SWIM and Horizon 2020 Support Mechanism

Working for a Sustainable Mediterranean, Caring for our Future

Biological Treatment

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Leachate Management Training Program

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Lecture 4

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Outline

1. Introduction
2. Classifications
3. Basic Steps
4. Selected Biological Treatment Processes
5. Performance

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Introduction

- Biological treatment is very effective at reducing high-strength biodegradable components
- Broadly speaking, divided to aerobic and anaerobic technologies
- Majority of leachate treatment schemes that have been successfully installed in landfill sites are anaerobic biological processes.
- The drawbacks generally experienced in biological treatment originate from operational problems such as foaming, metal toxicity, nutrient deficiency and sludge settling.
- Among the various biological treatment processes, Sequencing Batch Reactors (SBRs) has been to be proved a reliable and robust method for leachate treatment.

Definitions

BOD Biochemical oxygen demand:
A BOD5 value, the biochemical oxygen demand during a 5-day sampling period under standard conditions, expresses the amount of oxygen needed by aerobic micro-organisms to break down organic material. It is one of the so-called 'aggregate parameters' in that it does not allow the degradation of single compounds to be determined.

Chemical oxygen demand:
The Chemical oxygen demand, or COD, is another one of the so-called 'aggregate parameters' as it does not allow for the quantification of individual compounds. It is determined by means of oxidation of the sewage contents by potassium chromate and measures the oxygen demand for oxidizing a majority of organic substances. If there are also oxidizable inorganic compounds, such as sulphites, in the sewage, these are also entered as the COD.

Nitrogen:
Nitrogen normally appears in untreated sewage in the form of an organic compound (for example in proteins, nucleic acids, urea) in the form of ammonia ions (NH4+) and in small proportions also in the form of nitrate (NO3-) and nitrite ions (NO2-).

Biological Treatment Classification

Systems with suspended-growth biomass	Systems with attached/immobilized biomass
Activated sludge (AS): · Continuous flow reactors · Sequencing batch reactors (SBR)	Filters: · Upflow system · Downflow system
Membrane bioreactors (MBR): · External membrane module · Submerged/Immersed membrane module	Fluidized bed: · Sand carrier of biomass · Activated sludge carrier of biomass
	Upflow anaerobic sludge blanket (UASB): · Expanded granular sludge bed (EGSB)
	Moving bed bioreactors (MBBR) · Rotating biological contactors

Source: Gotvajn, A. Z. and Pavko, A., Perspectives on biological treatment of sanitary landfill leachate

Biological Treatment Applications (1)

Biological processes	Application	Comments
Aerobic system	Removal of organics	Refractory or slowly degrading compounds are not removed. Process cannot tolerate influent toxics. Biological sludge is produced. Needs separate clarifier.
Aerated stabilization ponds (lagoons)	Removal of organics	Requires large land area.
Fixed-film processes (trickling filters, biological contractors)	Removal of organics	Temperature-sensitive in cold weather. Cover may be needed.

Source: Kostova,I., Leachate from sanitary landfills- origin, characteristics and treatment, July 2006

Biological Treatment Applications (2)

Biological processes	Application	Comments
Anaerobic systems (anaerobic contractors and lagoons)	Removal of organics	Low operating costs and sludge production. Requires heating. Long detection times for high removal levels. Typically cannot tolerate influent toxics or high concentrations of some inorganics.
Nitrification and denitrification	Removal of nitrogen	Nitrification/denitrification can be accomplished along with removal of organics.

Source: Kostova,I., Leachate from sanitary landfills- origin, characteristics and treatment, July 2006

