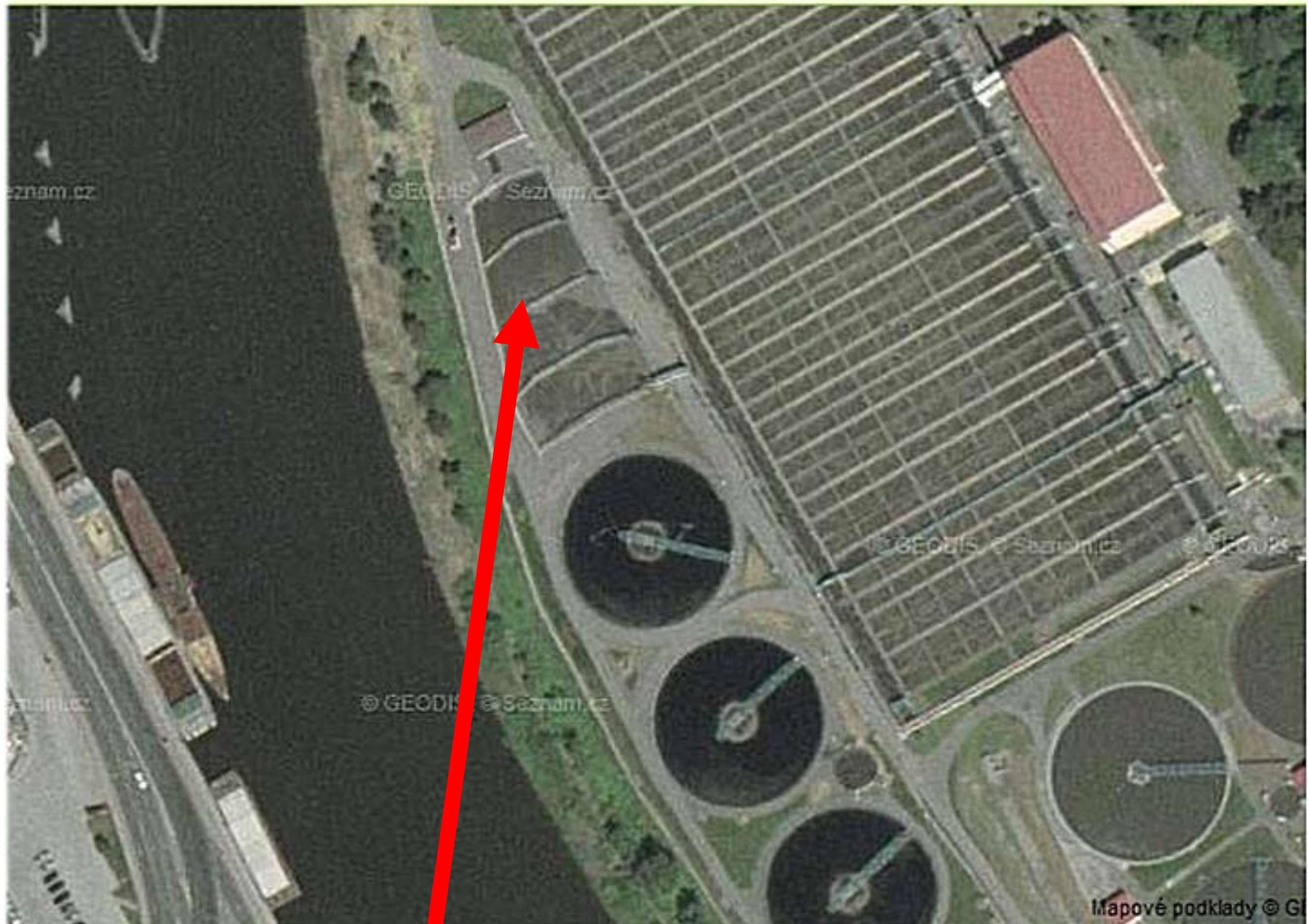
Contact stabilization/ AS process with regeneration



Contact stabilization/ AS process with regeneration

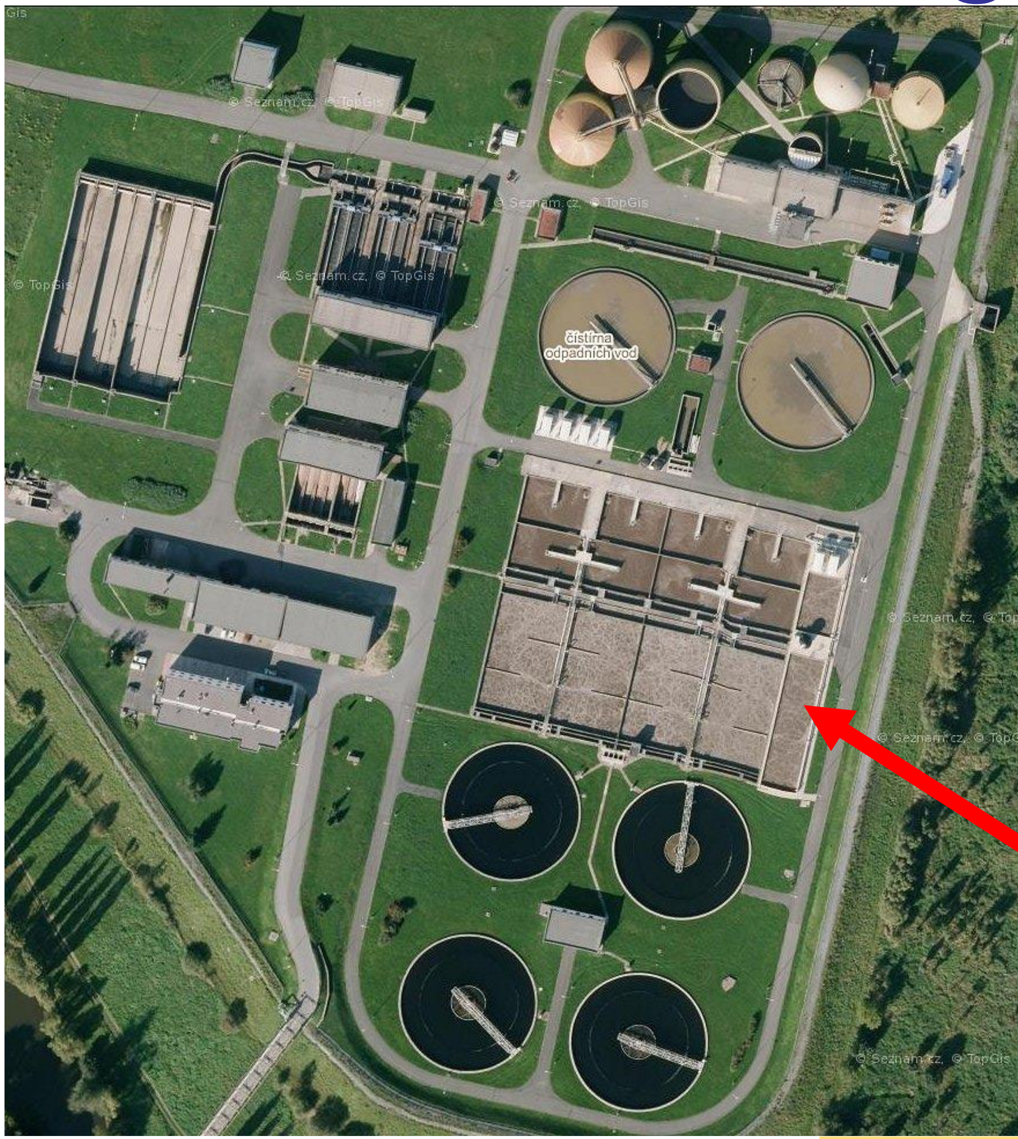
REGENERATION ZONE

Contact stabilization/ AS process with regeneration



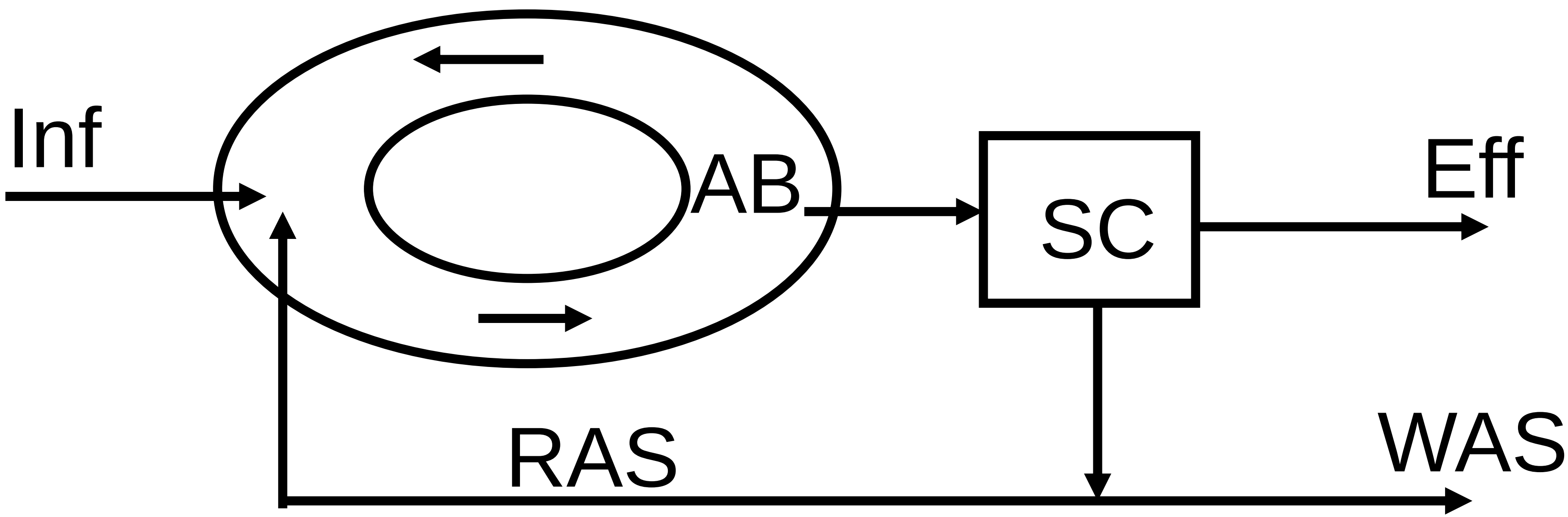
REGENERATION ZONE

Contact stabilization/ AS process with regeneration



REGENERATION ZON

Oxidation ditch
(basis for future arrangements like Carrousel activated sludge system)



Oxidation ditch – diffused air aeration

Oxidation ditch – mechanical aeration

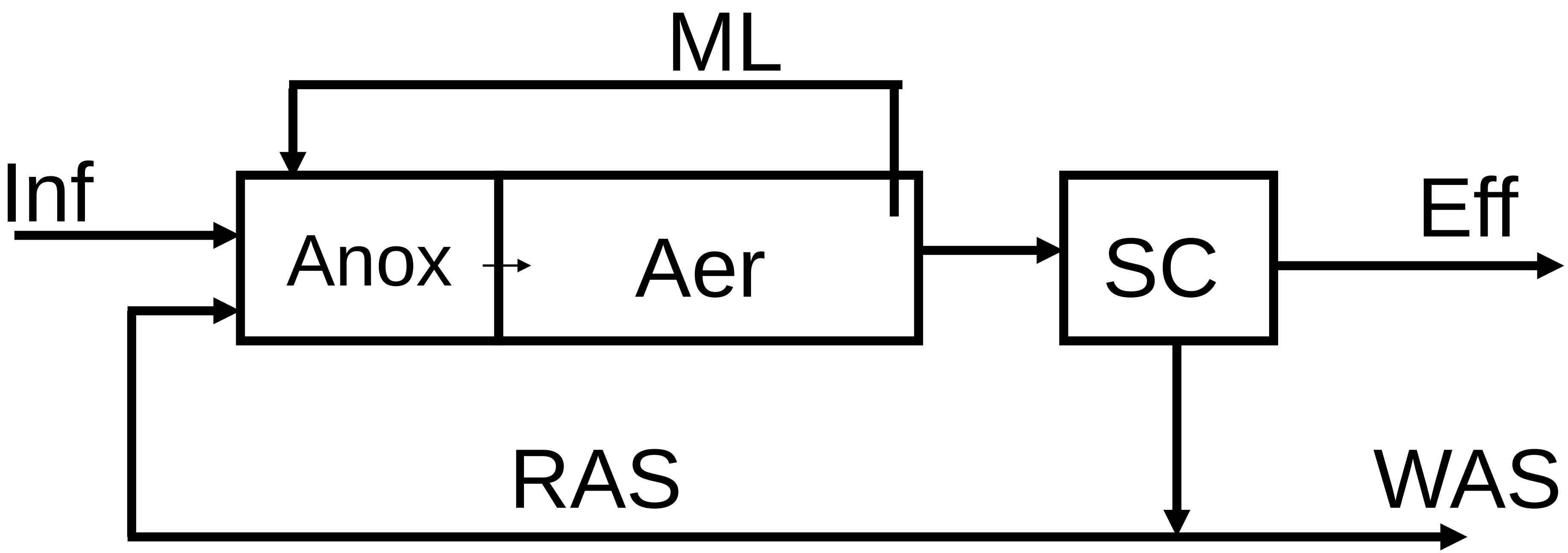
Carrousel activated sludge system

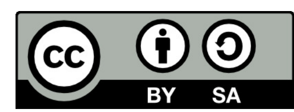
Continuous - flow system
with anaerobic zone

Intermittent aeration system

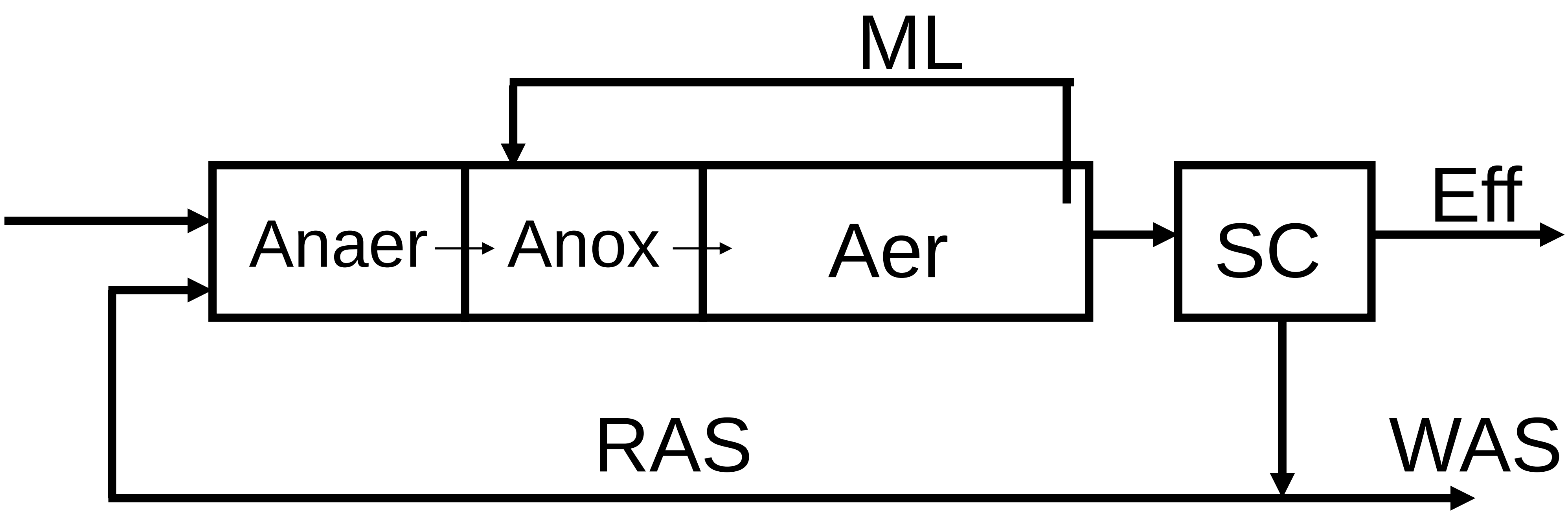
Nitrification/denitrification

Pre-denitrification system with internal
sludge liquor recirculation

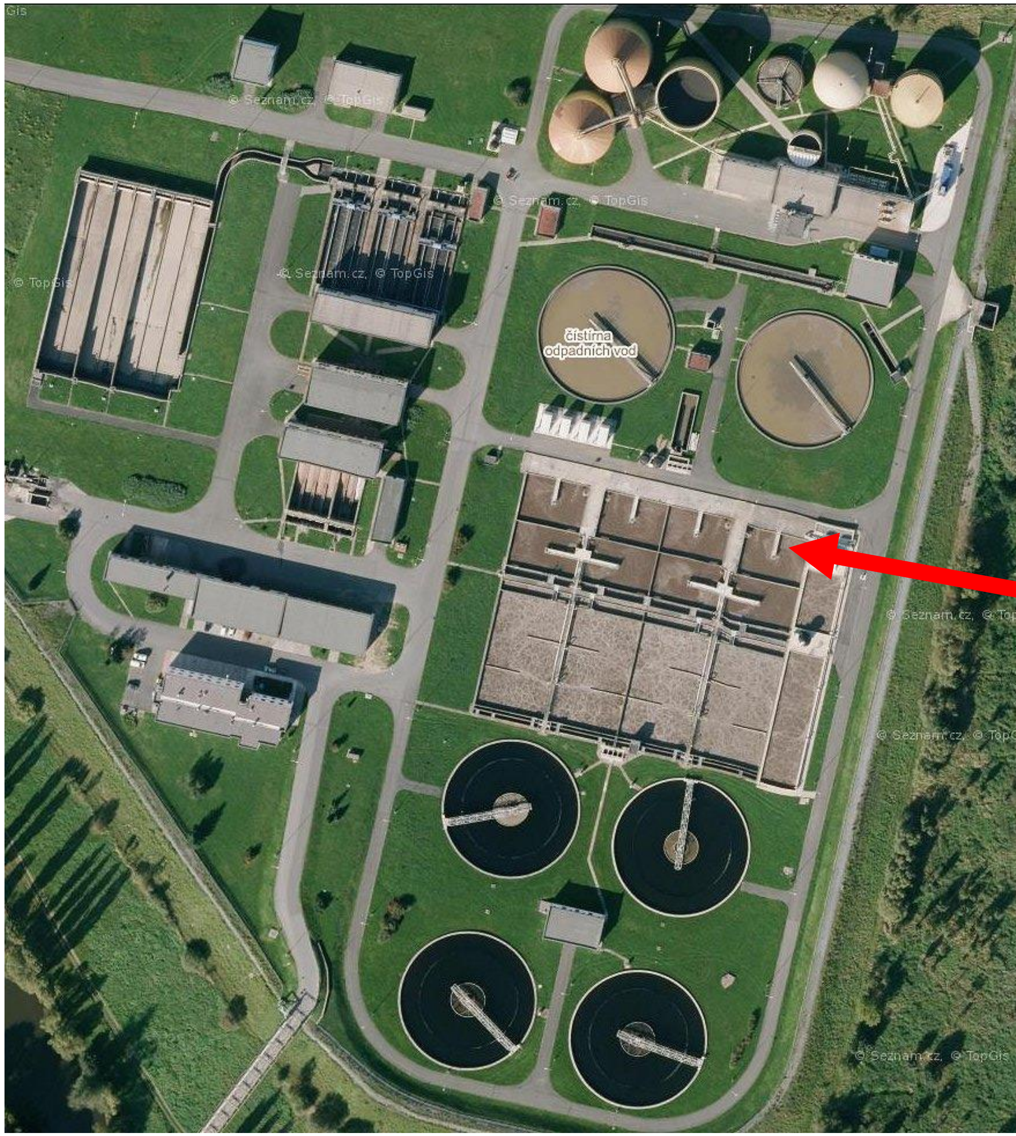




Enhanced biological phosphorus removal (EBPR) + D/N



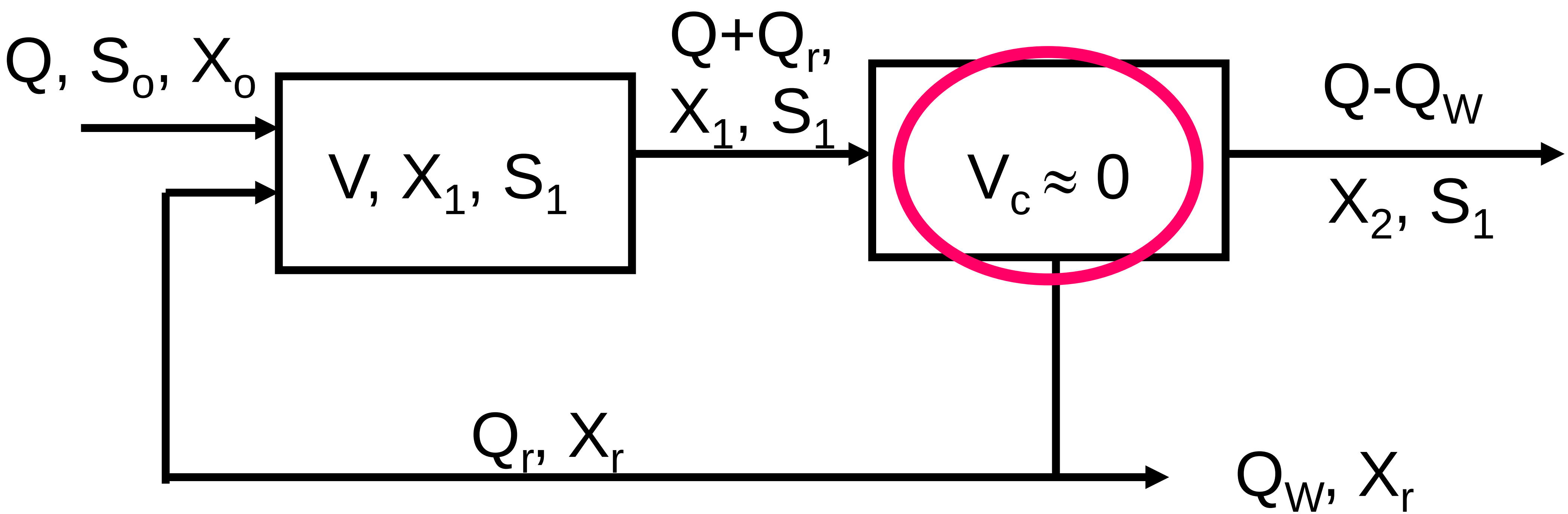
Enhanced biological phosphorus removal (EBPR) + D/N



Anaerobic zone

Activated Sludge Process Control: technological parameters

Basic flows and concentrations



Basic terms

	Flow	Solids	Substrate
Influent	Q	X_o	$X_o = 0$
Mixed Liquor	$Q + Q_R$	X_1	S_1
Effluent	$Q\ (-\ Q_W)$	X_2	$S_1(sol)$
RAS	Q_R	X_r	
WAS	Q_W	X_r	

Aeration basin volume $= V$

Secondary clarifier volume $= V_c = 0$

Hydraulic retention time, HRT, Θ

$$\Theta = V / Q \qquad [TIME]$$

$$R = Q_R/Q$$

Contact time, Θ_C

$$\Theta_C = V / (Q + Q_R) \qquad [TIME]$$

Treatment efficiency E

$$E = (S_0 - S_1) / S_0 \text{ x } 100 \ [\%]$$

Volumetric loading B_V

$$B_V = (S_0 \text{ x } Q) / V \quad [M.L^{-3}.T^{-1}]$$

Sludge loading B_X

B_X = kg substrate applied per day/kg sludge in system

$$B_X = (Q \times S_0) / (V \times X_1)$$

$$[M \,.\, M^{-1}.T^{-1}]$$

Sludge age Θ_X, Solids residence time (SRT), Mean cell residence time (MCRT)

The average time that sludge solids (biomass) stay in the system…this is longer that the hydraulic residence time because sludge is recycled from the secondary clarifier

MCRT = Θ_X

$$\theta_X = \frac{\text{kg sludge in system}}{\text{kg sludge removed/d}}$$

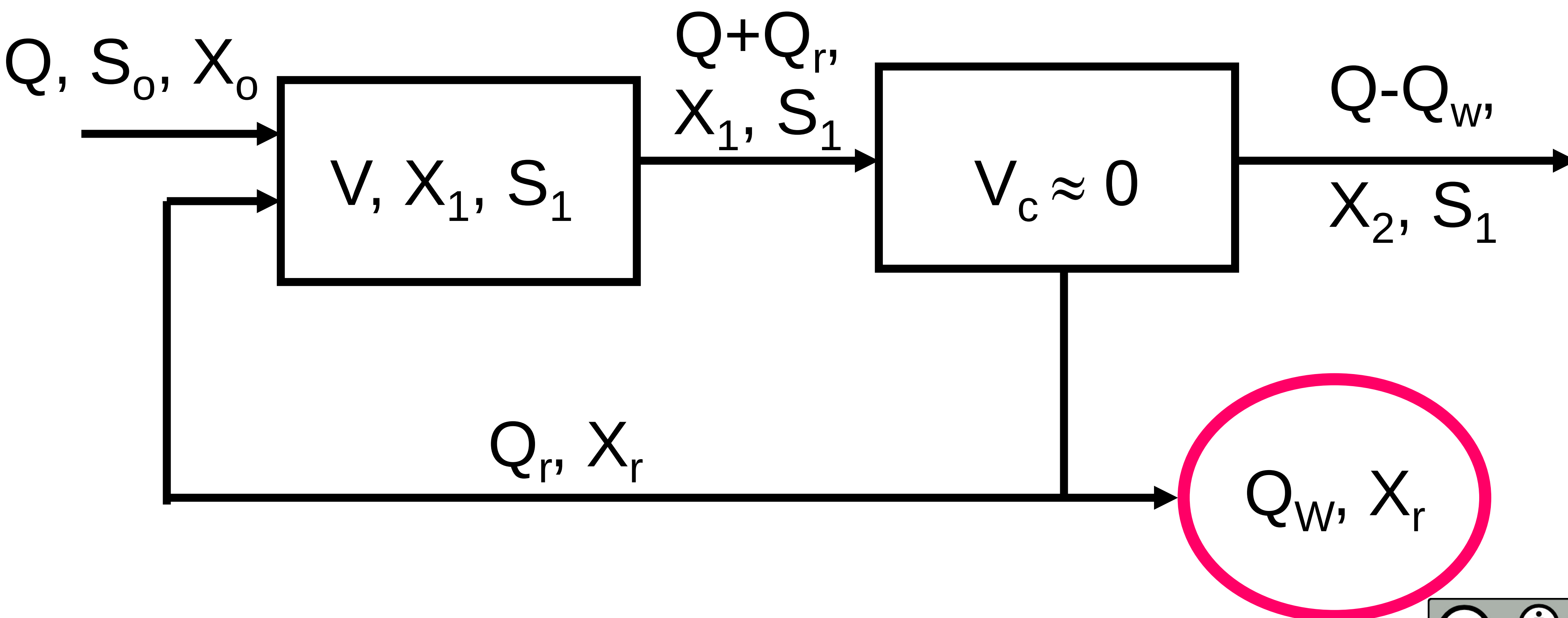
$$= \frac{\text{kg sludge in system}}{\text{kg sludge lost in effluent/d} + \text{kg sludge wasted/d}}$$

$$= \frac{VX_1}{(Q - Q_W)X_2 + Q_W X_r} \qquad \left(\text{units} = \frac{\text{kg}}{\text{kg/d}} = \text{days}\right)$$

The basis of operation is to maintain a given MCRT. When that is done, it is the equivalent of maintaining a given net growth rate

$$1/\Theta_X = \mu - b$$

The control of Sludge age Θ_X is achieved by manipulating Q_W.



Types of activated sludge process according to sludge age

- Long sludge age with aerobic sludge stabilization Θ_X = 25 d and more
- Long sludge age with nitrification-denitrification Θ_X = 12 – 18 d
- Conventional, medium sludge age

  Θ_X = 4 – 8 d
- Short sludge age, high loaded

  Θ_X = 3d and less

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Aeration and mixing:

i) Principles

ii) Aeration system

Lecture 6

Reactions consuming oxygen

- Oxidation of organic carbon (exogenous respiration)
- Synthesis when the source of carbon has average C oxidation less than 0
- Autooxidation of cell biomass (endogenous respiration)
- Nitrification
- Etc.

Oxygen consumption (uptake) rates
OUR

Volumetric rate

$$\boxed{r_V = Y'\Delta B_V + k_r X_O}$$

Specific rate

$$r_{XO} = \frac{rV}{X_O} = Y'\Delta B_X + k_r$$

$$Y'obs = Y' + \frac{k_r}{\Delta B_X}$$

Oxygen transfer to water

$$\frac{dc}{dt} = K_L \times \frac{A_f}{V} \times (c_s - c)$$

$$K_L \times \frac{A_f}{V} = K_L a$$

$$\boxed{\frac{dc}{dt} = K_L a \times (c_s - c)}$$

Oxygen transfer to water by its simultaneous consumption

$$\frac{dc}{dt} = K_L a \times (c_s - c)$$

$$\frac{dc}{dt} = K_L a \times (c_s - c) - r_V$$

Steady-state

$$\frac{dc}{dt} = 0 \qquad c = c^+$$

Steady state

$$\boxed{r_V = K_L a' \times (c_s' - c^+)}$$

$$c_s' = c^+ + \frac{r_V}{K_L a'}$$

i.e., concentration of dissolved oxygen plus oxygen uptake rate

if $r_v = 0$, then cs' = c+

Oxygenation capacity OC

Amount of oxygen supplied by aeration equipment in unit volume in unit time at zero concentration of DO

$g/m^3.h$ or $kg/m^3.d$

Clean water, standard conditions of aeration

T = 20 deg.C, p = 0.1 MPa

$$\boxed{OC = K_L a \times c_s}$$

Wastewater

$$OC' = K_L a' \times c_s'$$

Intensity of aeration I_V and OC

I_V in $m^3/m^3.h$

For OC units $g/m^3.h$

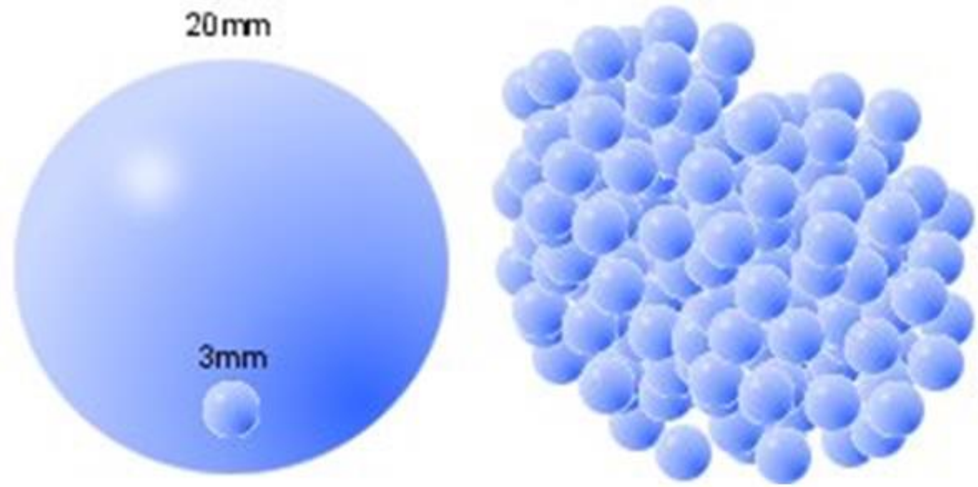
$$\boxed{OC' = 3\chi \times I_V}$$

For OC units $kg/m^3.d$

$$OC' = \frac{\chi \times I_V}{13.9}$$

Oxygen transfer and OC in wastewater effect of surface active compounds

$$\alpha = \frac{K_L a'}{K_L a}$$



Identical volume, 6.6x greater surface area

$$\beta = \frac{(C_s')_{ww}}{(C_s')_{treatedwater}}$$

Effect of temperature on OC

$$(K_L a)_{20} = (K_L a)_T \times \upsilon^{(20-T)}$$

Energy yield (efficiency)

kg O_2 /kW

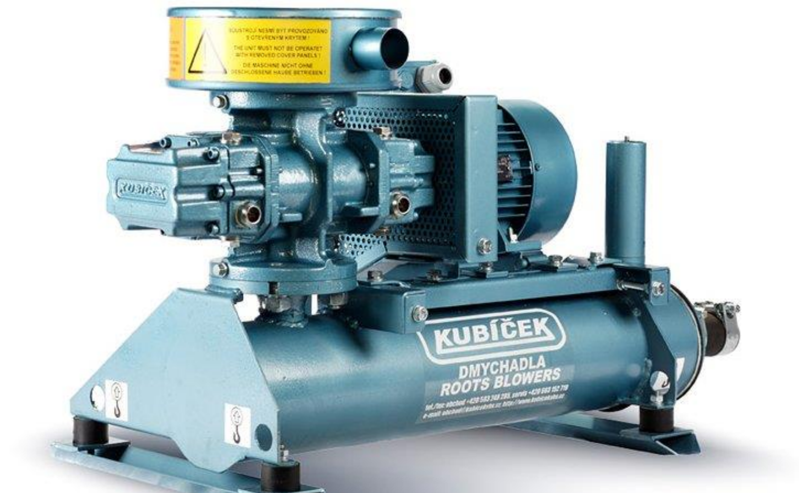
For OC units kg.m^{-3}.d^{-1}
W in kW.m^{-3}.d^{-1}

$$\boxed{E^{+} = \frac{OC}{W}}$$

Diffused air aeration

- Sources of pressurized air
- Air distribution system
- Aeration elements
  - Dome aerators made of porous materials (ceramics, plastics)
  - Membrane disc aerators, tubular membranes
  - Large area membrane aerators
- Installation in aeration tanks

Diffused air aeration

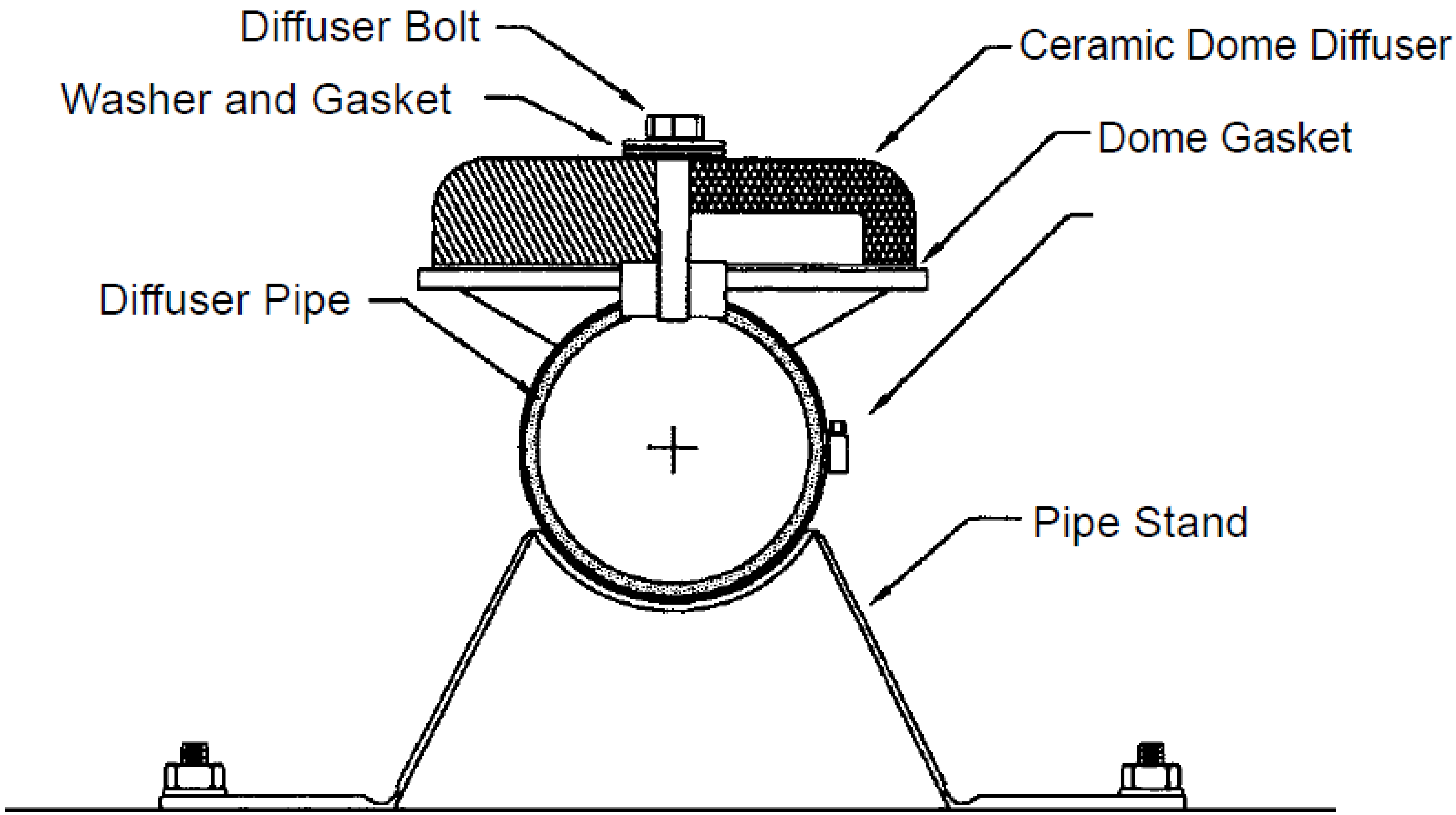


Diffused air aeration

Diffused air aeration

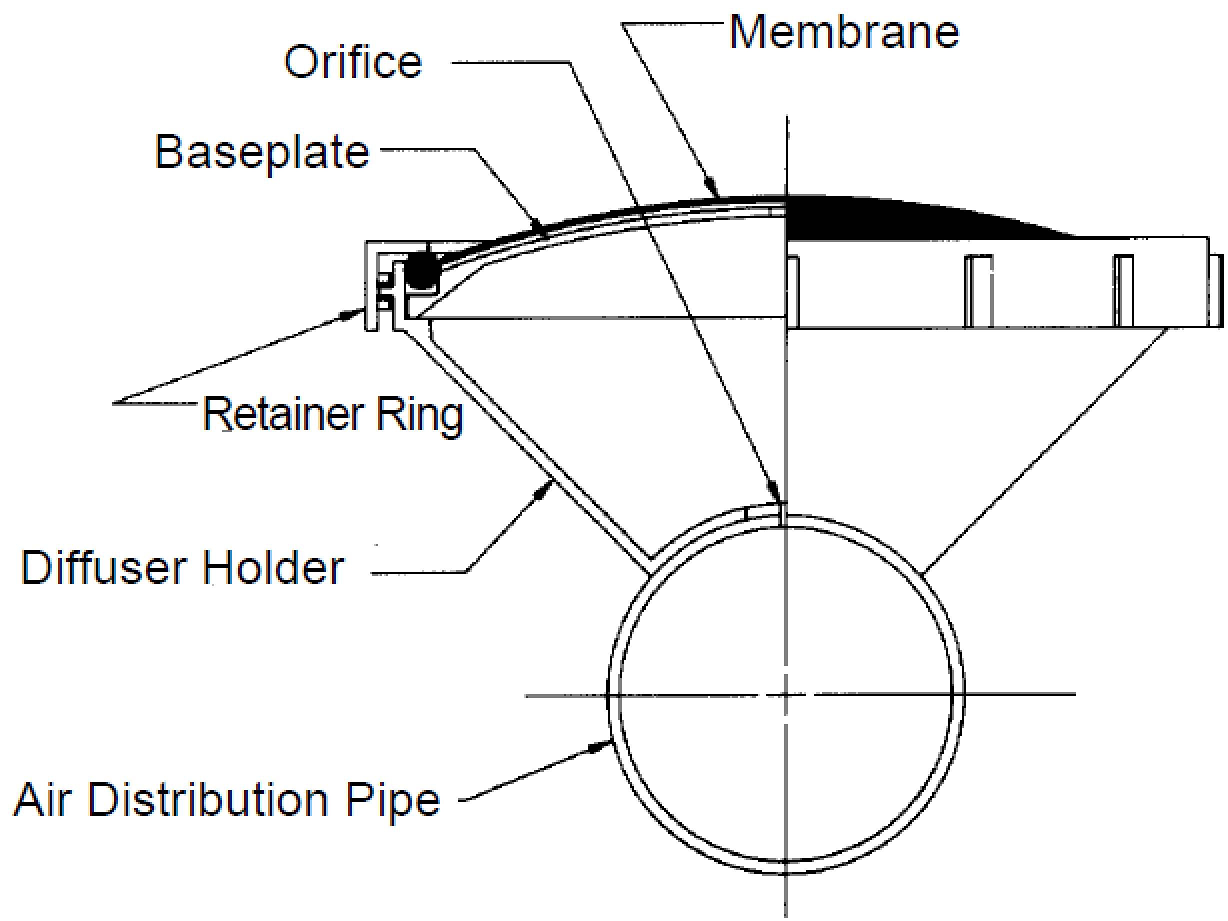
Diffused air aeration

Diffused air aeration



Dome Diffuser

Diffused air aeration



Membrane Disc Diffuser

Diffused air aeration

Diffused air aeration

Diffused air aeration

Diffused air aeration

Diffused air aeration

Diffused air aeration

Mechanical aerators

- Aeration turbines – aerators with vertical shaft
- Aeration brushes - aerators with horizontal shaft
- Aeration cylinders – mammoth rotors

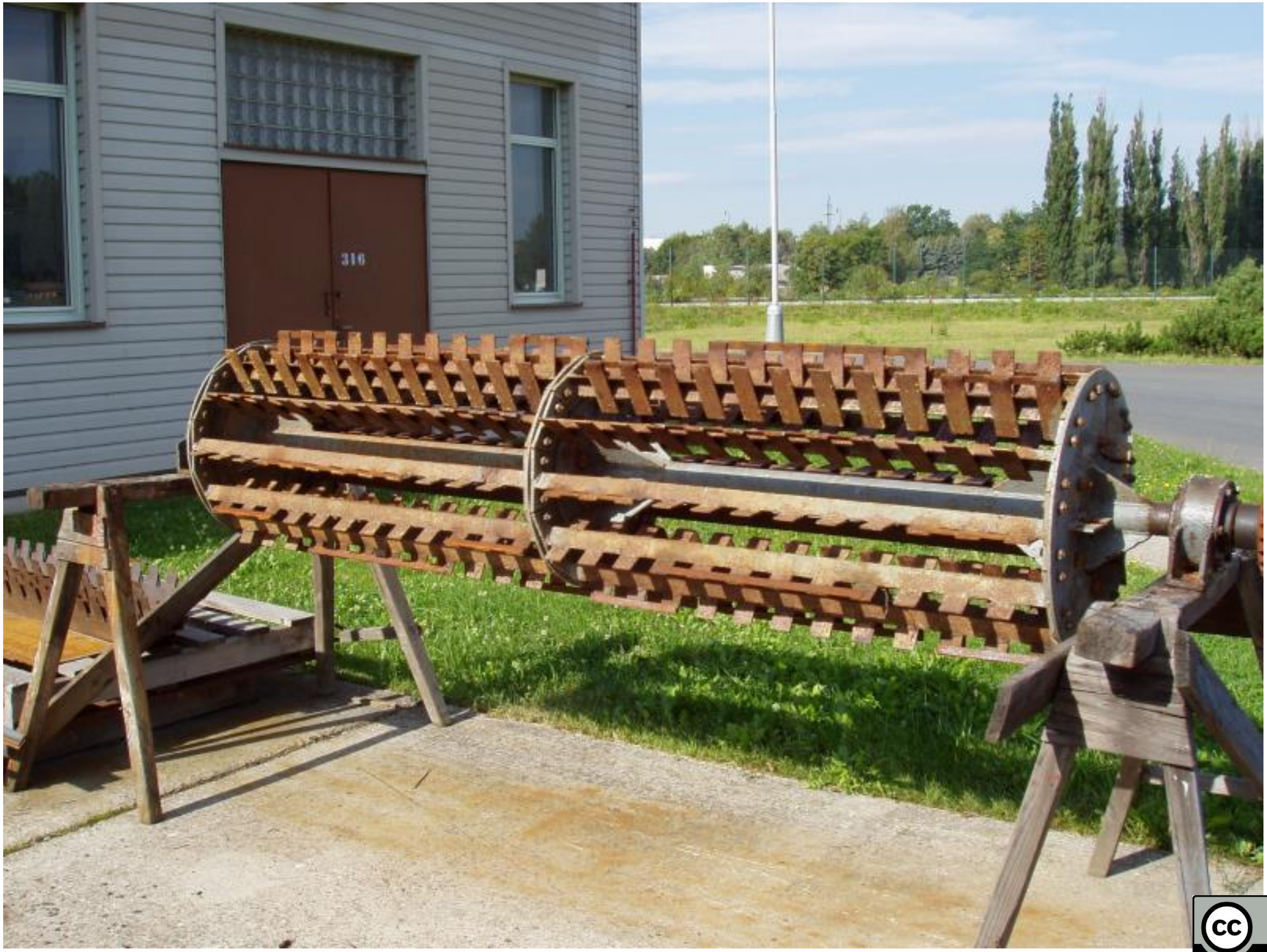
Jet aerators

- Jet aerators with pressurized air
- Jet aerators with air distribution turbines
- Ejectors