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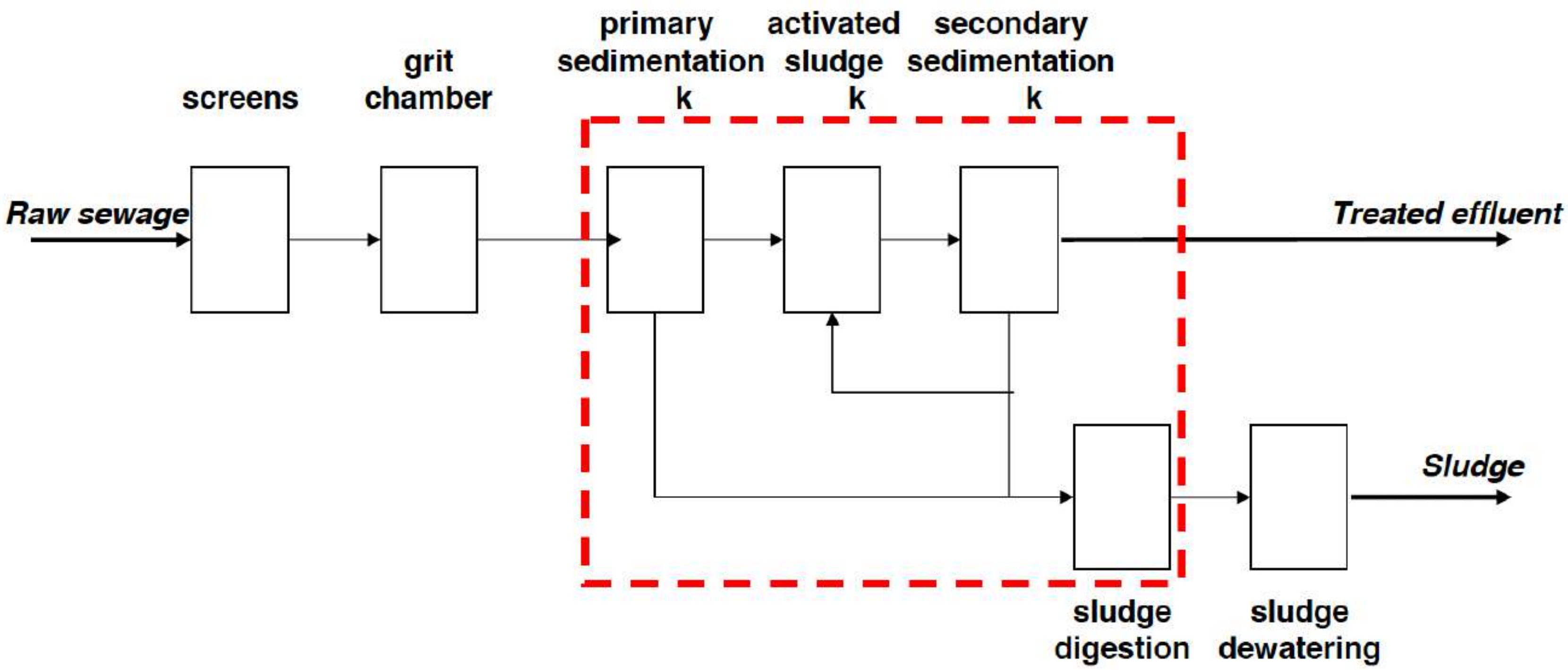
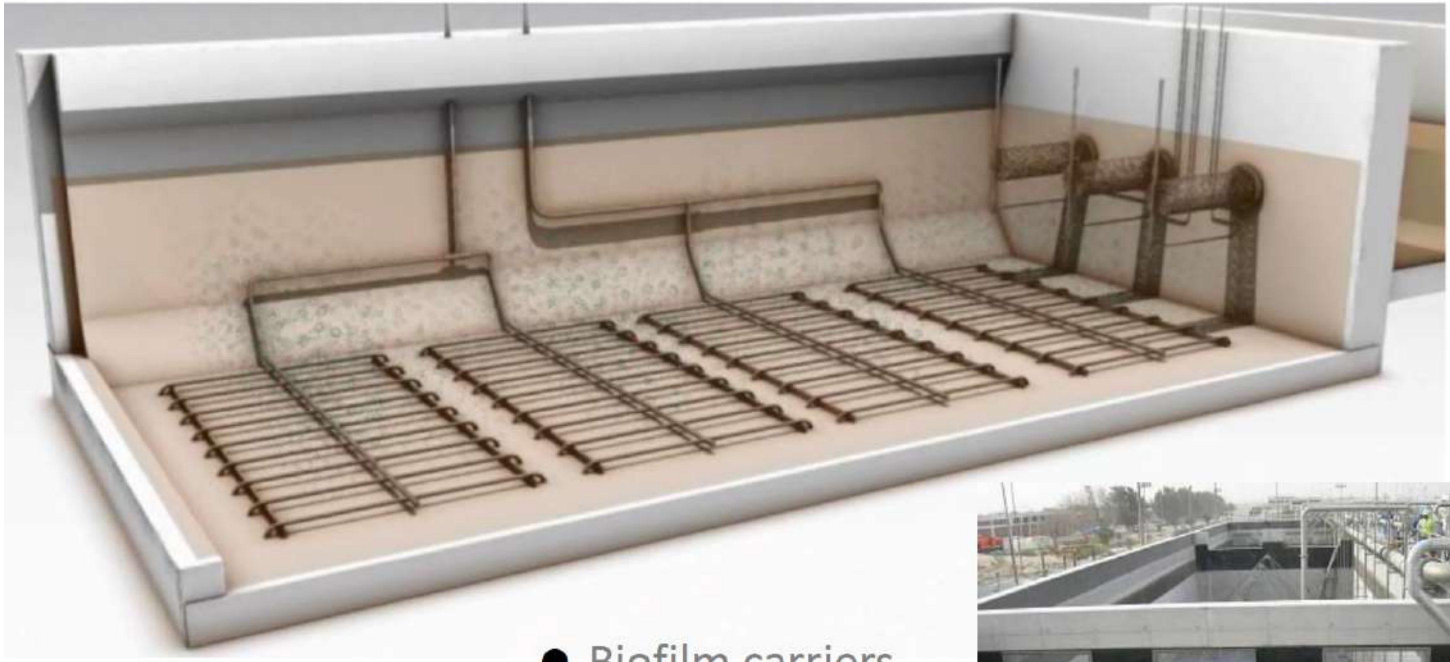
Basic steps in aerobic treatment