Mechanical aerators

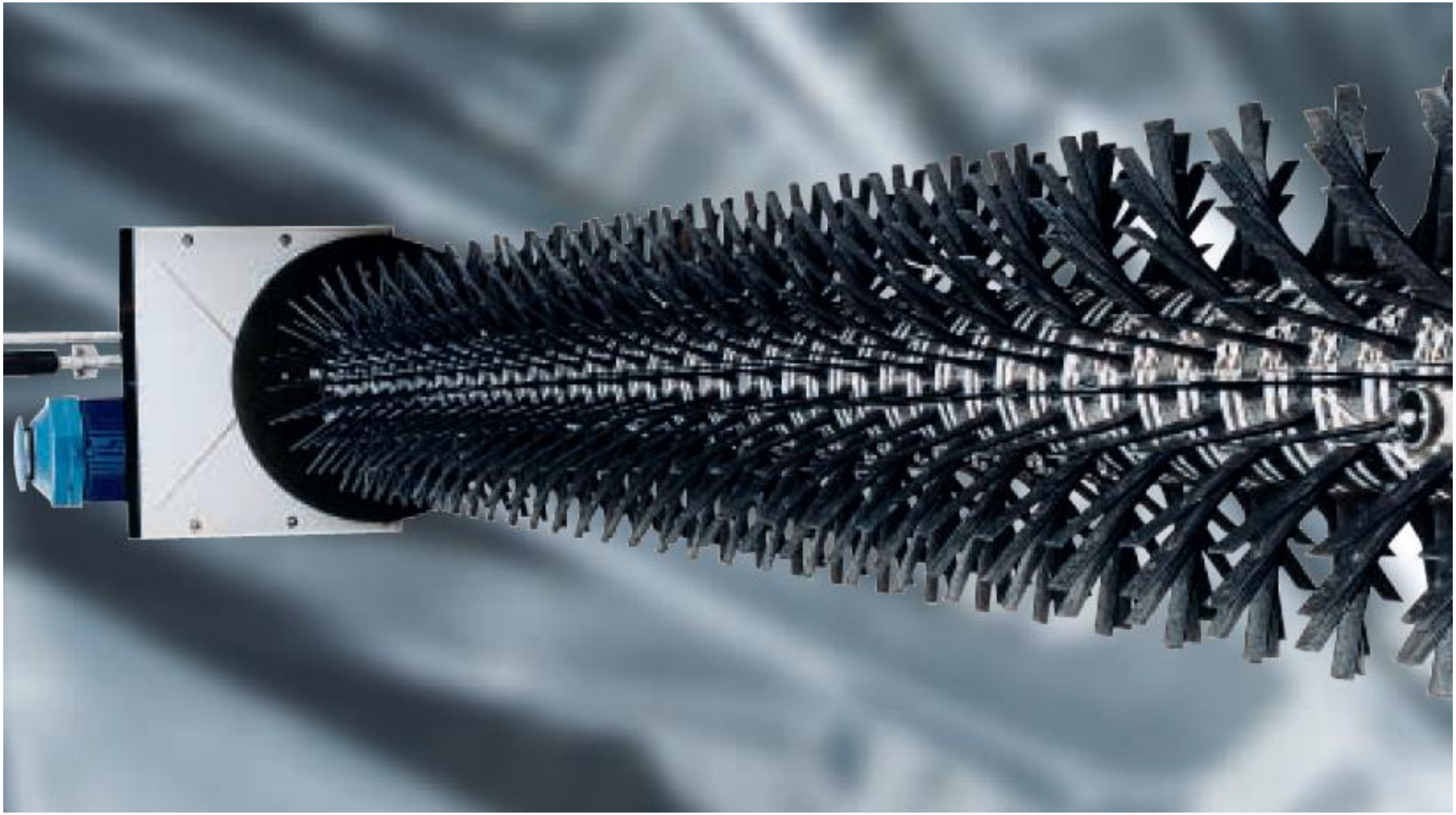
Mechanical aerators

Mechanical aerators



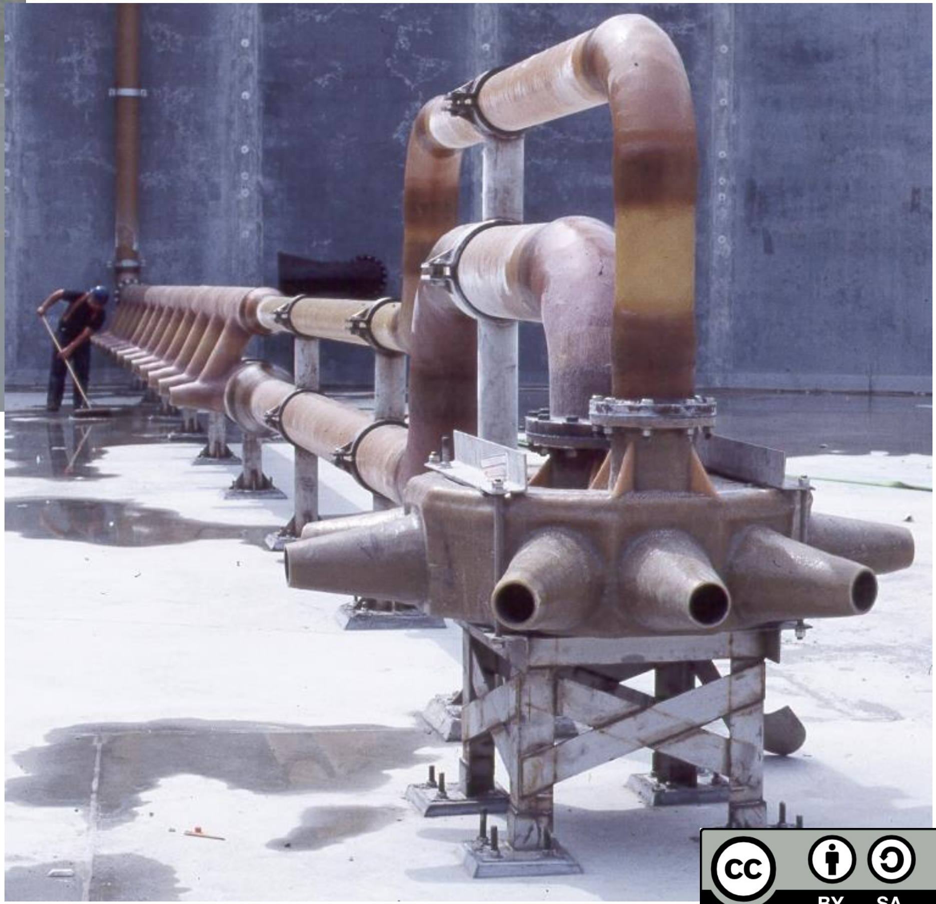
Mechanical aerators

Mechanical aerators

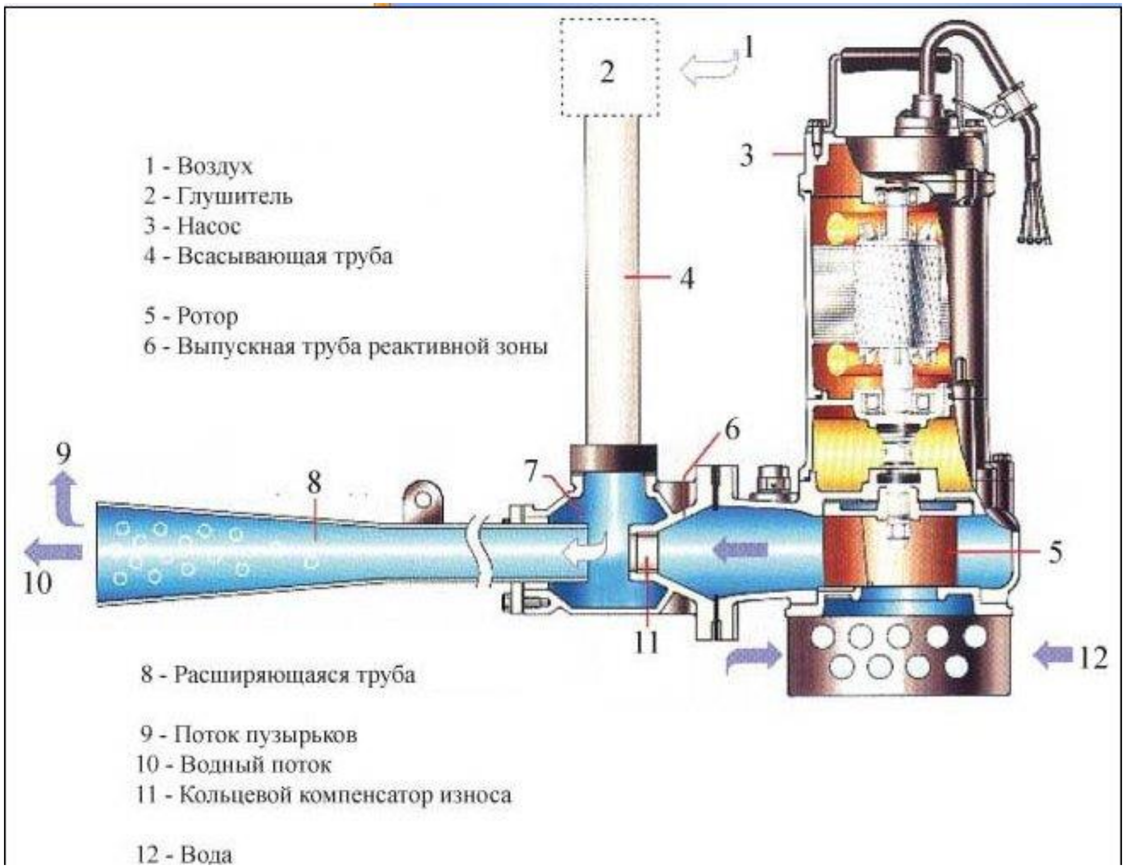


Mammoth rotors

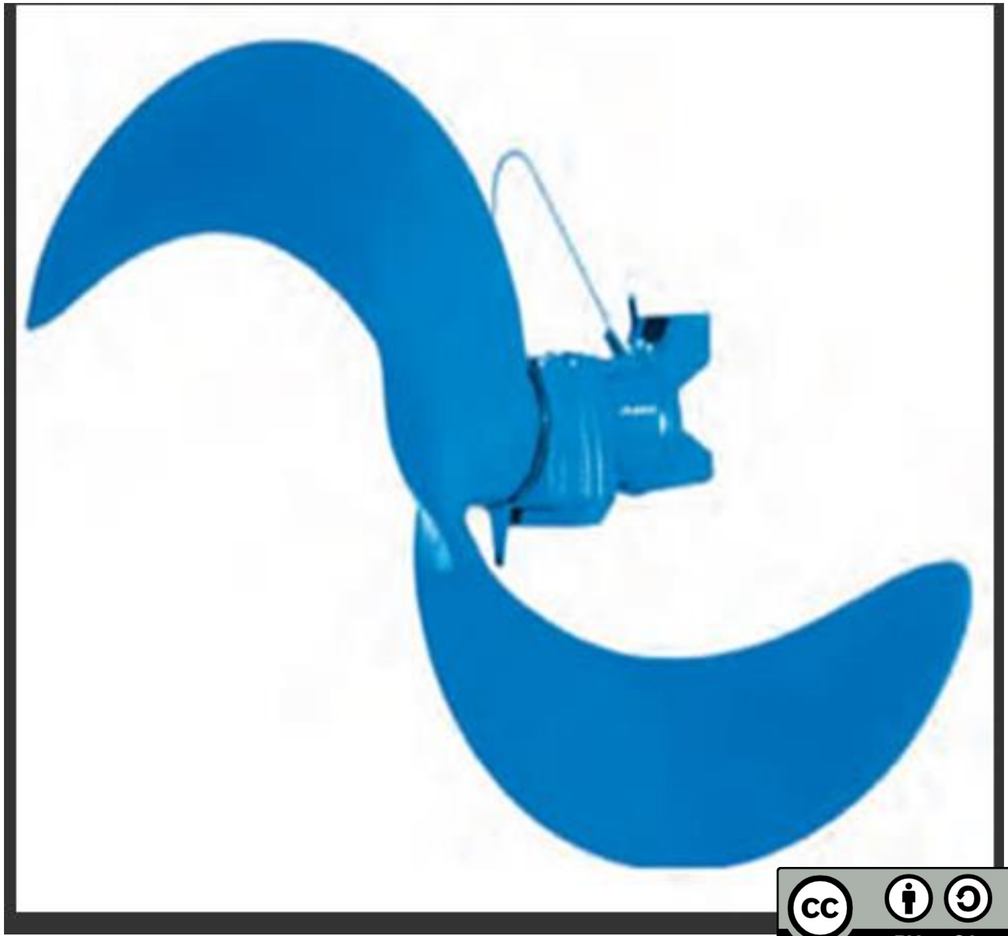
Jet aerators



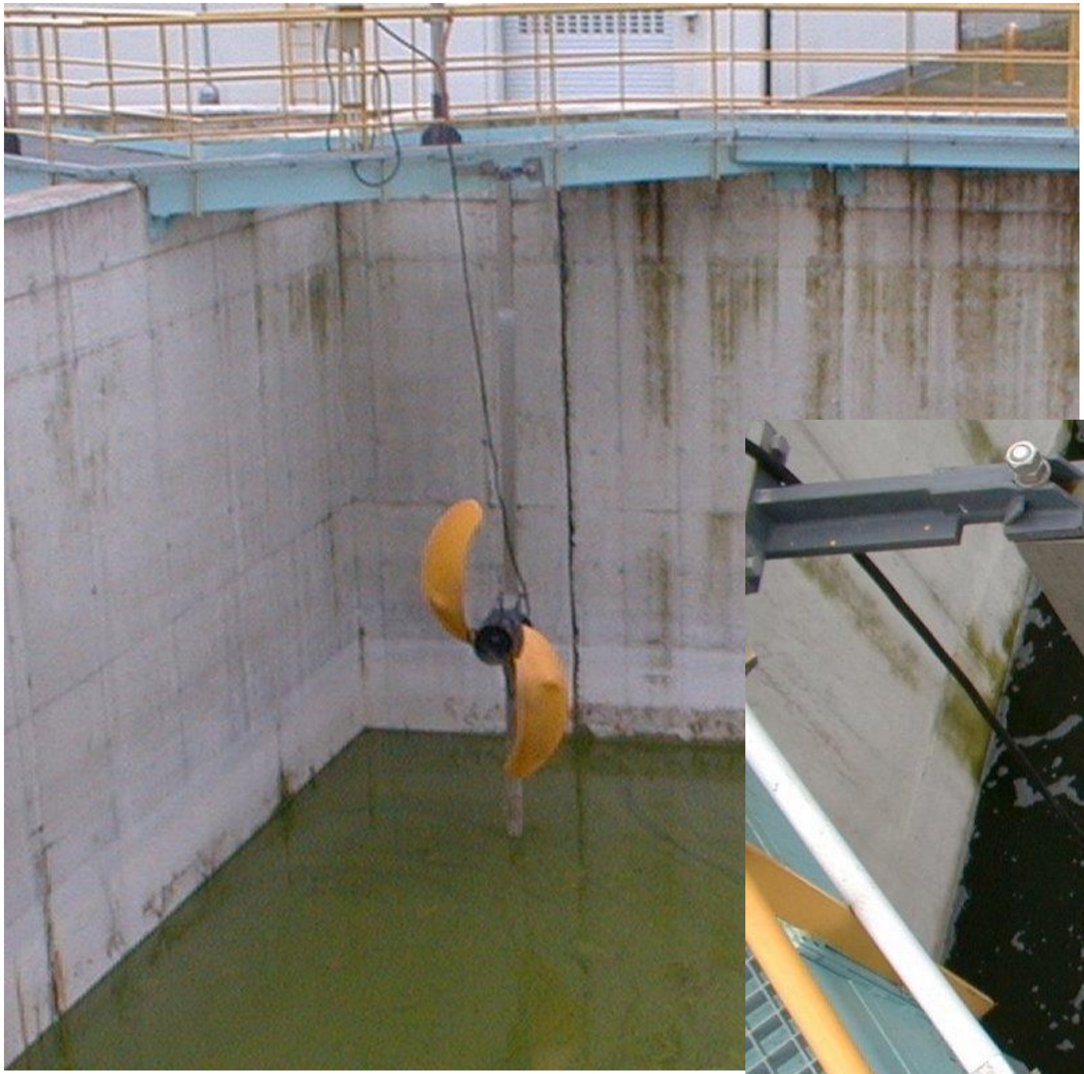
Jet aerators



Submerged mixers



Submerged mixers



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7. BIOLOGICAL NITROGEN REMOVAL

NUTRIENT REMOVAL - MAIN REASONS

- drinking water production
- eutrophication
- toxicity of ammonia (NH_3)

Limiting conditions for growth of algae depending on N/P (weight ratio)

	N-limiting	Mean value	P-limiting
Fresh water	≤ 4.5	4.5 – 6	≥ 6
Sea water (seacoast)	≤ 5	5 – 10	≥ 10

NITROGEN REMOVAL

Forms of nitrogen in wastewaters

- ammonia nitrogen ($N\text{-}NH_4^+$ and NH_3)
- organically bound nitrogen N_{ORG} ($-NH_2$)
- nitrite and nitrate nitrogen ($N\text{-}NO_2^-$, $N\text{-}NO_3^-$)

➢ $N\text{-}NH_4^+ + N_{ORG}$ = Kjeldahl nitrogen (TKN)

➢ $N\text{-}NH_4^+ + N\text{-}NO_3^- + N\text{-}NO_2^- = N_{INORG}$

➢ $N_{INORG} + N_{ORG} = N_{TOT}$

- $N\text{-}NH_4^+$ used for sludge growth (6 – 8 % of N in biomass)
- sludge management = source of $N\text{-}NH_4^+$ (recycle streams, e.g. sludge water)

Degradation of organic nitrogenous compounds (ammonification)

proteins (-NH_2) $\xrightarrow[\text{(proteolytic enzymes)}]{\text{hydrolytic reactions}}$ amino acids $\xrightarrow{\text{deamination enzymes}}$

ammonia nitrogen + organic compounds

→ nitrification

→ ox/anox $CO_2 + H_2O$

anaerobic fermentative reactions

Nitrification

- performed in two distinct processes by different kinds of chemolithotrophic microorganisms

  oxidation of ammonia to nitrite *(nitritation)*

  $NH_4^+ + 1.5\ O_2 = NO_2^- + H_2O + 2\ H^+$

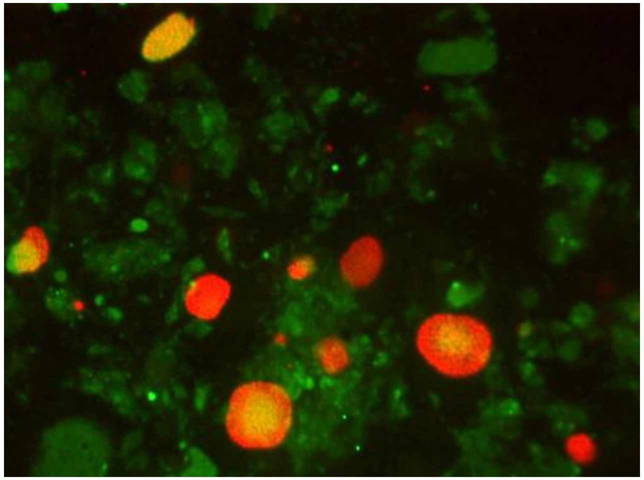
  oxidation of nitrite to nitrate *(nitratation)*

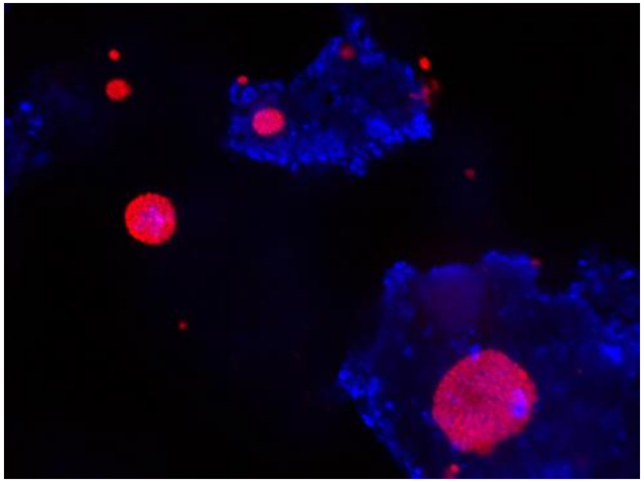
  $NO_2^- + 0.5\ O_2 = NO_3^-$

- most energy is produced in the first process
- under normal conditions, the rate of oxidation of nitrite is higher than that of ammonia; thus nitrite does not accumulate in nitrifying activated sludge systems
- total specific consumption of oxygen for ammonia oxidation is 4.57 g/g (O_2/N); should be reflected in the design of aeration systems (DO concentration 1.5 – 2.0 mg/l is recommended)
- protons released during the oxidation of ammonia affect the buffer capacity; if alkalinity is not high enough (at least 1.5 – 2 mmol/l at the end of nitrification), a significant decrease in pH may occur

Nitrifiying bacteria

- two groups of chemolithotrophic bacteria:
  ammonia oxidizers (AOB)
  nitrite oxidizers (NOB)
- slow-growing microorganisms (higher sludge age); growth rate strongly affected by temperature, DO concentration and pH
- susceptible to various inhibitory effects (metals, some organics), including self-inhibition by substrates (un-ionized forms of nitrogen, i.e., NH_3 and HNO_2)





Clusters of AOB (FISH)

Denitrification

- reduction of nitrite and nitrate to elementary nitrogen under anoxic conditions; nitrite and nitrate serve as electron acceptors instead of oxygen and organic substrates serve as electron donors for ATP (energy) production

$$10\ (H^+ + e^-) + 2\ H^+ + 2\ NO_3^- = N_2 + 6\ H_2O$$

- donors of activated hydrogen are predominantly external and readily biodegradable substrates, intracellular accumulated substrates or organic storage products (PHB); when exhausted, slow endogenous anoxic respiration derived from cellular materials is possible
- 1 g of $N\text{-}NO_3^-$ equals 2.86 g of O_2 in OR reactions; the actual consumption of readily biodegradable substrates for full denitrification of 1 g $N\text{-}NO_3^-$ expressed in COD units is estimated to be about 8 (sometimes external substrates)
- protons are consumed; alkalinity can be partly replenished under anoxic conditions

Denitrifiying bacteria

- anoxic/facultative aerobic chemoorganotrophic bacteria
- quite widespread among activated sludge microorganisms (80 %)
- less sensitive than nitriying bacteria

The energy produced under oxic conditions is only 7 % more than in anoxic conditions, if the same carbon source is used $\longrightarrow$ denitrification can be considered to be an equivalent alternative to oxic respiration from both the metabolic and thermodynamic points of view.

Benefits of denitrification

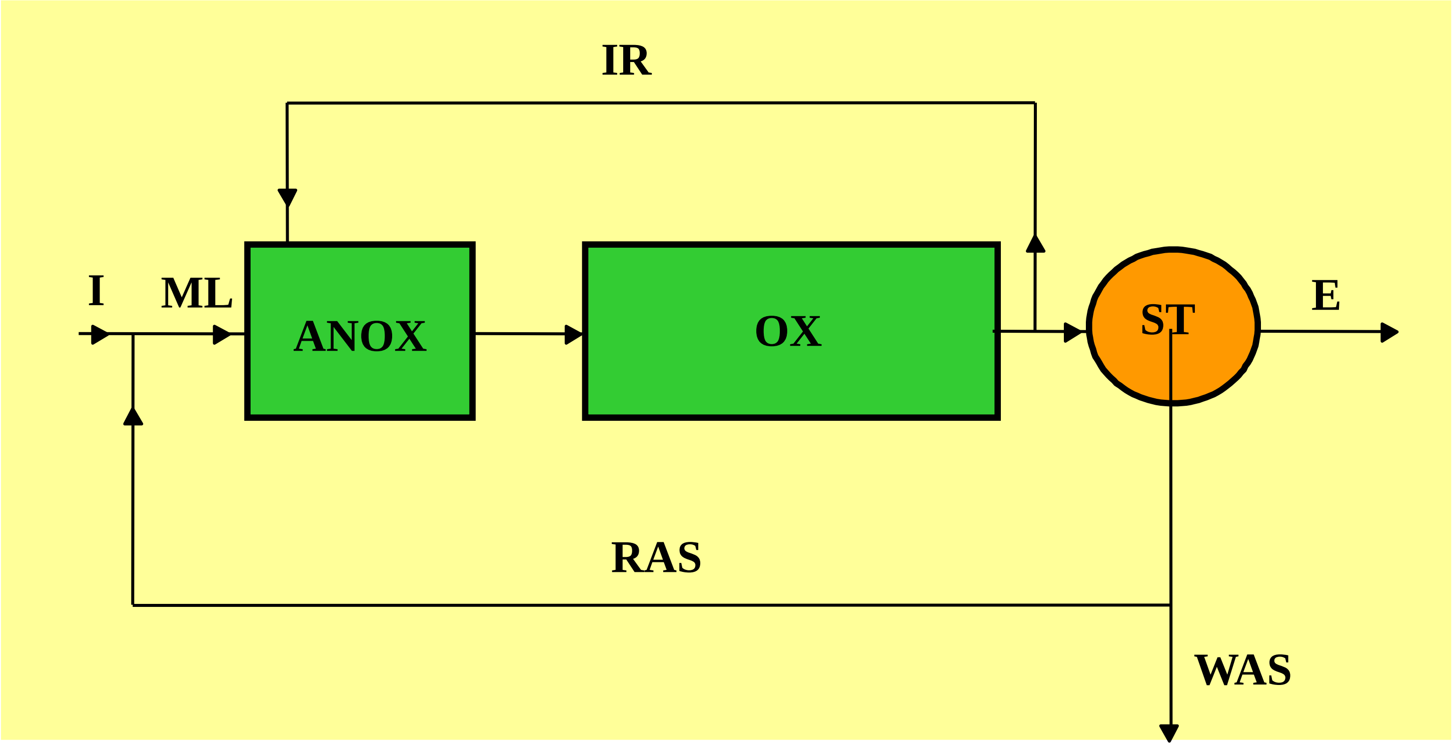
- *ecological*
  - nitrogen removal (90 – 95 %)

- *technological*
  - reduction in nitrate concentration which mitigates the problem of rising sludge from denitrification in the secondary settling tank
  - recovery of alkalinity

- *economic*
  - reduction of oxygen demand

Nitrogen removal activated sludge processes

1. Predenitrification systems



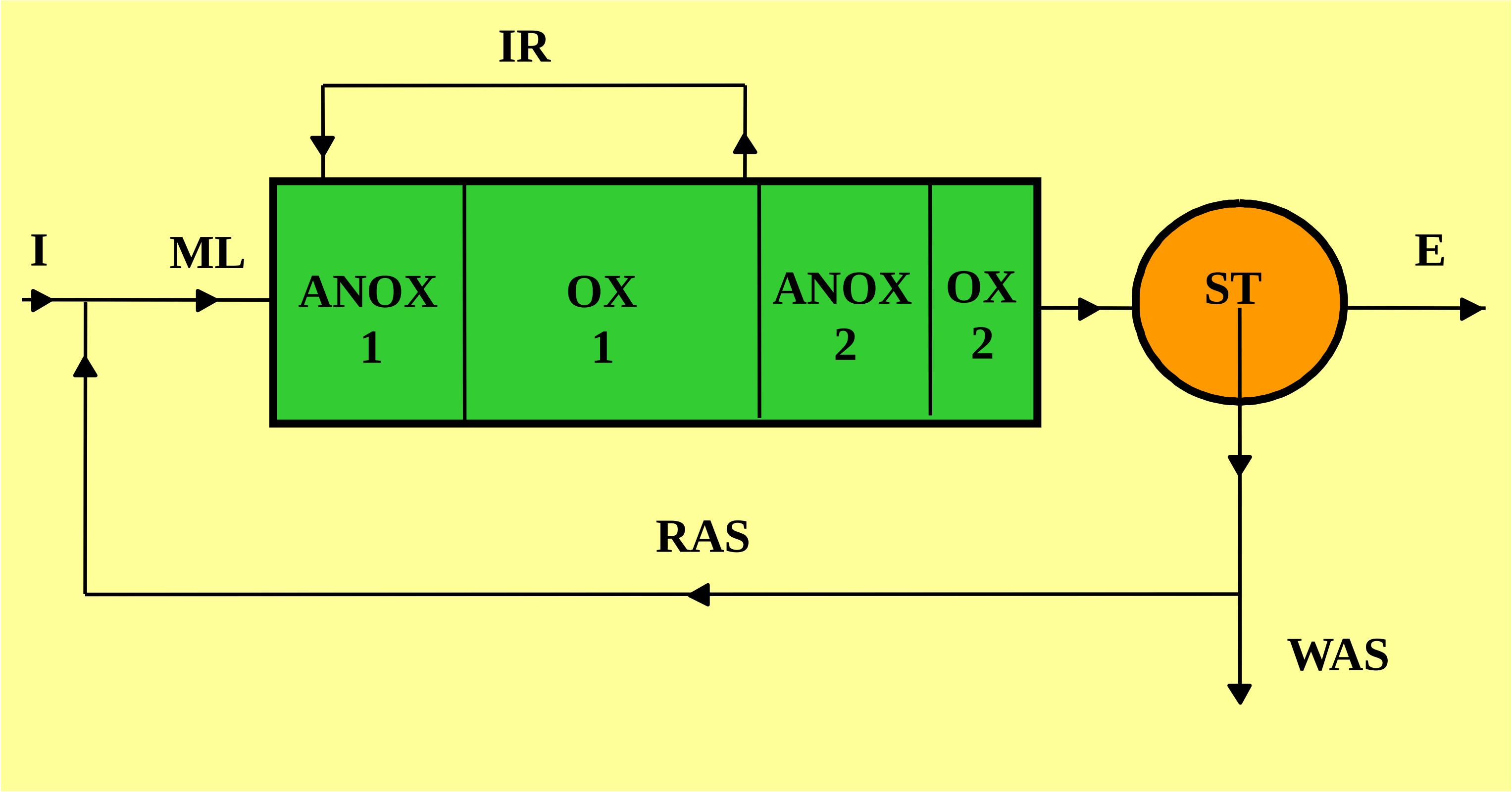
D-N system

I - influent, E - effluent, ML - mixed liquor, OX - oxic reactor, ANOX - anoxic reactor, ST - settling tank, RAS - return activated sludge, IR - internal recirculation, WAS - waste activated sludge

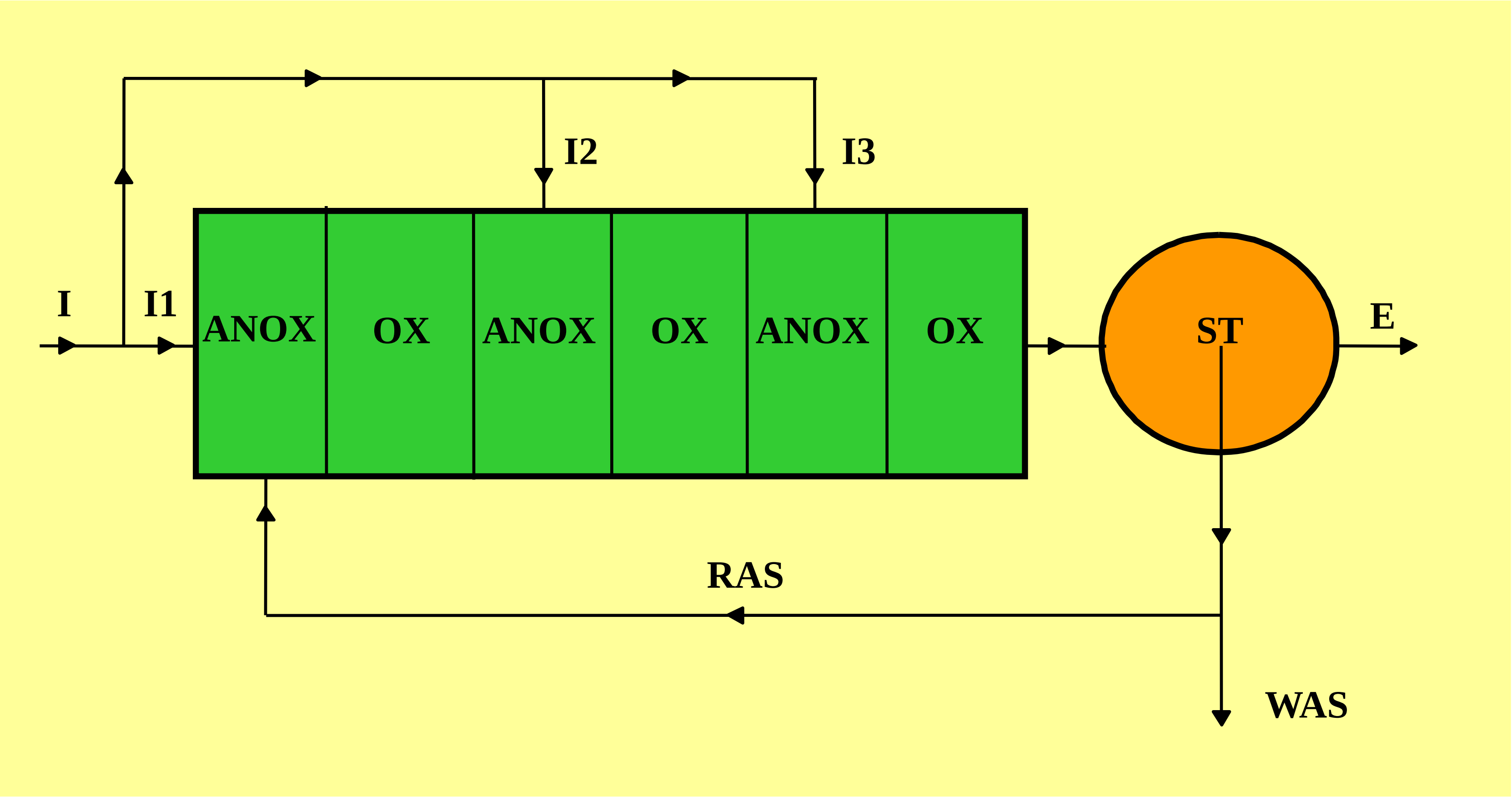
D-N system

D-N system - drawbacks

- high internal recirculation $\longrightarrow$ high energy consumption for pumping $\longrightarrow$ high operational costs
- high internal recirculation $\longrightarrow$ lower concentration gradient $\longrightarrow$ growth of filamentous microorganisms
- concentration of NO_3^- in the IR stream is the same as in the effluent (often too high)



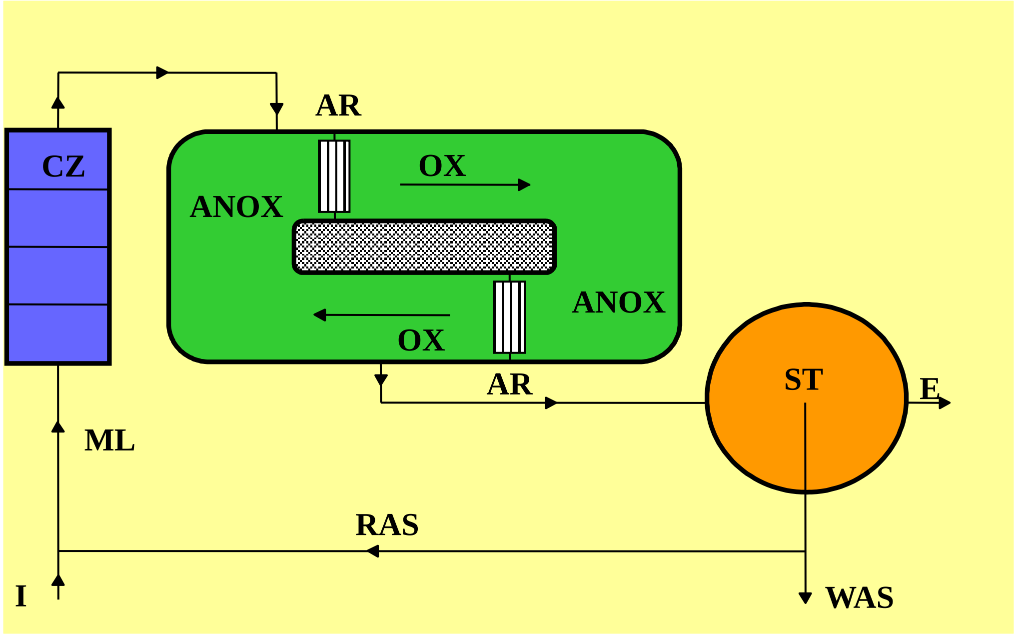
4-stage Bardenpho process



Alpha system

2. Simultaneous nitrification and denitrification

- both processes occur in one reactor in zones which are not separated physically by baffles
- anoxic conditions are created spontaneously by respiration activities of activated sludge microorganisms in those parts of the reactor where the supply of oxygen from aerators is no more sufficient, but enough energy is provided by the mixing action of aerators to keep the activated sludge in suspension (long corridors with surface aerators, oxidation ditches, Carrousel activated sludge system)



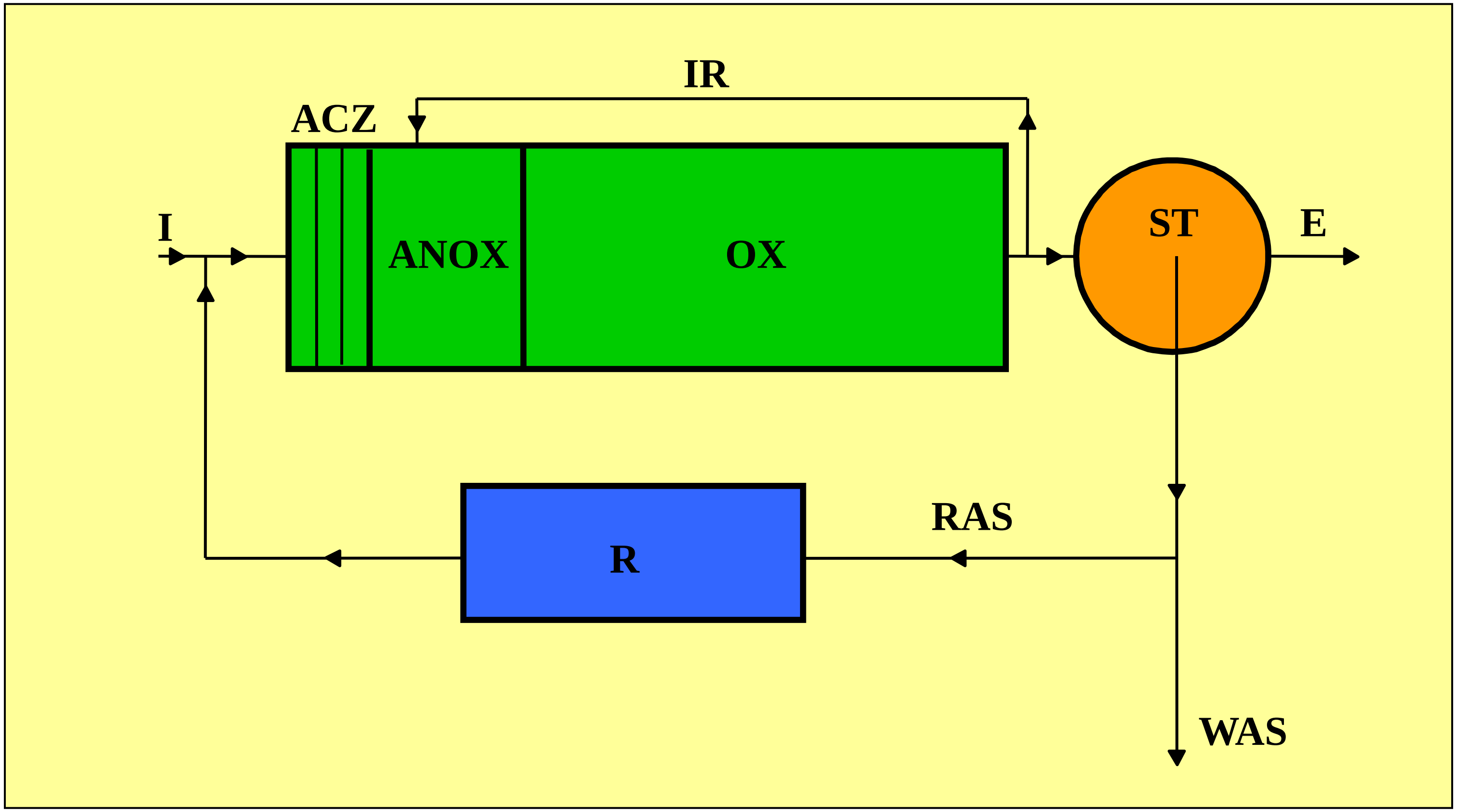
Carrousel activated sludge system with simultaneous nitrification - denitrification

CZ - contact zone
AR - aerator

Carrousel activated sludge system

Intermittent aeration

3. Predenitrification systems with regeneration



R-D-N system

ACZ - anoxic contact zone

R-D-N system

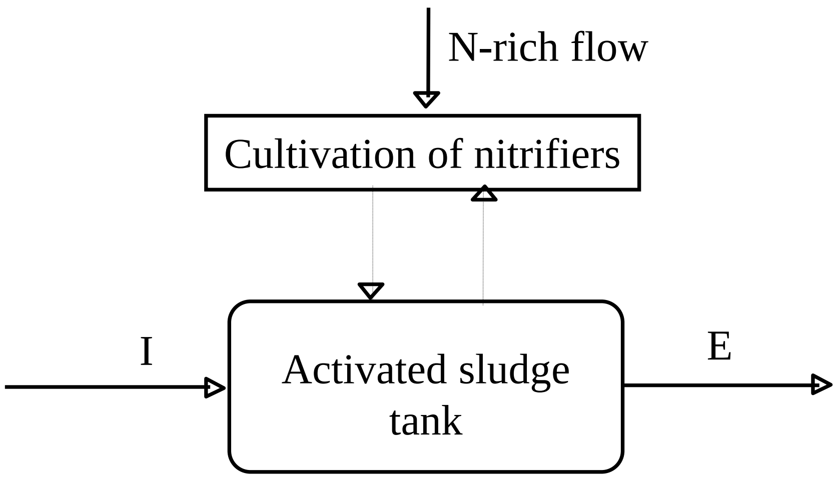
- optimum conditions for the growth of nitrifiers
  - aerobic sludge age
  - smaller extent of competition with organotrophs
- increased metabolic diversity
- R zone should not necessarily be aerated, the oxidation of intracellular storage products can also be performed by anoxic endogenous metabolism utilizing nitrate nitrogen in the return activated sludge (D-R-D-N process)

R zone

Intensification of nitrogen removal

Bioaugmentation of nitrification
= cultivation of nitrifying bacteria *in situ*

- side-stream aerobic reactor fed with internal N-rich flow (i. e. sludge water)



- nitrification reactor in sludge return line (for example: regeneration tank)

Sludge age increasing

- biomass carriers (biofilm)
- good growth conditions for slow-growing microorganisms (i. e. nitrifying bacteria), see lecture 11

External substrate for denitrification

- C/N ratio improvement
- alcohols (methanol), waste organic products

Regulation and optimization of processes at WWTPs

- based on DO, N-NH_4^+ and N-NO_3^- concentration measurements (sensors)

Alternative methods of nitrogen removal

- heterotrophic nitrification
- ANAMMOX
- SHARON
- CANON
- NO_X process

Physico-chemical methods of nitrogen removal

- mainly for industrial wastewaters

- stripping (ammonium)
- precipitation (struvite - magnesium ammonium phosphate, MAP)
- sorption (zeolites for ammonium)

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8. BIOLOGICAL AND CHEMICAL PHOSPHORUS REMOVAL

BIOLOGICAL PHOSPHORUS REMOVAL

Forms of phosphorus in wastewaters

- various forms of orthophosphate (PO_4^{3-}, HPO_4^{2-}, $H_2PO_4^{-}$ = ortho-P)
- polyphosphates (PP)
- organically bound phosphorus (P_{ORG})

➢ ortho-P + PP + P_{ORG} = P_{TOT}

In conventional activated sludge systems, phosphorus is utilized only for the synthesis of new biomass components (2 % P in dry biomass).

Degradation of P-containing organic substances and polyphosphates

PO_4^{3-}, HPO_4^{2-}, $H_2PO_4^{-}$

degradation

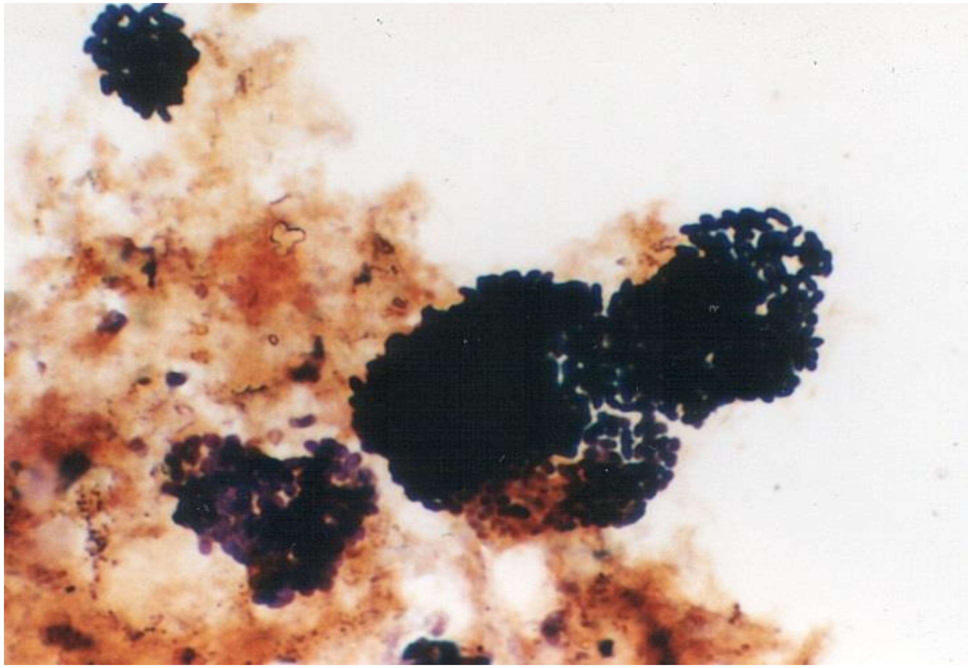
hydrolysis

P_{ORG}

PP

Enhanced biological phosphorus removal (EBPR)

When activated sludge is alternately exposed to anaerobic and oxic conditions, P is taken up by the cells in excess compared to synthesis purposes and the content of P in dry biomass may reach more than 10 % (EBPR).