Source: Lettinga Associates Foundation, Delft University of Technology, November 2010

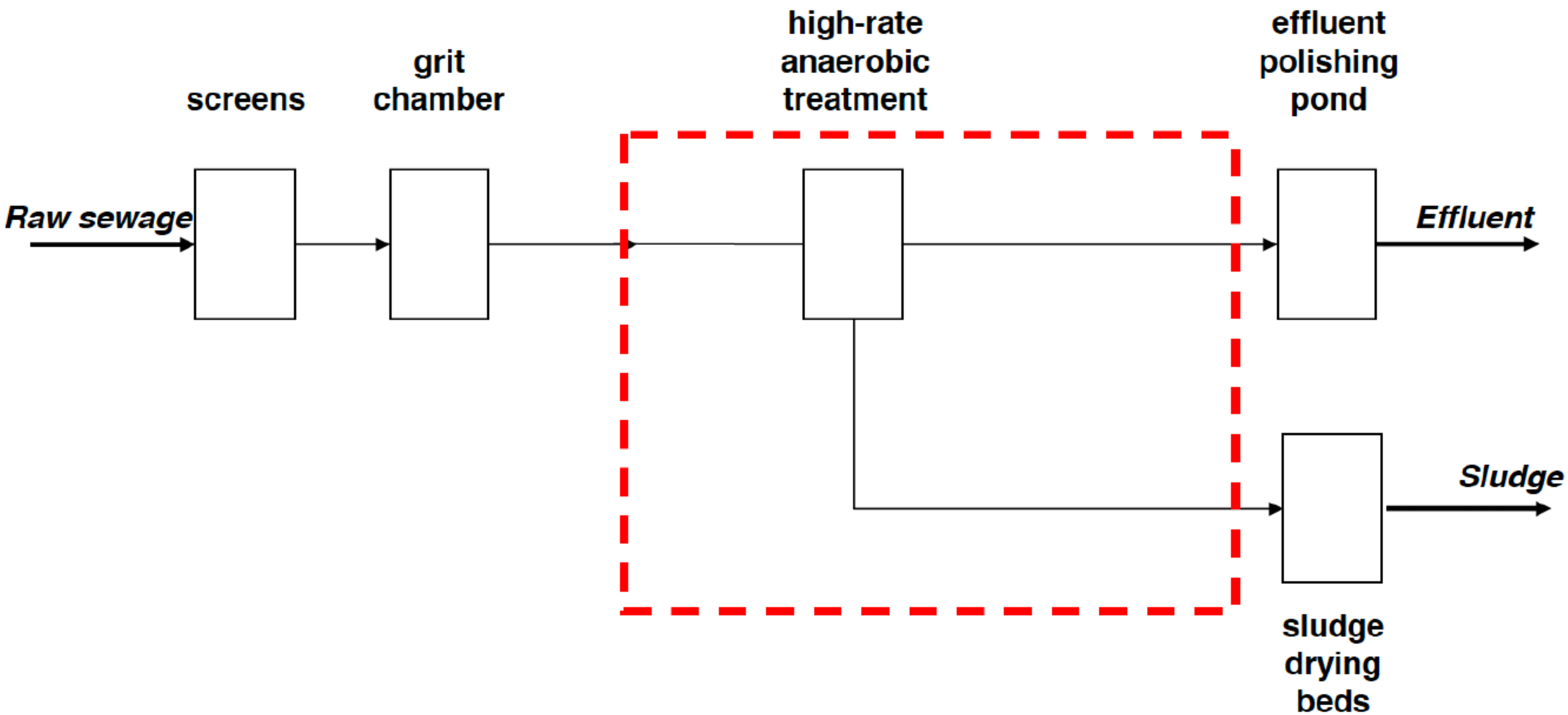
Key elements in aerobic bio-reactor



- Biofilm carriers
- Air grid system
- Retaining sieves

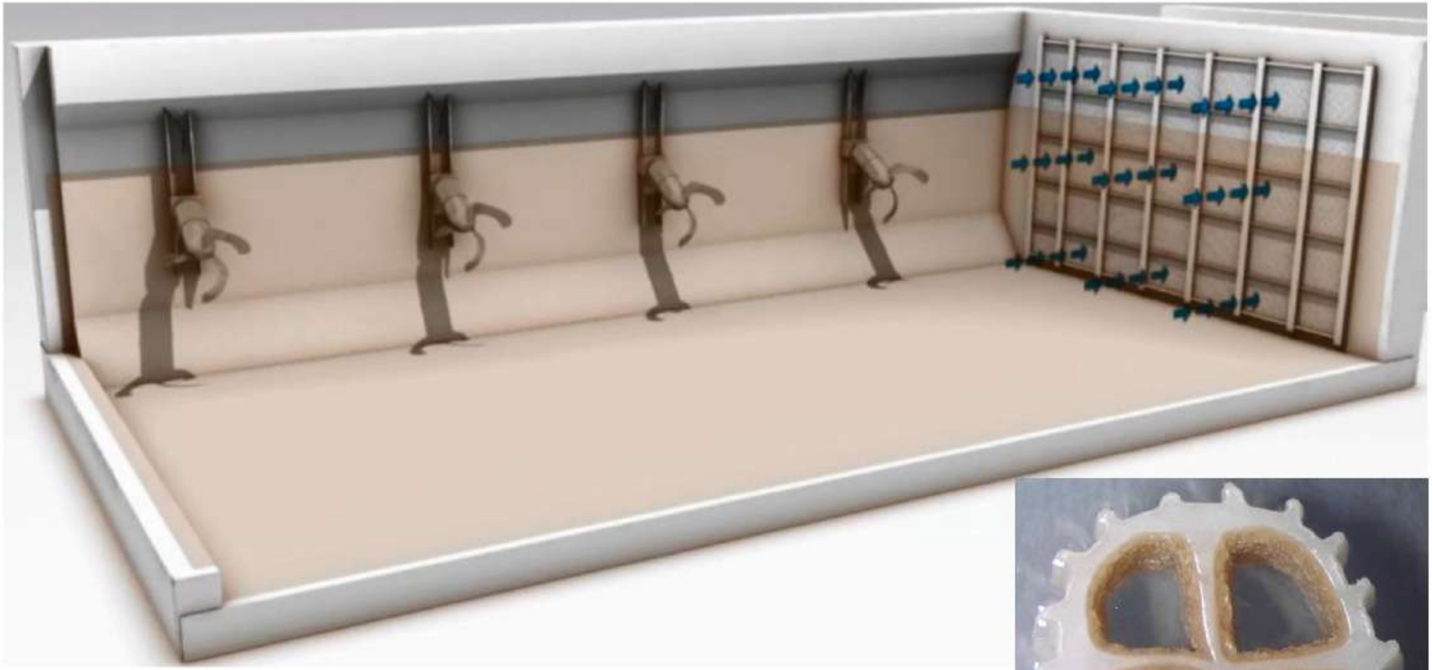
Source: Ping, K.,Veolia , Wastewater treatment technologies, December 2013

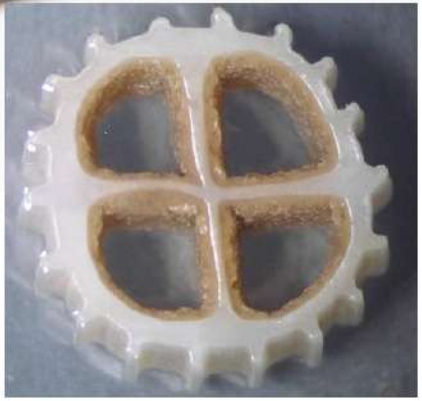
Basic Steps of anaerobic treatment



Source: Lettinga Associates Foundation, Delft University of Technology, November 2010

Key elements in anaerobic bio-reactor





- Biofilm carriers
- Retaining sieves
- Submersible

Source: Ping, K.,Veolia , Wastewater treatment technologies, December 2013

Solid separation in a biological treatment plant

Conventional Clarifier

Dissloved Air Floation (DAF)

Lamella Plate Settler (Multiflo / Actiflo)