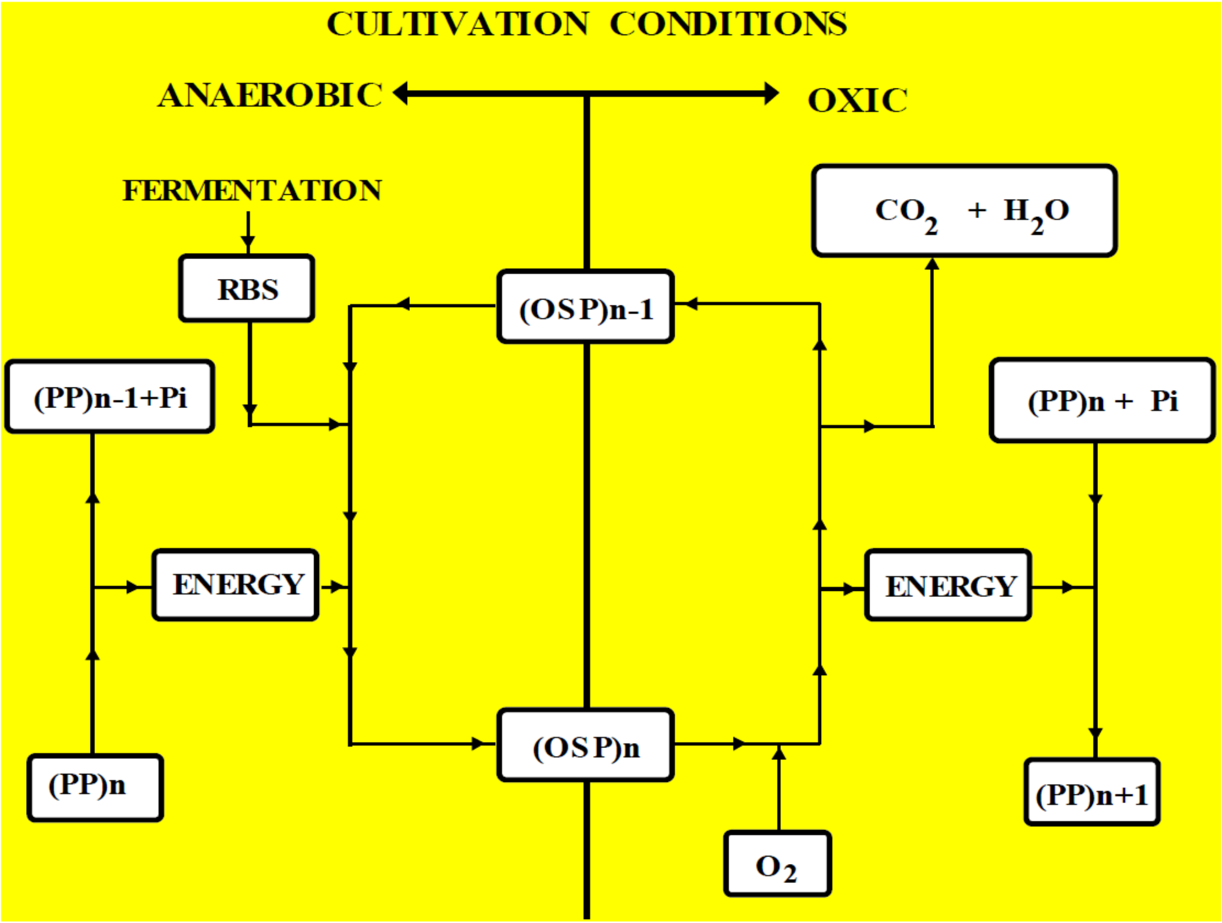


Typical clusters of polyphosphate accumulating organisms (PAOs) after Neisser staining

Principle of EBPR

- under anaerobic conditions, readily biodegradable substrates (RBSs) are converted to organic storage products as poly-hydroxyalkanoates (PHAs) by PAOs; PP degradation as an energy source (P release)
- in the presence of oxygen (or nitrate under anoxic conditions) as an external electron acceptor, PAOs utilize the stored PHA as a carbon and energy source for energy generation and growth of new cells
- PHA is also used as an energy source to take up P from the bulk solution to regenerate PP used in anaerobic conditions and to synthesize PP in the new cells that are generated (P uptake); this means that more P is taken up than is released in the previous anaerobic conditions
- PAOs, with stored PP, are removed via the waste sludge stream

Transport of energy between anaerobic and oxic cultivation conditions by means of organic storage products and polyphosphates



RBS - readily biodegradable substrate

PP - polyphosphate

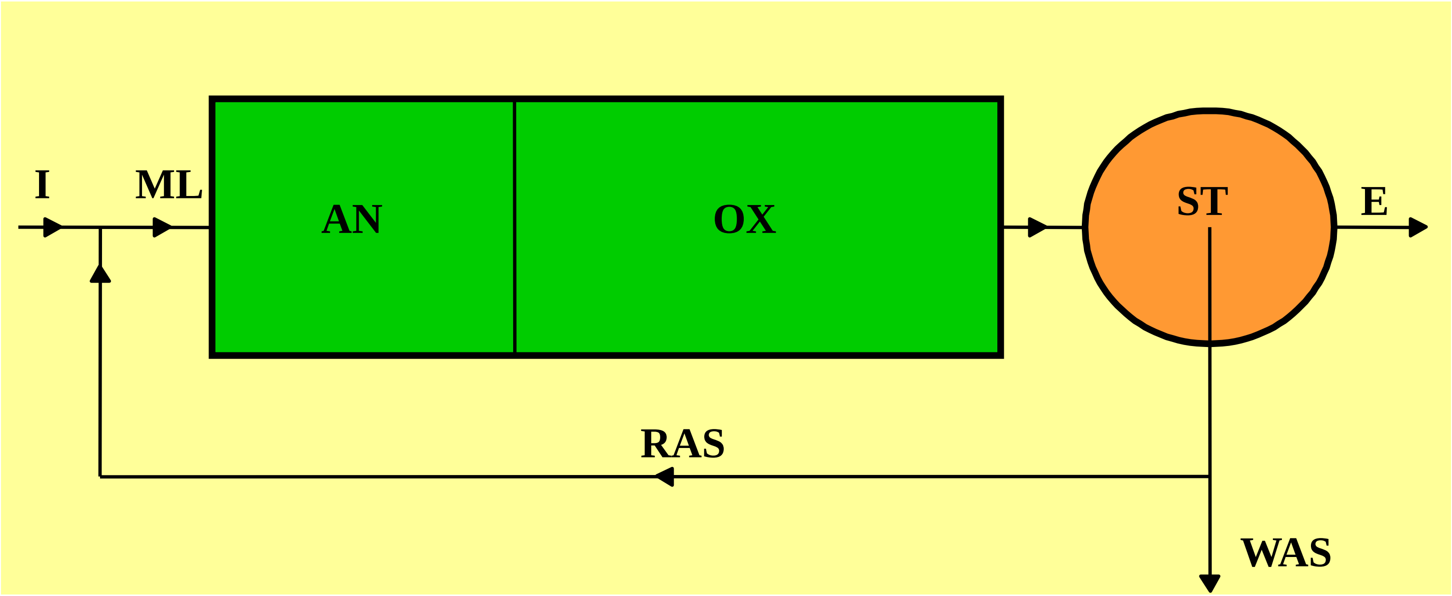
Pi - orthophosphate

OSP - organic storage product

n - number of monomers

Activated sludge systems with EBPR

1. Main line

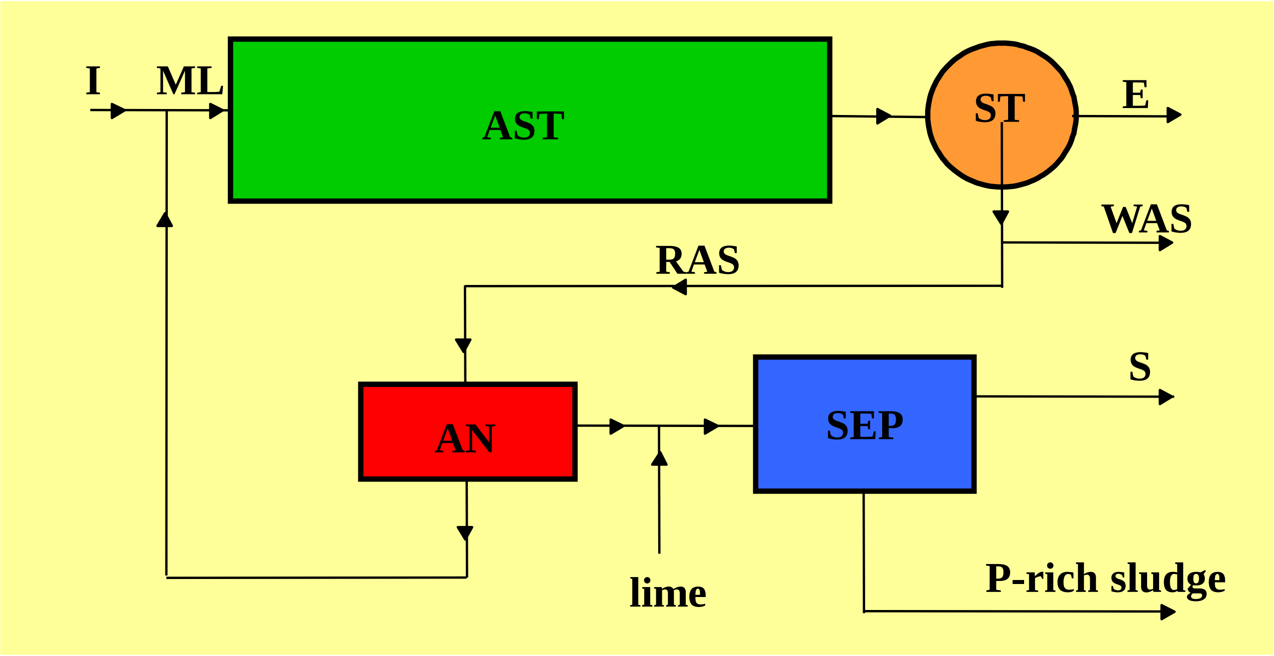


A/O system

I - influent, E - effluent, ML - mixed liquor, OX - oxic reactor, AN - anaerobic reactor, ST - settling tank, RAS - return activated sludge, WAS - waste activated sludge

2. Sidestream process

- P is biologically accumulated in the aeration basin in the activated sludge
- excessive accumulated P is stripped out from the return sludge in anaerobic conditions and precipitated with lime



PhoStrip system

AST - activated sludge tank (oxic reactor), AN - anaerobic (“stripper“) tank, S - supernatant, SEP - separation

CHEMICAL PRECIPITATION OF PHOSPHORUS

- addition of Ca, Fe or Al salts to form insoluble phosphates
- lime addition preferably to precipitate phosphorus in sludge water
- produces additional sludge

1. pre-precipitation

- before primary sedimentation
- need for phosphorus for biomass synthesis in activated sludge tank

2. simultaneous precipitation

- activated sludge tank, before secondary settling, RAS stream - most common way of phosphorus precipitation
- simultaneously with biological processes
- precipitate included in waste activated sludge

3. post-precipitation

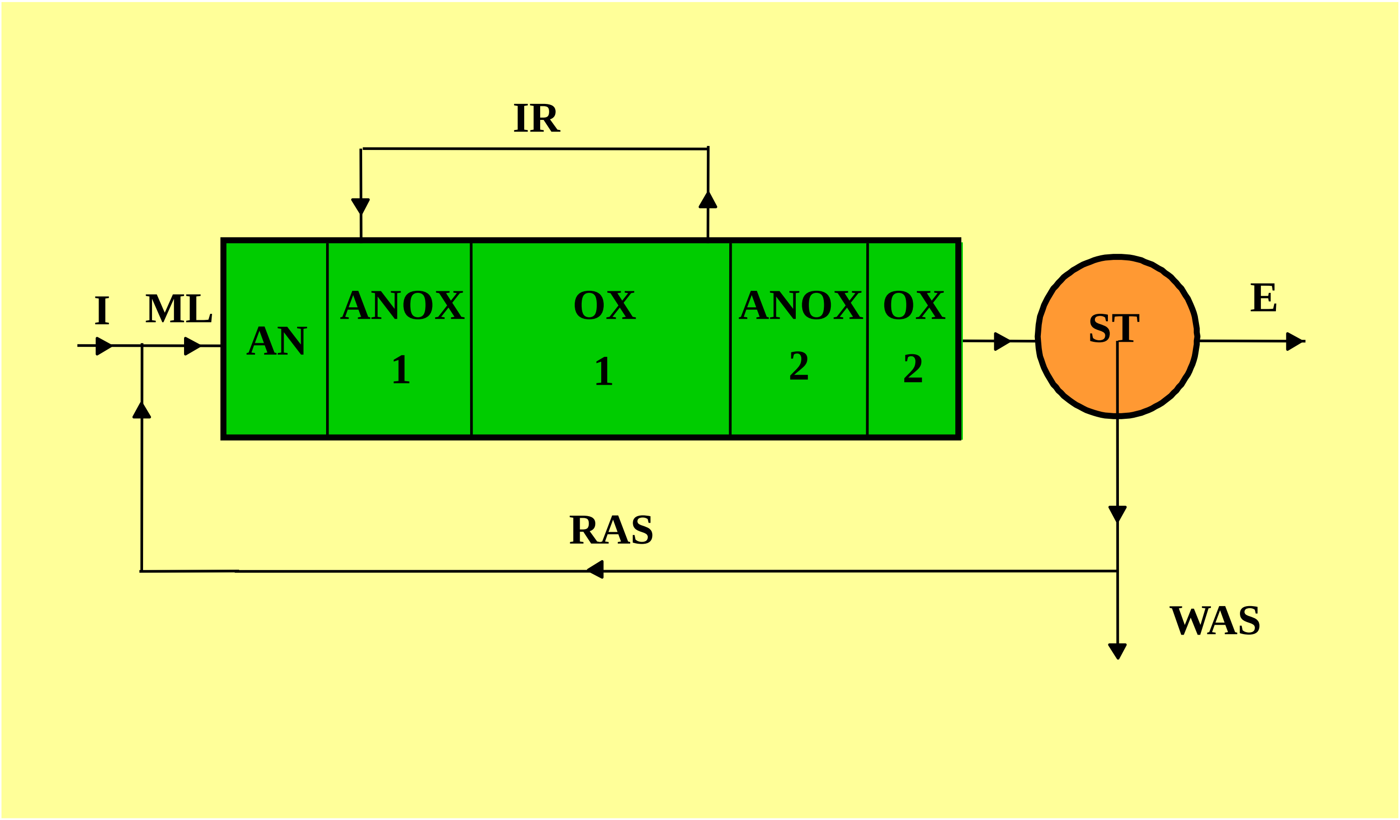
- after secondary settling (tertiary treatment)
- additional technological units needed (reactor for precipitation, settler for floc separation)
- polymers/flocculants added to obtain flocs with higher settling rate

BIOLOGICAL NUTRIENT (N and P) REMOVAL

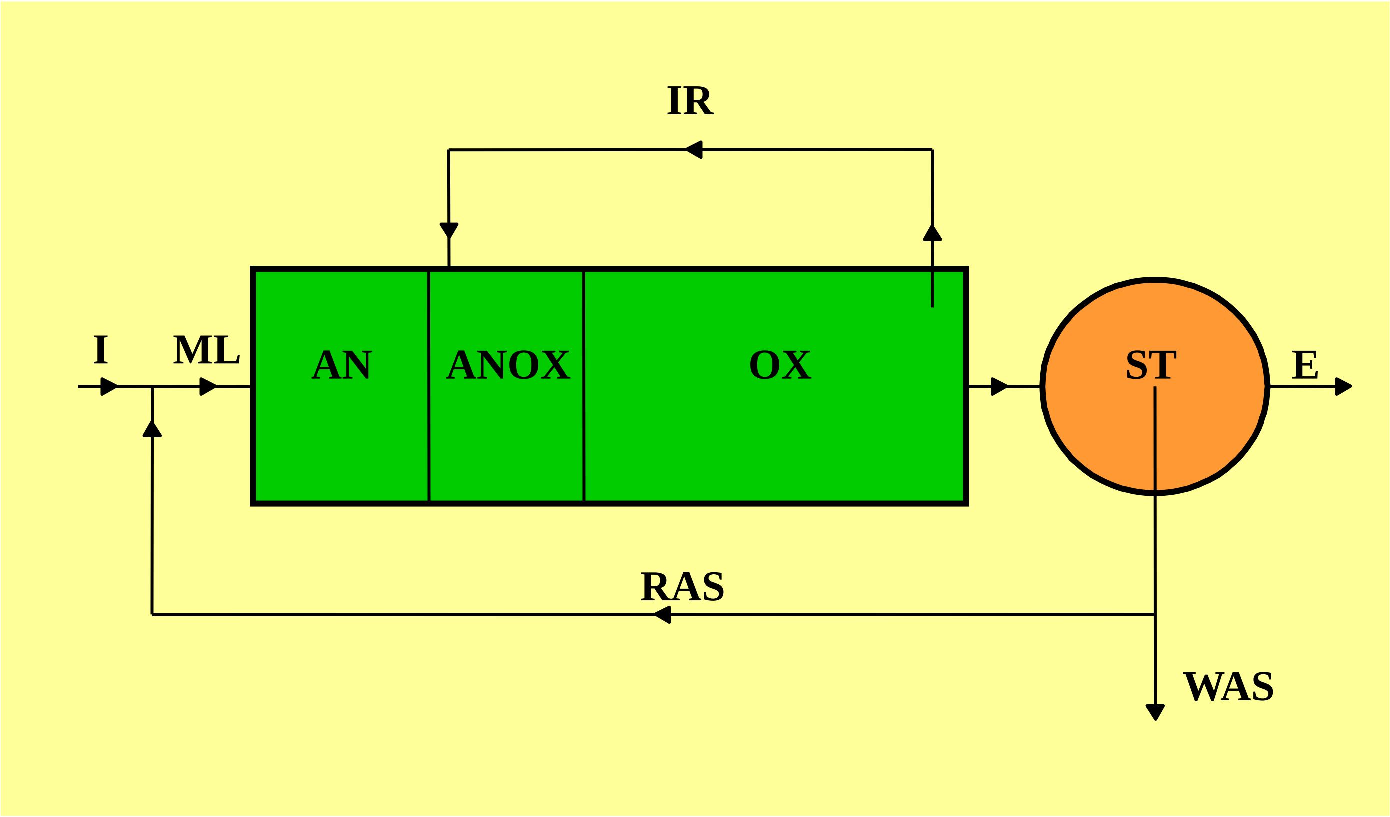
Antagonisms

- slow-growing nitrifying organisms ⟶ higher sludge age ⟶ lower activity of denitrifiers and PAOs
- denitrifiers and PAOs require RBCOD ⟶ strong competition for organic substrates
- nitrifiers as oxic microorganisms ⟶ slower or no metabolism under anoxic and anaerobic conditions
- recycling of nitrates from oxic zone (via RAS stream) ⟶ anoxic zone instead of anaerobic ⟶ loss of RBCOD (for denitrification not for PAOs)

Activated sludge systems of biological nutrient removal



5-stage Bardenpho process

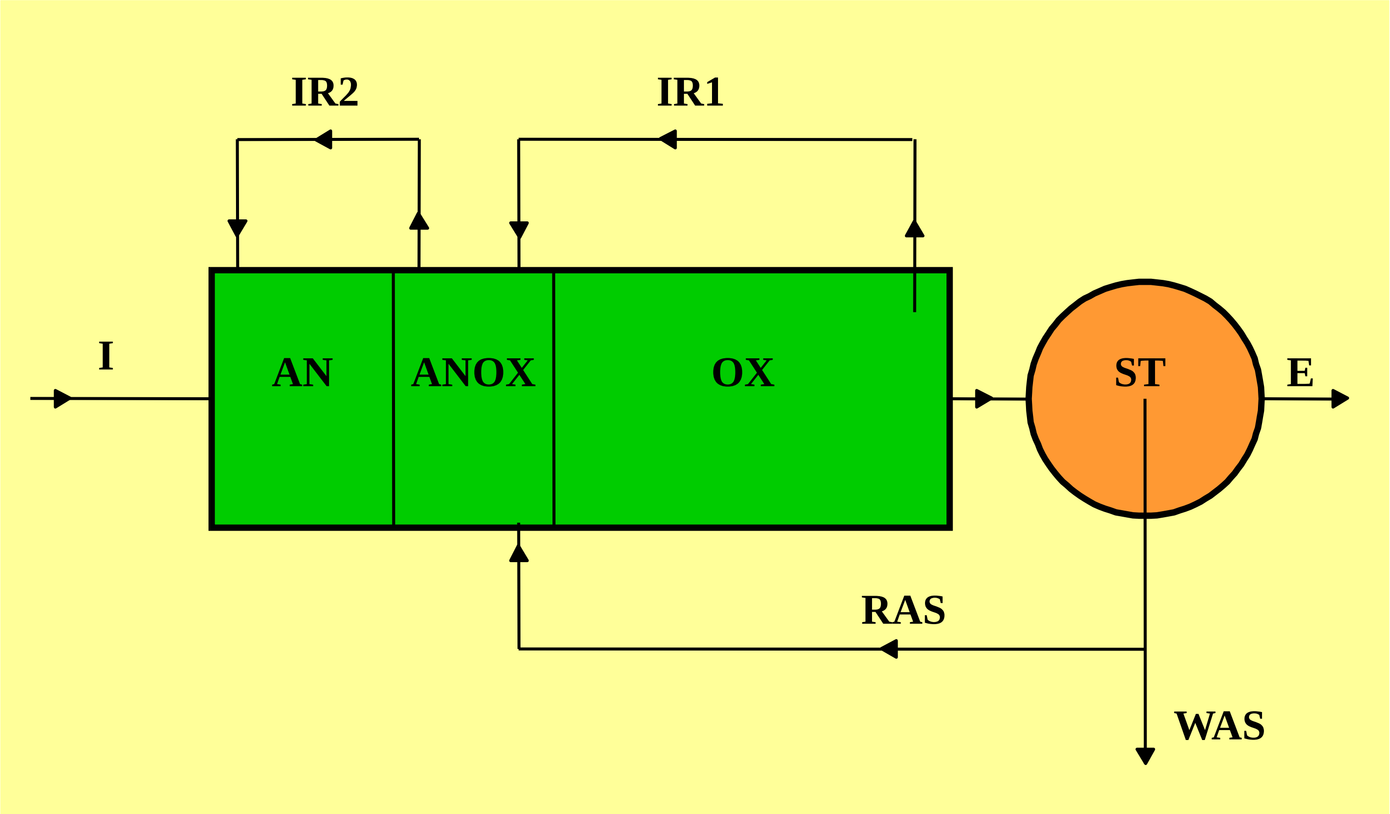


A^2/O process

WWTP Děčín – anaerobic, anoxic and oxic tanks

WWTP Pilsen - R-An-D-N process

WWTP Nymburk - Carrousel plant with simultaneous nitrification, denitrification and bio P removal



UCT process

- no recycling of nitrate to the anaerobic reactor via RAS stream

Extensive ways of nutrient removal

Constructed wetland

Biological lagoon (pond)

Design of biological nutrient removal systems

- required effluent quality ⟶ technological scheme selection
- wastewater composition ⟶ P_{TOT}/BOD_5 (COD), N_{TOT}/BOD_5 (COD), RBCOD
- based on nitrification (the slowest technological process) ⟶ sludge age design (depending on temperature) ⟶ concentration of biomass (X) ⟶ process volume requirements

Mixed liquor contact times (recommended values)

- anaerobic zone: 1 – 3 h (according to P_{TOT}/BOD_5)
- anoxic zone, $N_{TOT}/BOD_5 \leq 0.2$: min. 0.5 h
- anoxic zone, $N_{TOT}/BOD_5 \geq 0.3$: > 1 h
- oxic zone: $\geq$ 1.5 h (reduced forms of nitrogen loading $\leq$ 0.06 g/(kg·d))

Nitrogen from the sludge water stream must be added to the amount of nitrifiable nitrogen in calculations.

PHOSPHORUS RECOVERY

- high-grade deposits of phosphate rocks are utilized as the main source for the production of fertilisers and other industrial phosphates (increasing price)

- known reserves have a limited lifetime of about 50 – 100 years $\longrightarrow$ phosphorus recovery importance

- precipitation of struvite (i.e. magnesium ammonium phosphate, MAP) is the most widely developed technique

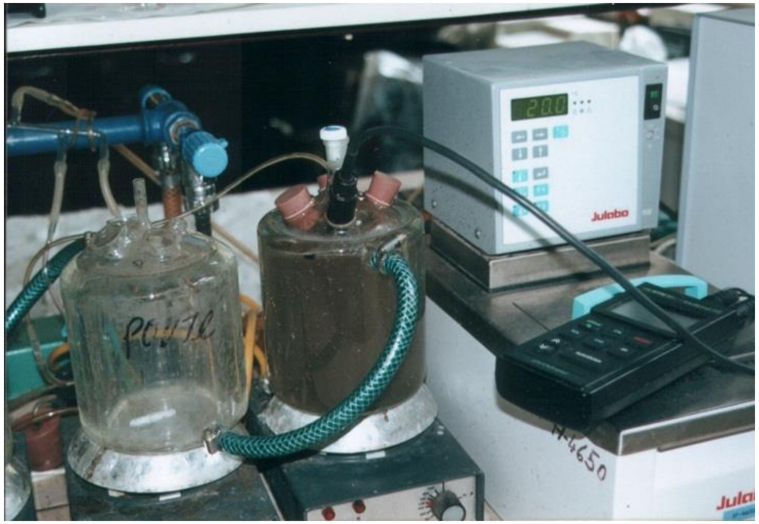
$$Mg^{2+} + NH_4^+ + PO_4^{3-} = MgNH_4PO_4$$

- MAP process is suitable for high-strength wastewater, such as digester supernatant

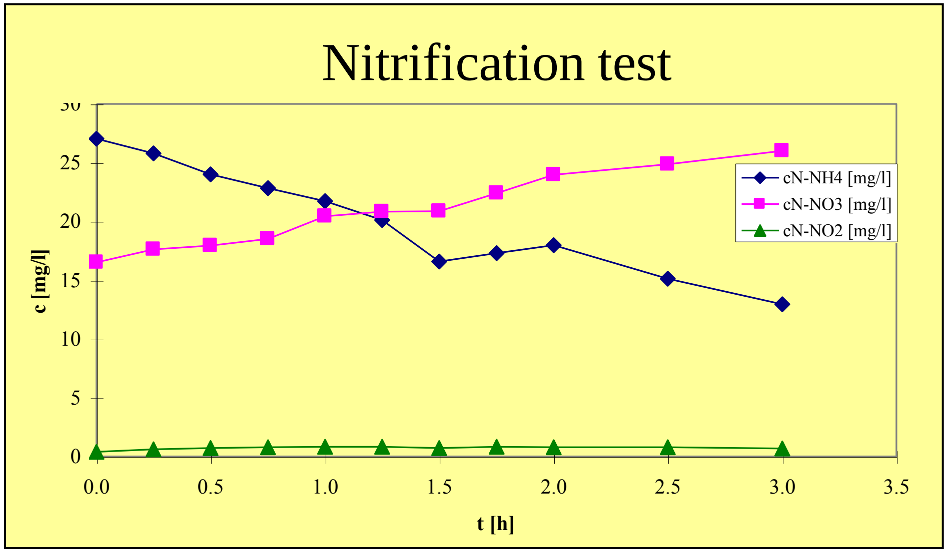
- struvite produced by precipitation can be used as an agricultural fertiliser

LABORATORY KINETIC BATCH TESTS

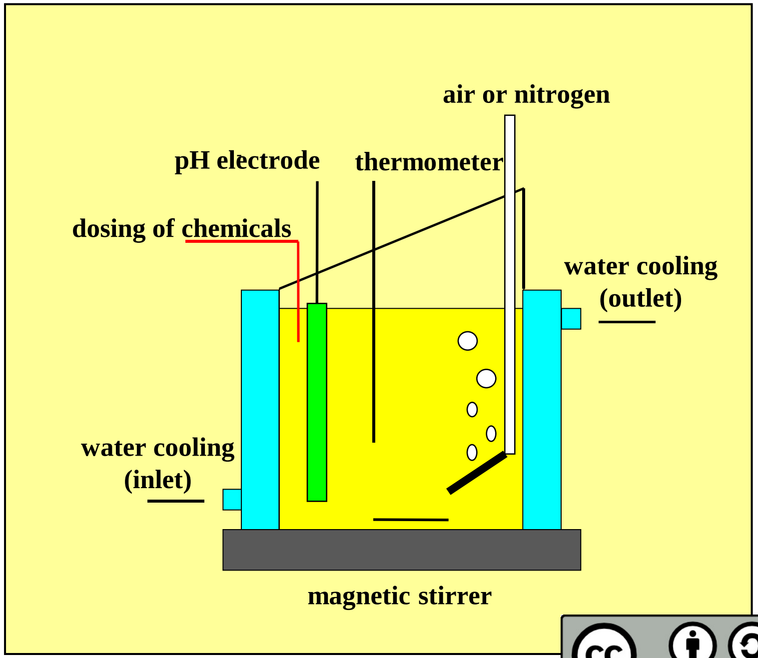
- respiration (oxygen uptake rate - OUR)
- nitrification (ammonia uptake rate - AUR)
- denitrification (nitrate uptake rate - NUR)
- phosphorus release (PRR) and accumulation (PAR) rate



Laboratory equipment



specific rate r_X mg/(g·h)



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10. CONTROL OF ACTIVATED SLUDGE SEPARATION AND THICKENING

CONTROL OF ACTIVATED SLUDGE SEPARATION AND THICKENING

Separation problems

1. Dispersed growth
2. Microflocs (pinpoint flocs)
3. Viscous bulking
4. Rising sludge
5. **Filamentous bulking**
6. **Foaming/scum formation**

Control of filamentous bulking

1. Specific methods

- selectively targeted at achieving proper composition of activated sludge biocenoses

2. Non-specific methods

- treating consequences (symptoms) of elevated occurrence of filamentous microorganisms in activated sludge

Kinetic selection

based on different growth and substrate removal rates of floc-forming and filamentous microorganisms

Main factors affecting kinetic selection:

(i) wastewater composition
(ii) biomass retention time (sludge age)
(iii) actual substrate concentration in reactor
(iv) concentration of dissolved oxygen in mixed liquor

(i) Wastewater composition

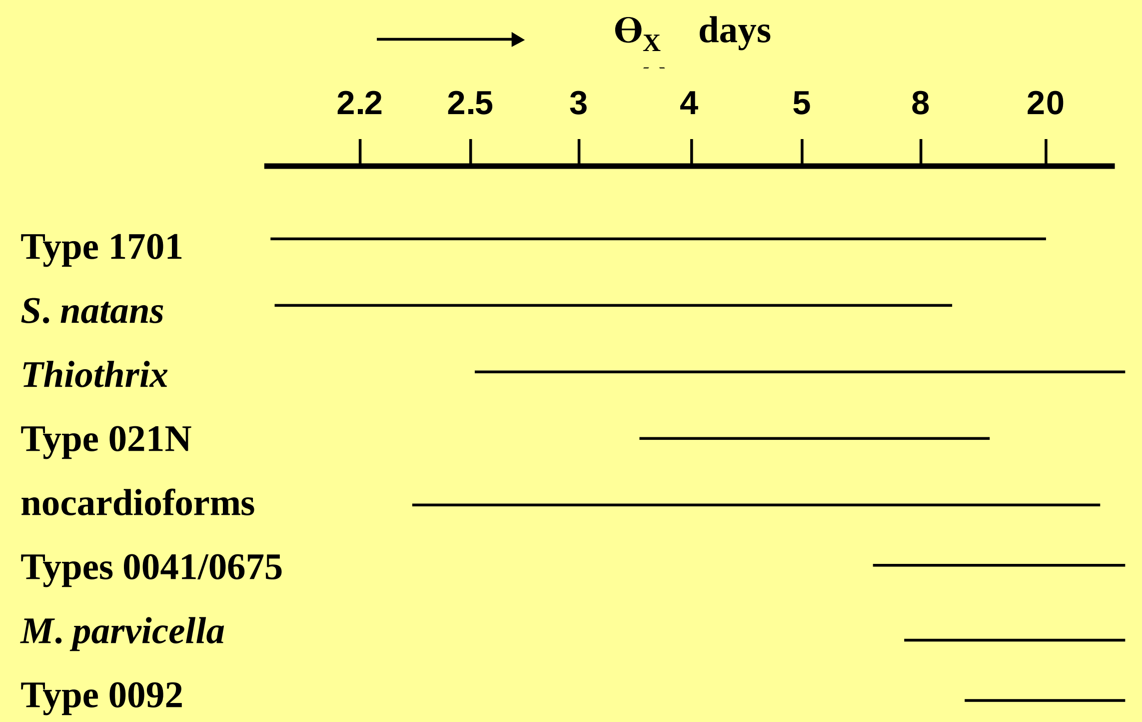
Type of substrate
- readily biodegradable
- sulphur compounds
- higher fatty acids and lipids

Inoculation of activated sludge system
- microorganisms from sewers

Concentration of nutrients
- lack of N/P
- trace elements

pH value
- low values

(ii) Biomass retention time (sludge age)



Relationship between biomass retention time Θ_X
and occurrence of filamentous microorganisms

(adapted from: Jenkins, Richard, Daigger (1993) Manual on the Causes and Control of Activated Sludge Bulking and Foaming, 2nd edition, Lewis Publishers, Inc., USA)

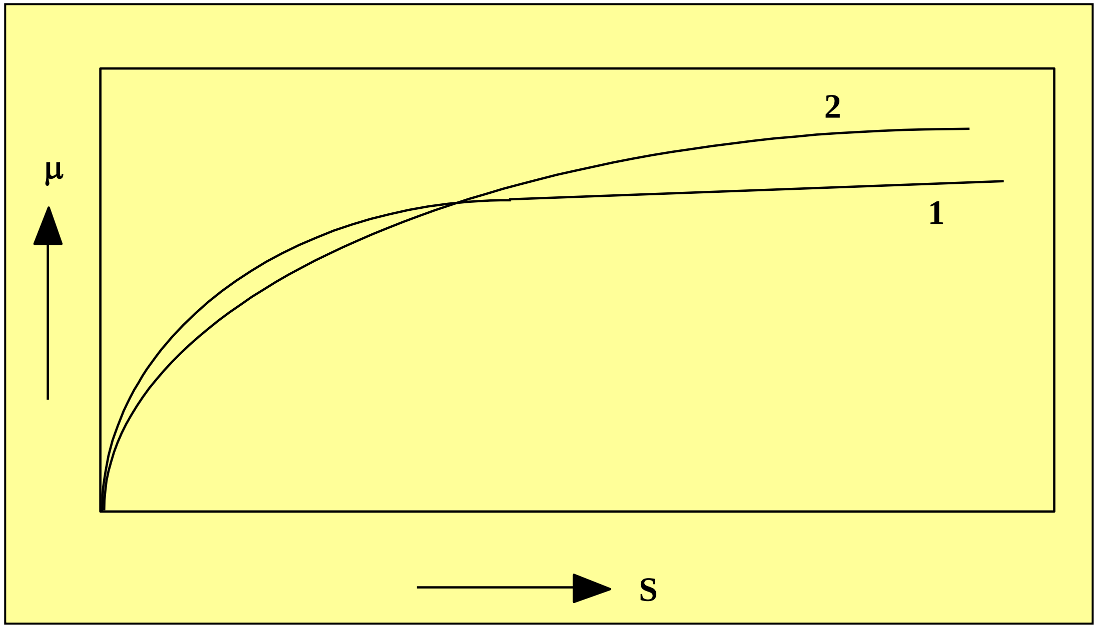
- critical sludge age values too low (less than 3 days) $\longrightarrow$ washout of slow-growing species (nitrifiers), dispersed growth of bacteria

(iii) Actual substrate concentration in reactor

Balanced growth - the uptake of substrates and the cell growth occur simultaneously.

The competition between floc-forming and filamentous microorganisms for one substrate is based on the different rate of substrate utilization (different constant values in Monod equation).

$$\mu = \mu_{\max} \cdot \frac{S}{K_S + S}$$



1 - K strategy (filaments)

2 - r (or μ_{max}) strategy
(floc-forming)

μ - growth rate

S - substrate concentration

Unbalanced growth - phases of the substrate (and/or nutrients) uptake and cell growth are partially or fully separated.

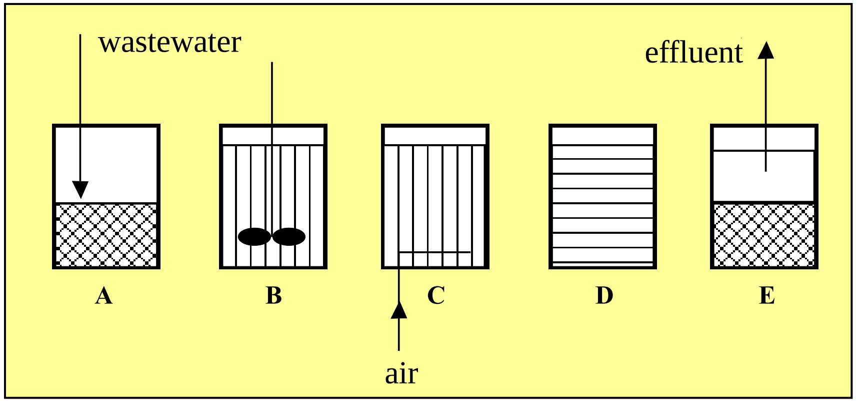
Microorganisms are able to accumulate the substrate and synthesize storage products = selective advantage when sufficient time is provided for the regeneration of both accumulation and storage capacities.

$\Downarrow$

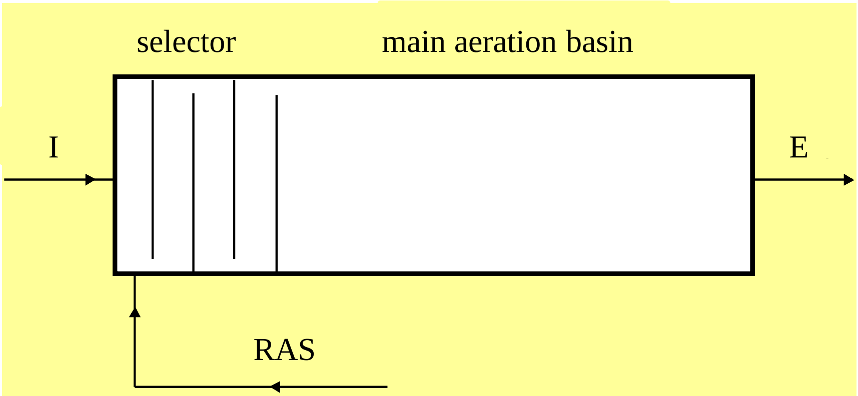
Systems with concentration gradients

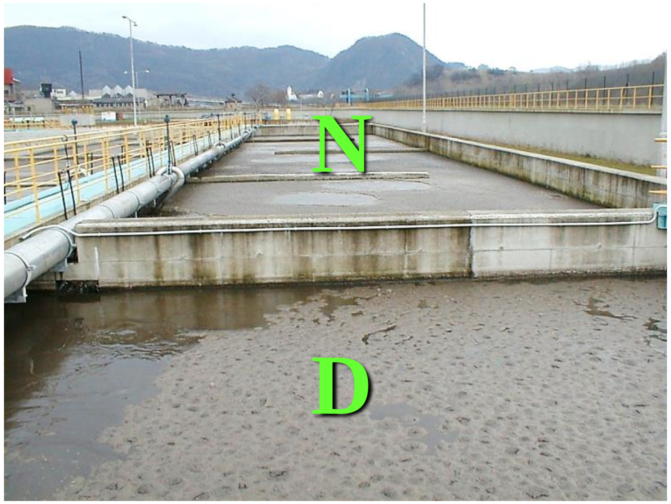
Concentration gradient

- SBRs systems



- compartments/selector (contact zone)





(iv) Concentration of dissolved oxygen in mixed liquor

- certain filaments exhibit a higher affinity to dissolved oxygen (DO) at low concentrations

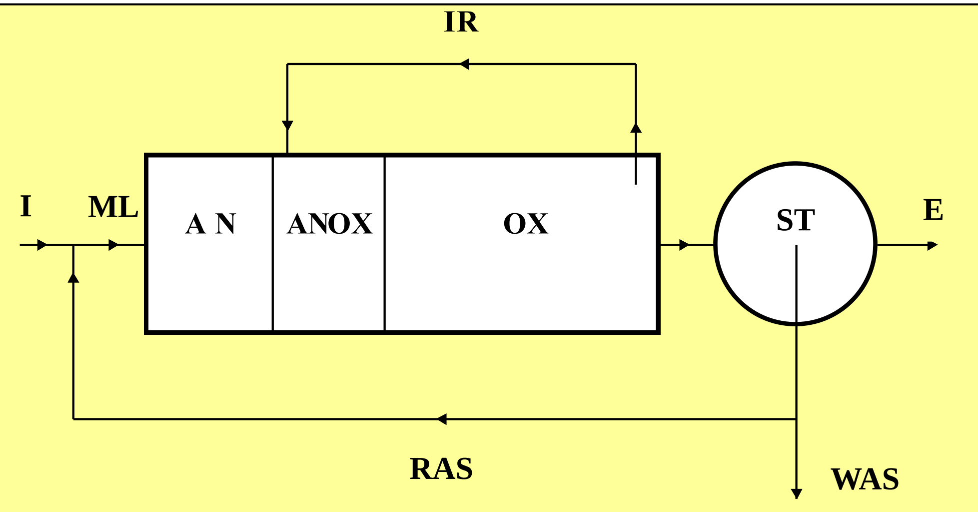
Relationship between B_X and „safe“ DO concentrations in oxic contact zones

B_X kg/(kg·d)(COD/MLVSS)	DO mg/l
0.3	1.0
0.5	2.0
0.75	3.0
0.9	4.0

Metabolic selection

- based on (in)ability to metabolize substrates under given cultivation conditions

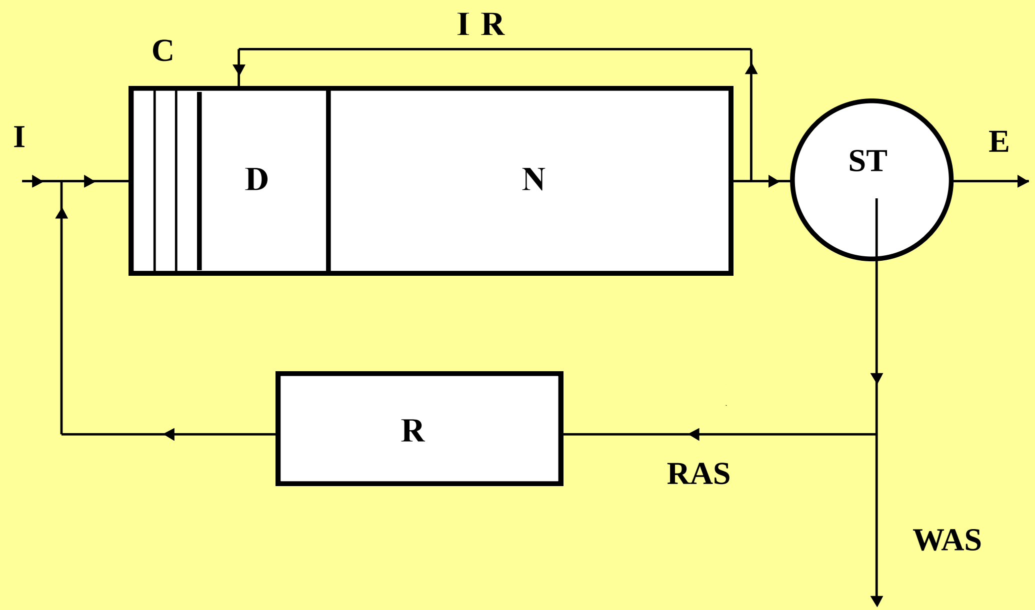
- biological nutrient removal systems (anoxic and/or anaerobic zones)



Schematic diagram of the An-D-N system

AN - anaerobic zone, ANOX - anoxic zone, OX - oxic zone,
I - influent, E - effluent, ML - mixed liquor, IR - internal recirculation, ST - settling tank,
RAS - return activated sludge, WAS - waste activated sludge

Combination of kinetic and metabolic selections



Schematic diagram of the R-D-N process

C - compartmentalized anoxic contact zone, D - denitrification zone (ANOX),
N - nitrification zone (OX), R - regeneration zone

Non-specific methods of activated sludge separation control

Filamentous bulking control

(i) Damaging filamentous microorganisms by toxicants (chlorine)

- overall mass dose rate of chlorine 1 – 15 g/(kg·d) (Cl_2, MLSS), dose rates above 5 g/(kg·d) require regular microscopic checking of activated sludge
- local specific mass dose at the dosing point - max. 15 – 20 g/kg (Cl_2, MLSS)
- frequency of activated sludge exposure to chlorine dose at least 2.5 – 3x day^{-1}

(ii) Weighting of activated sludge

- Fe/Al inorganic coagulants can be combined with phosphorus chemical precipitation

Filamentous foaming control

Strategies used to control biological foaming in the Czech Republic (62 WWTPs)

Measures	**Number of WWTPs**	**[%]**
Water sprays	26	42
Mechanical skimming	18	29
Return activated sludge manipulation	16	26
Reduction of sludge age	15	24
Additional installations of scum baffles	13	21
Application of contact zones (selectors)	10	16
Chlorination	3	5

Use of water sprays

- system reinoculation by filaments
- efficient improvement of final effluent quality

Eikelboom, D.H. (2000) Process Control of Activated Sludge Plants by Microscopic Investigation, first ed. IWA Publishing, London.

Use of water sprays in activated sludge basins

Use of water sprays

- on final clarifier surface

- in the channel connecting activated sludge basin and secondary clafirier

Foam spraying

Skimming and mechanical foam removal

- increase in cell dilution rate of foam-forming filamentous microorganisms

In most cases, foam is mechanically skimmed from the surface of secondary clarifiers (see lecture 12).

Example of mechanical foam skimming in connecting channel

Return activated sludge manipulation

- higher recirculation ratio

⬇

- lower risk of denitrification and carrier gas formation

Reduction of sludge age

- critical sludge age values - too low to wash out foam-forming filamentous microorganisms

⬇

- not applicable to biological nutrient removal systems

Additional installations of scum baffles (see lecture 12)

Contact zones (selectors)

- not very effective in foam-forming microorganisms growth control

Chlorination

- directly onto foam
- lower efficiency of nitrification, lower efficiency of biological phosphorus removal at higher chlorine dosages
- risk of chlorine overdosing ➡

regular microscopic examinations of both foam and mixed liquor

Application of mineral coagulants

- Fe and Al salts
- weighting effect, fixation of filaments into activated sludge flocs
- inhibitory/partial toxic effect of Al on certain filaments growth

Selective floatation

- insertion of floatation unit between main aeration basin and secondary clarifier

Bioadditives

- antifoam agents
- enzymatic agents

Operation and design of secondary clarifiers (see lecture 12)

IDENTIFICATION OF FILAMENTOUS MICROORGANISMS

Identification methods

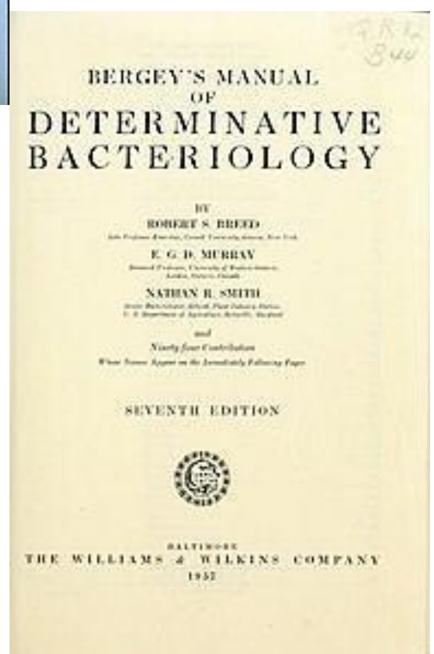
(i) conventional (cultivation) methods

(ii) identification of types

(iii) methods of molecular biology

(i) Conventional (cultivation) methods

- based on isolating microorganisms from mixed cultures and on subsequent tests of morphological, biochemical and physiological features


BERGEY'S MANUAL
OF
DETERMINATIVE
BACTERIOLOGY

BY
ROBERT S. BREED

E. G. D. MURRAY

NATHAN R. SMITH

SEVENTH EDITION

BALTIMORE
THE WILLIAMS & WILKINS COMPANY
1957

Main disadvantages:

• at least 30 stable features needed for formal recognition of nomenclatoric taxon

• lack of filamentous microorganism pure cultures for comparisons

• physiological, morphological and genetic changes in filamentous microorganisms in comparison with pure cultures of the same organisms

• some filaments exhibit low growth rates

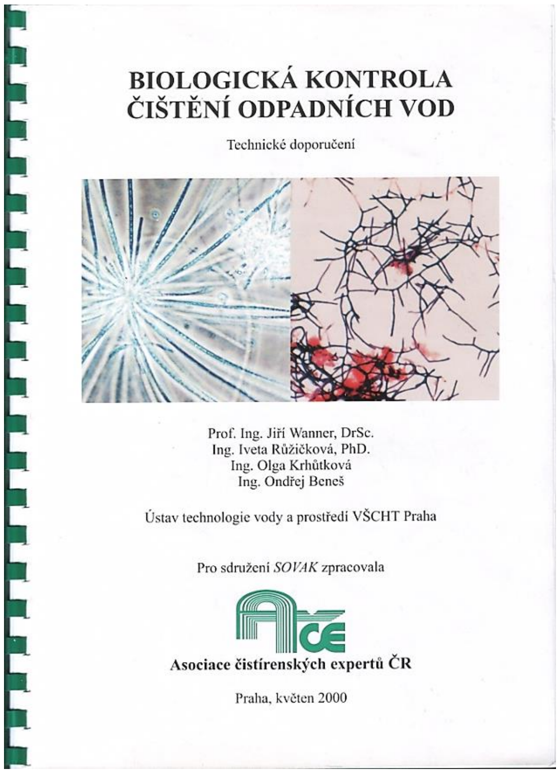
• the great plate count anomaly (*Acinetobacter* spp.)