Disfilter

Source: Ping, K.,Veolia , Wastewater treatment technologies, December 2013

Activated Sludge

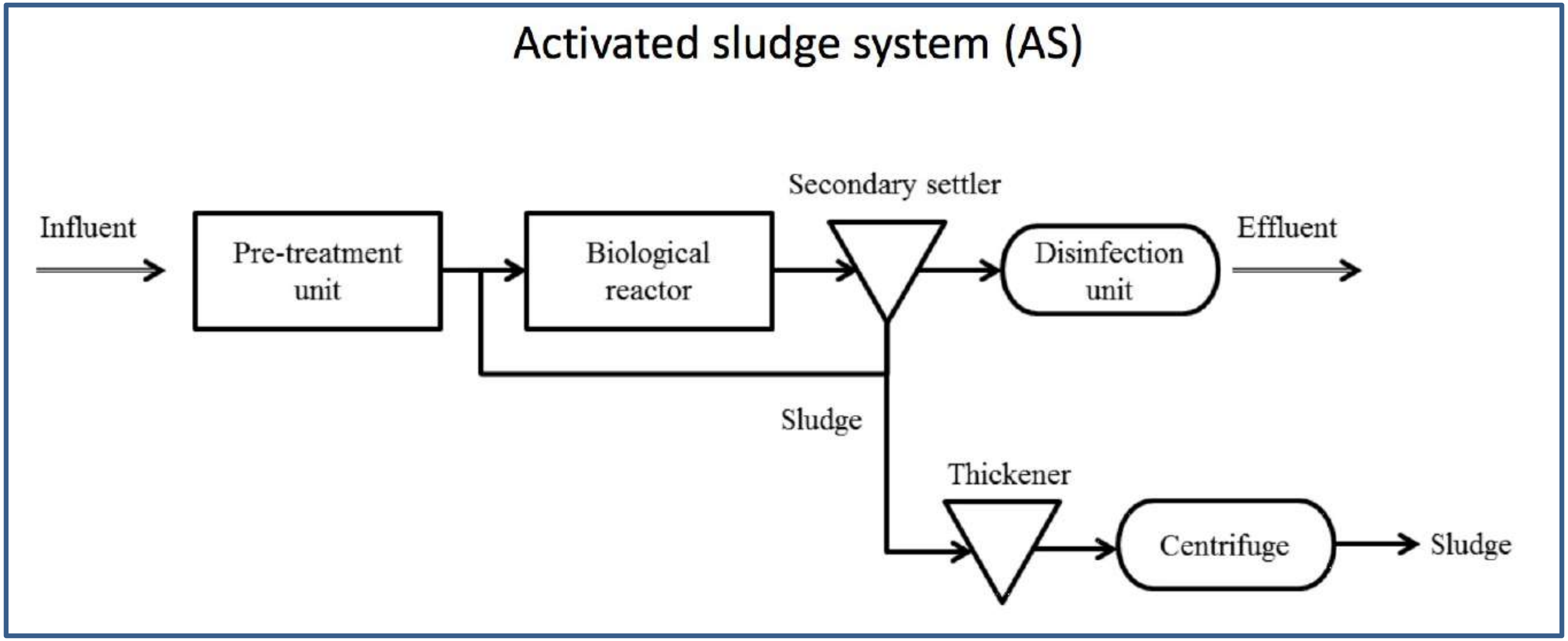
- The activated sludge process can successfully treat BOD, TSS and ammonia.
- To incorporate nitrification with BOD removal, the conventional activated sludge process requires the addition of an anoxic treatment stage. Generally, in an aerobic zone (in the presence of oxygen) ammonia is converted to nitrate.
- There are many alternative layouts for activated sludge with a nitrification process. The general flow diagram for leachate treatment using an activated sludge process is as follows:

Raw Wastewater → Equalization Pond or Tank(s) → Activated Sludge Process (aerobic) → Clarifier → Chemical Precipitation/Filtration → Reverse Osmosis (RO) → Ion Exchange (IE) → Phosphorous Removal→ Effluent Holding Ponds or Tanks

- This system requires regular sludge management. Sludge would be collected from the chemical precipitation process and the clarifier on a frequent basis. The equalization pond/tank(s) is also expected to require sludge removal every 4-5 years. Waste liquid from RO and IE would be evaporated and solidified prior to disposal.

Source: TAGGART, Technical Support Document #10, Leachate management, December 2014

Basic configuration of the activated sludge process



Sequential Batch Reactors

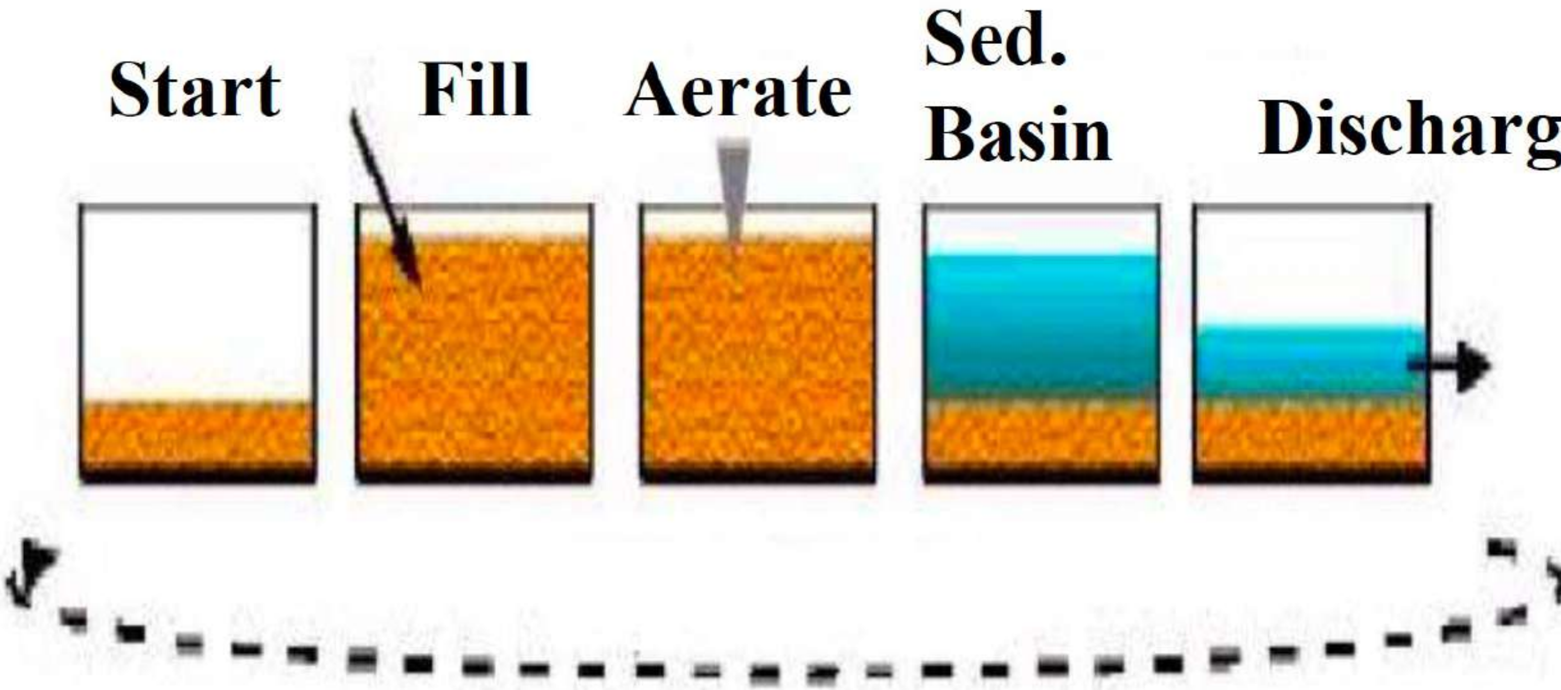
- The SBR process has three stages with recycling between stages (sludge storage, mixed liquor digestion, followed by SBR stage) and can incorporate not only BOD removal but also nitrification and denitrification.
- Additionally, it can provide sludge reduction inside the system. To remove phosphorus, additional treatment would be required following the SBR stage. The general flow diagram for leachate treatment using the SBR process is as follows:

Raw Wastewater → → Equalization Pond or Tank(s) → SBR Process→ Chemical Precipitation/Filtration → Reverse Osmosis (RO) → Ion Exchange (IE) → Phosphorous Removal→ Effluent Holding Ponds or Tanks

- This system requires regular sludge management. Sludge would be collected from the chemical precipitation process on a frequent basis. The equalization pond/tank(s) will also likely require sludge removal every 4-5 years.
- Waste liquid from RO and IE would be evaporated and solidified prior to disposal.

Source: TAGGART, Technical Support Document #10, Leachate management, December 2014

Sequential Batch Reactors-Operation Sequence



Rotating Biological Discs

- The RBC process uses a fixed film of bacterial growth attached to a large disc, which rotates in a concrete tank where it makes contact with the influent leachate. The disc is partially submerged in the leachate in the tank to allow the bacteria exposure to oxygen when the disc rotates out of the leachate. The biological treatment occurs on the surface of the disc as the biomass gradually accumulates. When mass builds and anaerobic conditions develop at the disc interface, the excess biomass naturally shears off and accumulates inside the tank. Several RBC units are required to treat large flows and/or high contaminant loadings.
- The general flow diagram for leachate treatment using RBC units is as follows:

Raw Wastewater → Equalization Pond or Tank(s) → RBC → Denitrification Unit(s) → Clarifier → Chemical Precipitation/Filtration → Reverse Osmosis (RO) → Ion Exchange (IE) → Phosphorous Removal → Effluent Holding Ponds or Tanks

- This system requires regular sludge management. Sludge would be collected from the chemical precipitation process and the clarifier on a frequent basis. The equalization pond/tank(s) will also likely require sludge