Advantages:

• unambiguous taxonomic position of microorganisms

(+ methods of chemical analyses and molecular biology)

(ii) Identification of types (Eikelboom, 1975)



<u>Type</u> (Latin name, numerical code)
- different organisms with similar morphology and staining responses
(cca 30 morphotypes x 100 genotypes)

<u>Disadvantage:</u>
• taxonomic position uncertain or unknown

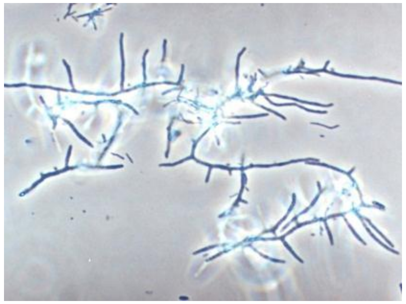
<u>Advantages:</u>
• rapid and simple method
• common laboratories
• suits practical needs

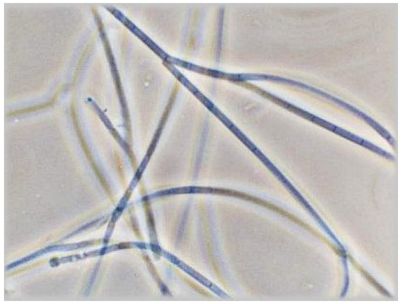
Morphological features of filamentous microorganisms

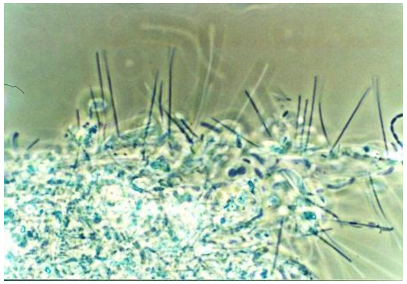
phase constrast, ca. 1,000x

fixed x variable

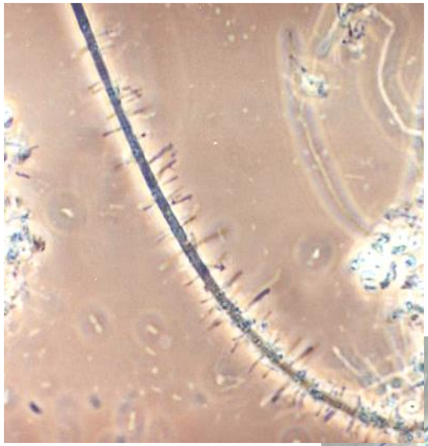
- branching
(true, false)
- motility
- filament shape
(straight, bent, curved, chain of cells, …)
- filament location
(within flocs, protruding from flocs, dispersed in bulk liquid)

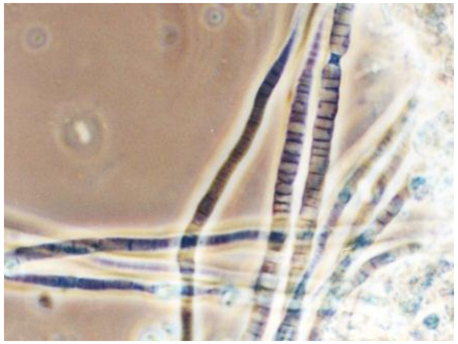


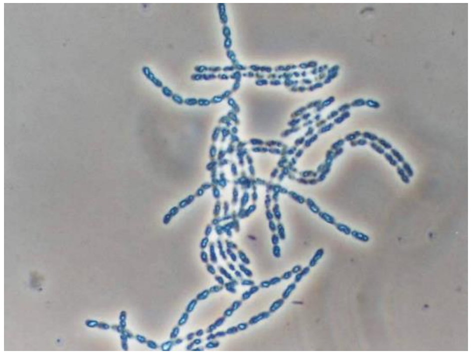




- attached growth
- presence of cell septa
- cell size and shape
(rectangles, squares, ovals, rods, …)
- filament diameter and length
- intracellular granules
(sulphur, PHB)
- presence of sheaths





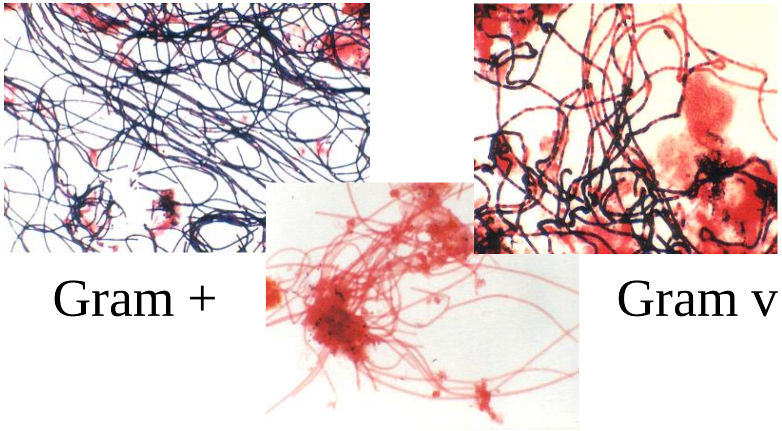


Staining rections
direct illumination, cca 1,000x

air dried smears

Gram stain
- different chemical composition of bacterial cell walls, therefore different responses to the Gram stain

Gram staining



Gram +

Gram v

Gram –

- 1. Crystal violet
- 2. Lugol solution (I + KI)
- 3. Decolorizing solution – ethanol, 95%
- 4. Safranin O

<u>Neisser stain</u>

- 1. methylene blue

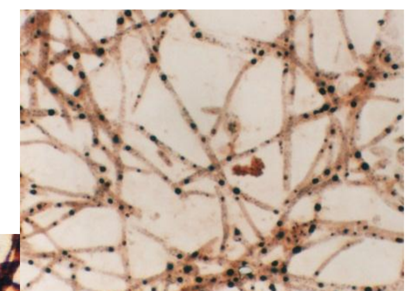
(in ethanol and acetic acid)

and crystal violet (2:1)

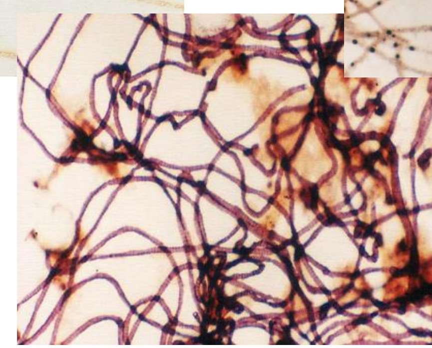
- 2. Bismarck brown - water solution

Neisser staining

Neisser –



Neisser + granules

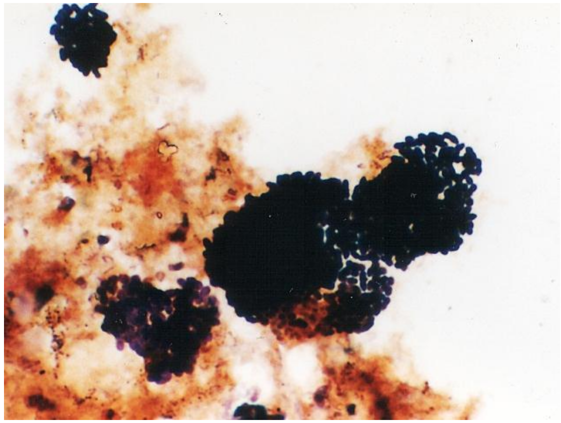


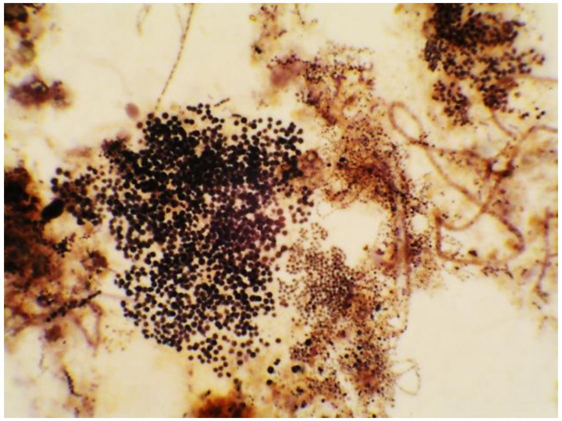
Neisser +

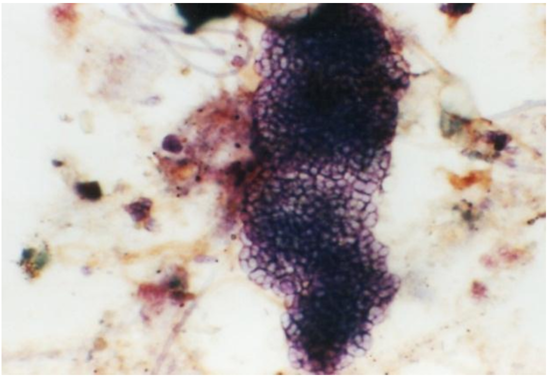
Neisser staining - detection of phosphorus metabolism microorganisms

<u>polyphosphate accumulating organisms (PAOs)</u>

- enhanced biological phosphorus removal - activated sludge is alternately exposed to anaerobic and oxic conditions
- release and accumulation of phosphorus



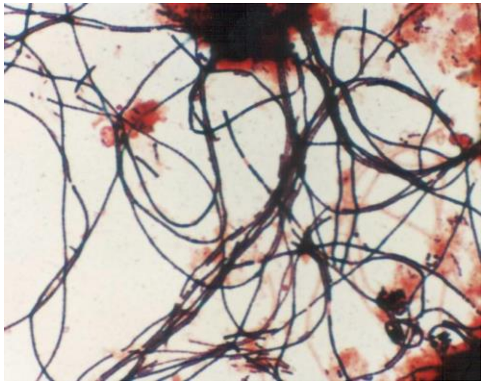




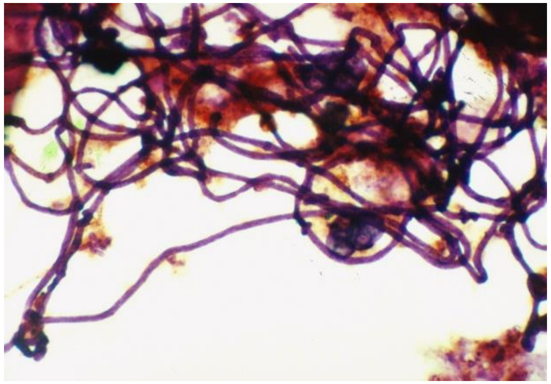
Glycogen accumulating organisms (GAOs)

Most common filamentous microorganisms at WWTPs in the Czech Republic

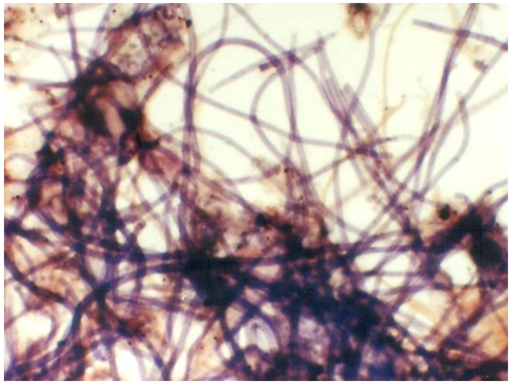
<u>dominant in sludges</u>



Microthrix parvicella



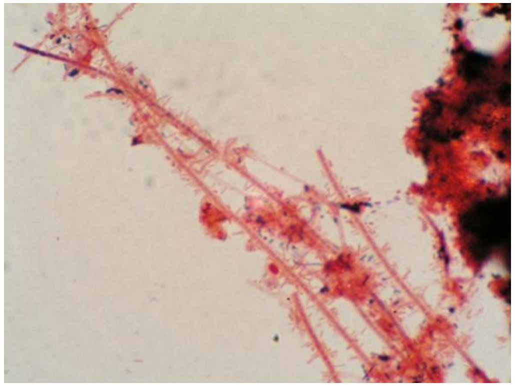
Nostocoida limicola



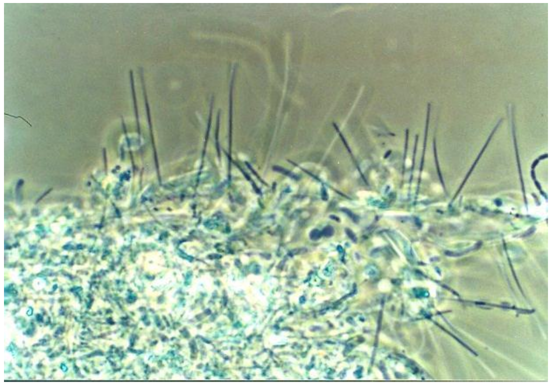
Typ 0092

<u>secondary in sludges</u>

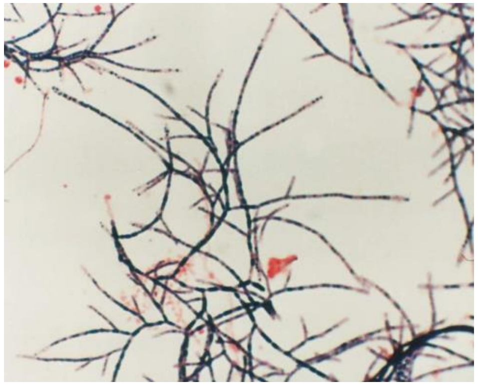
<u>dominant in foams</u>



Typ 0041/0675



Haliscomenobacter hydrossis



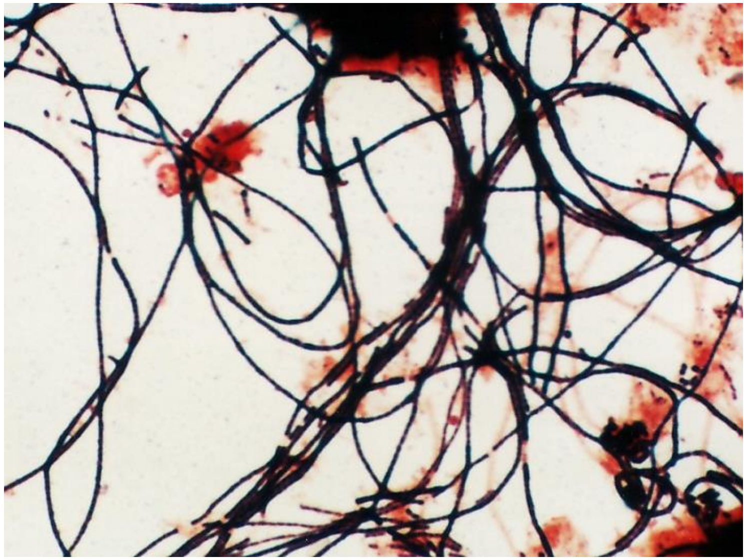
GALO

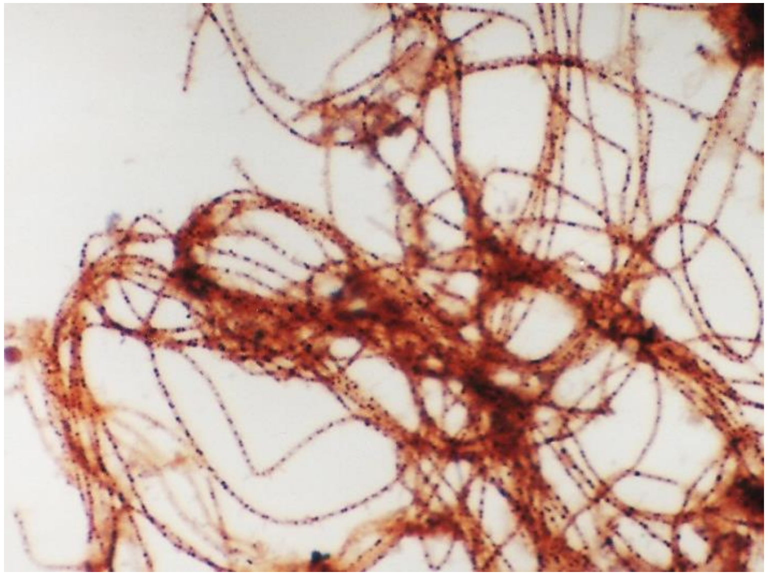
Microthrix parvicella

- irregularly coiled
- cell septa cannot be seen
- length: 50 – 200 μm,

diameter: 0.6 – 0.8 μm

- G+, N– and N+ granules





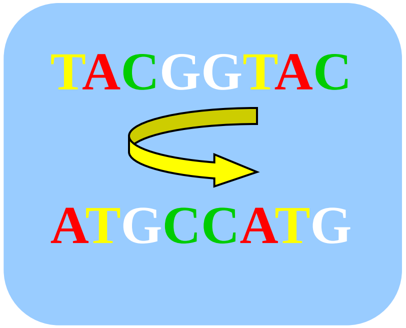
Microthrix parvicella

Substrate and nutrient requirements, physiology:

• long chain fatty acids in esterified forms x readily biodegradable substrates?
• ability to denitrify?
  $NO_3^- \Rightarrow NO_2^-$ x $\Rightarrow N_2$
• enhanced biological phosphorus removal?
• sporulation?
• optimum pH = 7.7 – 8.0; no growth at pH < 7.1 x WWTP?
• reduced forms of N and S
• psychrophilic organism, growth occurs down to 8 °C but ceases at 35 °C

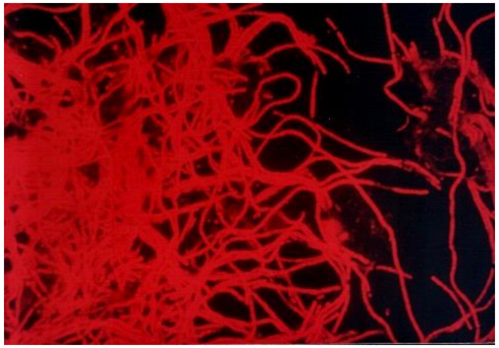
(iii) Methods of molecular biology

- based on analyses of specific RNA/DNA sequences (16S, 23S) by means of gene probes:

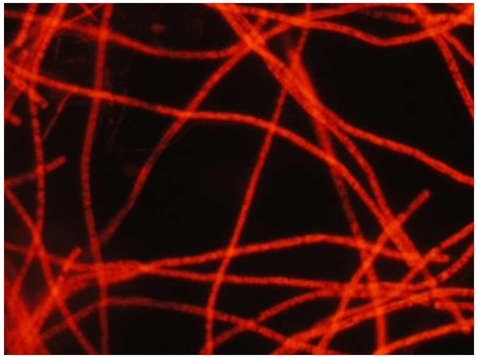


- ability to hybridize with targeted nucleotic acids on the basis of base pairs complementarity
- fluorescently labeled ⇒

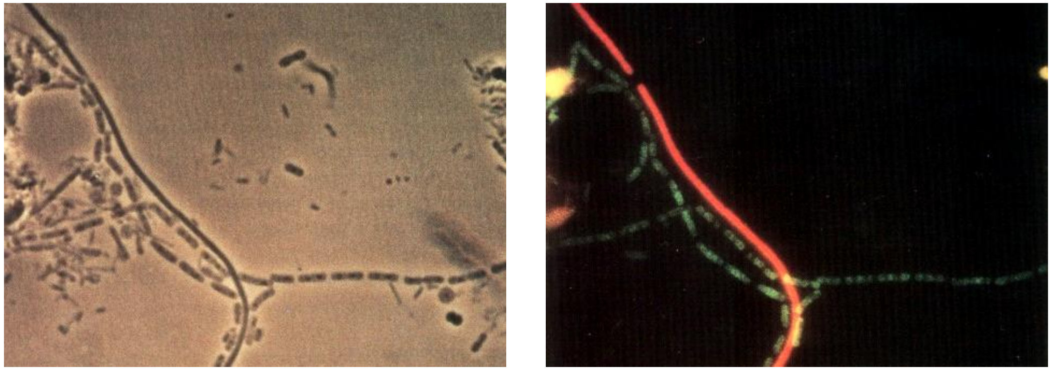
fluorescent *in situ* hybridization (FISH)



Microthrix parvicella



Thiothrix spp.



Type 021N - red
Sphaerotilus natans - green

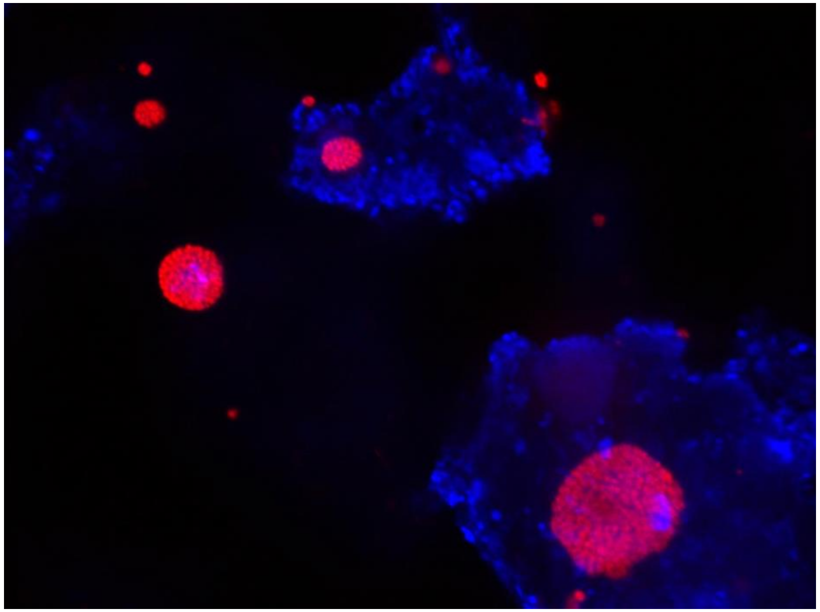
Wagner M., Amann R., Kämpfer P., Assmus B., Hartmann A., Hutzler P., Springer N., Schleifer K. H. (1994) Identificatio
detection of gram-negative filamentous bacteria in activated sludge. System Appl Microbiol 17, 405 – 417.

Advantages:

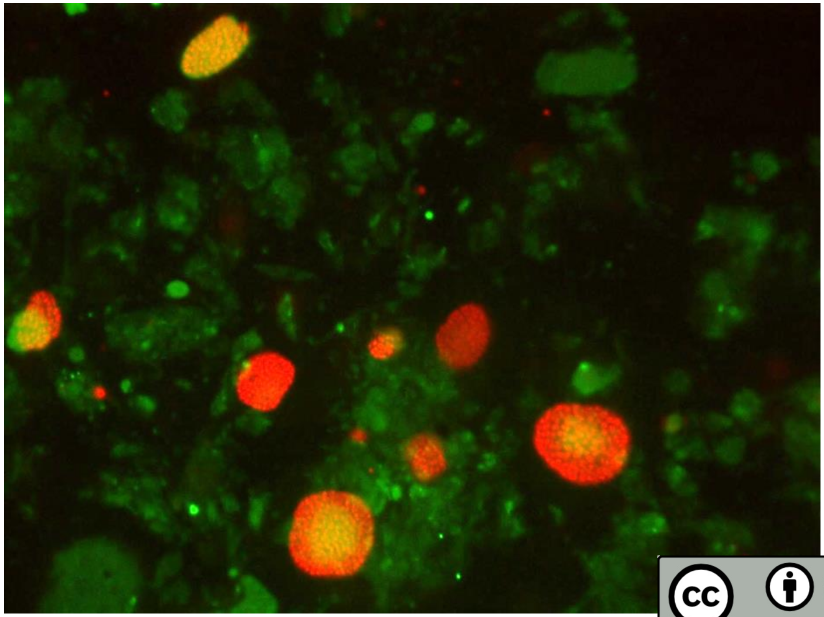
- fast and unambiguous identification (morphologically similar organisms exhibit different growth and nutrient requirements)
- specificity (individual microorganisms x physiological groups)
- identification independent on actual morphology

Disadvantages:

- financial costs, equipment requirements
- lack of available gene probes



nitrifying bacteria



EUROPEAN UNION
European Structural and Investing Funds
Operational Programme Research, Development and Education

MINISTRY OF EDUCATION, YOUTH AND SPORTS

11. BIOFILM PROCESSES

BIOFILM PROCESSES

A biofilm is an aggregate of microorganisms in which cells adhere to each other on a surface. These adherent cells are frequently embedded within a self-produced matrix of extracellular polymeric substances (EPS, glycocalyx).

Biofilm EPS is a polymeric conglomeration generally composed of extracellular DNA, proteins and polysaccharides. This matrix protects the cells within it and facilitates communication among them through biochemical signals.

Biofilms may form on living or non-living surfaces.

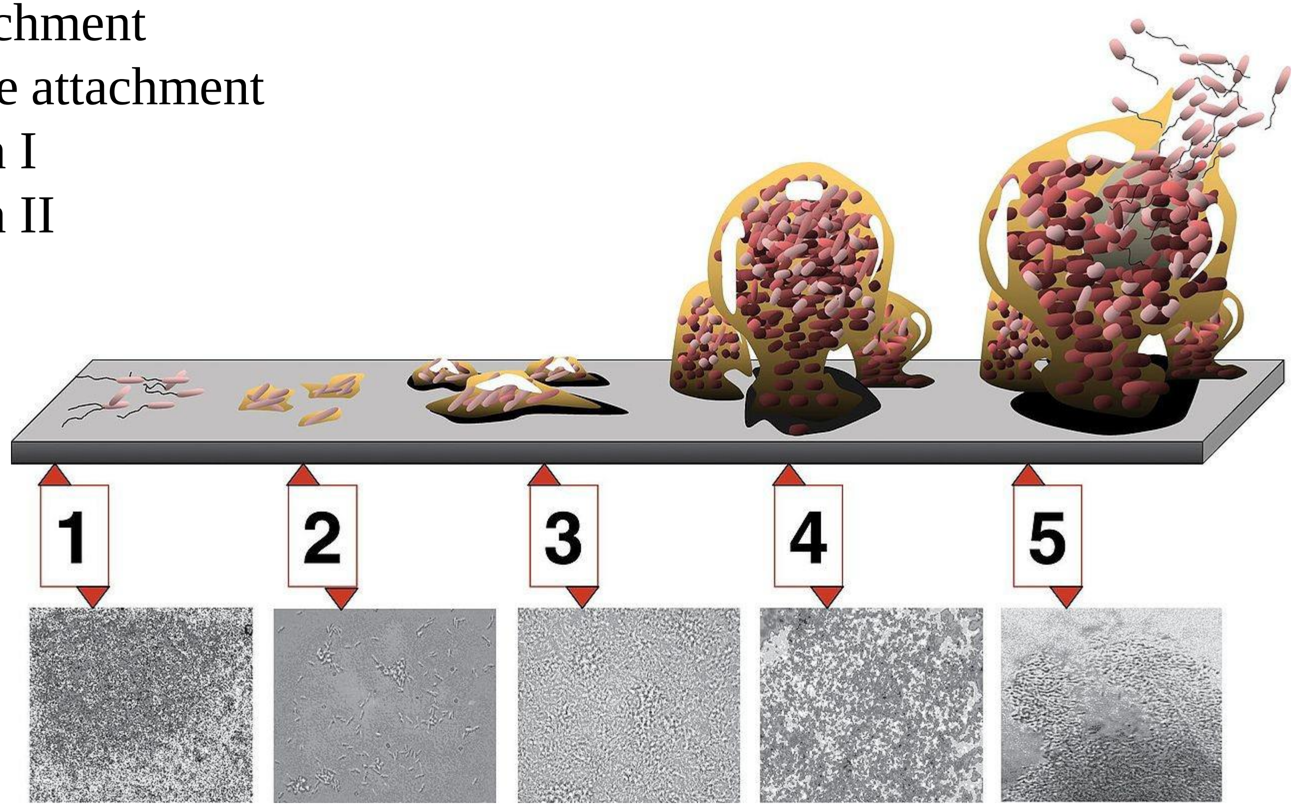
FORMATION AND DEVELOPMENT OF BIOFILMS

Formation of a biofilm begins with the attachment of free-floating microorganisms to a surface. These first colonists initially adhere to the surface through weak, reversible adhesion via van der Waals forces. If the colonists are not immediately separated from the surface, they can anchor themselves more permanently using cell adhesion structures.

The first colonists facilitate the arrival of other cells by providing more diverse adhesion sites and beginning to build the matrix that holds the biofilm together. Once colonization has begun, the biofilm grows through a combination of cell division and recruitment. The final stage of biofilm formation is known as development and it is the stage in which the biofilm is established and may only change in shape and size. The development of a biofilm may allow for an aggregate cell colony (or colonies) to become increasingly resistant to detergents and antibiotics.

Biofilm development

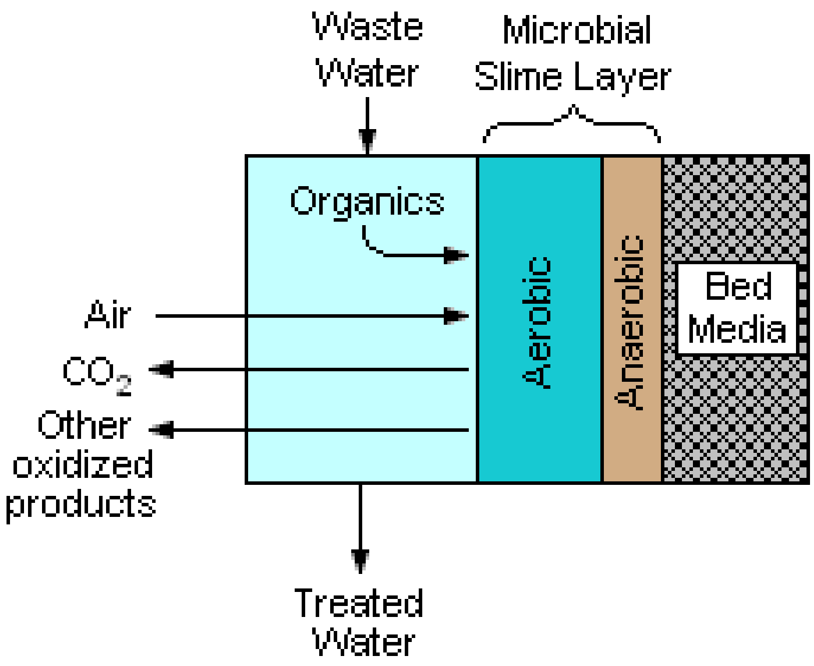
- stage 1 - initial attachment
- stage 2 - irreversible attachment
- stage 3 - maturation I
- stage 4 - maturation II
- stage 5 - dispersion

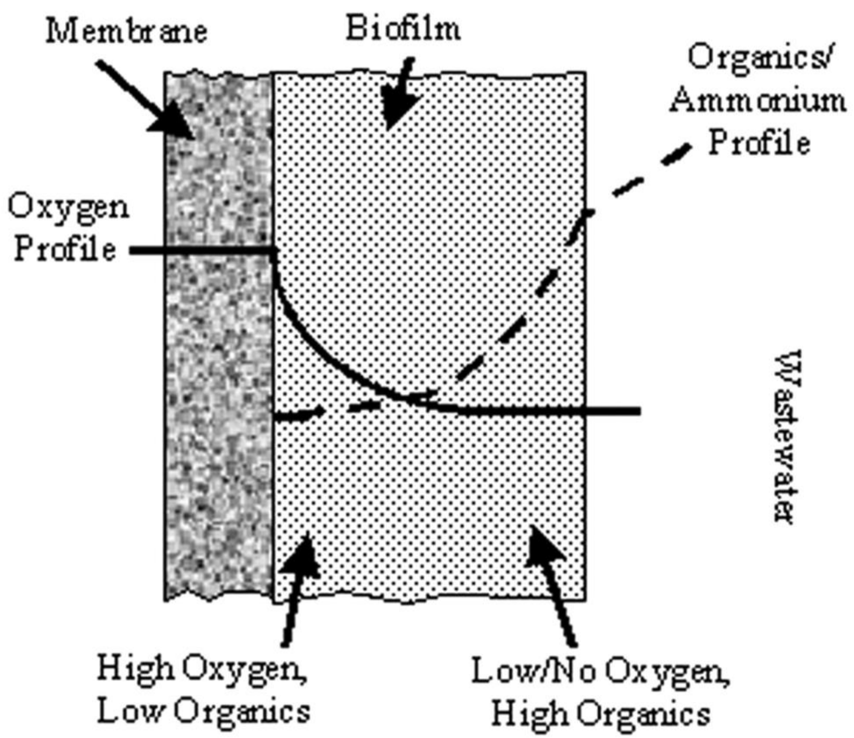


Each stage of development in the diagram is paired with a microphotograph of a developing *Pseudomonas aeruginosa* biofilm.

All photomicrographs are shown at the same scale.

Stratification of biofilms - limitation by diffusion

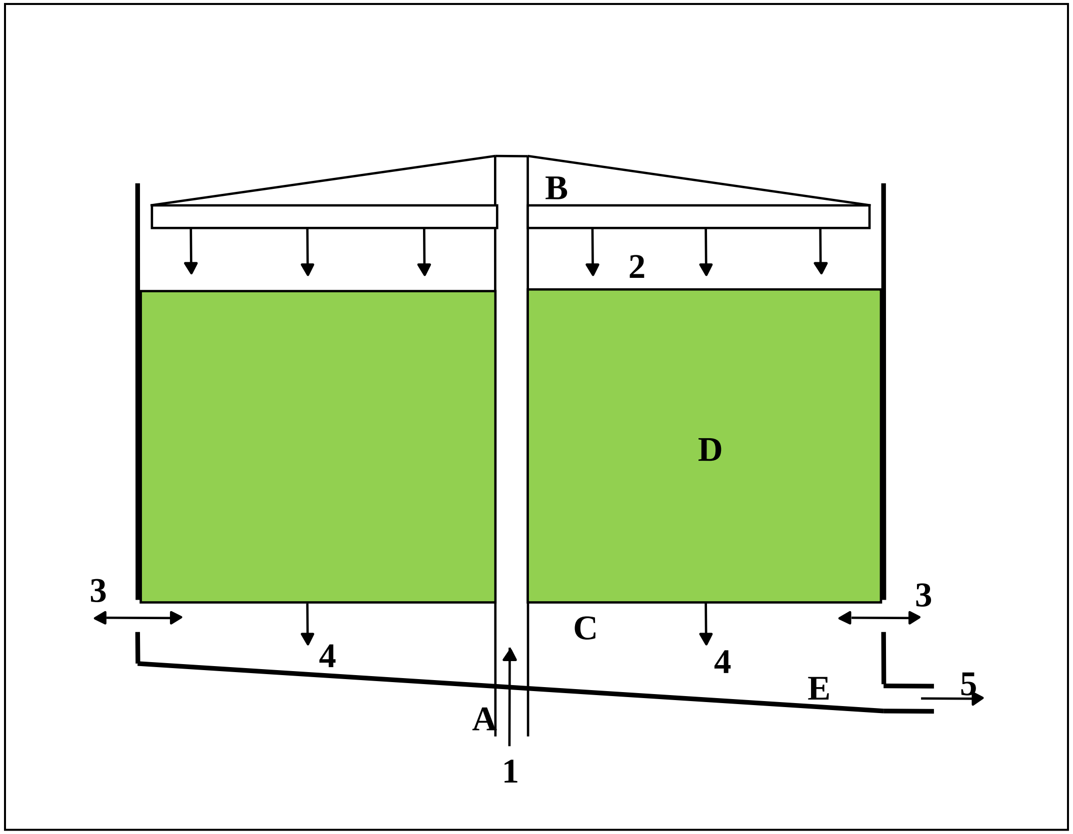




BIOFILM REACTORS

- Trickling filters (biofilters)
- Rotating biofilm contactors (RBCs)
  - rotating discs
  - rotating cage reactors
- Biofilm reactors with fluidized bed
- Biofilm reactors with expanded bed
- Combined cultivation of activated sludge and biofilms

Trickling filters



A trickling filter consists of a fixed bed of filter media over which sewage or other wastewater flows downward and causes a layer of microbial slime (biofilm) to grow, covering the bed of media.

A - center well/feed pipe, B - rotating sprinklers,
C - support grill and under-drainage system, D - biofilter media,
E - sloped floor with effluent channel
1 - influent, 2 - wastewater distribution, 3 - ventilation opening,
4 - treated wastewater and detached biomass, 5 - effluent

Trickling filters

Settlers after trickling filters

Trickling filter ventilation

1) natural convection

- based on different temperature values inside and outside reactors
- ventilation opening area appr. 2 % of cross sectional area

2) *forced air ventilation*

- countries with warmer climate or industrial wastewater treatment

standard: 10 m^3 of air per 1 m^3 of wastewater and hour

Ventilation openings

Wastewater inlet - distribution system

Circular trickling filter with rotary arms (Segner wheel)

Under-drainage system

- strong enough to support biofilter media
- allows water and air to pass through
- perforated blocs are used, can be made of precast concrete, vitrified clay or plastics

Trickling filter media - technological parameters

Specific surface area

$$a = A_f / V \quad [m^2/m^3]$$

Porosity (void space)

$$\varepsilon = (V - V_M) / V \cdot 100 \quad [\%]$$

where A_f is the effective surface area of the biofilm [m^2]
V is the volume of the biofilm reactor containing the filter material [m^3]
V_M is the volume of the biofilter media [m^3]

The filter medium provides a surface for a biological slime layer (biofilms) to attach and grow.

The filter media needs to be durable, insoluble and resistant to chemicals.

Trickling filter media - classification

1. Mineral media

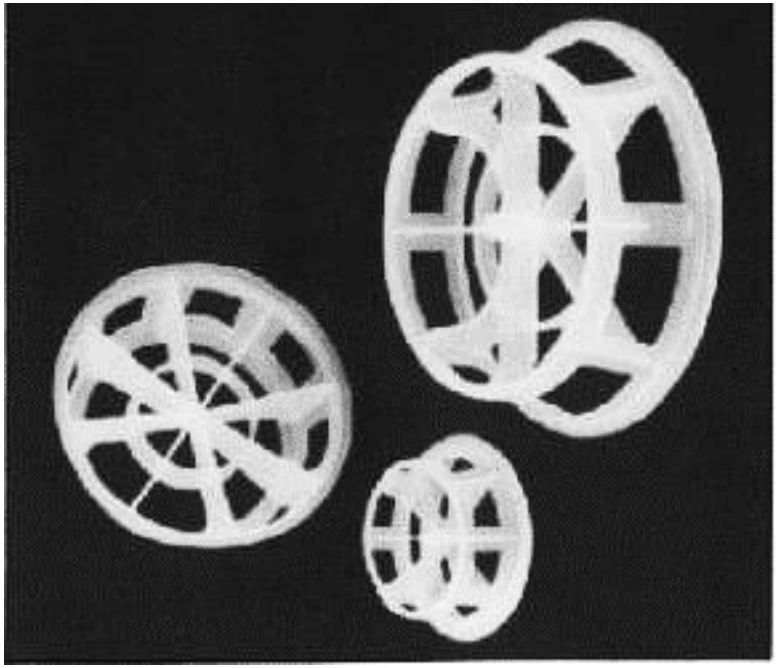
- fixed beds of rocks, lava, coke, gravel, slag,…
- 30 – 100 mm in diameter
- basic parameters:

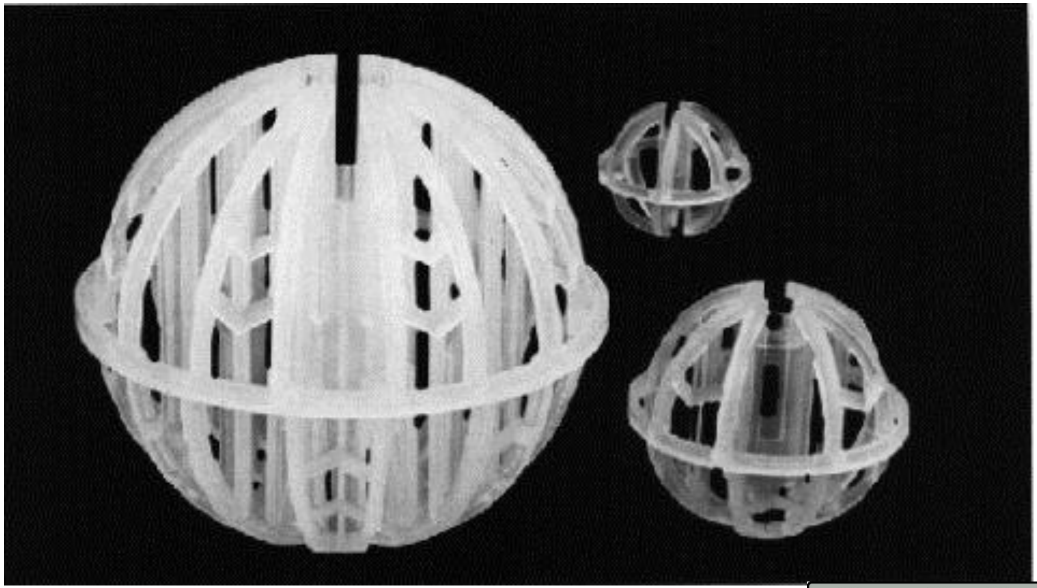
  a = 40 – 50 m^2/m^3, ε = 35 – 50 %, up to 1 500 kg/m^3
- biofilter clogging - chlorination

2. Plastic material - random packings

- different types of plastic shapes, available in wide variety of specific surface areas
- randomly dumped into biofilters
- good void fraction, relatively light weight
- basic parameters:

$$a = 100 – 400\ m^2/m^3,\ \varepsilon = 80 – 95\ \%,\ 50 – 200\ kg/m^3$$





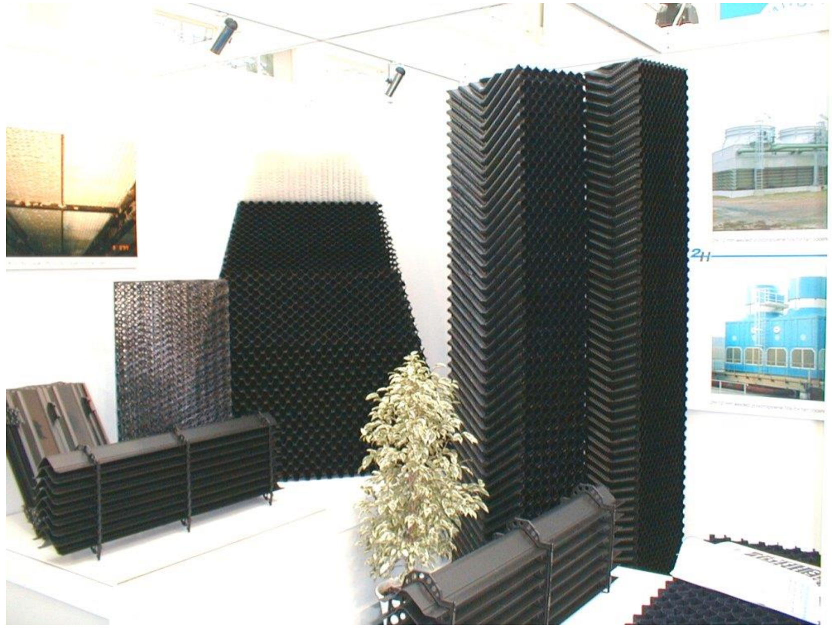
Trickling filter with randomly dumped plastic biomass carriers

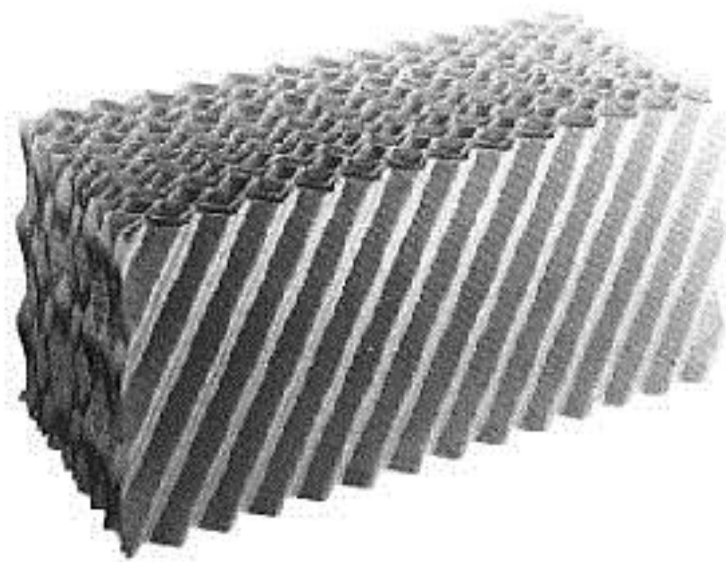
3. Plastic material - structured packings

- wide range of specific surface area, good void fraction, light weight
- basic parameters:

  $a = 80 – 200\ m^2/m^3$, ε = up to 97 %, max. 50 kg/m^3

- typically constructed of vacuum formed sheets of PVC; the sheets of PVC are welded or glued together to form rectangular blocks
- cross corrugated structured packing
- relatively high resistance to plugging
- used in high loading systems (treatment of highly concentrated/polluted wastewaters)





Trickling filter media - structured packings

Trickling filter media - basic technological parameters

Hydraulic loading

$$\nu = Q/A_R \qquad [m^3/(m^2 \cdot h)]$$

where A_R is the cross sectional area of the biofilm reactor in the flow direction

Volumetric loaging

$$B_V = Q\ S_1/V \qquad [kg/(m^3 \cdot d)]$$

Surface loading

$$B_A = Q\ S_1/A_f \;\rightarrow\; B_V/a \qquad [g/(m^2 \cdot d)]$$

in fact: $A_f < V \cdot a$ $\longrightarrow$ correction coefficient *f*

f - the coefficient of the specific surface area of biofilter media utilization (empirical values)

Trickling filter media	***f***
rocks (new)	0.7 – 0.8
rocks (old)	0.5 – 0.7
plastics - structured packings $a < 120\ m^2/m^3$	0.7 – 0.8
plastics - structured packings $a > 120\ m^2/m^3$	0.5 – 0.7
plastics - random packings $a < 150\ m^2/m^3$	0.6 – 0.7
plastics - random packings $a > 150\ m^2/m^3$	0.4 – 0.6

Hydraulic retention time

$\Theta = V/Q = H/\nu$

Minimum wetting rate (MWR)

is the lowest flow rate that wets all of the media in the filter. The MWR is important since media not wetted will not support bacterial growth.

If the minimum flow rate is too low, a recycle is introduced.