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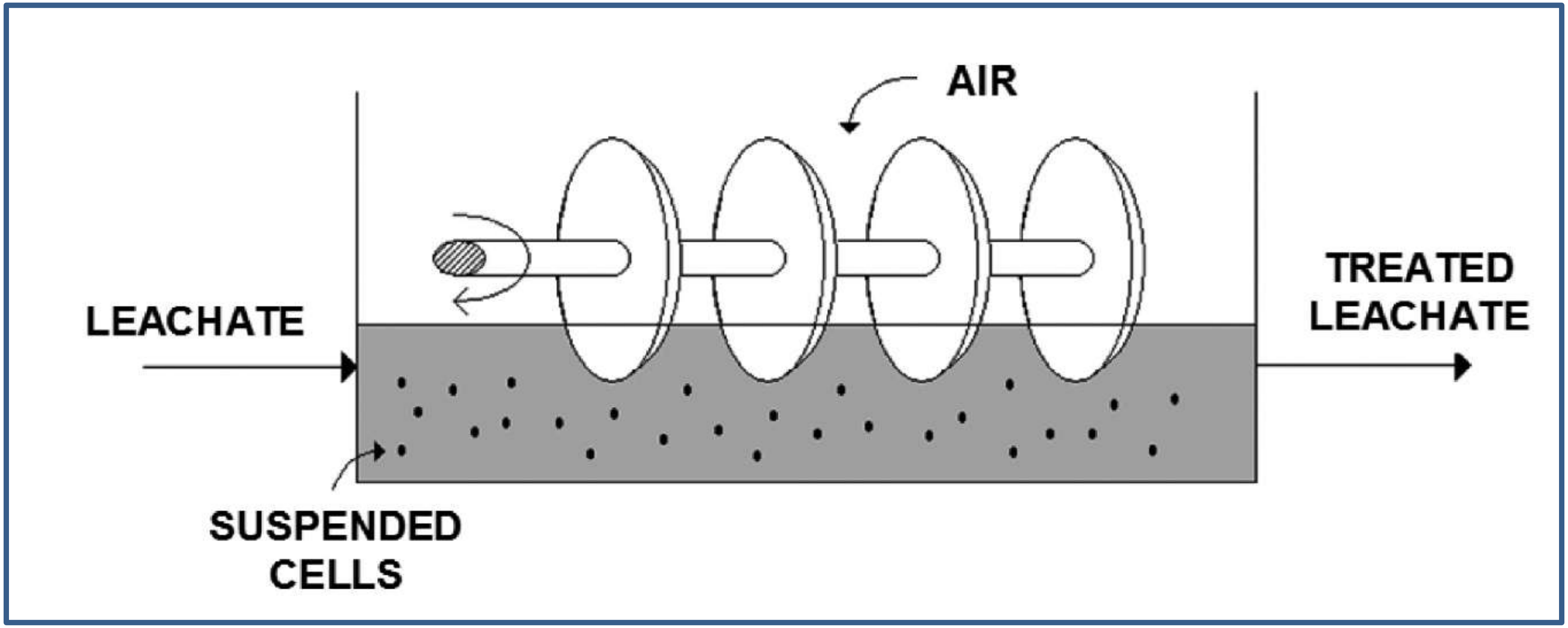
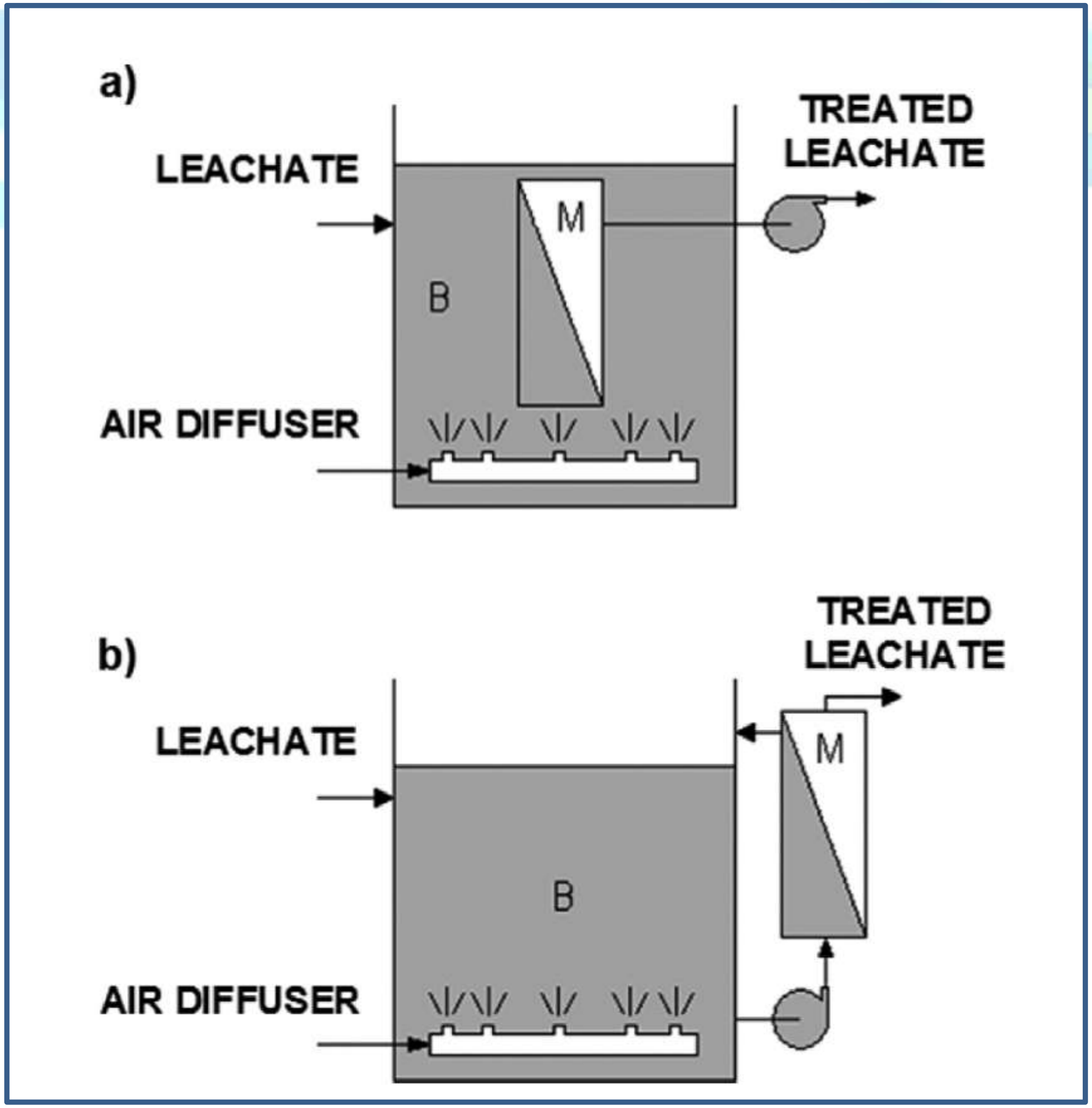
Source: TAGGART, Technical Support Document #10, Leachate management, December 2014