$Q_S = Q + Q_r$

$R = Q_r/Q$ (not constant)

Waste activated sludge

- Imhoff tank - cold anaerobic digestion
- digestion time - 150 days

Trickling filters - classification according to loading

Loading	**Media**	**B_V (BOD_5) kg/(m³·d)**	**Efficiency E (%)**
low	rocks	≤ 0.2	90 – 95
	plastics random packings	< 0.5	90 – 95
high	plastics structured packings	1 (max. 6)	40 – 60

$$E = 90 – 95\ \%\ (BOD) \quad \rightarrow \quad B_A \leq 8\ g/(m^2 \cdot d)$$

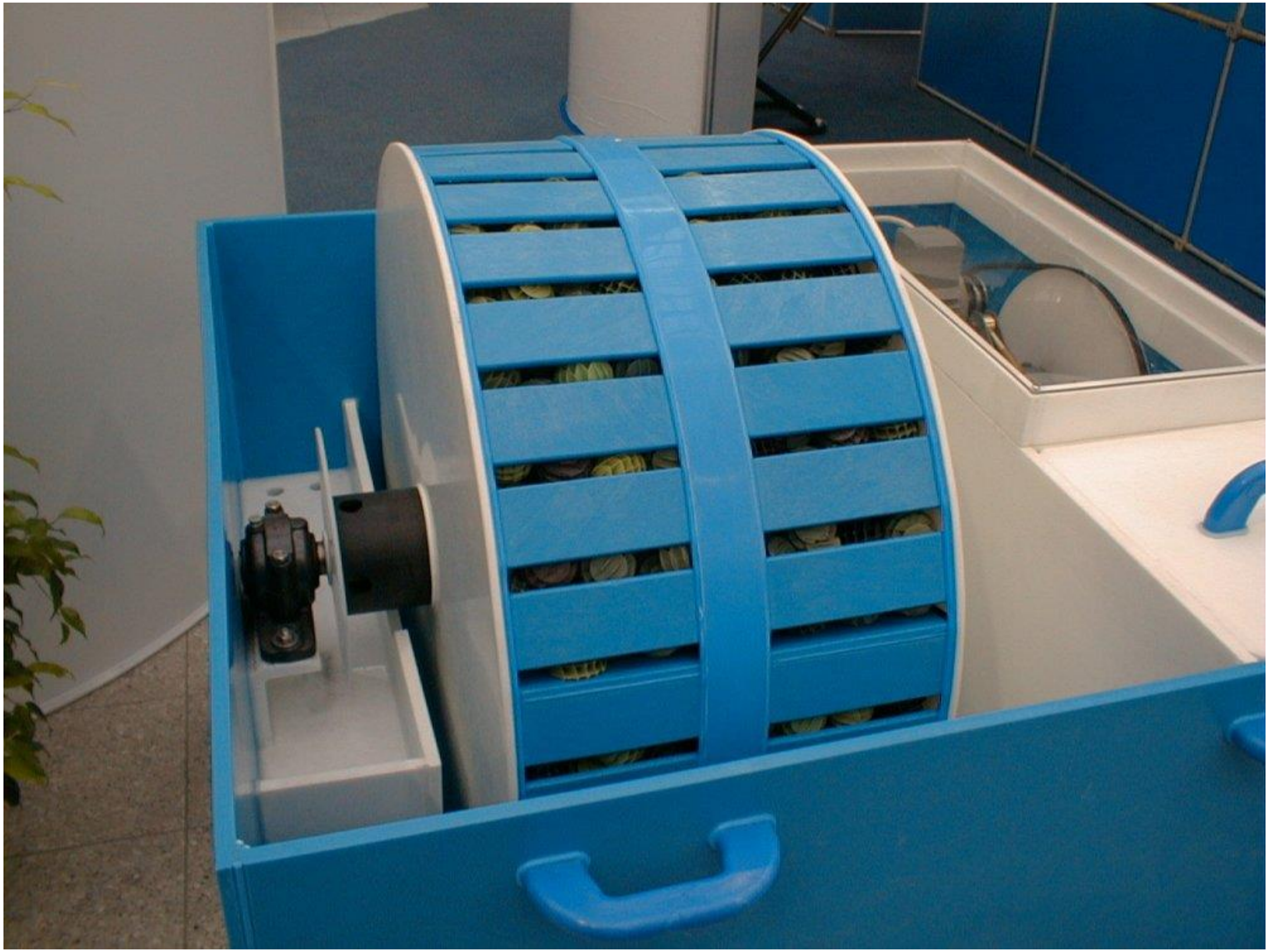
$$E = 90 – 95\ \%\ (BOD + nitrification) \rightarrow B_A \leq 3\ g/(m^2 \cdot d)$$

Rotating biofilm contactors (RBCs) - rotating discs

- use lightweight plastic discs that are mounted on a rotating shaft and partially submerged in water
- rotation of the discs provides both aeration (when the biofilm is out of the water) and shear to control the biofilm growth (when the biofilm moves through the water)
- discs are most commonly made of high-density plastic sheets (PE, PVC) and are usually ridged, corrugated or lattice-like to increase the specific surface area
- submerging level varies from 40 to 80 %, usual rotating speed is 1 to 2 rpm, a common disc diameter is between 0.6 and 3 m
- BOD reduction of 80 to 90 %
- collected sludge in the secondary clarifier requires further treatment for stabilisation, such as (cold) anaerobic digestion

Rotating discs

Rotating biofilm contactors (RBCs) - rotating cage reactors

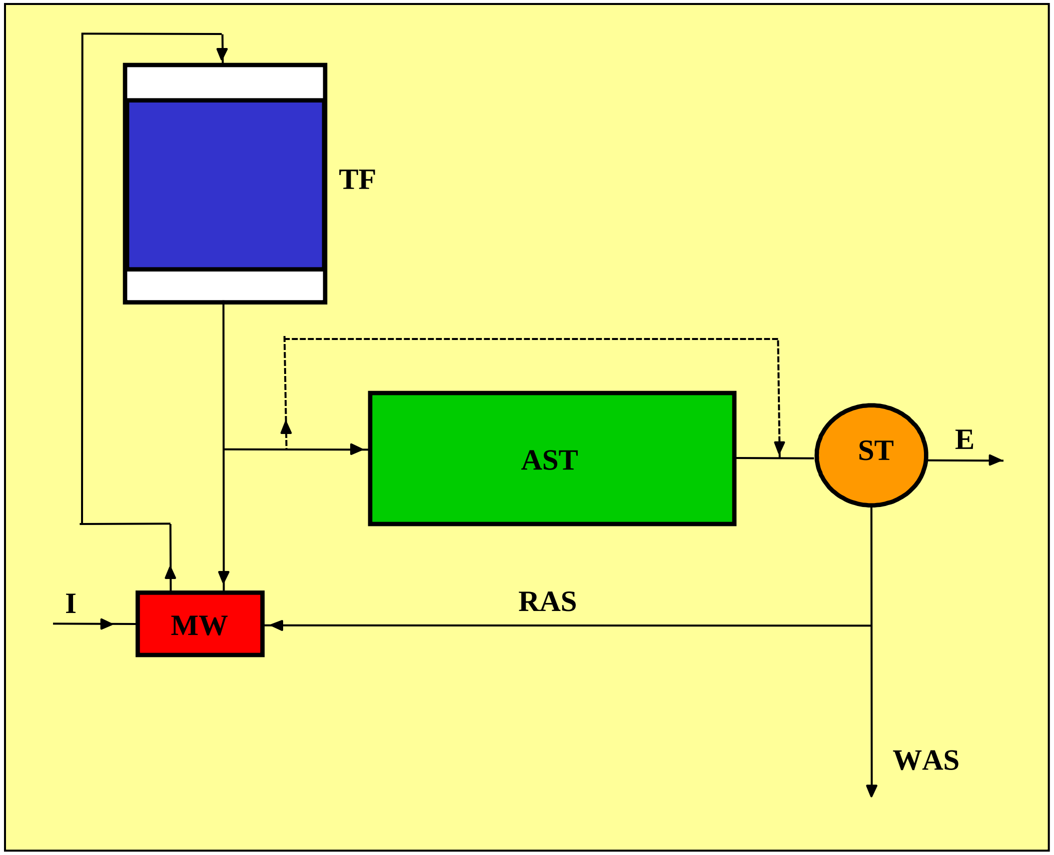


Fluidized bed biofilm reactors

- support medium is kept in suspension by introducing water or air to the bottom of the reactor resulting in large upflow water velocities (10 – 30 m/h)
- fixation of microorganisms on the surface of small-sized particles leading to high content of active biomass and large surface area available for reaction with the liquid
- various types of packing materials - sand, glass beads, plastics, etc.
- <u>expanded bed reactors</u> are similar to fluidized bed reactors but they are operated with smaller upflow velocities resulting in incomplete fluidization of the biofilm support medium

Expanded bed biofilm reactor - denitrification

Combined cultivation of activated sludge and biofilms



ABF process

I - influent
E - effluent
AST - activated sludge tank
MW - mixing well

ST - settling tank
RAS - return activated sludge
TF - trickling filter
WAS - waste activated sludge

- two-reactor arrangement with trickling filter followed by aeration basin
- RAS is led to the head end of the trickling filter
- the activated biofilter removes most organic pollution, while the aeration tank serves as a polishing or nitrification stage

Activated sludge systems with biomass carrier (structured packings)

Activated sludge system with biomass carrier (random packings)

<u>Advantages</u>

1. Total concentration of biomass is much higher than can be achieved in a single activated sludge system. Increased biomass concentration does not result in the increased loading of solids in secondary clarifiers.

2. Highly suitable for upgrading activated sludge plants overloaded by BOD_5

3. Good growth conditions for slow-growing microorganisms (nitrifying bacteria)

4. Higher filamentous and viscous bulking resistance

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Secondary clarifiers – construction and operation, technological parameters
Lecture 12

- **Separation of activated sludge in secondary clarifiers**
- **Construction of modern secondary clarifiers**
- **Examples from Czech WWTPs**
- **Design criteria used in the Czech Rep.**

1. EFFLUENT QUALITY

$$(BOD_5)_{TOT.} = (BOD_5)_{SOL.} + k \times X$$

$$k = \frac{0.7 \times (X_0 / X)}{1 + 0.044 \times \Theta_X}$$

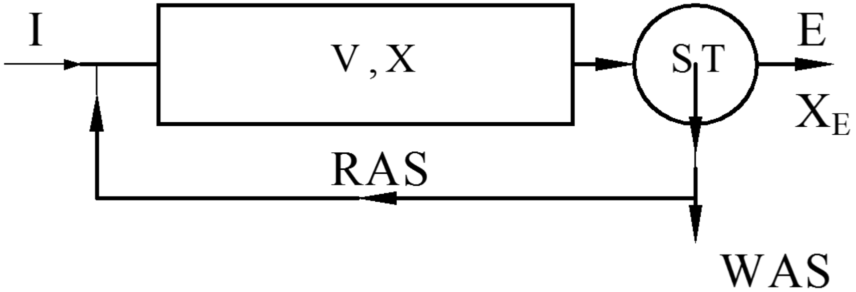
COD: 1 mg X_0 ≈ 1,4 mg COD

TKN: 6-8% N_{ORG} IN X

$P_{TOT.}$: ca 2 % P IN X

UP TO 9-10% IN EBPR

2. THICKENING OF RAS and WAS



$X_R = X_W$

$$X = \frac{R}{1+R} \times X_R$$

LOW X_R and X_W $\Rightarrow$

- PROBLEMS WITH Θ_X
- OVERLOADING OF SLUDGE HANDLING FACIL

BASIC CLARIFIER CONFIGURATIONS

- **CIRCULAR, RADIAL FLOW („DORR“)**
- **RECTANGULAR, HORIZONTAL FLOW:**
  - LONGITUDINAL FLOW
  - TRANSVERSE FLOW
- CIRCULAR or RECTANGULAR, VERTICAL FLOW

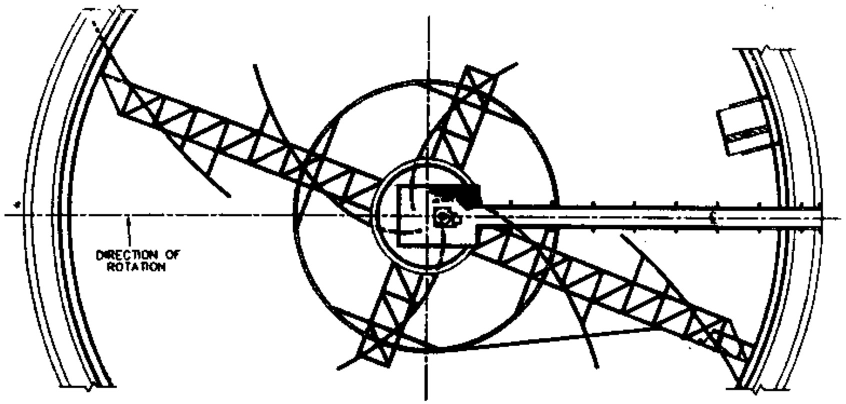
CONTEMPORARY DESIGN AND OPERATION OF SECONDARY CLARIFIERS

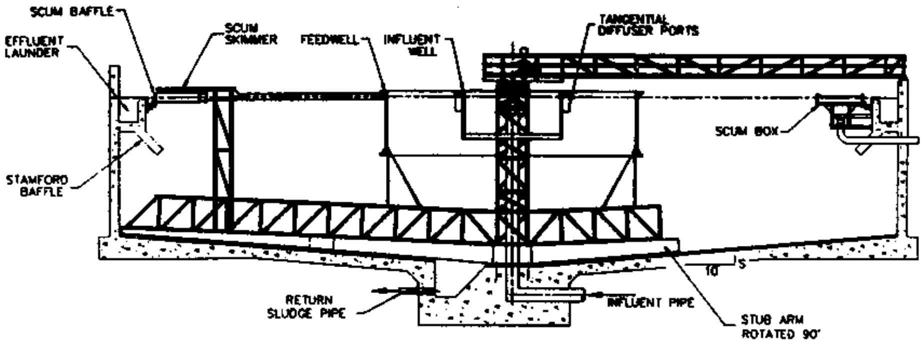
DEGASIFICATION OF ACTIVATED SLUDGE MIXED LIQUOR

CONTEMPORARY DESIGN AND OPERATION OF SECONDARY CLARIFIERS

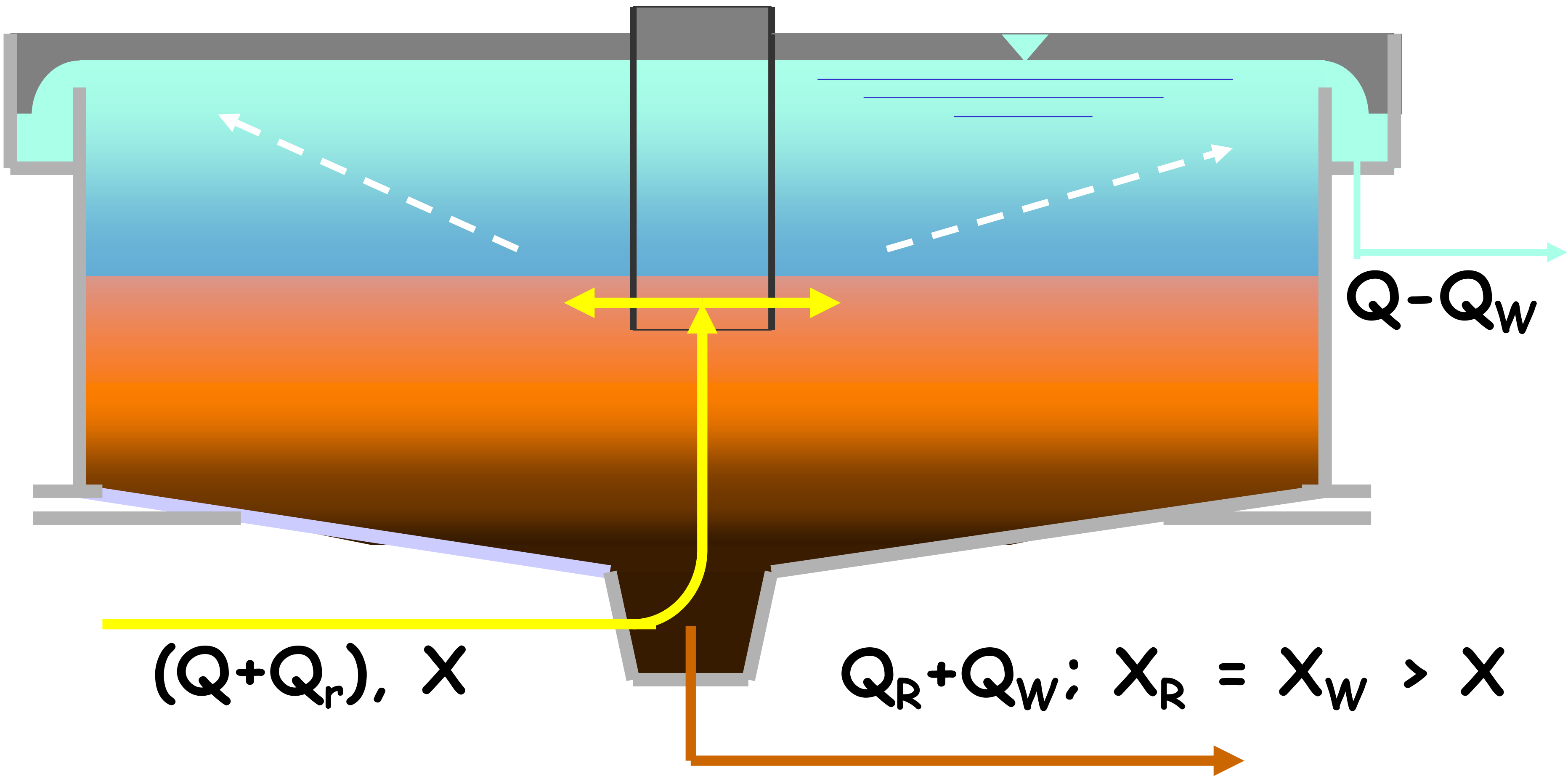
CIRCULAR, RADIAL FLOW, according to Albertson

- INLET STRUCTURE
- EFFICIENT SLUDGE SCRAPER
- SCUM SKIMMER
- OUTLET STRUCTURE

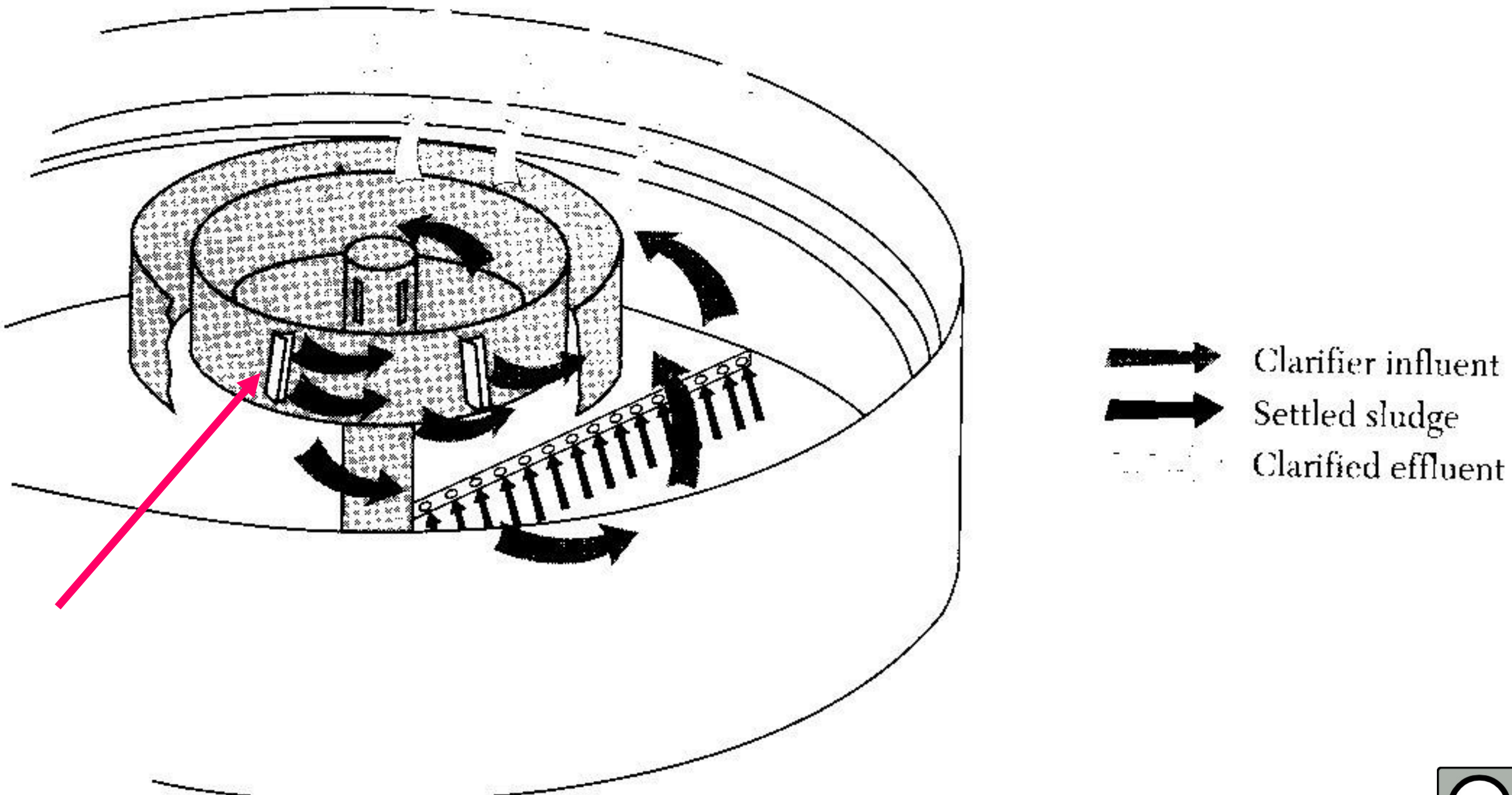




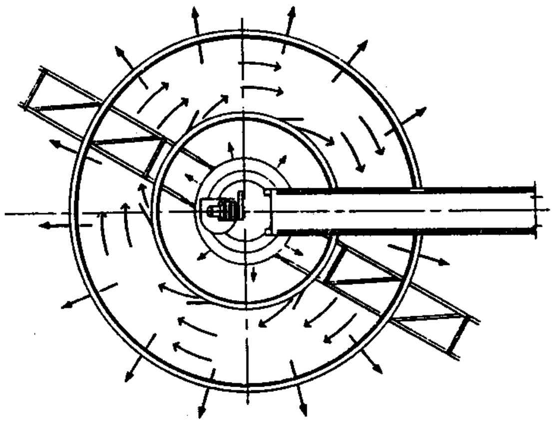
CONTEMPORARY DESIGN AND OPERATION OF SECONDARY CLARIFIERS



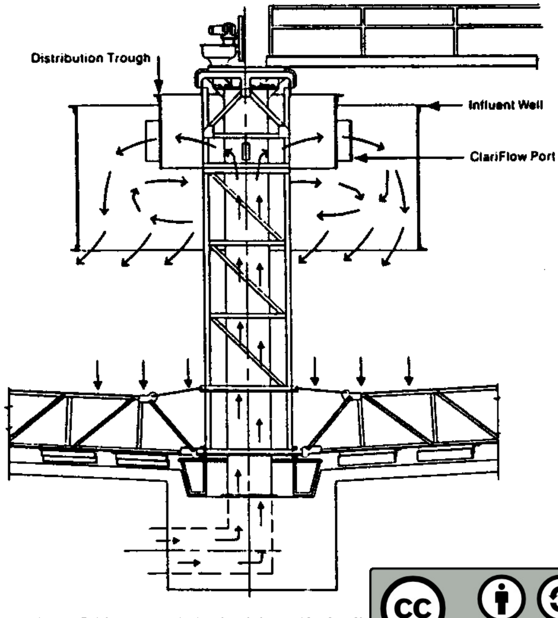
FLOW DIAGRAM OF CIRCULAR CLARIFIER (IAWQ STR No.6)



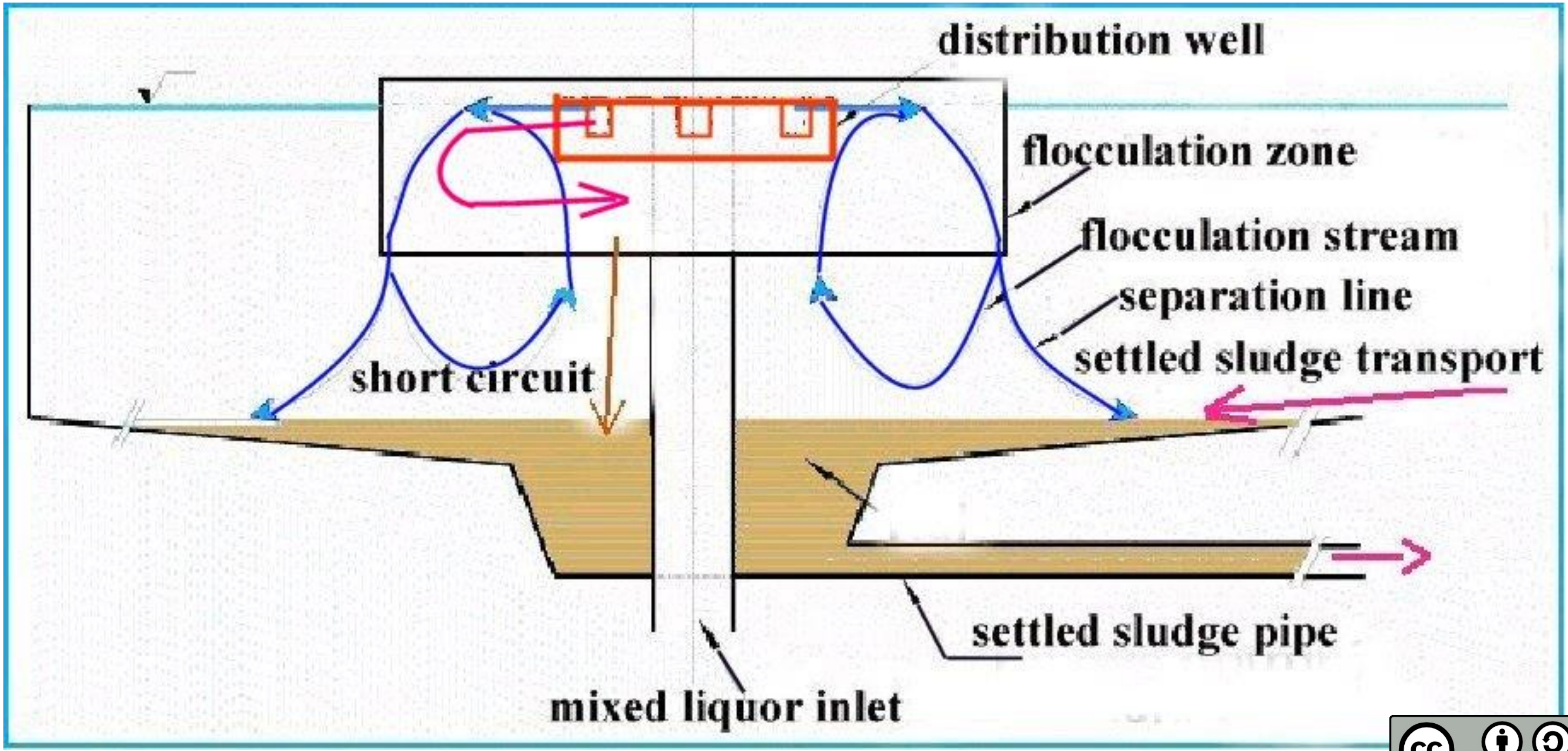
INLET STRUCTURE



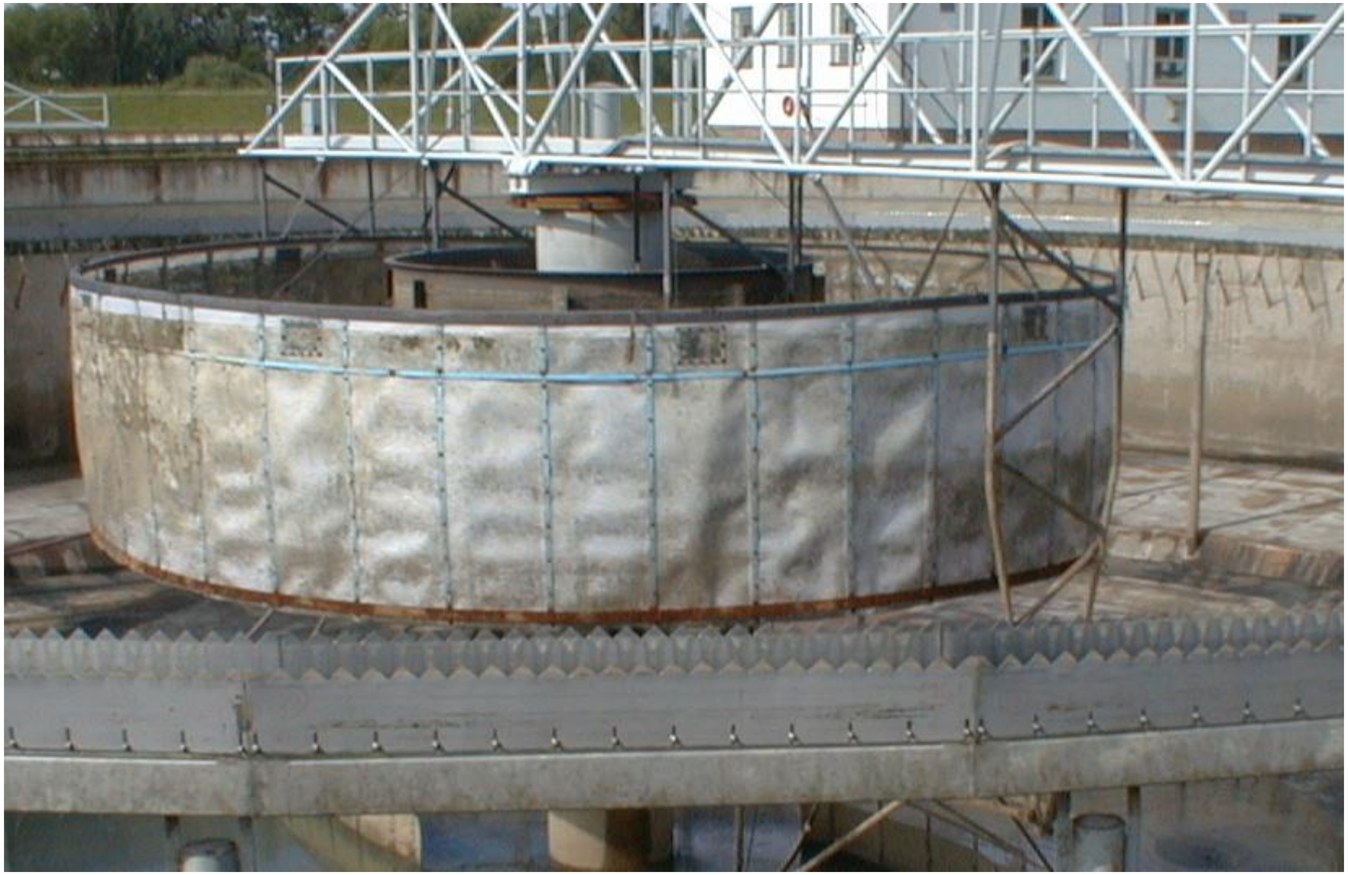
- INFLUENT, ENERGY DISSIPATING WELL
- „CLARIFLOW“ PORTS FOR TANGENTIAL FLOW (**questionable**)
- FLOCCULATION ZONE



WHAT HAPPENS IN CLARIFIERS WITH FLOCCULATION ZONE



FLOCCULATION ZONE



CONTEMPORARY DESIGN AND OPERATION OF SECONDARY CLARIFIERS

No flocculation zone

Flocculation zone

CONTEMPORARY DESIGN AND OPERATION OF SECONDARY CLARIFIERS

Scum accumulation with tangential inflow

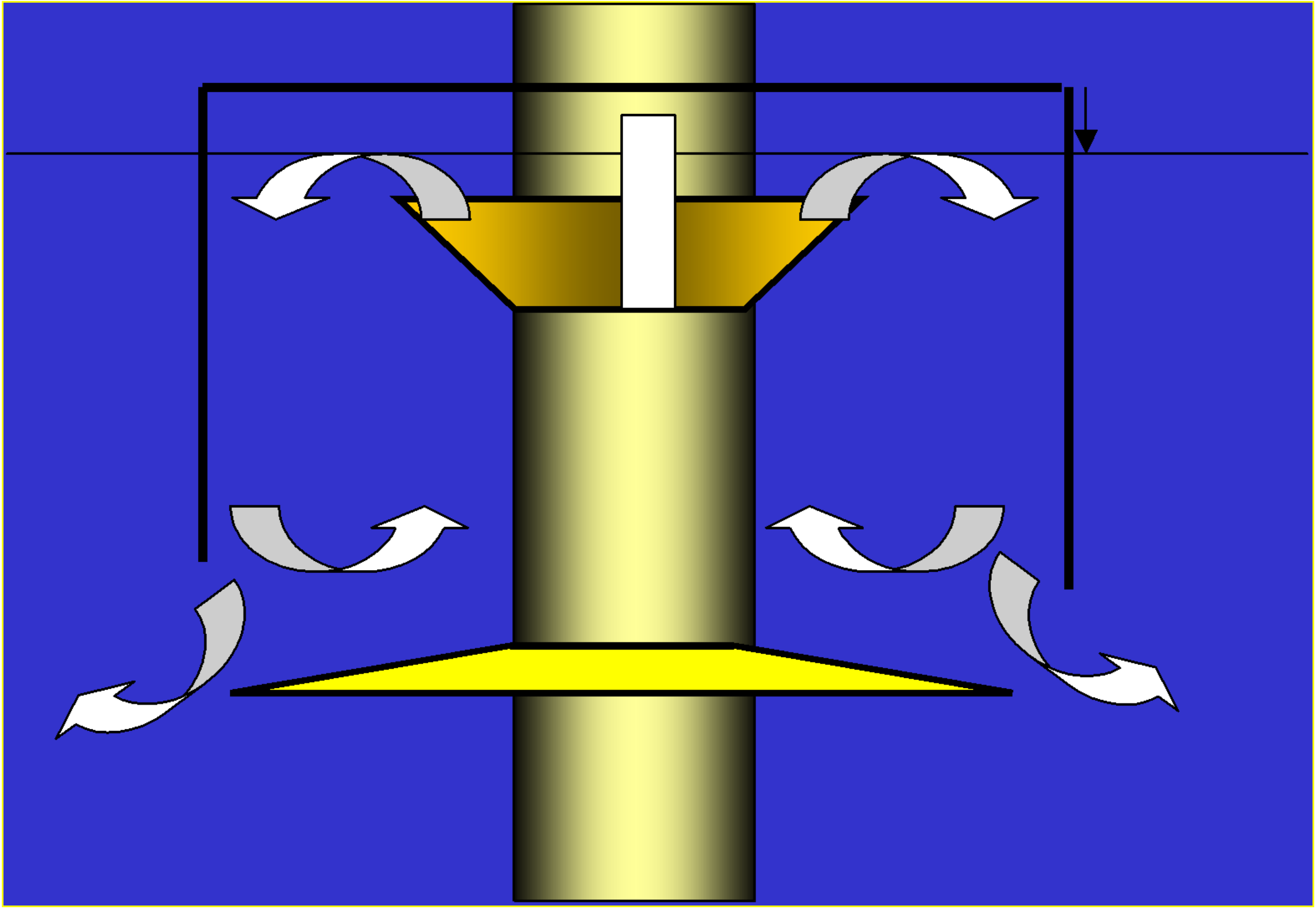
Unprotected weirs of effluent launder

FLOCCULATION ZONE

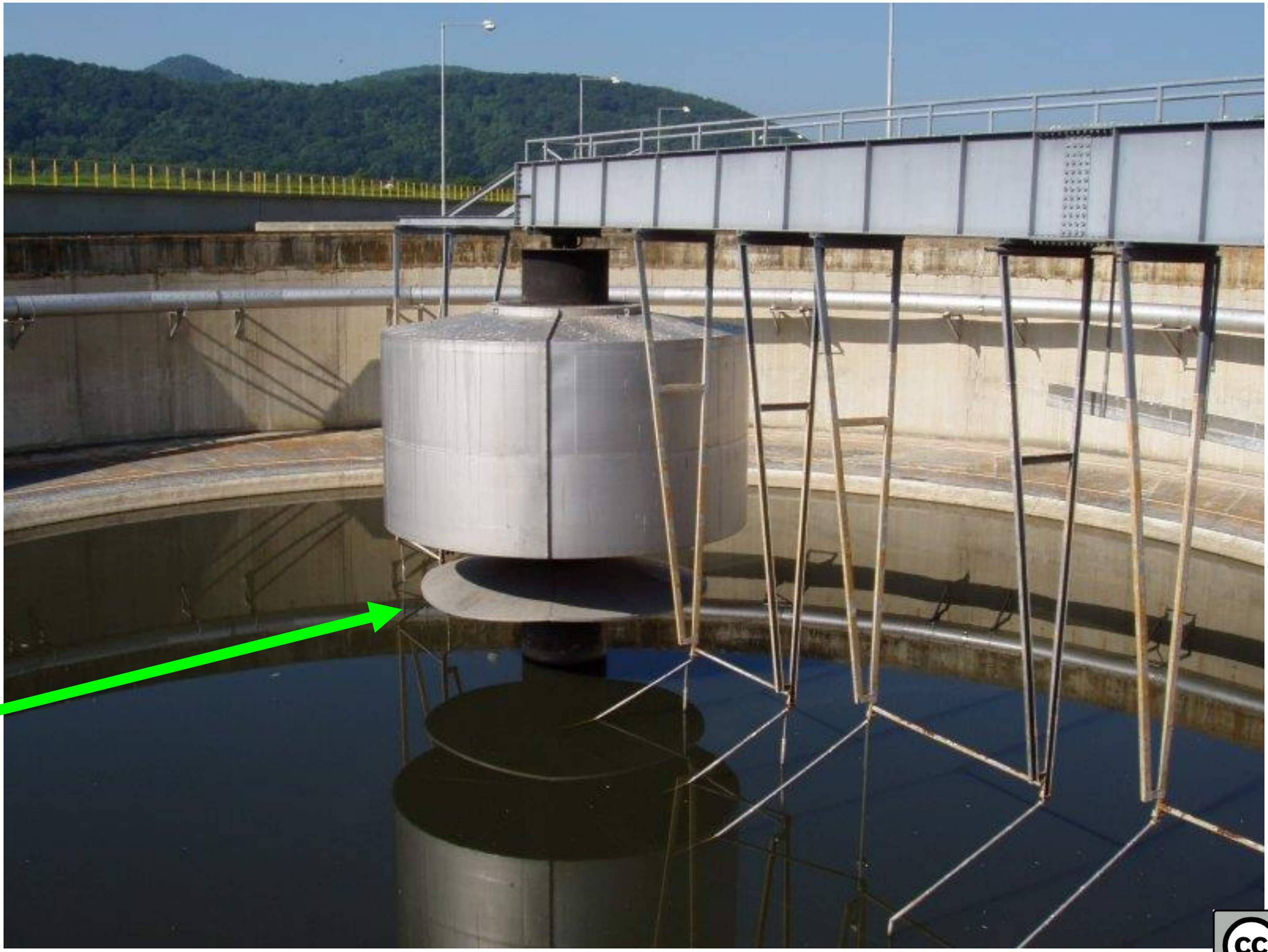
- New construction of flocculation zone
- Upper deflector preventing the accumulation of scum
- Lower deflector preventing the disturbances in separation and thickening zones

CONTEMPORARY DESIGN AND OPERATION OF SECONDARY CLARIFIERS

FLOCCULATION ZONE



CONTEMPORARY DESIGN AND OPERATION OF SECONDARY CLARIFIERS



deflector

CONTEMPORARY DESIGN AND OPERATION OF SECONDARY CLARIFIERS

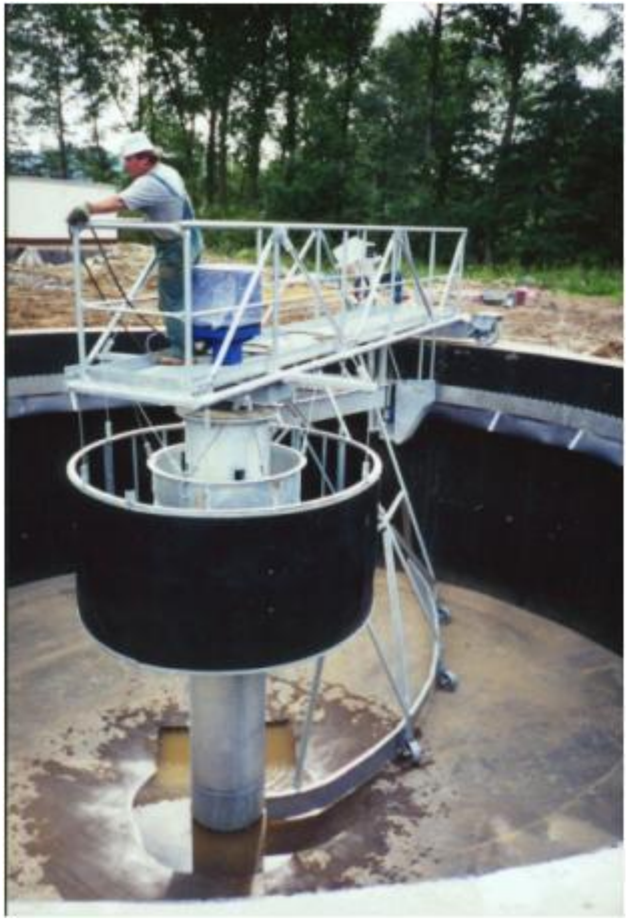
CONTEMPORARY DESIGN AND OPERATION OF SECONDARY CLARIFIERS

COVER

INLET

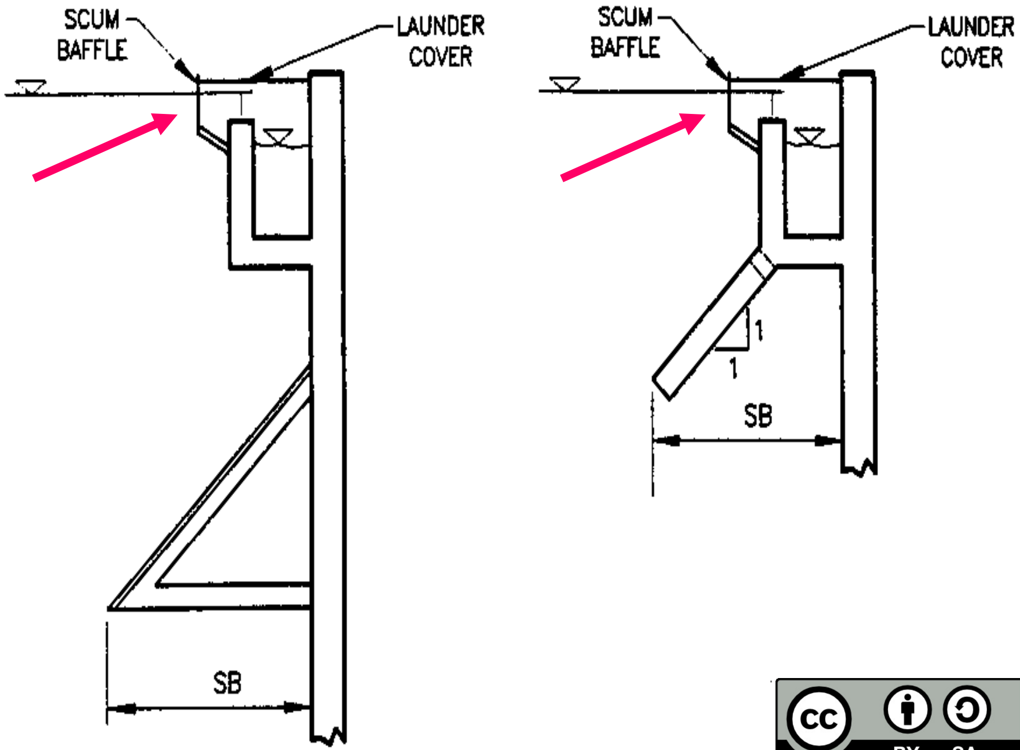
FOR LARGE CLARIFIERS …

… AND FOR SMALL CLARIFIERS (10.5 m total Ø)



OUTLET STRUCTURE

- PREFERABLY PERIPHERAL LAUNDER AND WEIR
- LAUNDER SOMETIMES COVERED (against algae growth)
- SCUM BAFFLE
- STAMFORD BAFFLE



STAMFORD BAFFLE – DEFLECTOR (SEE LATER)

CONTROL OF ALGAE GROWTH

THE IMPORTANCE OF SCUM BAFFLES

WITHOUT BAFFLES:

FLOATING BIOMASS ESCAPES TO (INTO??) EFFLUENT

WITH BAFFLES:

- CLEAR EFFLUENT
- PROBLEMS WITH COLLECTED SCUM

THE IMPORTANCE OF SCUM BAFFLES

Floating sludge

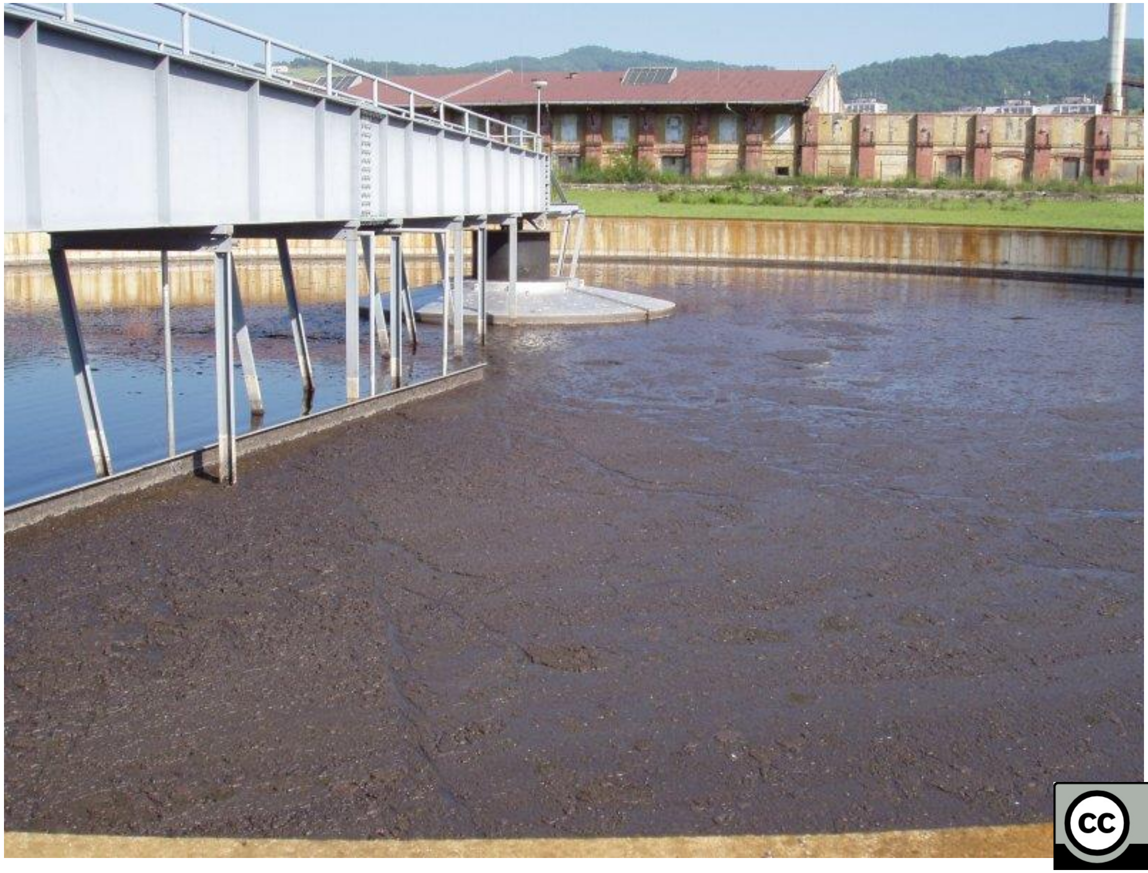
EFFLUENT PIPES INSTEAD OF SCUM BAFFLES

COLLECTION OF SCUM

classic scum box - low efficiency

COLLECTION OF SCUM

classic scum box - low efficiency



COLLECTION OF SCUM

classic scum box - often overloaded with scum

COLLECTION OF SCUM

"travelling scum box"

COLLECTION OF SCUM

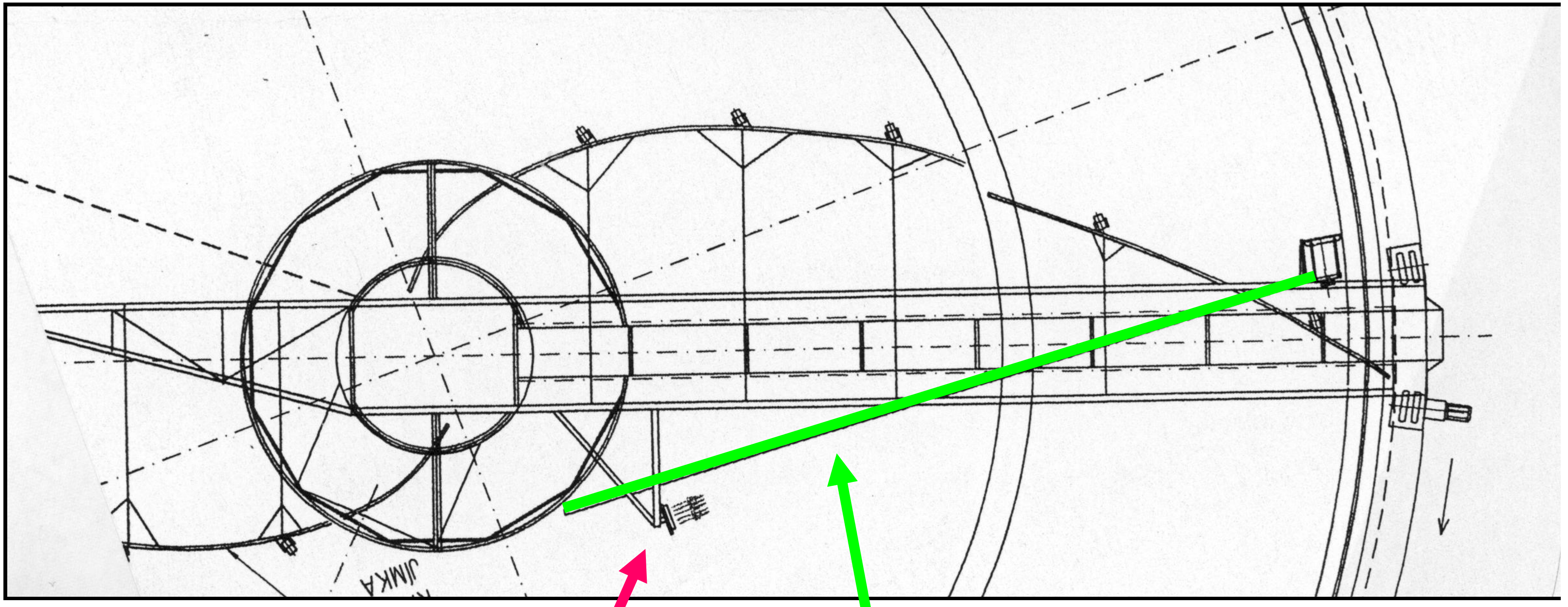
“travelling scum box”

COLLECTION OF SCUM

“pneumatic systems”

COLLECTION OF SCUM

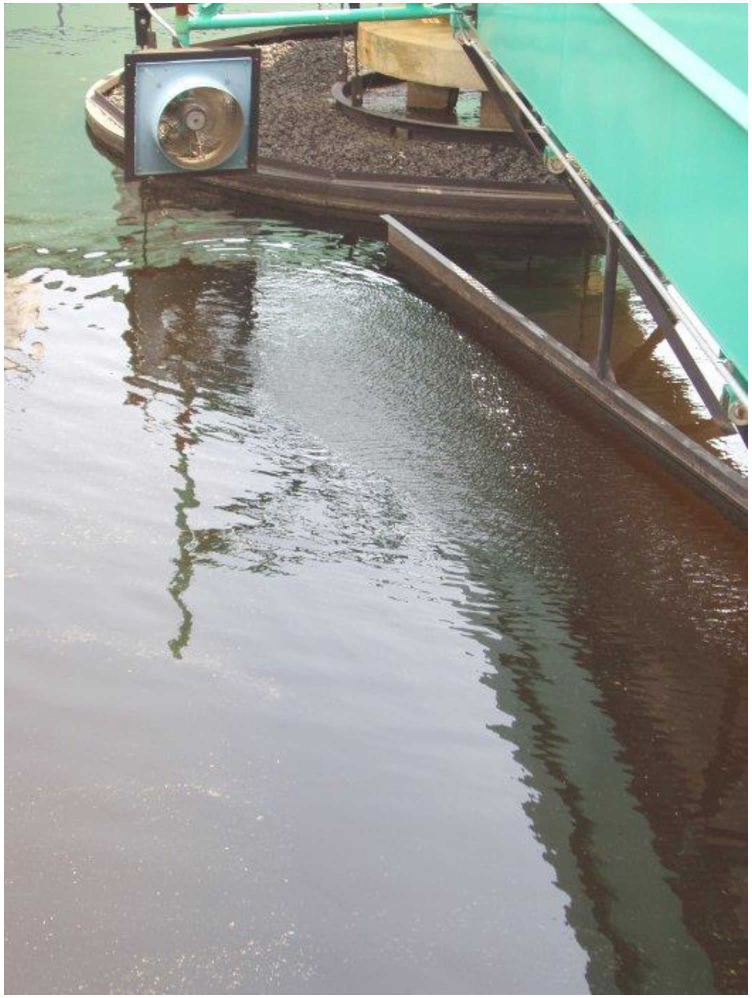
"pneumatic systems"



VENTILATOR

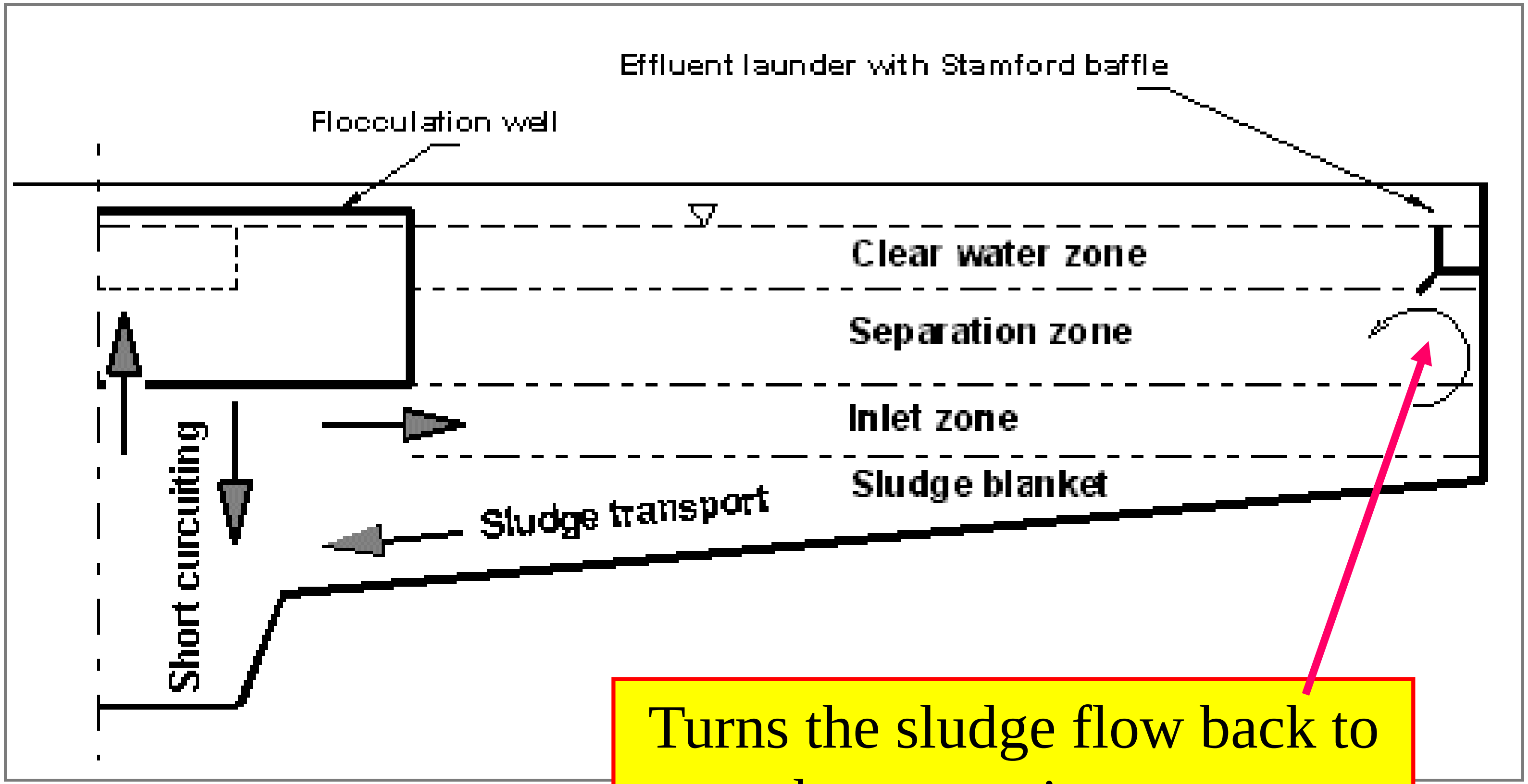
SCUM SKIMMER

COLLECTION OF SCUM "pneumatic systems"



COLLECTION OF SCUM "pneumatic systems"

THE ROLE OF STAMFORD BAFFLE



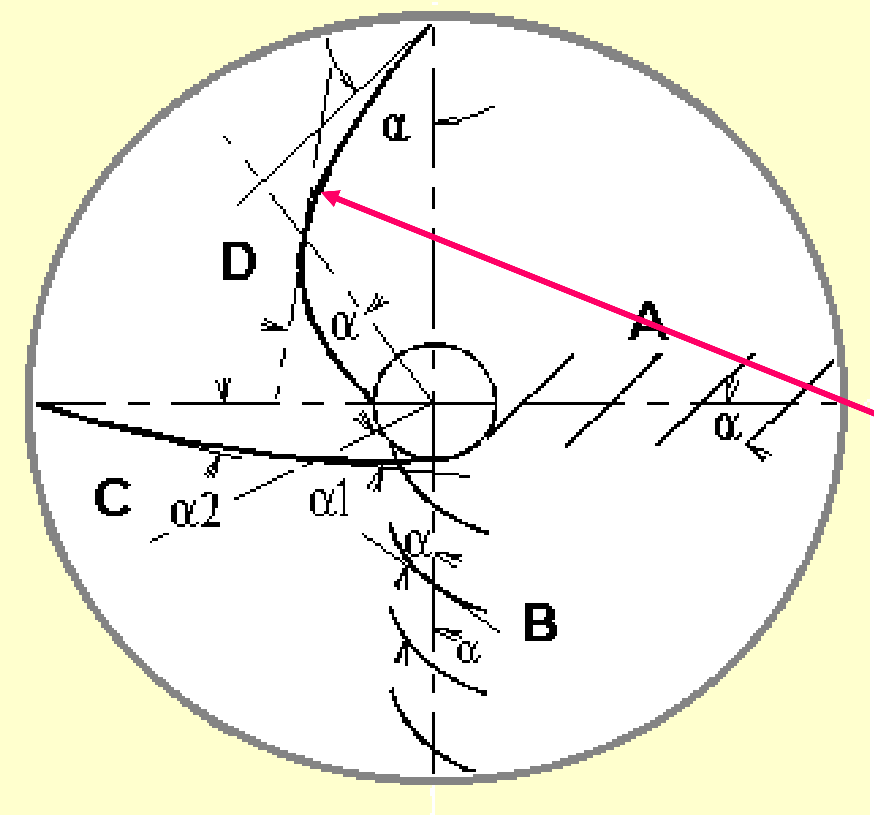
Turns the sludge flow back to the separation zone

CONTEMPORARY DESIGN AND OPERATION OF SECONDARY CLARIFIERS

Stamford baffle with peripheral launders

no need of Stamford baffle with internal launders

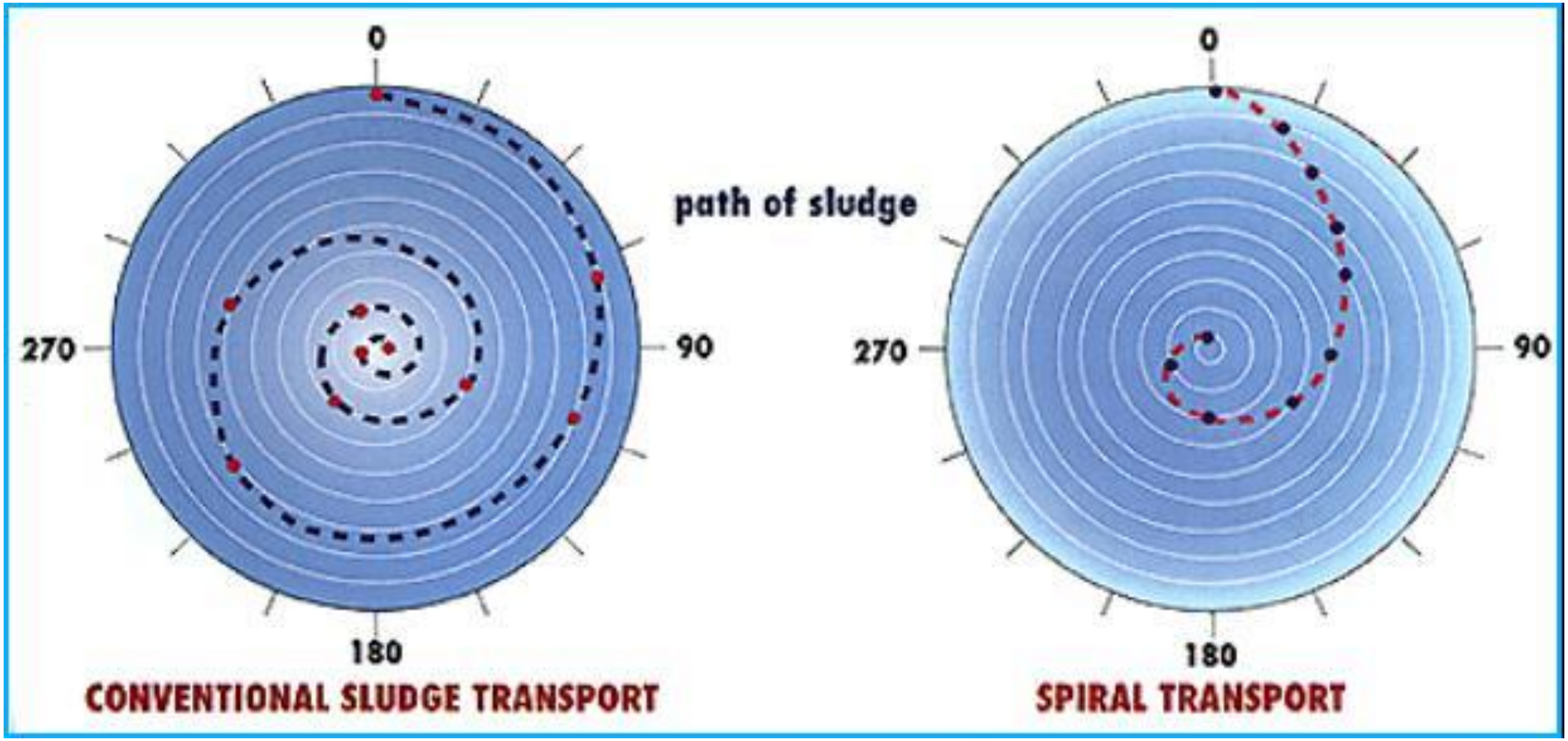
REMOVAL OF THICKENED SLUDGE



MOST COMMON TODAY

SPIRAL SCRAPERS

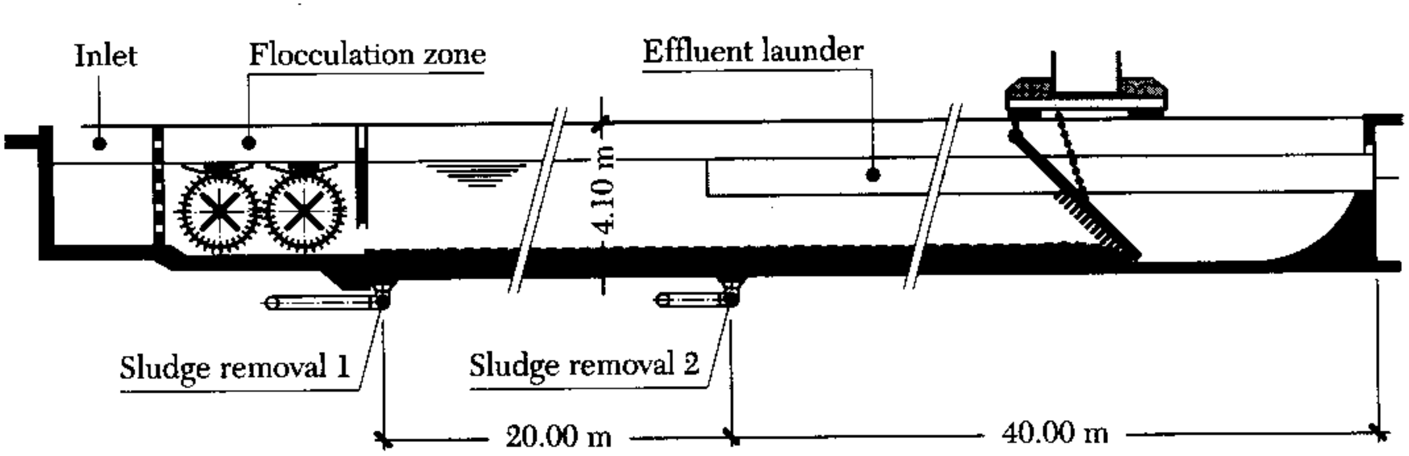
SPIRAL SCRAPERS



REMOVAL OF THICKENED SLUDGE

combined shape of scraper

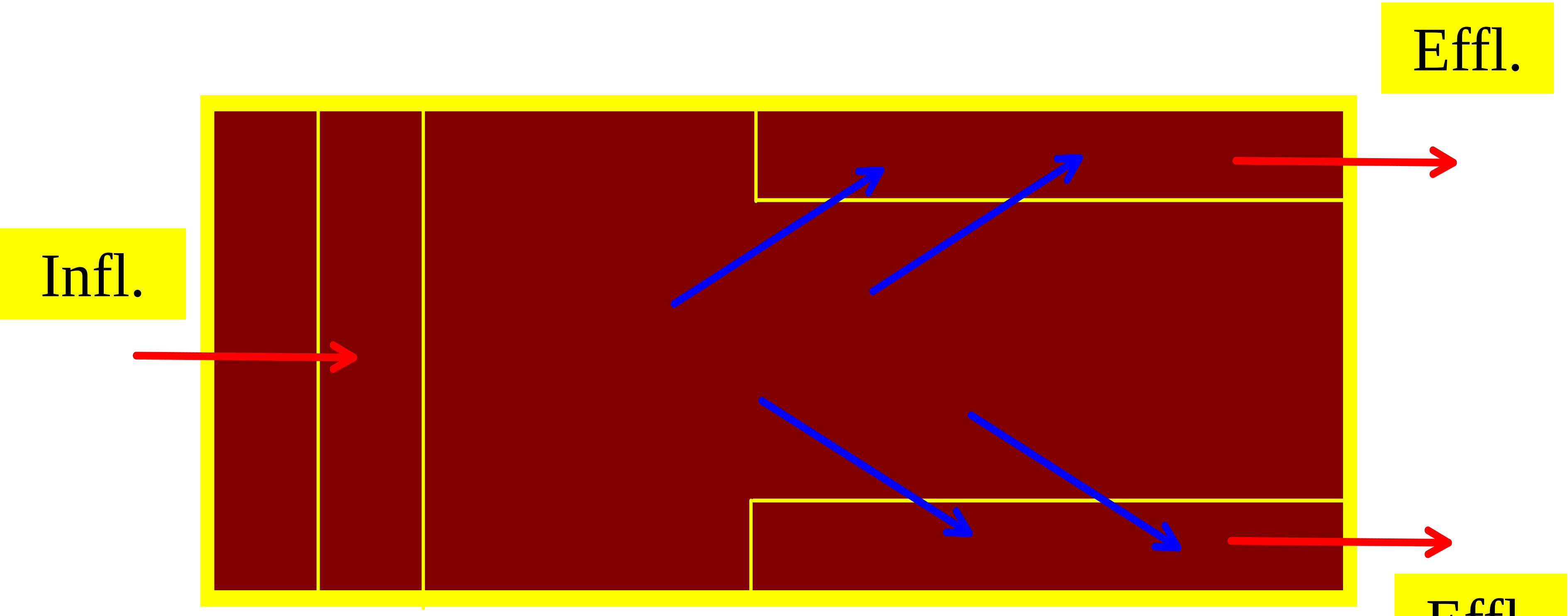
RECTANGULAR CLARIFIERS



- inlet baffle: energy dissipation, mixed liquor distribution
- flocculation zone: mechanical or hydraulic mixing
- effluent launders at side walls

CONTEMPORARY DESIGN AND OPERATION OF SECONDARY CLARIFIERS

FLOW REGIME IN RECTANGULAR CLARIFIERS



effluent launders at side walls

CONTEMPORARY DESIGN AND OPERATION OF SECONDARY CLARIFIERS

effluent launders at side walls

hydraulic removal of thickened sludge

SKIMMERS AND SCRAPERS ON ENDLESS CHAIN

SKIMMERS AND SCRAPERS ON ENDLESS CHAIN

CLARIFIER DESIGN PARAMETERS ACCORDING TO CSN 75 6401

- hydraulic loading $v = Q/A$

  1.6 m/h for Q_{max}; 0.7-1.2 for Q_{24}
- HRT 1.8 h
- solids flux $N_A = (Q \times X)/A$ 6 kg/(m^2.h)
- hydraulic loading of effluent weir

  < 10 m^3/(m.h)
- $R = Q_R/Q < 1.5$ and SVI < 150 ml/g

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Lecture 13
Part 1: Membrane technologies for activated sludge separation

MEMBRANE BIOREACTORS

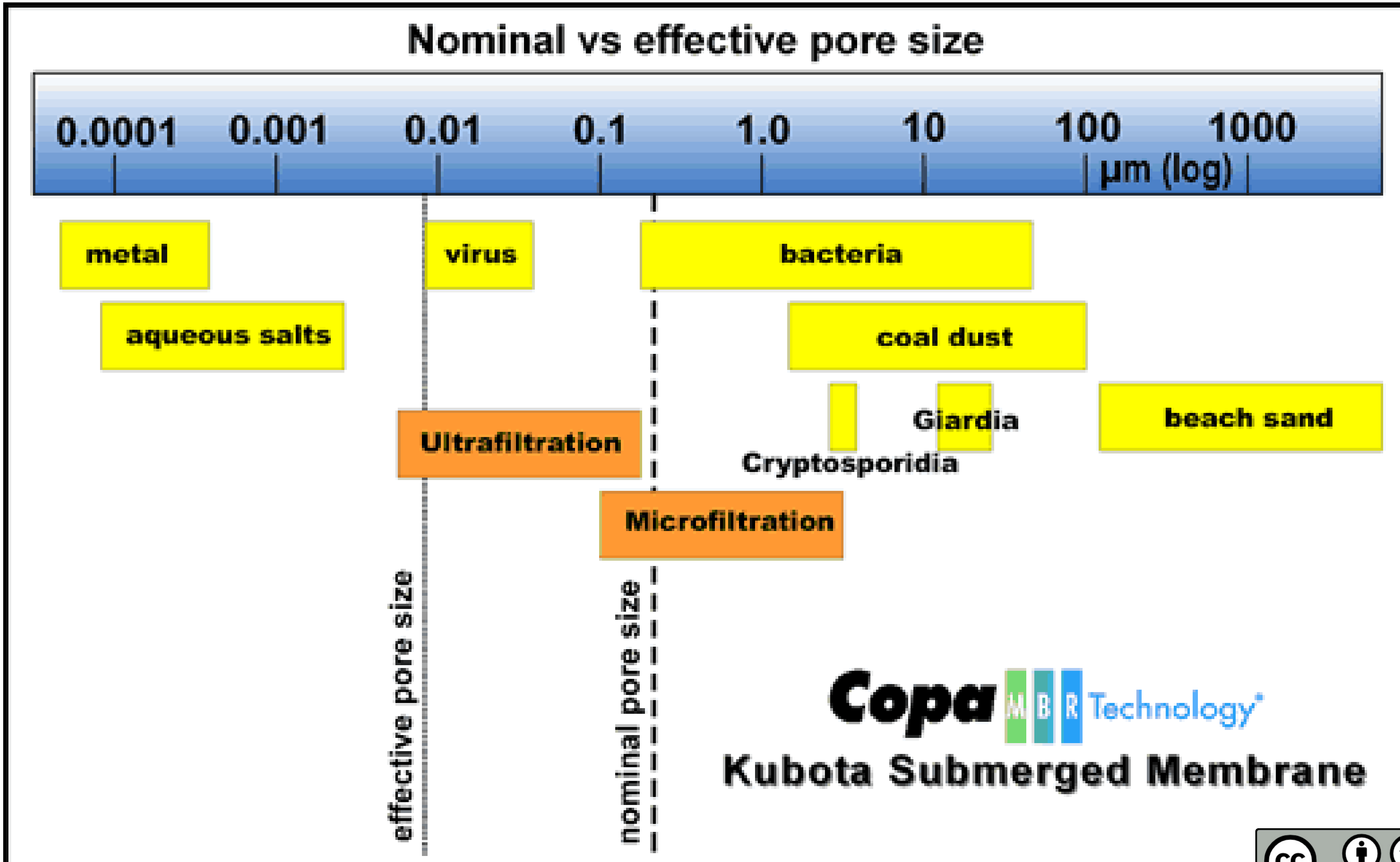
BIOMEMBRANES – ALTERNATIVE TO SECONDARY CLARIFIER

REDUCTION OF AREA OCCUPIED BY SECONDARY CLARIFIERS – e.g. WWTP Bottrop, Emschergenossenschaft

MEMBRANE BIOREACTORS

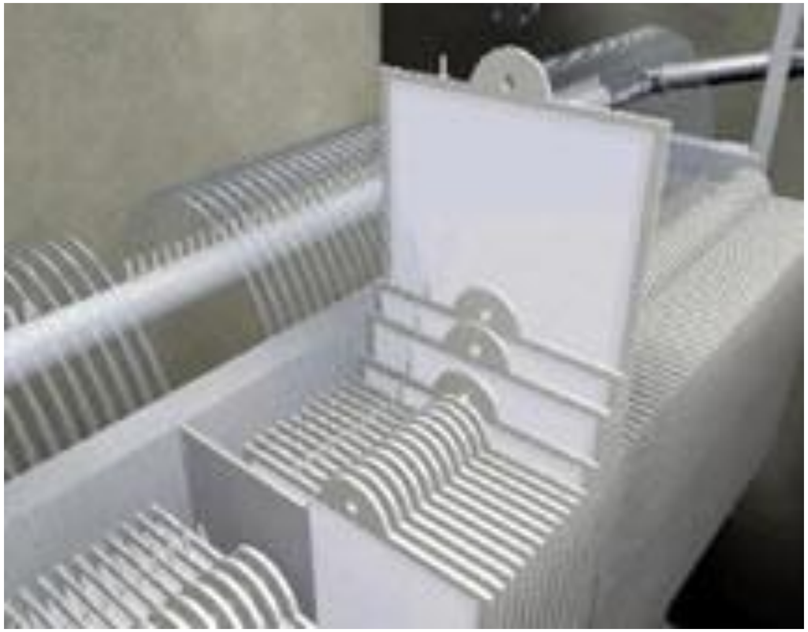
REDUCTION OF AREA OCCUPIED BY SECONDARY CLARIFIERS – e.g. Central WWTP Vienna – Simmering

MEMBRANE BIOREACTORS



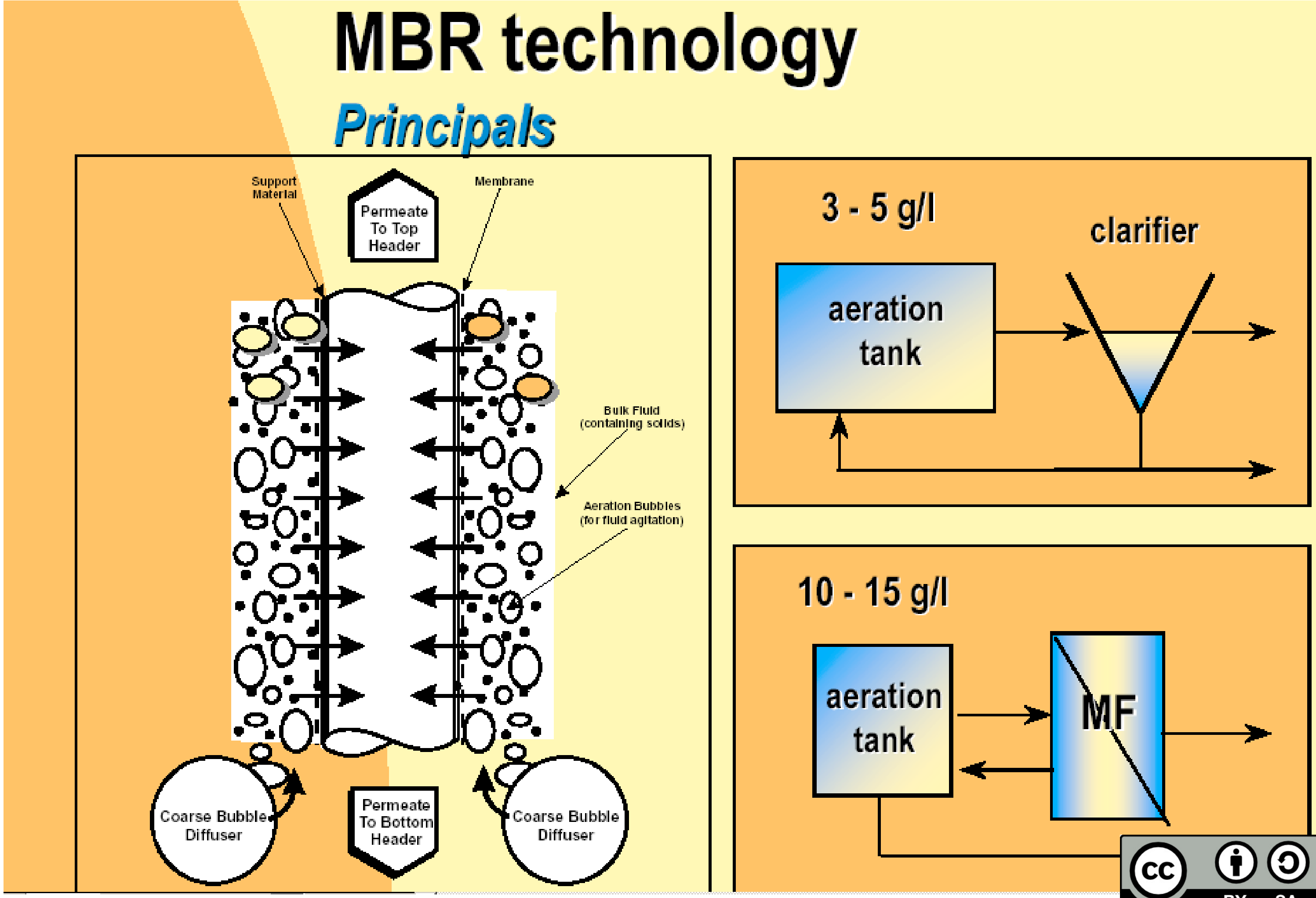
MEMBRANE BIOREACTORS

SUBMERGED
DESK MODULES



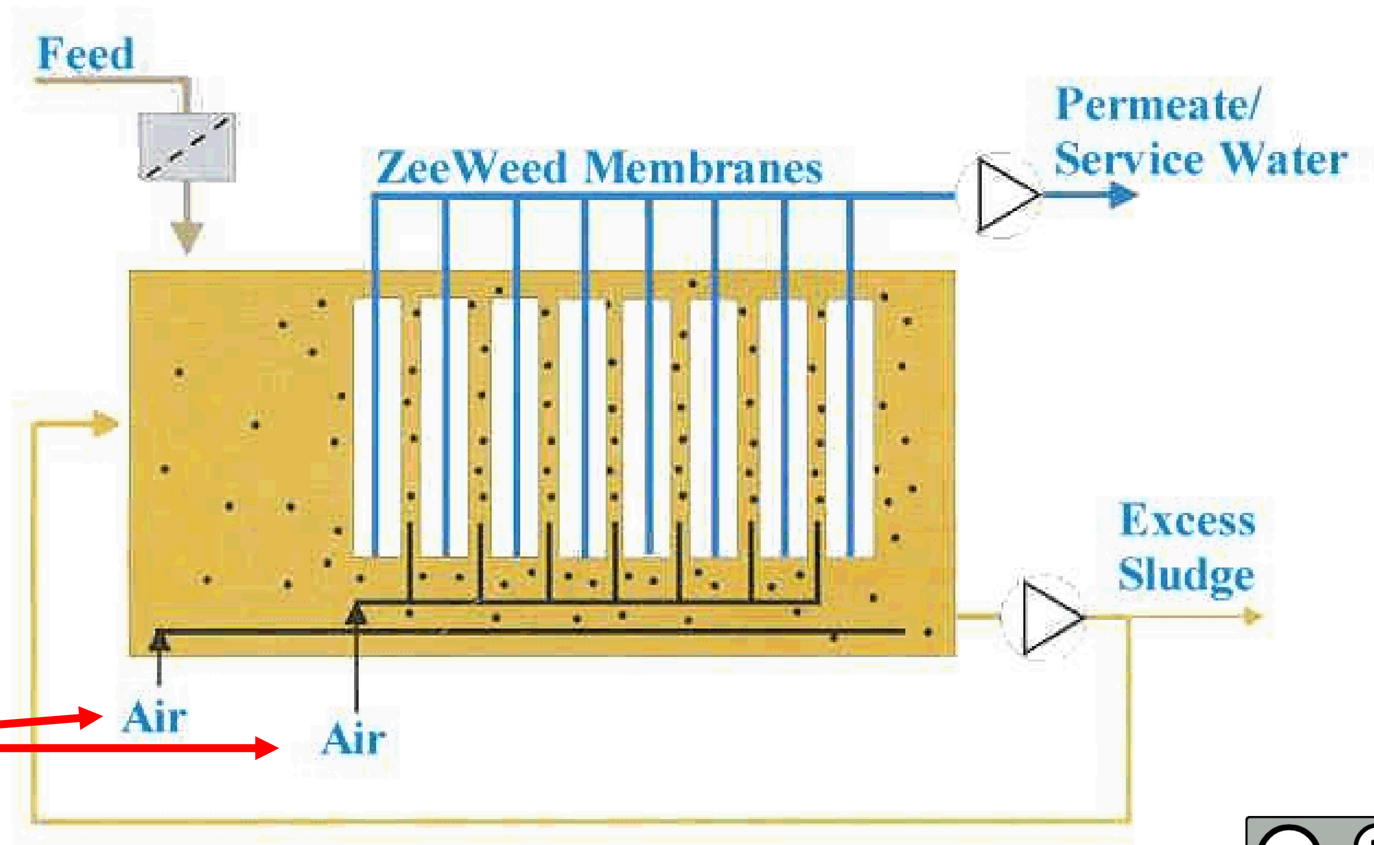
MEMBRANE BIOREACTORS

Submerged hollow fiber modules



MEMBRANE BIOREACTORS

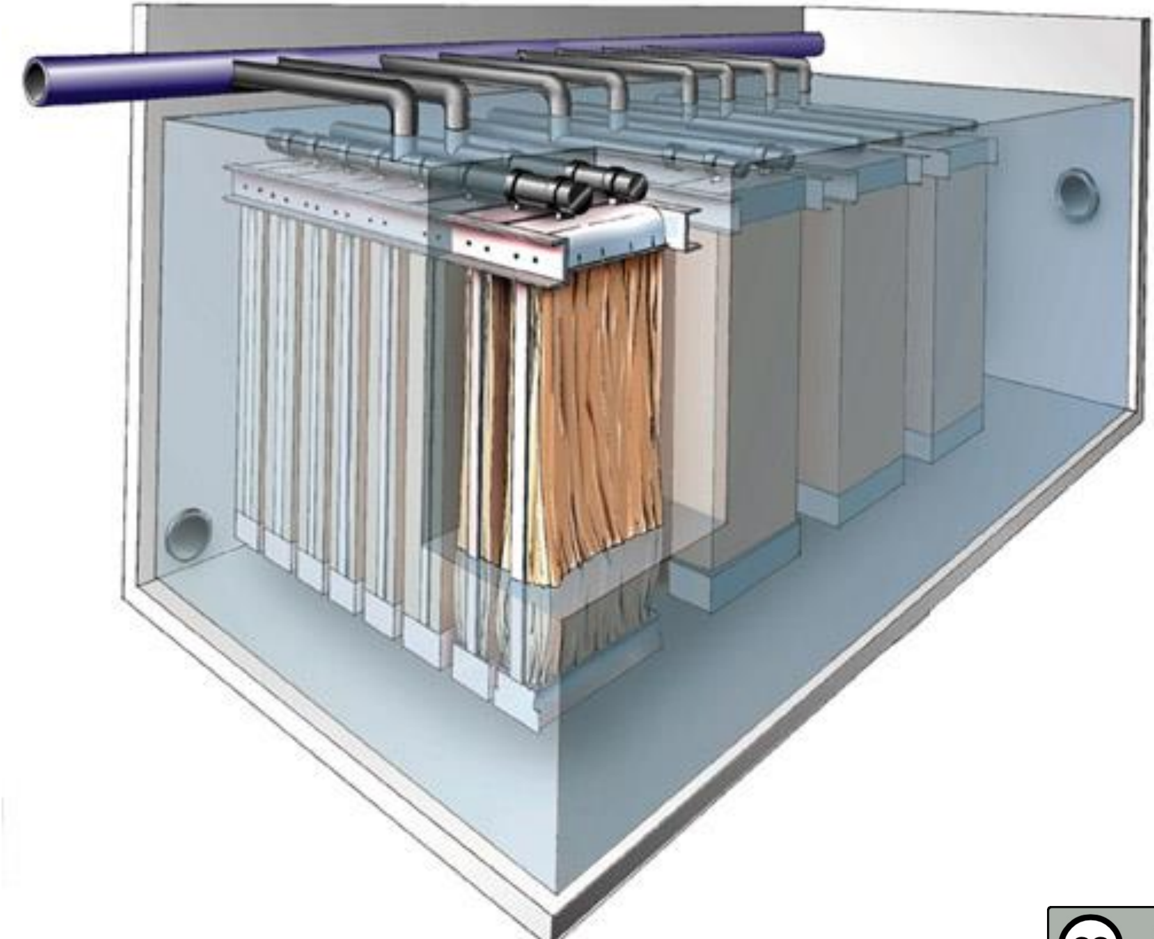
Submerged hollow fiber modules, e.g. ZeeWeed®-membranes



MEMBRANE BIOREACTORS

Submerged hollow fiber modules, e.g.

ZeeWeed® membranes



MEMBRANE BIOREACTORS

Example of installation:
WWTP Markranstädt
12,000 PE

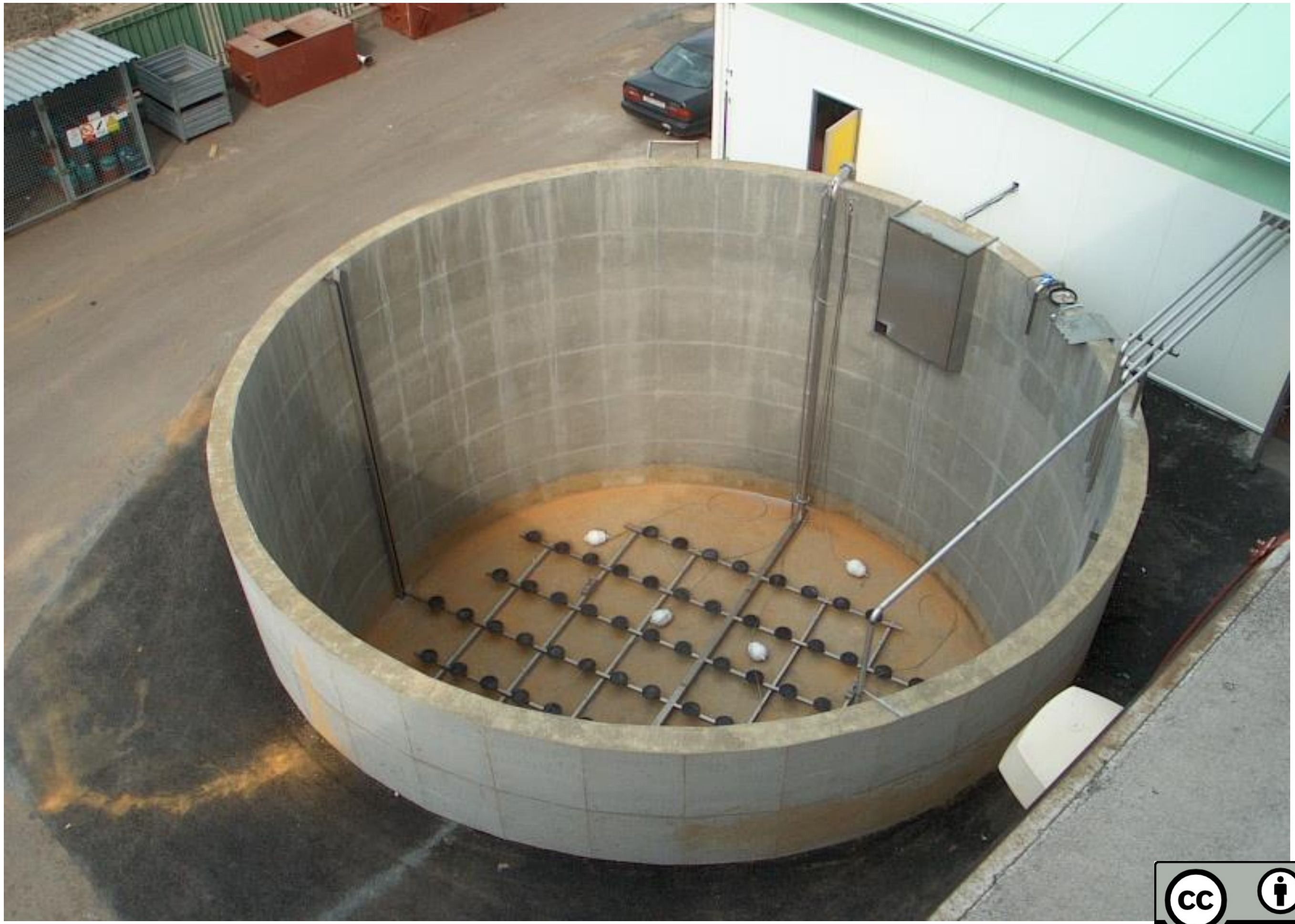
440 m^2 per module

MEMBRANE BIOREACTORS

Submerged modules in operation

MEMBRANE BIOREACTORS

External modules



MEMBRANE BIOREACTORS

External modules

MEMBRANE BIOREACTORS

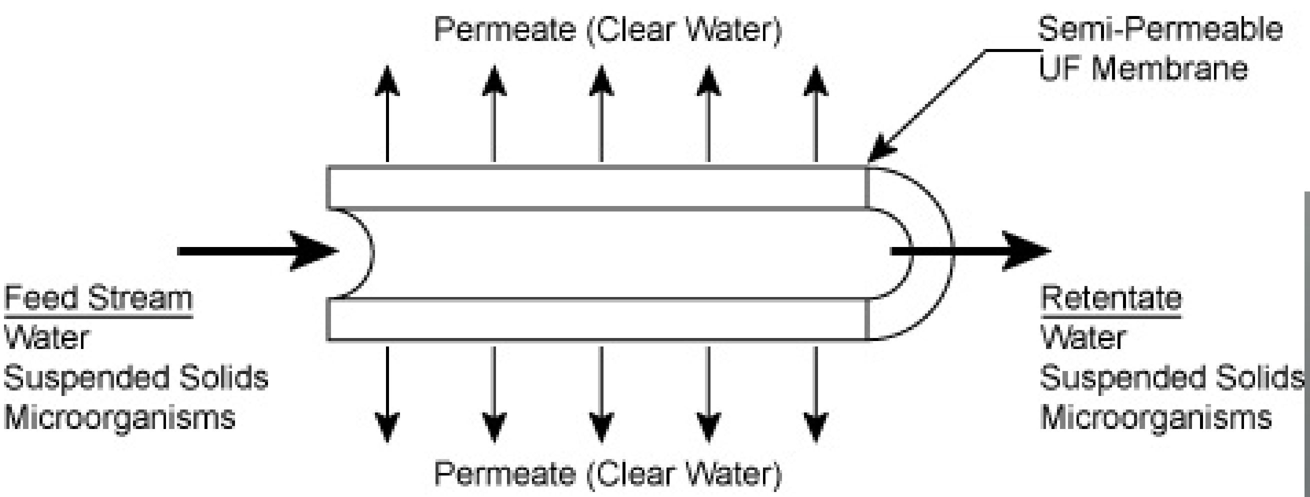
External modules

PLEIADE Ultrafiltration modules

Rhodia

MEMBRANE BIOREACTORS

External tubular modules



MEMBRANE BIOREACTORS

Operational problems:

• perfect mechanical pre-treatment (hair)
• requirement of rather constant flow
• biomass concentration limited by oxygen transfer
• risk of intensive foaming (biopolymers)
• complicated cleaning and maintenance of biomembranes

MEMBRANE BIOREACTORS

Main advantages:

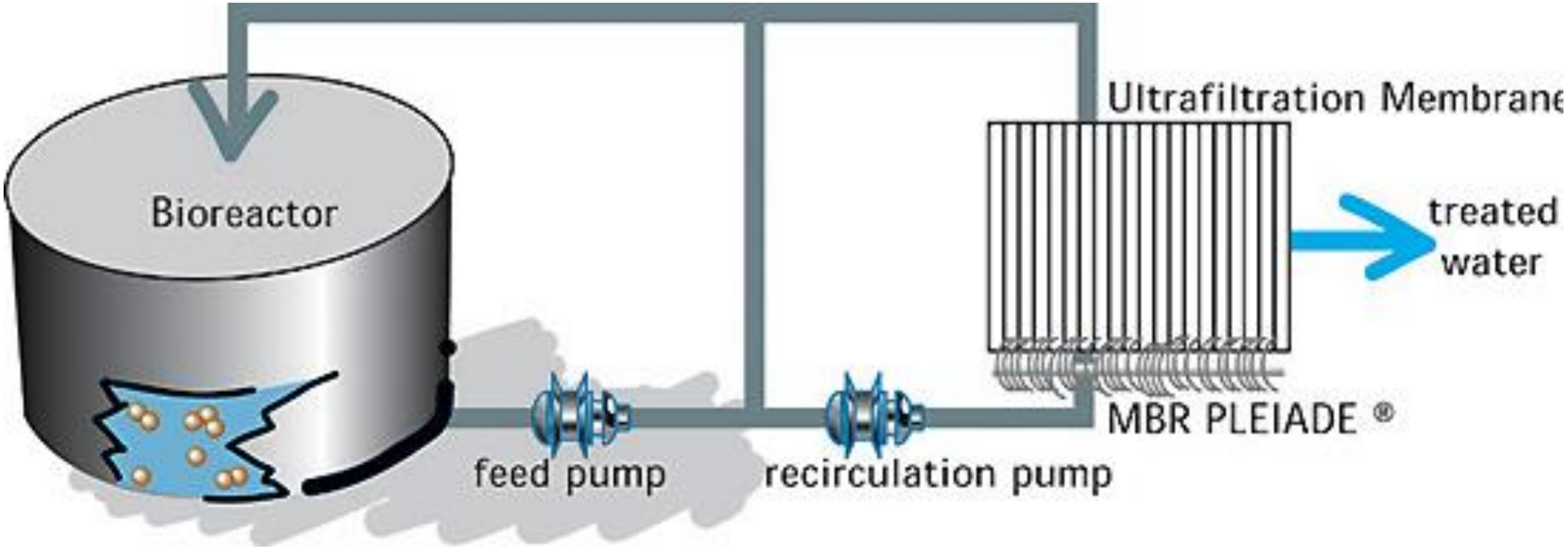
• small built-up area
• almost zero SS
• almost zero bacteria in permeate, reduction of viruses concentration
• permeate quality does not depend on the properties of activated sludge
• possibility of wastewater reuse

MEMBRANE BIOREACTORS

ORELIS MEMBRANE BIOREACTOR HAS BEEN SELECTED FOR THE SHIP QUEEN MARY 2

MEMBRANE BIOREACTORS

ORELIS MEMBRANE BIOREACTOR HAS BEEN SELECTED FOR THE SHIP QUEEN MARY 2



MEMBRANE BIOREACTORS

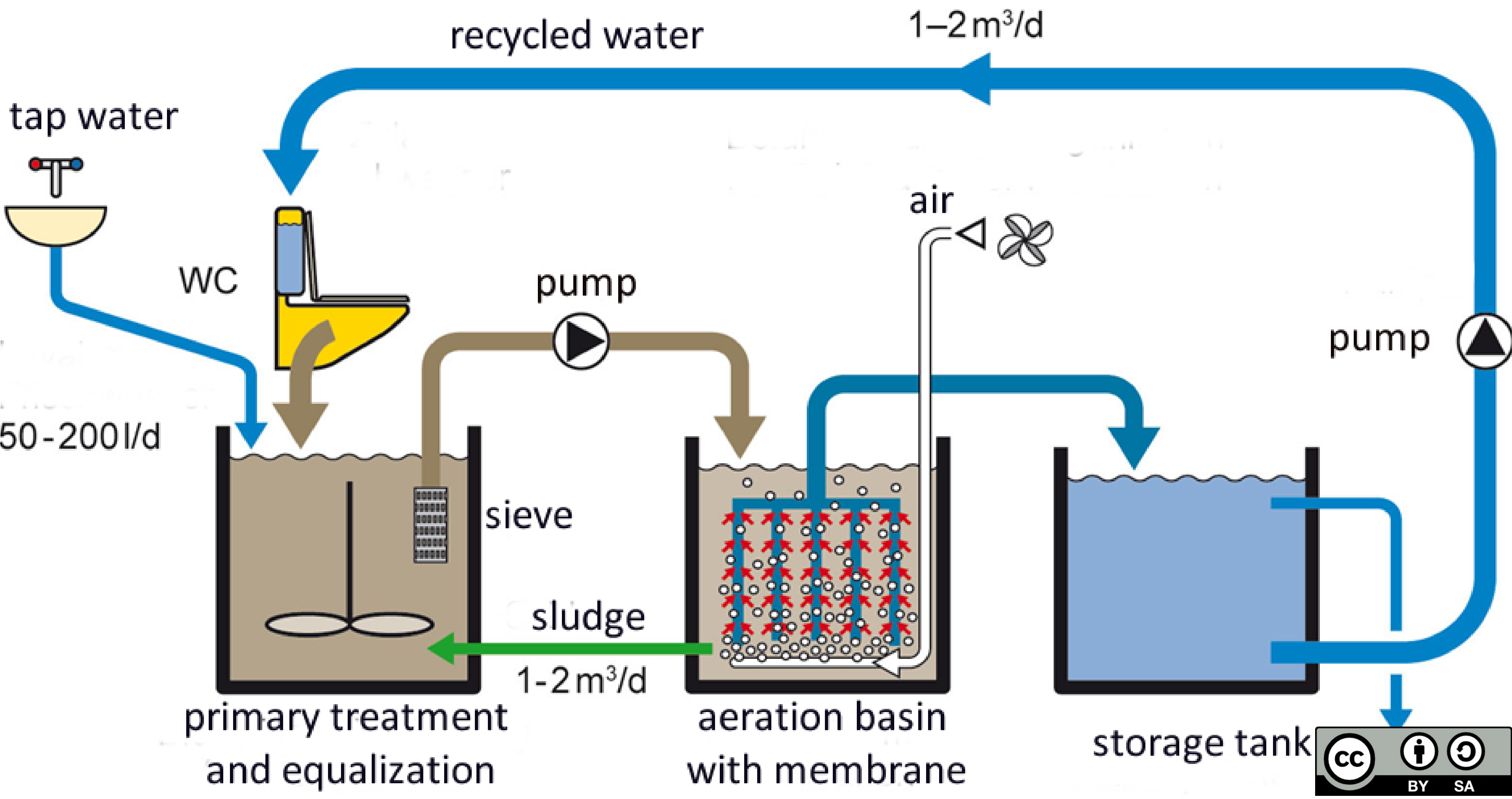
ORELIS MEMBRANE BIOREACTOR HAS BEEN SELECTED FOR THE SHIP QUEEN MARY 2

Highest located plant in Europe

Hohtälli ob Zermatt: **3,286 m above sea-level**

Highest located plant in Europe

Hohtälli ob Zermatt



Highest located plant in Europe

Hohtälli ob Zermatt

MEMBRANE BIOREACTORS

Future of membrane filtration in Europe:

- **legislation for sensitive areas, application of effluent limits based on combination of effluent and water quality standards**

- **<u>reuse of membrane filtration effluent (permeate)</u>**

- **water shortage - possible side effect of *global warming***

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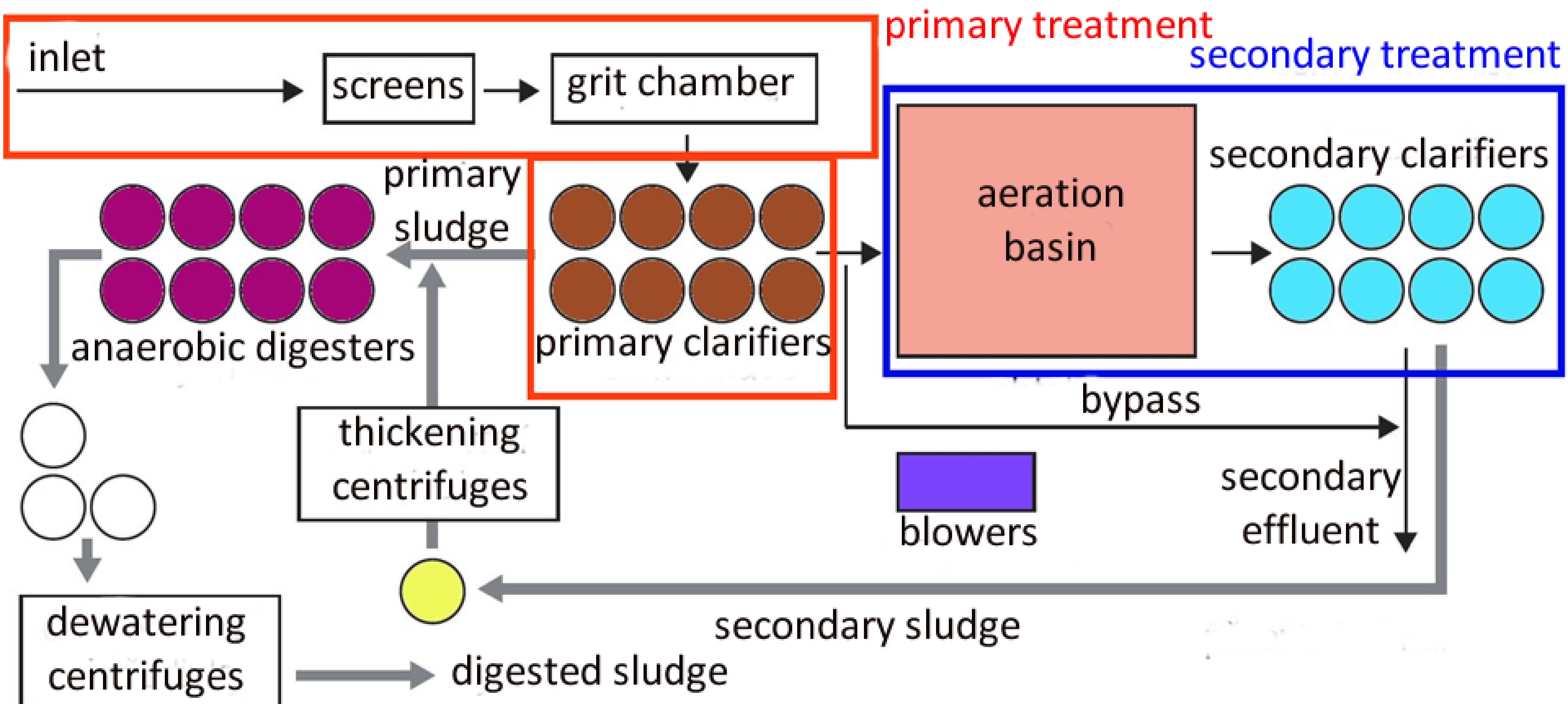
Lecture 13
Part 2: Tertiary wastewater treatment

Flow scheme of municipal WWTP

Flow scheme of municipal WWTP



Requirements of 91/271/EEC for nutrient removal

Ukazatele Parameters	Koncentrace Concentration	Minimální procento úbytku [1] Minimum percentage of reduction [1]	Referenční metoda stanovení Reference method of measurement
Celkový fosfor Total phosphorus	2 mg/l (10 000-100 000 EO) (10 000-100 000 p.e.) 1 mg/l (nad 100 000 EO) (more than 100 000 p.e.)	80	Molekulová absorpční spektrofotometrie Molecular absorption spectrophotometry
Celkový dusík [2] Total nitrogen [2]	15 mg/l (10 000-100 000 EO) [3] (10 000-100 000 p.e) [3] 10 mg/l (nad 100 000 EO.- p.e.) [3] (more than 100 000 p.e.) [3]	70-80	Molekulová absorpční spektrofotometrie Molecular absorption spectrophotometry

Definition of tertiary treatment

Tertiary treatment can be defined as:

"Additional treatment of the effluent from secondary treatment with the aim to improve the water quality above the requirements of Appendix II of Urban wastewater treatment directive 91/271/EEC"

Reasons for tertiary treatment

- More stringent requirements for effluent water quality in connection with achieving the "good water status" – particular concern about phosphorus
- Reduction of bacterial pollution in receiving waters used for recreation - example of several rivers in Germany
- Wastewater recycling – use of treated wastewater instead of drinking water for certain purposes

Most common processes of tertiary treatment

- Biological lagoons
- Filtration through microsieves, microstrains
- Coagulation and/or precipitation
- Sand filtration of precipitated phosphorus
- Sedimentation or floatation for precipitated P
- Disinfection
- Membrane filtration
- Chemical oxidation
- Sorption of organic compounds

The last two processes are currently also called "quaternary treatment"

Biological lagoons

- Dilution and equalization effect
- Sedimentation
- Organotrophic and nitrifying bacteria

- Additional aeration to enhance biological action

Microsieves, microstrains

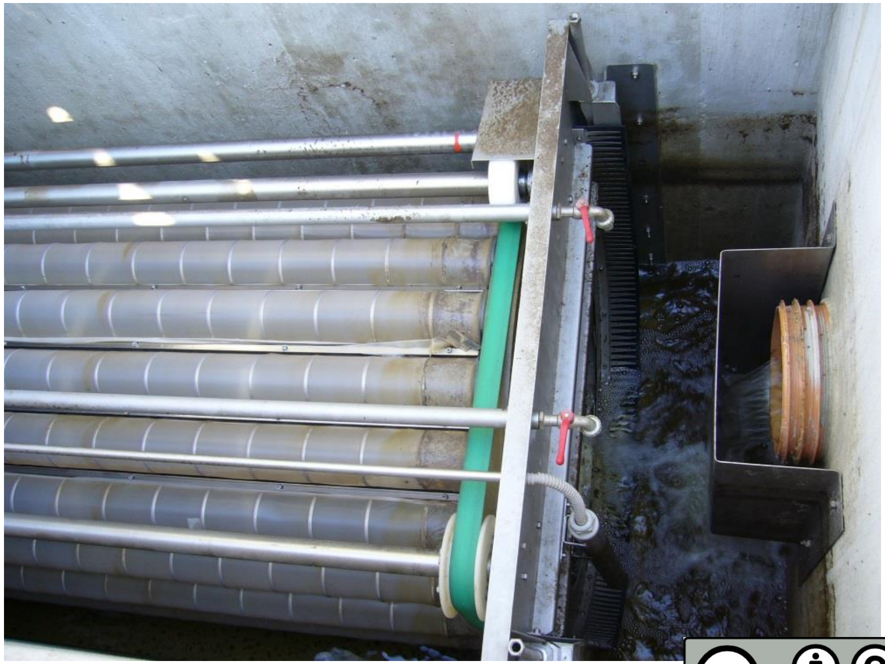
– filtration of residual suspended solids through special filter cloth

– most common process of secondary effluent polishing

– production of service water for WWTP or first step before other tertiary treatment processes

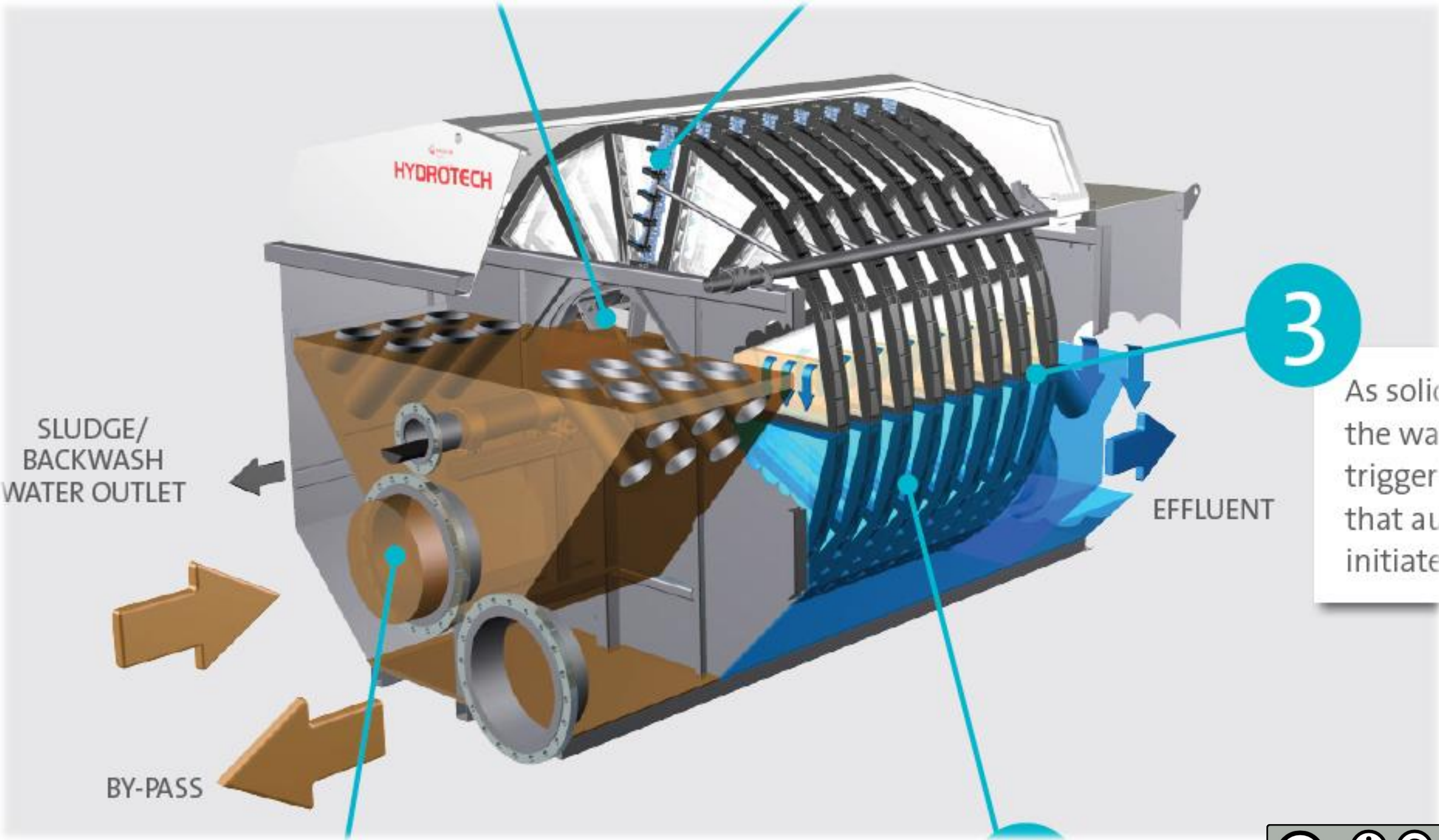
Filter cloth made of steel or plastic fibers

Rotating drum sieves



Microsieves, microstrains

Rotating disc microstrains/microfilters



Microsieves, microstrains

Rotating disc microstrains/microfilters

Tertiary coagulation and/or precipitation

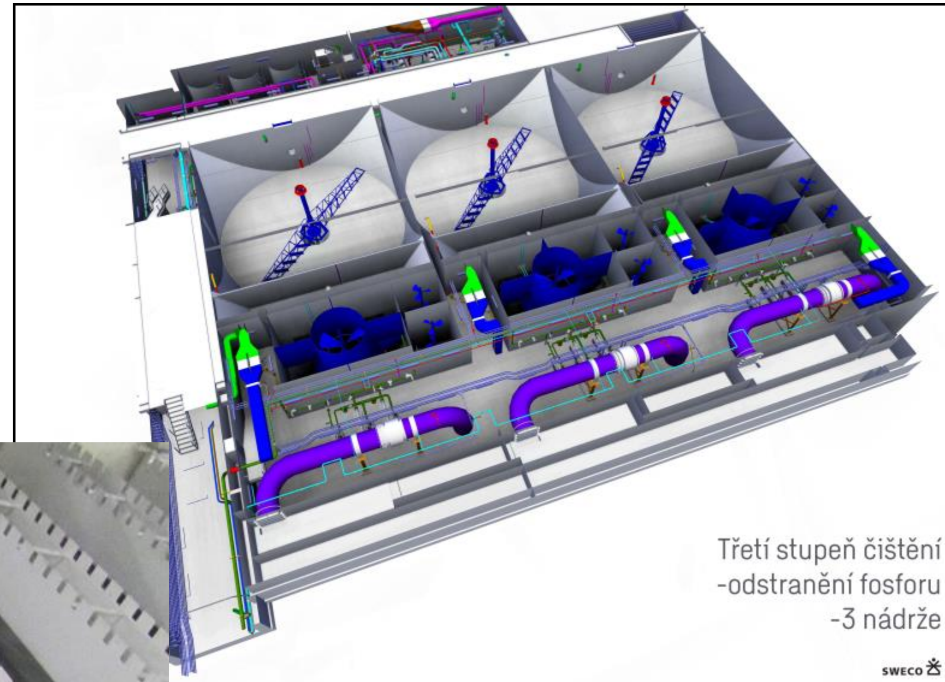
- Removal of fine solids and colloids
- Tertiary phosphorus precipitation

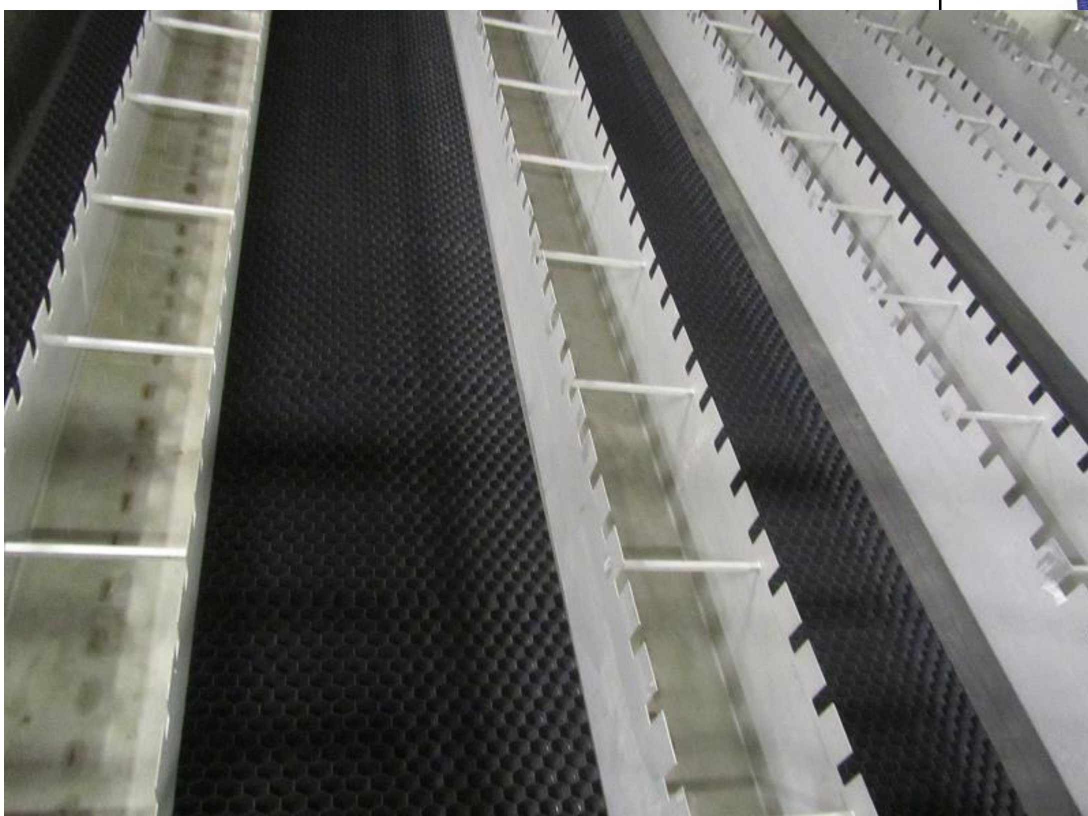
Separation of precipitate

- Simple sedimentation after rapid/slow mixing

Separation of precipitate

- Sedimentation in lamella settlers
- NVL ÚČOV Praha



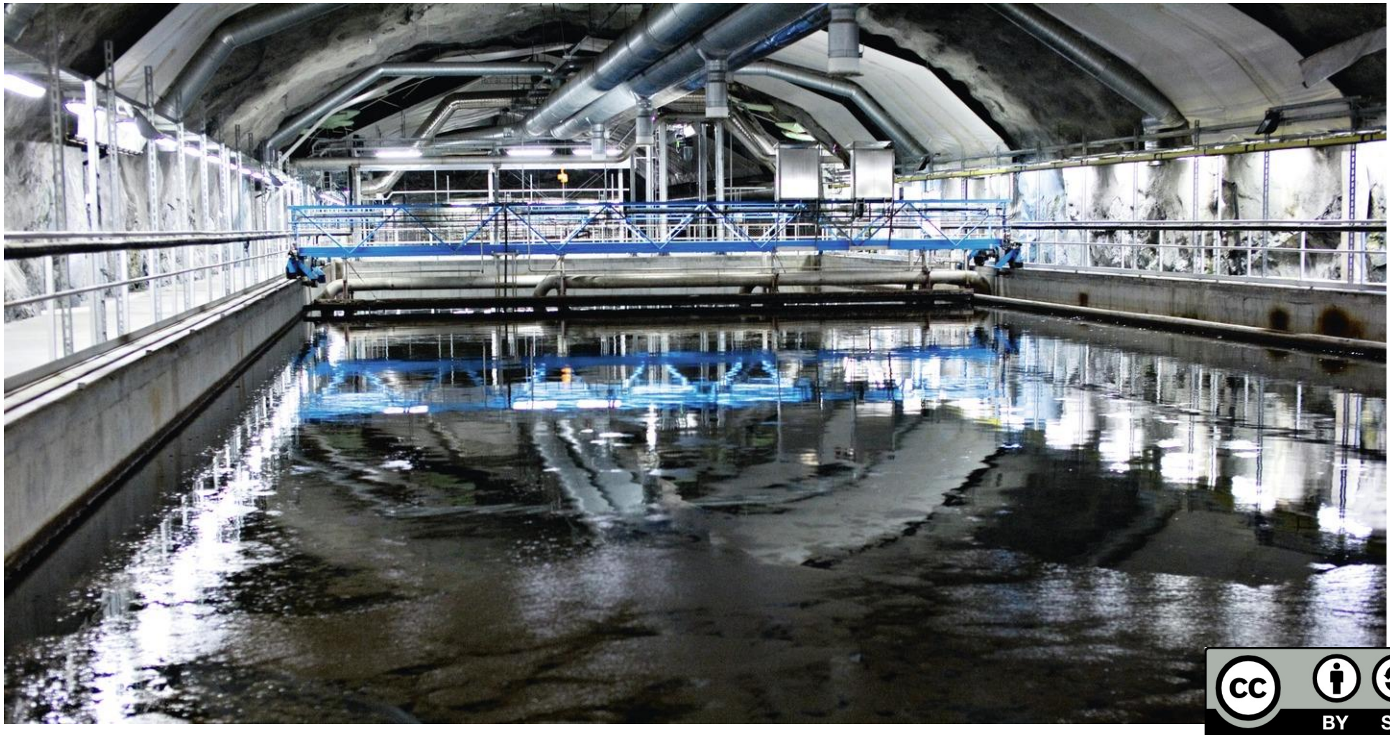


Separation of precipitate

- Conventional sand filters (like in waterworks)

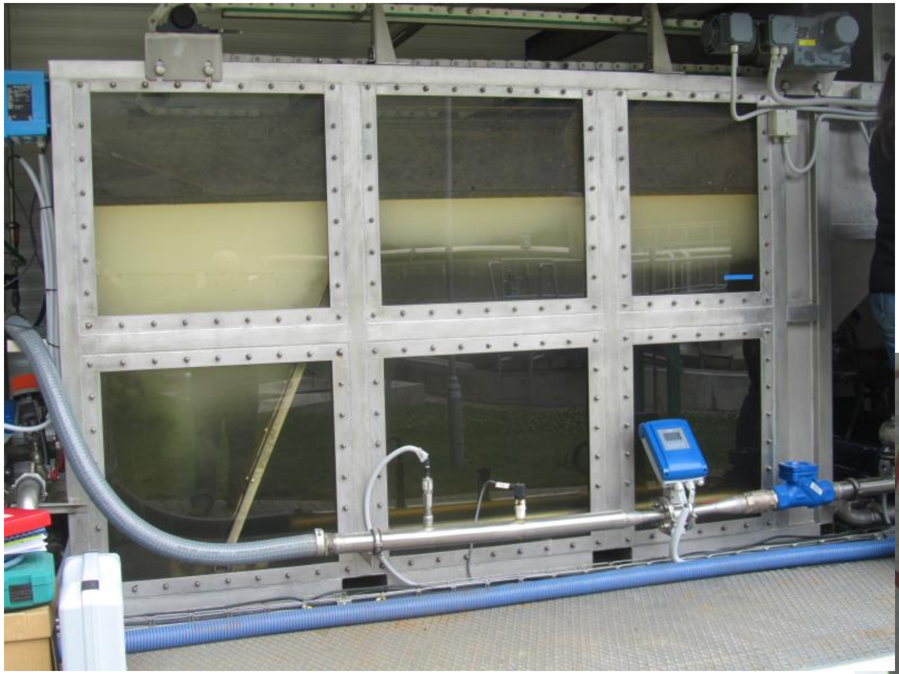
Oslo WWTP in rock

Oslo WWTP



Separation of precipitate

- Floatation



Sand filtration prior to UV disinfection

Possible combination with post-denitrification

WWTP Munich – Gut Marienhof

Chlorine disinfection

- Relatively cheap, available on market
- Effectiveness of chlorination affected by higher concentrations of suspended solids, organics and ammonia
- Disinfection effect lasting for longer period of time => protection of water in distribution system
- Prevention of biofilms in pipes and water reservoirs
- => combination with UV disinfection
- Chlorine dosed as “chlorine water” or hypochlorite solution

UV disinfection

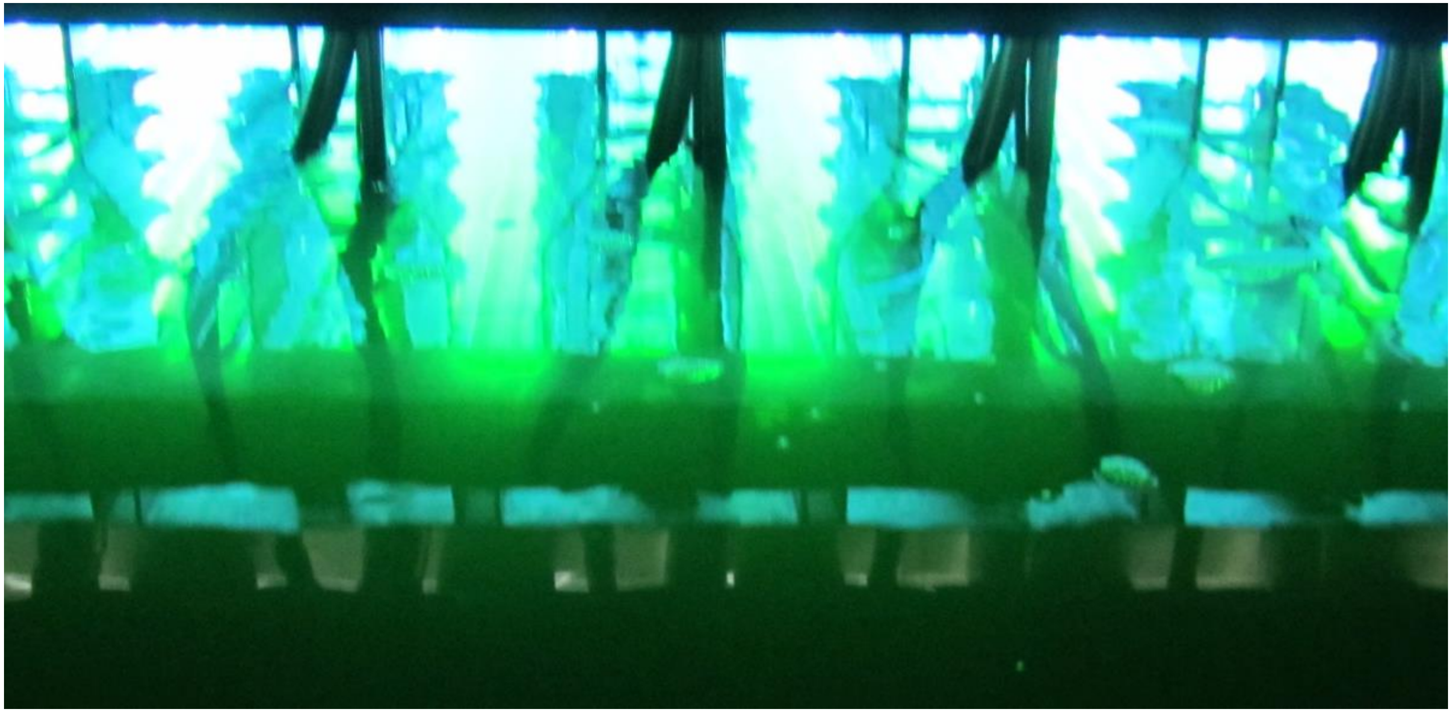
Physical method of disinfection

- effect depending on radiation intensity and exposure time
- UV light in water penetrating only into limited depth

- no production of dangerous by-products
- high investment costs, high energy consumption, high operation and maintenance costs

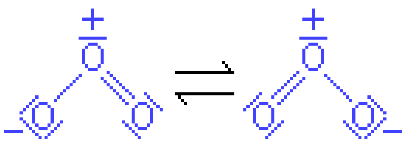
UV disinfection

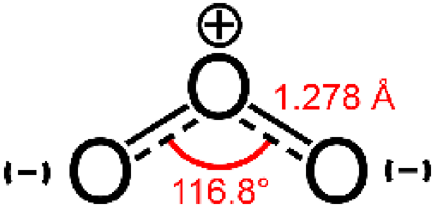
WWTP Munich – Gut Marienhof

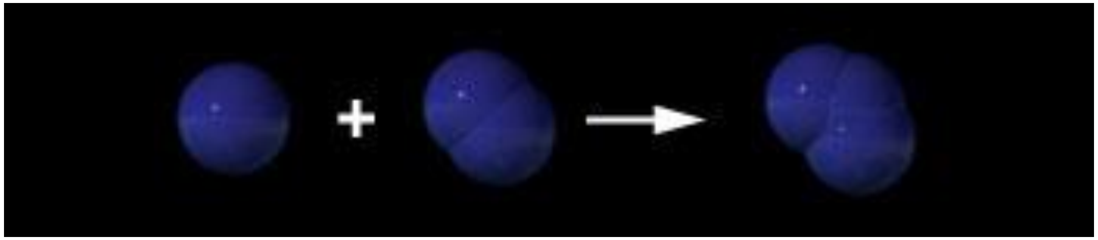


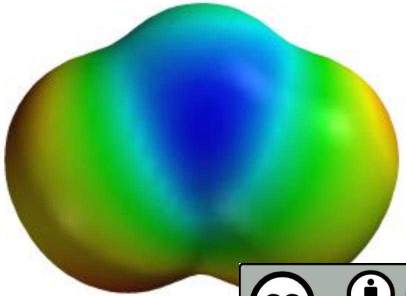
Ozone disinfection

- Ozone is a very strong oxidation agent
- Elimination of viruses and bacteria more effective than with chlorine
- Economically very demanding: both investment and operation
- Ozone efficiency depends on contact time ozone concentration and organism sensitivity to ozone

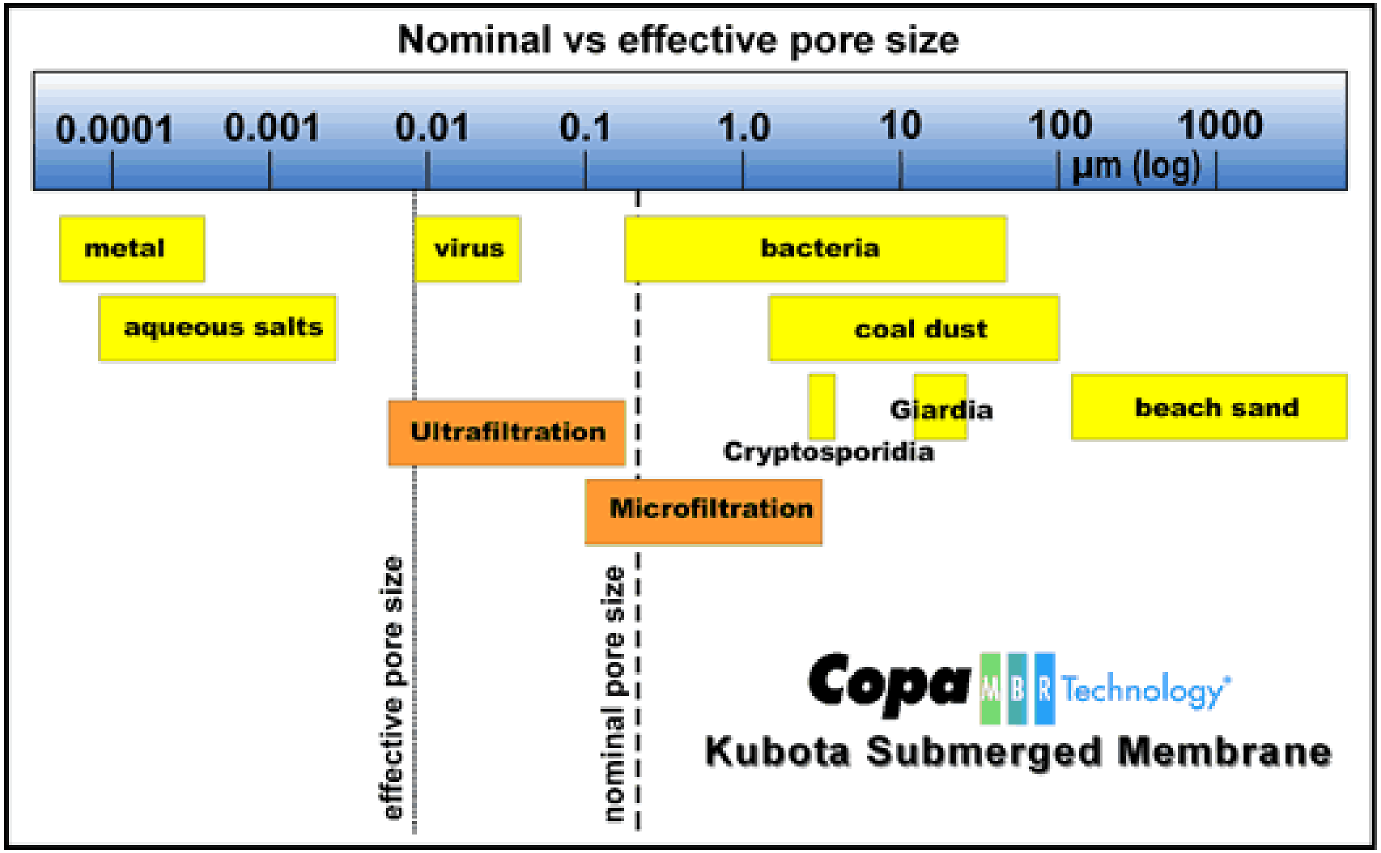








Membrane ultrafiltration



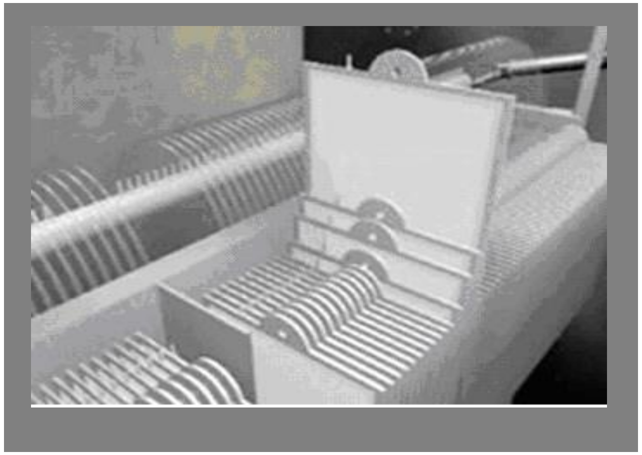
• Microfiltration – pore size of microfiltration membrane in the range of **0.1 – 1.0 µm.** This filtration removes most of particles and bacteria.

• Ultrafiltration – pore size between **0.01 – 0.1 µm**. The membrane removes bacteria, viruses and larger molecules.

Membrane ultrafiltration

Membrane technology

- effective in achieving high quality of effluent from municipal WWTP
- it combines the removal of pollutants residual concentrations with disinfection
- more practical applications because of decreasing price and more practical knowledge
- from point of view of chemical and bacteriological quality: effluent from membrane ultrafiltration = **valuable product**



Ultrafiltration membranes

Hollow fibers

Desk modules

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Tertiary wastewater treatment and Reuse of treated wastewaters – quality requirements, fields of applications

Lecture 14

EUROPEAN
COMMISSION

Brussels, XXX
COM(2018) 337/3

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Proposal for a

REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

on minimum requirements for water reuse

(Text with EEA relevance)

{SWD(2018) 249} - {SWD(2018) 250}

Table 1 Classes of reclaimed water quality and allowed agricultural use and irrigation method

<table>
<tr><th>Minimum reclaimed water quality class</th><th>Crop category</th><th>Irrigation method</th></tr>
<tr><td>A</td><td>All food crops, including root crops consumed raw and food crops where the edible part is in direct contact with reclaimed water</td><td>All irrigation methods</td></tr>
<tr><td>B</td><td rowspan="2">Food crops consumed raw where the edible part is produced above ground and is not in direct contact with reclaimed water, processed food crops and non-food crops including crops to feed milk- or meat-producing animals</td><td>All irrigation methods</td></tr>
<tr><td>C</td><td>Drip irrigation* only</td></tr>
<tr><td>D</td><td>Industrial, energy, and seeded crops</td><td>All irrigation methods</td></tr>
</table>

Table 2 Reclaimed water quality requirements for agricultural irrigation

Reclaimed water quality class	Indicative technology target	Quality requirements				
		E. coli (cfu/100 ml)	BOD_5 (mg/l)	TSS (mg/l)	Turbidity (NTU)	Other
A	Secondary treatment, filtration, and disinfection	≤10 or below detection limit	≤10	≤10	≤5	*Legionella* spp.: <1,000 cfu/l where there is risk of aerosolization in greenhouses
B	Secondary treatment, and disinfection	≤100	According to Council Directive 91/271/EEC[1] ((Annex I, Table 1)	According to Directive 91/271/EEC ((Annex I, Table 1)	-	Intestinal nematodes (helminth eggs): ≤1 egg/l for irrigation of pastures or forage
C	Secondary treatment, and disinfection	≤1,000			-	
D	Secondary treatment, and disinfection	≤10,000			-	

The reclaimed water will be considered compliant with the requirements set out in Table 2 if the measurements meet all of the following criteria:

- The indicated values for *E. coli*, *Legionella spp* and Intestinal nematodes are met in 90 % or more of the samples. None of the values of the samples can exceed the maximum deviation limit of 1 log unit from the indicated value for *E. coli* and *Legionella* and 100 % of the indicated value for intestinal nematodes.
- The indicated values for BOD_5, TSS, and turbidity in Class A are met in 90 % or more of the samples. None of the values of the samples can exceed the maximum deviation limit of 100% of the indicated value.

Table 3 Minimum frequencies for routine monitoring of reclaimed water for agricultural irrigation

	Minimum monitoring frequencies					
Reclaimed water quality class	***E. coli***	**BOD_5**	**TSS**	**Turbidity**	***Legionella* spp. *(when applicable)***	**Intestinal nematodes *(when applicable)***
A	Once a week	Once a week	Once a week	Continuous	Once a week	Twice a month or frequency determined by the reclamation plant operator according to the number of eggs in waste water entering the reclamation plant
B	Once a week	According to Directive 91/271/EEC ((Annex I, Section D)	According to Directive 91/271/EEC (Annex I, Section D)	-		
C	Twice a month			-		
D	Twice a month			-		

Table 4 Validation monitoring of reclaimed water for agricultural irrigation

Reclaimed water quality class	Indicator microorganisms (*)	Performance targets for the treatment chain (log_{10} reduction)
A	*E. coli*	≥ 5.0
	Total coliphages/ F-specific coliphages/somatic coliphages/coliphages(**)	≥ 6.0
	Clostridium perfringens spores/spore-forming sulfate-reducing bacteria(***)	≥ 5.0

(*) The reference pathogens Campylobacter, Rotavirus and Cryptosporidium can also be used for validation (of??) monitoring purposes instead of the proposed indicator microorganisms. The following $\log_{10}$ reduction performance targets should then apply: Campylobacter (≥ 5.0), Rotavirus (≥ 6.0) and Cryptosporidium (≥ 5.0).

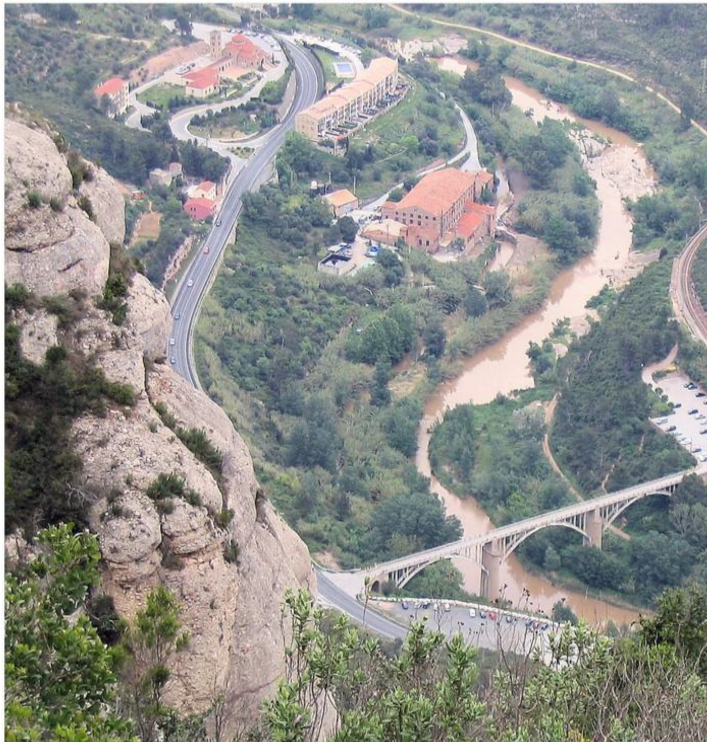
(**) Total coliphages are selected as the most appropriate viral indicator. However, if the analysis of total coliphages is not feasible, at least one of them (F-specific or somatic coliphages) has to be analyzed.

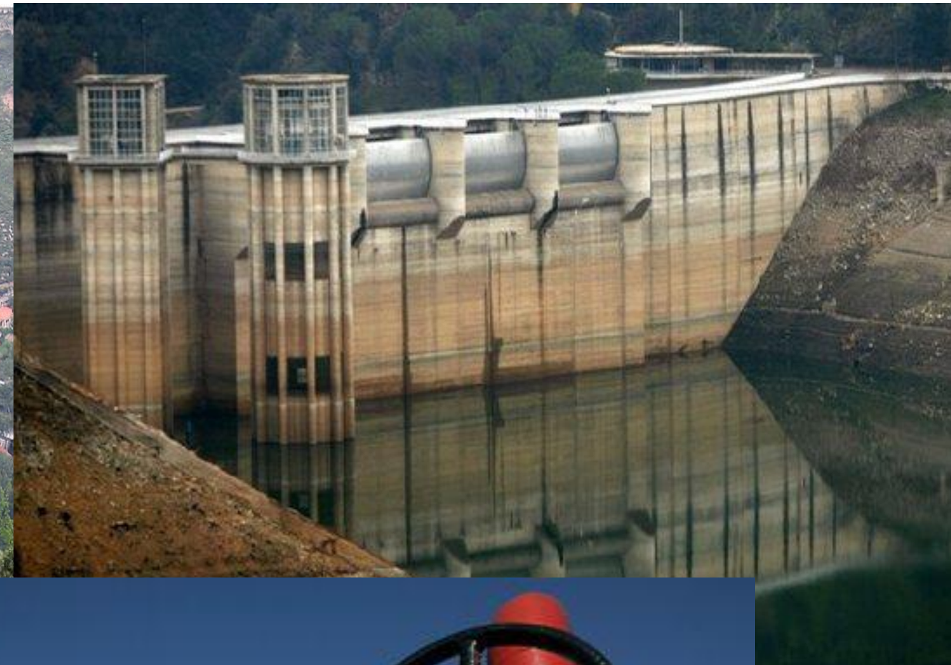
(***) Clostridium perfringens spores are selected as the most appropriate protozoa indicator. However, sporeforming sulphate-reducing bacteria are an alternative if the concentration of Clostridium perfringens spores does not allow to validate the requested log10 removal.

Methods of analysis for monitoring shall be validated and documented by the operator in accordance with EN ISO/IEC-17025 or other national or international standards which ensure an equivalent quality.

Examples of successful European projects of tertiary treatment for water reuse

Barcelona exploits its wastewater

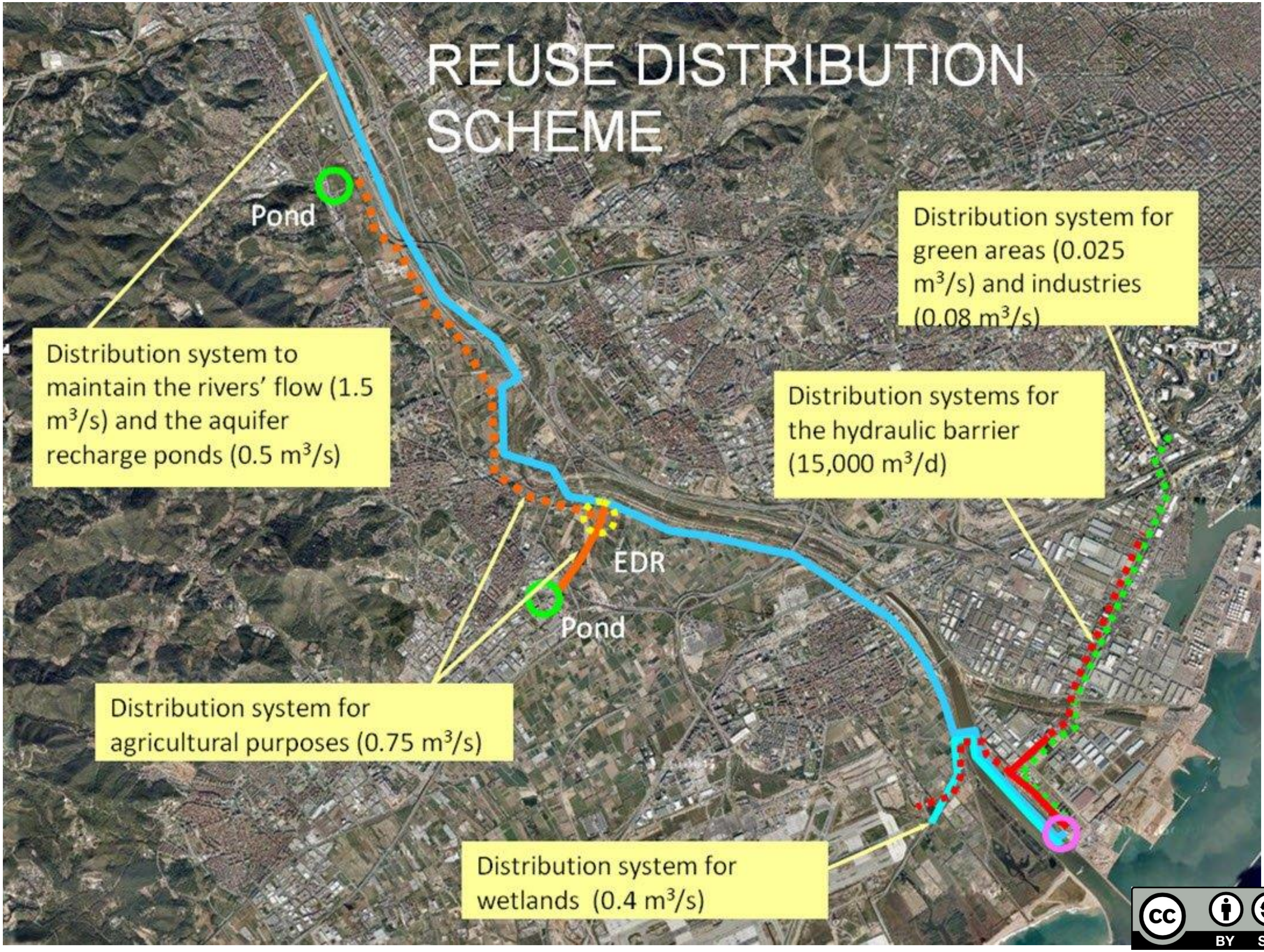




El Llobregat river

Severe lack of water in the 1st decade of 2000

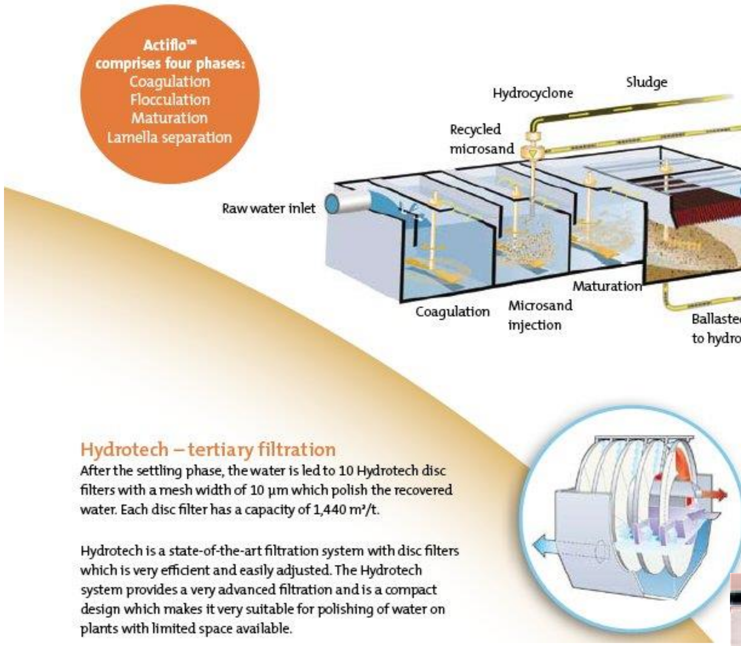
Barcelona exploits its wastewater



Barcelona exploits its wastewater

ATLL Concesionaria de la Generalitat de Cataluña

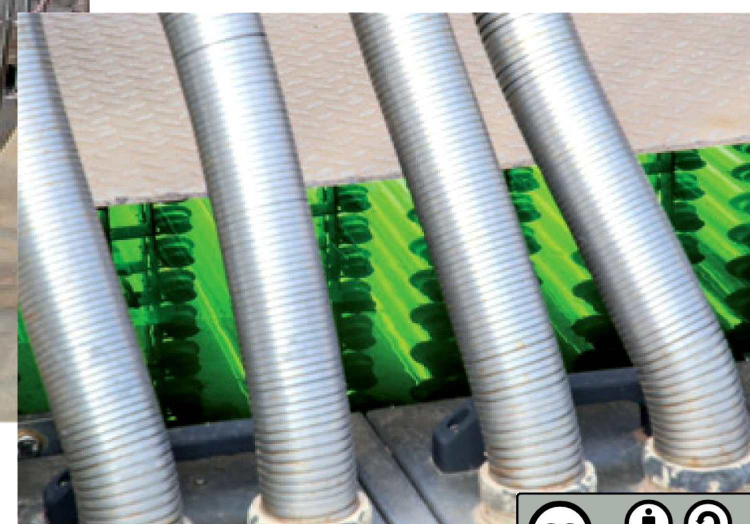
Barcelona exploits its wastewater



1) Irrigation in agriculture
2) Increase of water flow in local river
3) Watering of urban greenery
4) After reverse osmosis: water for hydraulic barrier along the sea coast

Barcelona exploits its wastewater

UV disinfection



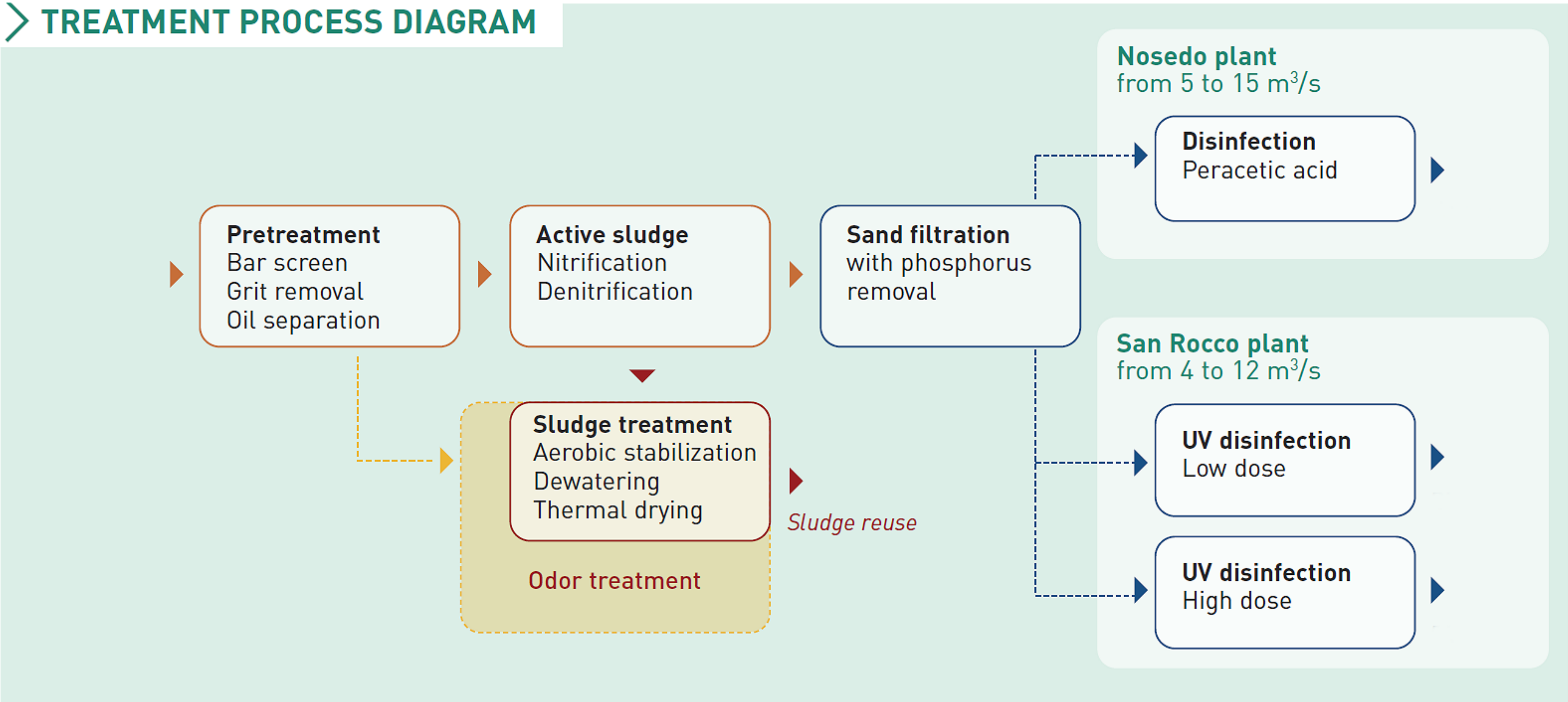
Lombardy exploits wastewater from Milan

WWTP San Rocco

Lombardy exploits wastewater from Milan

WWTP Nosedo

Lombardy exploits wastewater from Milan



- Tertiary phosphorus removal
- Tertiary disinfection
- Two different types of disinfection
  - Peracetic acid PAA
  - UV disinfection with variable intensity of radiation
- Growing season: effluent used for irrigation
- Rest of the year: discharge into local receiving water

Lombardy exploits wastewater from Milan

Water distributed to fields and vineyards by irrigation channels

Famous overseas water reuse projects

- Windhoek Goreangab Reclamation Plant, Namibia
- Californian water supply system
- Water reuse in Victoria and Southern Australia
- „New Water“ of Singapore

Windhoek Goreangab Reclamation Plant, Namibia

- The project started in the 1970s
- Since 2002, a new water treatment plant - the old one is used for irrigation purposes
- Combination of various water resources: water from river reservoirs, wells and effluent from water recycling plant

Windhoek Goreangab Reclamation Plant, Namibia

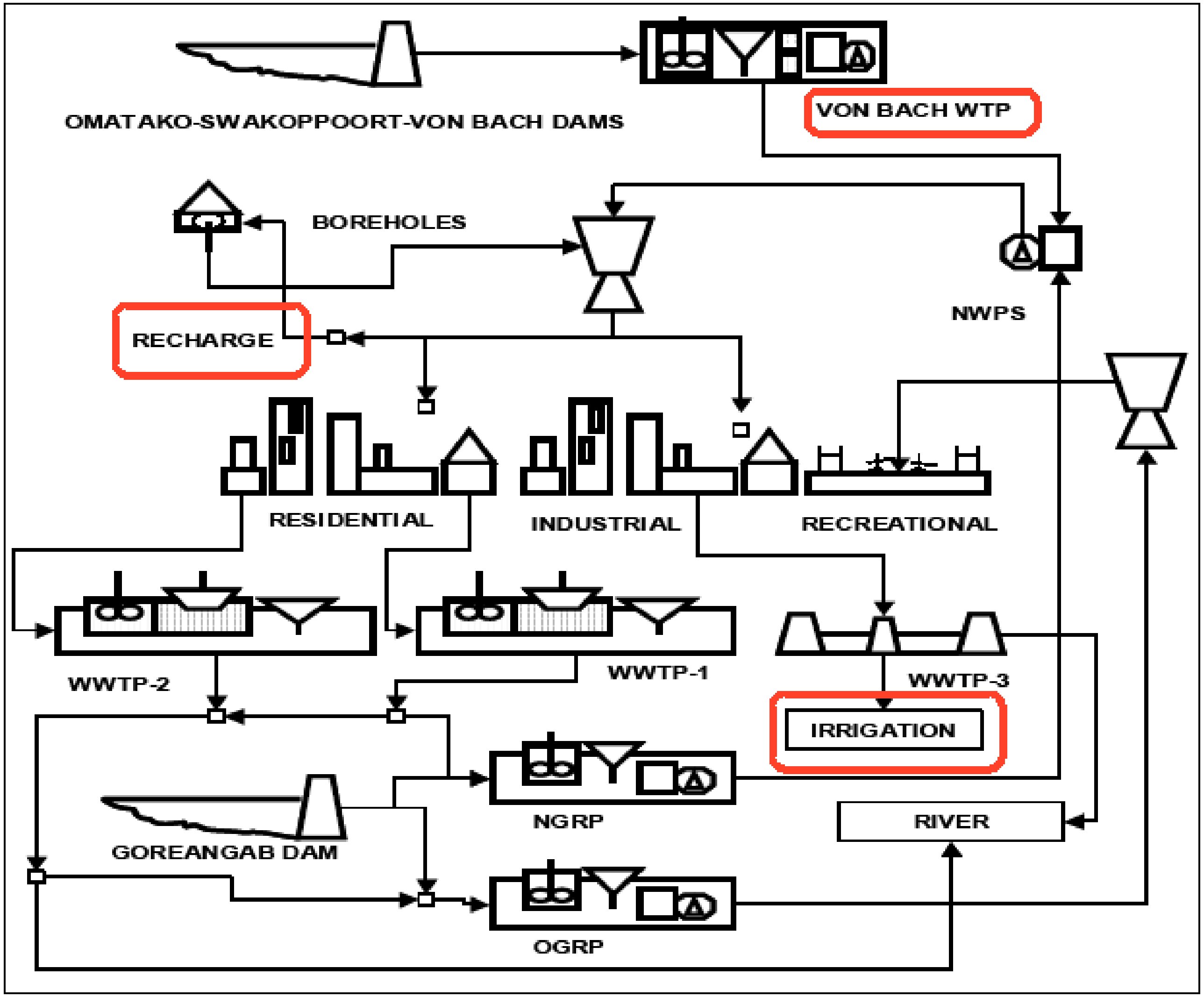


Figure 1 -: The Windhoek Water Cycle – Drinking water supply, reclamation and reuse scheme.

Windhoek Goreangab Reclamation Plant, Namibia

Chemical coagulation

Reverse osmosis

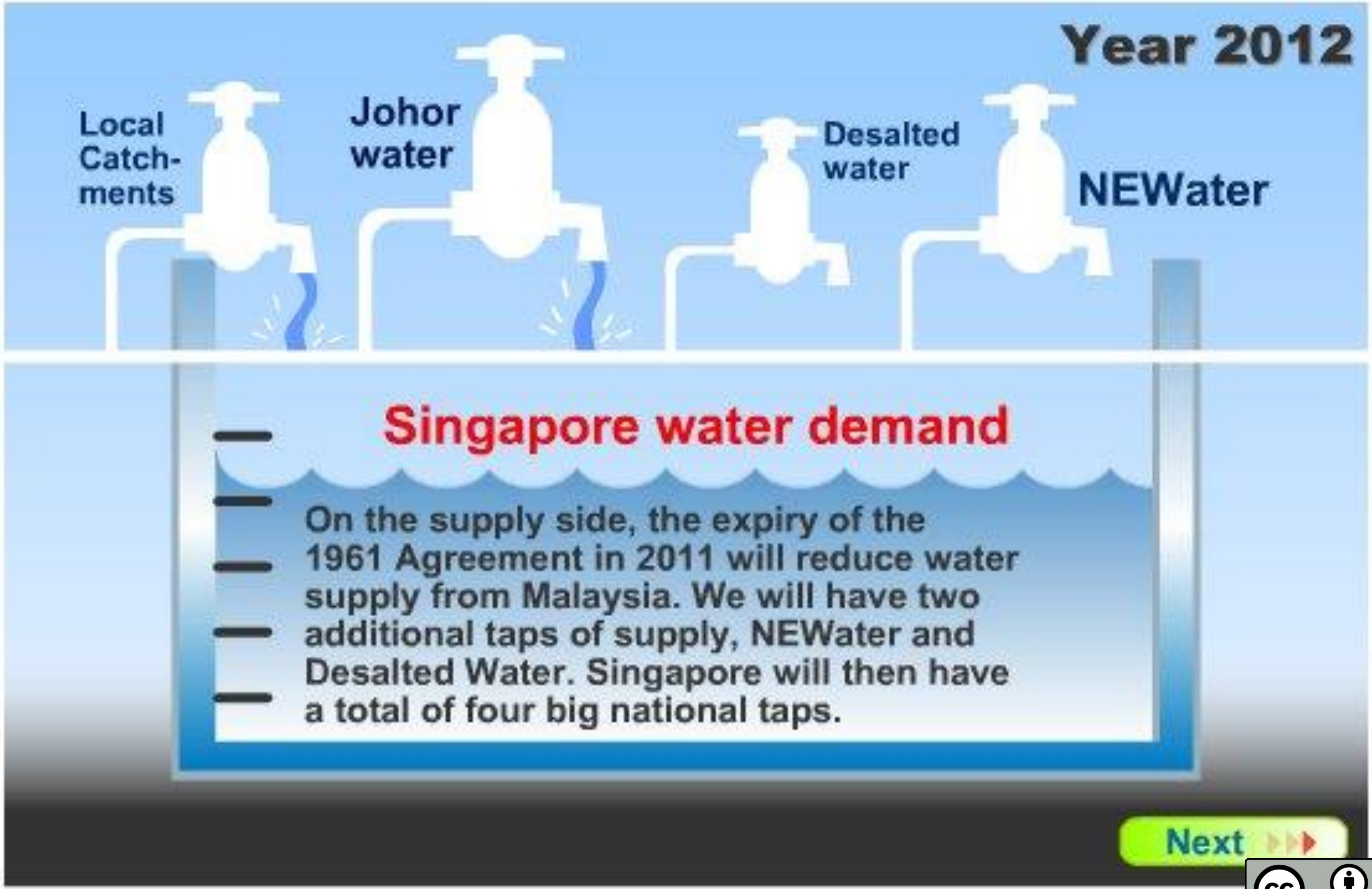
California water supply system

Wastewater reuse in Victoria and Southern Australia

Melbourne – Altona Meadows

Wastewater reuse in Victoria and Southern Australia

„New Water“ in Singapore



„New Water“ in Singapore

Final product on the market

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YOUTH AND SPORTS

BIOLOGICAL WASTEWATER TREATMENT

SEMINARS

WEEK 1

QUALITATIVE PARAMETERS OF TREATED WASTEWATERS, CZECH AND EU LEGISLATION

1) Effluent standards according to Directive 91/2721/EEC for urban wastewater treatment plants:

a. Limited parameters
Definition of standards for individual parameters
(permitted non-compliance vs. annual average)
- Standard analytical procedures for individual emission standards

b. Construction of standards and plant size
- Relation between numerical values and plant size

c. Required types of samples
- Sampling procedures, automatic sampler

d. Reflection of EU standards in the Czech water law
- Explain Tables 1-3 in Annex 1, Government Regulation 401/2015 Coll.

QUALITATIVE PARAMETERS OF TREATED WASTEWATERS, CZECH AND EU LEGISLATION

2) Wastewater treatment in sensitive areas

a. Definition of treatment technology requirements

b. Balance of nitrogen and phosphorus in receiving waters; concentration limits of nutrients for eutrophication; calculation of nutrient concentration in receiving waters

c. Balance of nutrient load from non-point sources

3) Calculation of effluent limits by the combined method

WEEK 2

HYDRAULIC REGIME OF BIOCHEMICAL REACTORS

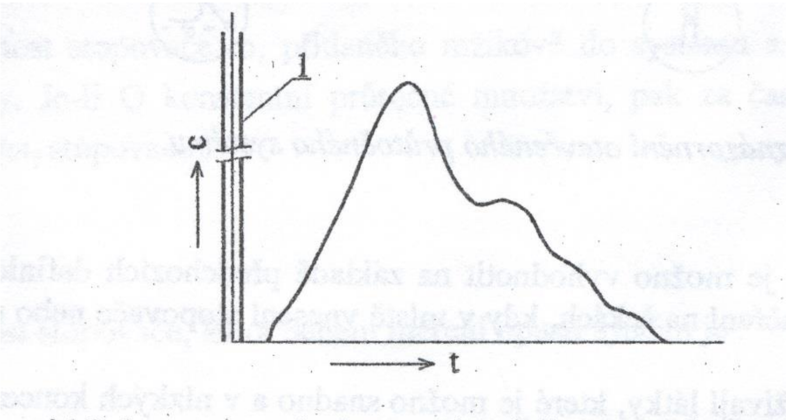
a. Evaluation of tracer tests

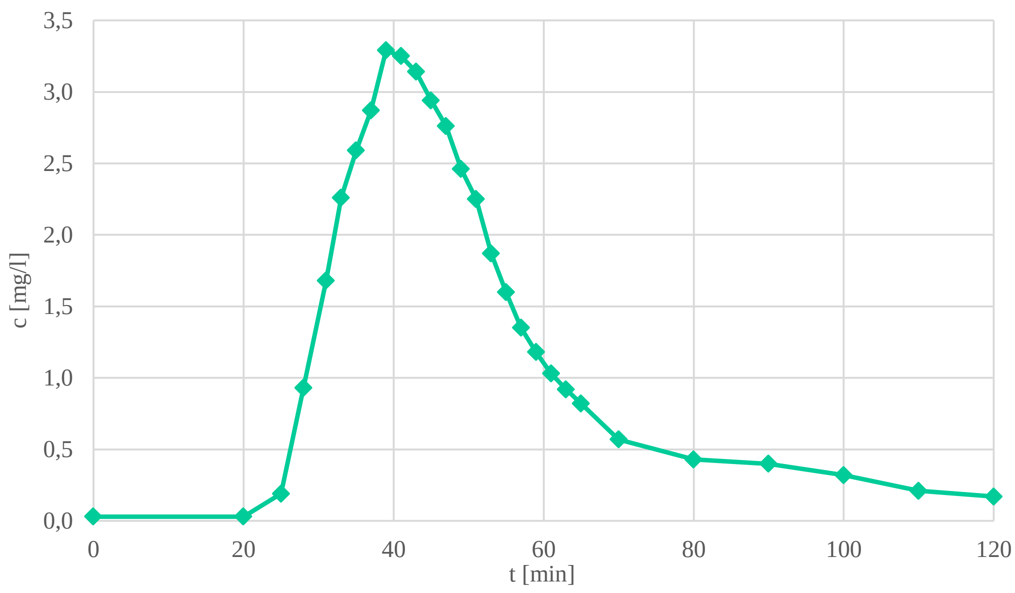
b. Calculation of number of ideal mixers and dispersion number

c. Relation between growth rate and hydraulic regime

WEEK 2

HYDRAULIC REGIME OF BIOCHEMICAL REACTORS

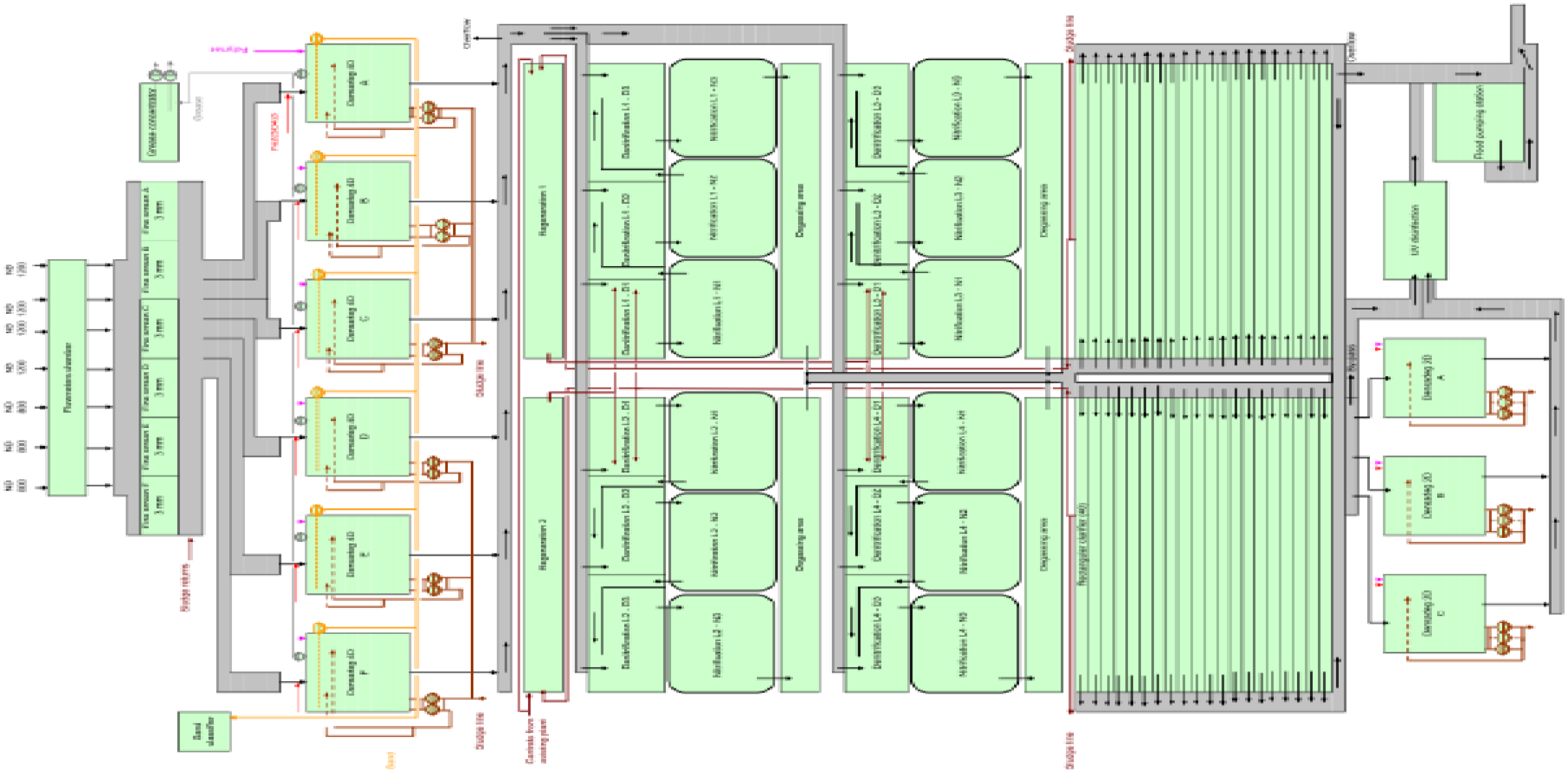




Describe the impulse - response curve

WEEK 3

TECHNICAL EXCURSION AT WWTP

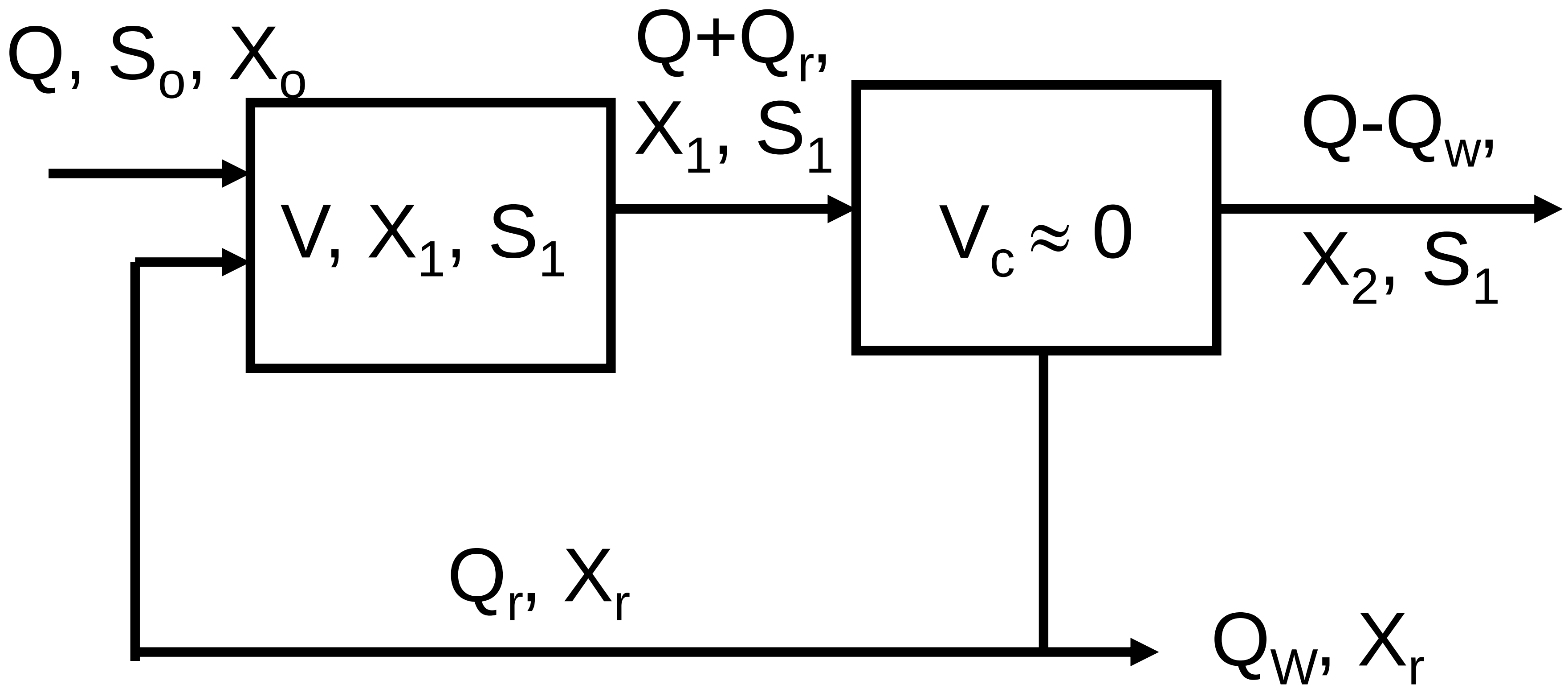


Describe wastewater and activated sludge flows in New Water Line of Prague Central Wastewater Treatment Plant

WEEK 4

TECHNOLOGICAL PARAMETERS OF ACTIVATED SLUDGE PROCESS

a. Calculation of basic technological parameters of activated sludge process
b. Characteristic design values for individual activated sludge systems



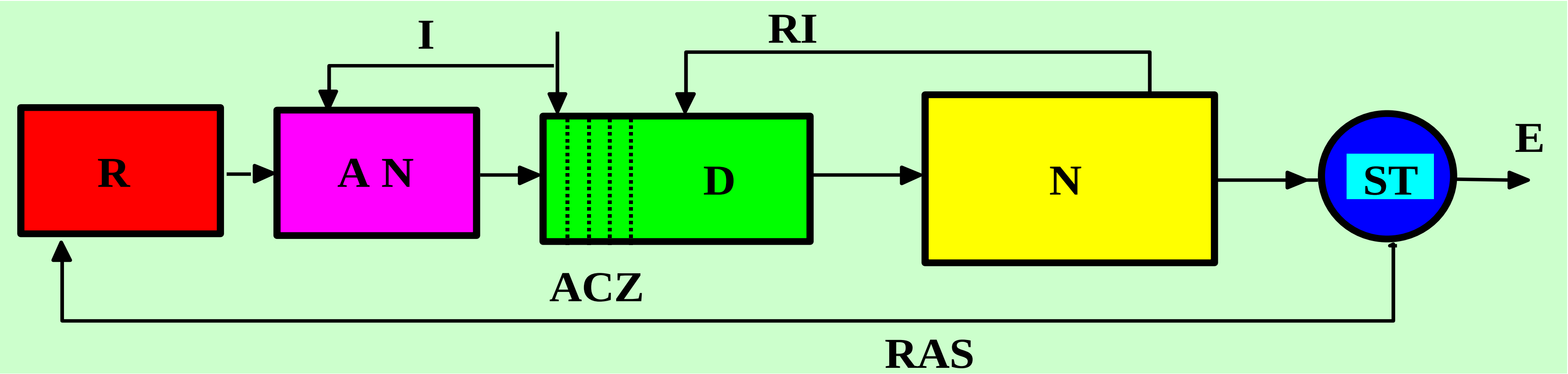
Define the sludge age for this system, how its value can be controlled

WEEK 5

ACTIVATED SLUDGE PROCESS

a. Design of regeneration zone for activated sludge regeneration and bulking control

b. Design parameters of contact zones to establish unbalanced growth



Calculate the contact time in the regeneration zone in this arrangement

WEEK 6

AERATION

a. Calculation of required oxygenation capacity (OC) for carbon removal and for carbon removal combined with nitrification

b. Measurements of coefficients α and χ

c. Calculation of operational aeration intensity based on OC, α and χ values

Design the capacity of the blower for the aeration tank provided you know: Q_{inflow}, $BOD_{5,inflow}$, B_V, X, H, α, χ, T = 20 deg.C, normal atmospheric pressure

WEEK 7

REPORTS – PART 1

Reports of individual students on the results of their literature review covering selected topics from wastewater treatment and reuse.

Suggested topics:

Membrane technology for wastewater treatment
Tertiary wastewater treatment
Wastewater reuse – examples from municipal and industrial WWTPs
Wastewater treatment in agglomerations below 2,000 PE
External substrate dosing at WWTPs
New/alternative methods in nutrient removal
Control of activated sludge separation properties
Removal of specific organic pollutants from wastewater (pharmaceuticals, sweeteners, contrast agents)
Extensive wastewater treatment systems
Phosphorus recovery from wastewater and sludge
Upgrade of biological wastewater treatment plants
Bioreactors with combined suspended and fixed biomass

WEEK 8

BIOLOGICAL NUTRIENT REMOVAL

a. Dimensioning of anaerobic zone for EBPR and anoxic zone for denitrification

b. Calculation of critical solids retention time for nitrification

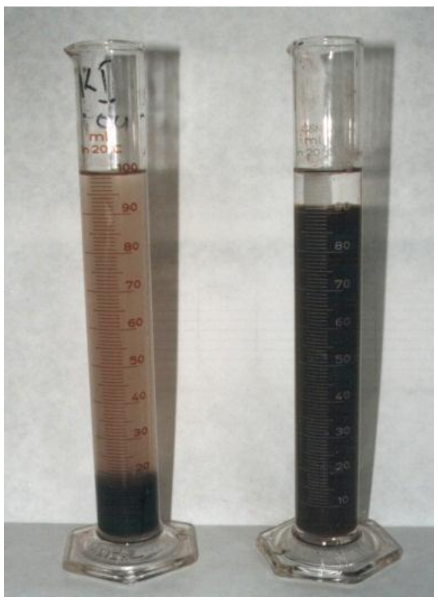
WEEK 9

ACTIVATED SLUDGE SEPARATION

Measurement and calculation of different sludge volume indices (SVIs), correlation between SVI and zone settling velocity (ZSV)

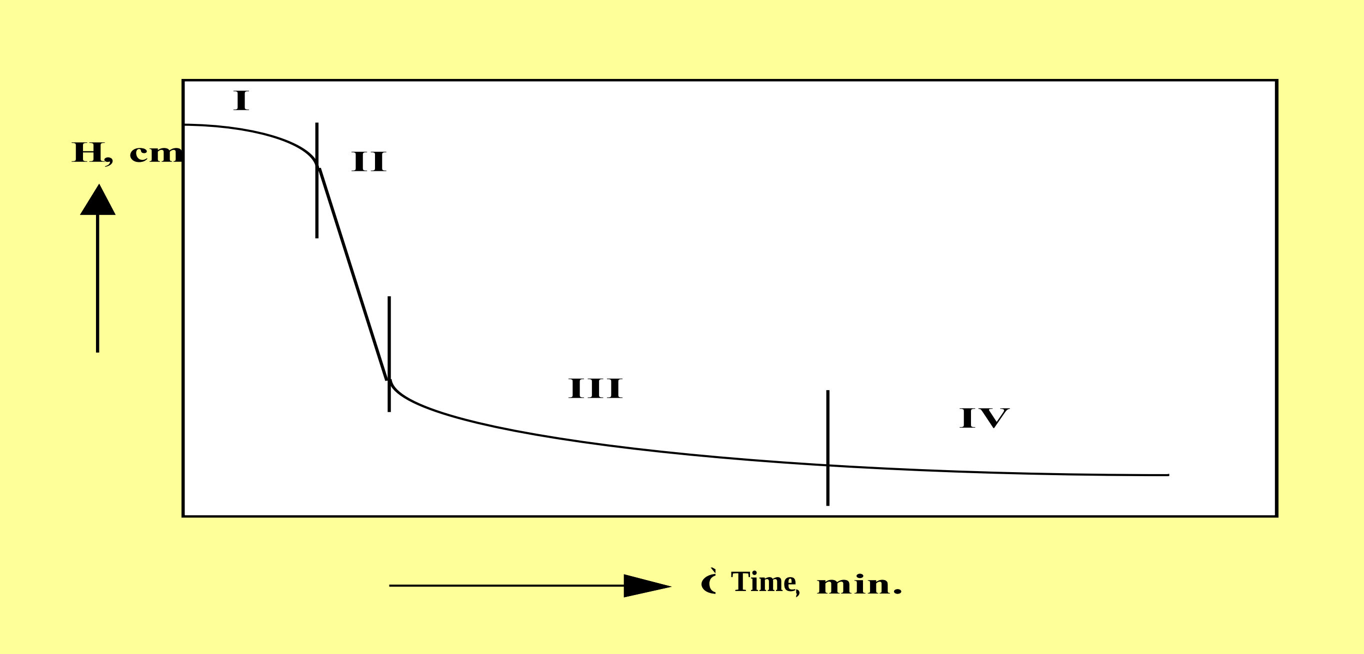
1. Sludge volume index (SVI)

$$SVI = V_{30}/X \text{ [ml/g]}$$



Type of sludge	SVI [ml/g]
Well settling	< 100
Light	100 – 200
Bulking	> 200

2. Zone settling velocity (ZSV)



I - reflocculation
II - zone settling sedimentation
III - transition
IV - compaction

Type of sludge	ZSV [m/h]
Well settling	> 3
Light	2 – 3
Bulking	< 1.2

WEEK 10

MICROSCOPIC ANALYSIS OF ACTIVATED SLUDGE

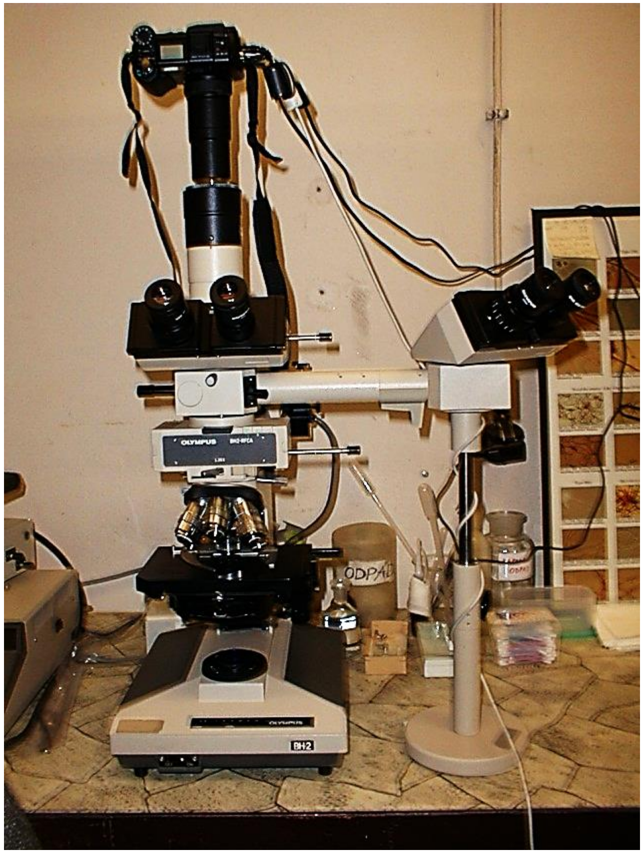
a. Analysis of basic morphological characteristics of activated sludge flocs

b. Microfauna of activated sludge

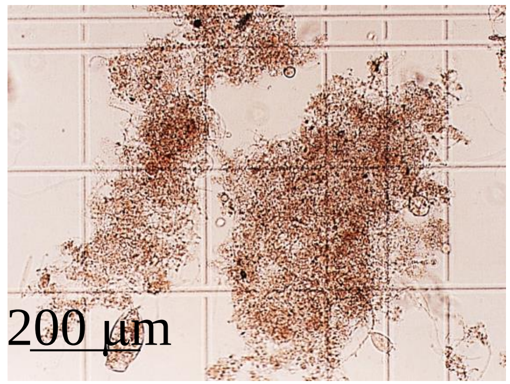
c. Abundance of filamentous microorganisms

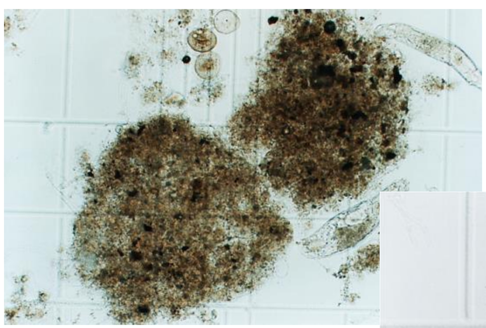
d. Identification of filamentous microorganisms

e. Estimation of activated sludge separation problems based on microscopic analysis results

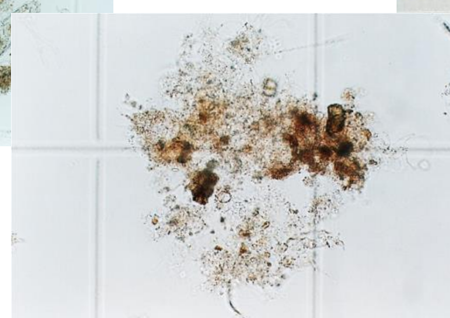


a. Analysis of basic morphological characteristics of activated sludge flocs
- size, shape and structure of flocs, pin-point flocs/fragments, freely dispersed bacteria



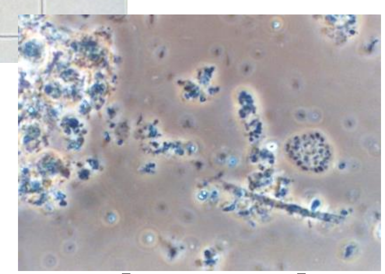


compact



compact cores

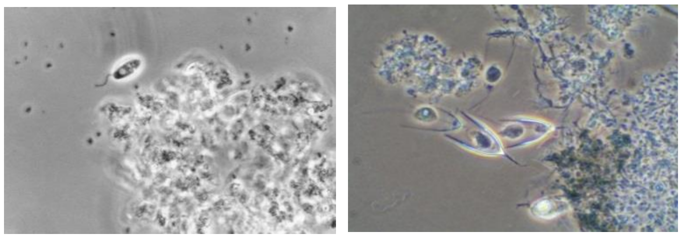
diffuse



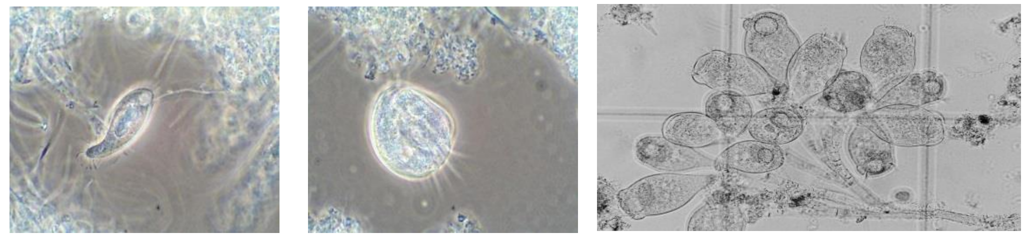
dispersed bacteria

b. Microfauna of activated sludge

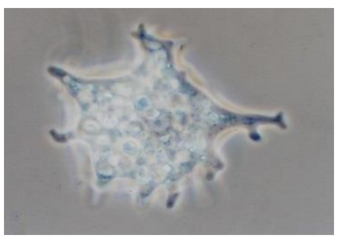
- protozoa (flagellates, amoebae, testate amoebae, cilliates), metazoa (rotifers, tardigrades, nematodes,…)



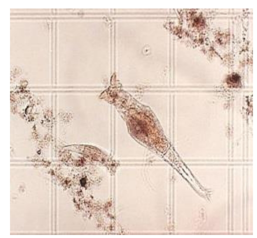
flagellates



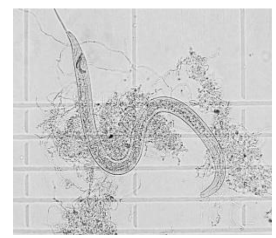
ciliates



amoeba

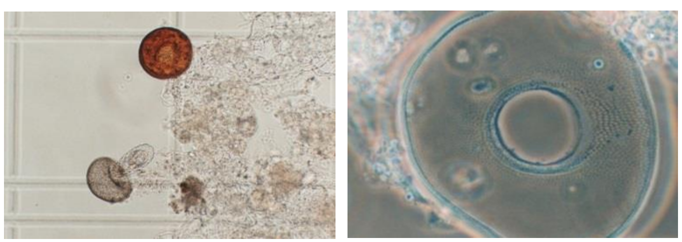


rotifer

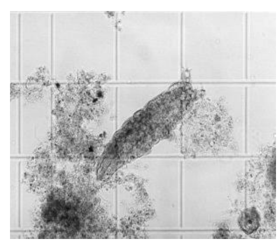


nematode

worm



testate amoebae



tardigrade
(water bear)

activated sludge
acarid

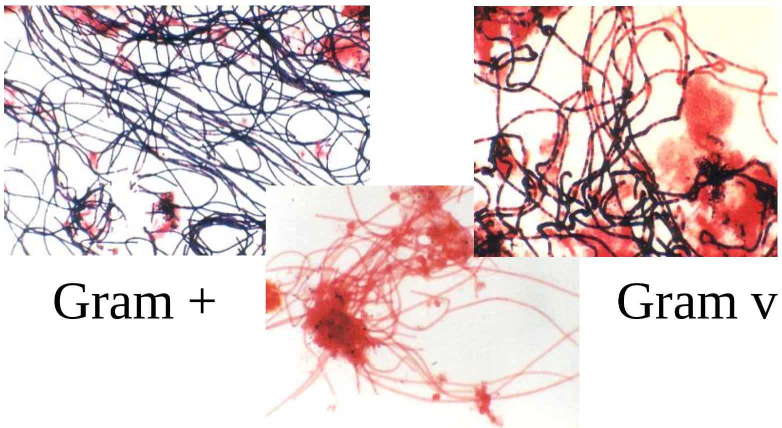
c. Abundance of filamentous microorganisms

Numerical value	**Explanation**
0	No filaments observed
1	Filaments present, but only observed in occasional flocs
2	Filaments commonly observed, but not present in all flocs
3	Filaments observed in all flocs, but at low density (1 – 5 filaments per floc)
4	Filaments observed in all flocs at medium density (5 – 20 filaments per floc)
5	Filaments observed in all flocs at high density (> 20 filaments per floc)
6	Filaments observed in all flocs - occurrence of more filaments than flocs

c. Identification of filamentous microorganisms

- morphological features (branching, shape, location, attached growth, cell size, diameter, granules,….) and staining reactions (Gram and Neisser stain)

Gram staining

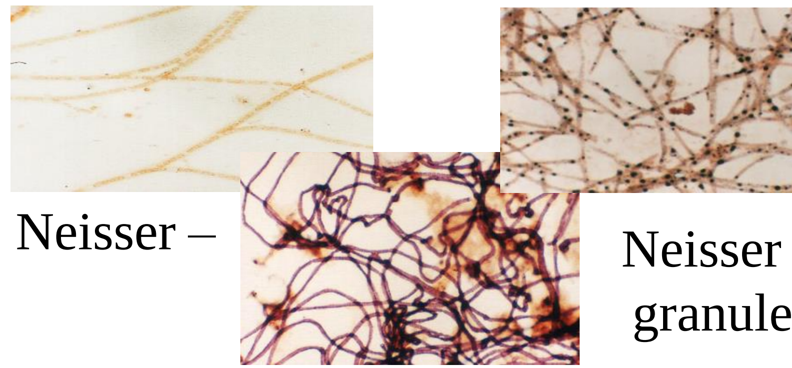


Gram +

Gram v

Gram –

Neisser staining



Neisser –

Neisser + granules

Neisser +

- 1. Crystal violet
- 2. Lugol solution (I + KI)
- 3. Decolorizing solution - ethanol
- 4. Safranin O

- 1. methylene blue

(in ethanol and acetic acid)

and crystal violet (2:1)

- 2. Bismarck brown - water solution

WEEK 11

BIOFILM PROCESSES

a. Basic technological parameters of biofilm processes: definition, calculation, design values

Which parameters describe this block biofilm carrier?

WEEK 12

SECONDARY CLARIFIERS

1) Construction of secondary clarifiers:

   a. Construction principles of clarifier main operational parts (selection of flocculation zone type, shape of sludge scraper, position of effluent launders, skimming of water surface)

   b. Basic design parameters and their calculation

2) Effect of secondary clarifier thickening function on operation of aeration basins:

   a. Construction of working curve of secondary clarifier - use of solids flux theory

   b. Operation in stable and unstable regime in relation to concentration of return activated sludge

WEEK 13

REPORTS – PART 2

Reports of individual students on the results of their literature review covering selected topics from wastewater treatment and reuse.

Suggested topics:

Membrane technology for wastewater treatment
Tertiary wastewater treatment
Wastewater reuse - examples from municipal and industrial WWTPs
Wastewater treatment in agglomerations below 2,000 PE
External substrate dosing at WWTPs
New/alternative methods in nutrient removal
Control of activated sludge separation properties
Removal of specific organic pollutants from wastewater (pharmaceuticals, sweeteners, contrast agents)
Extensive wastewater treatment systems
Phosphorus recovery from wastewater and sludge
Upgrade of biological wastewater treatment plants
Bioreactors with combined suspended and fixed biomass

WEEK 14

TERTIARY TREATMENT

a. Basic operation parameters of membranes for separation of activated sludge; measurement, dimensioning

b. Calculation of chlorine doses for effluent disinfection, capacity of UV lamps for effluent disinfection

c. Design parameters of sand filters installed prior to UV disinfection