Rotating biological discs



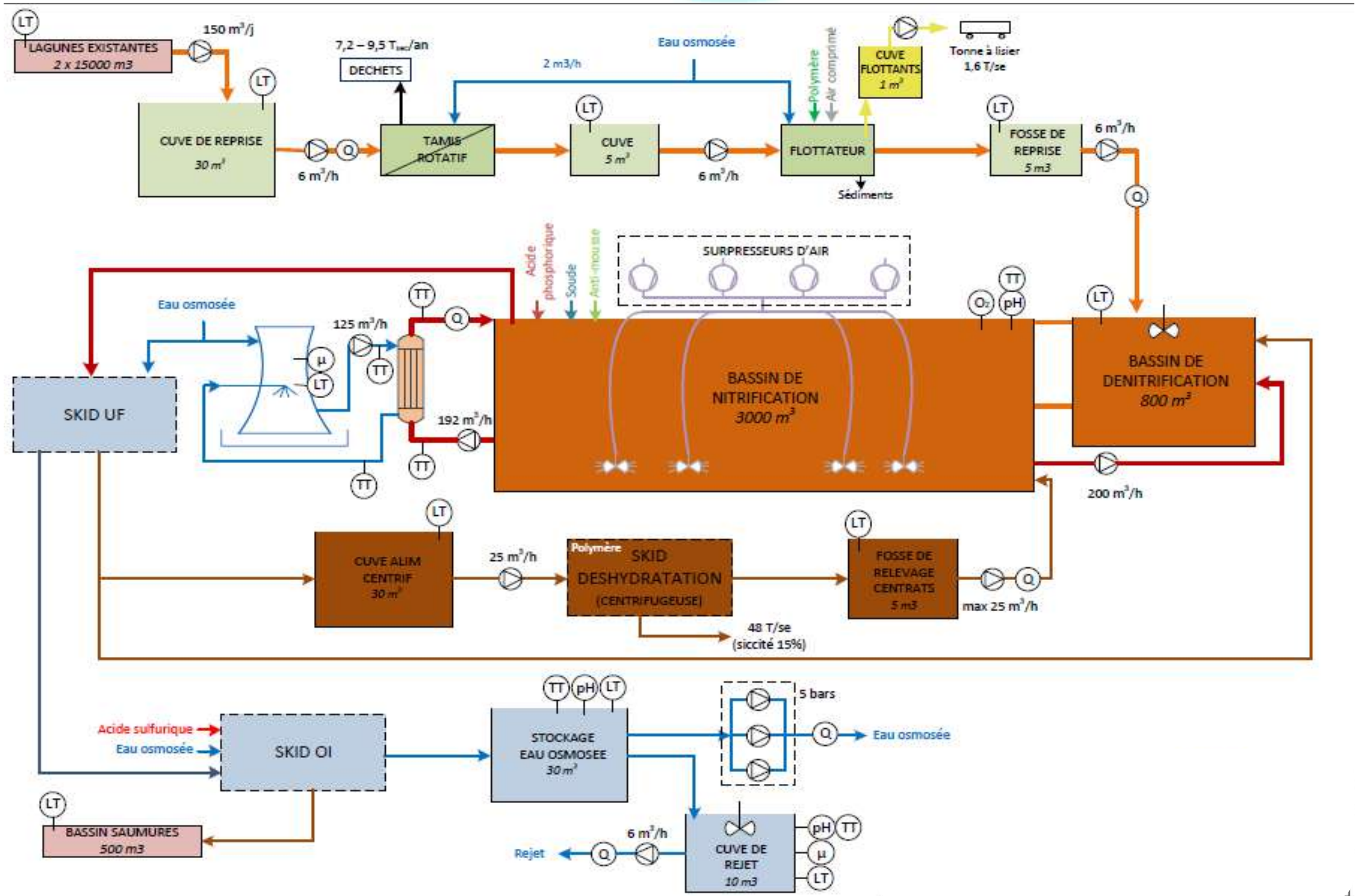
Membrane Bioreactor Reactor (MBR)

Membrane bioreactors are high-cell-concentration biosystems, where leachate passes through ultrafiltration membranes with maximum pore diameters
typically ranging from 0.01 to 0.1 mm, which retain entirely biomass and suspended solids. Microbial cells are recycled by a centrifugal pump, the pollutant degradation
is ensured by aeration from the bottom, and the operation takes place under a pressure of about 10–15 kPa. Membrane bioreactors can be divided into two categories, according to the internal or external location of the membrane inside the Reactor.

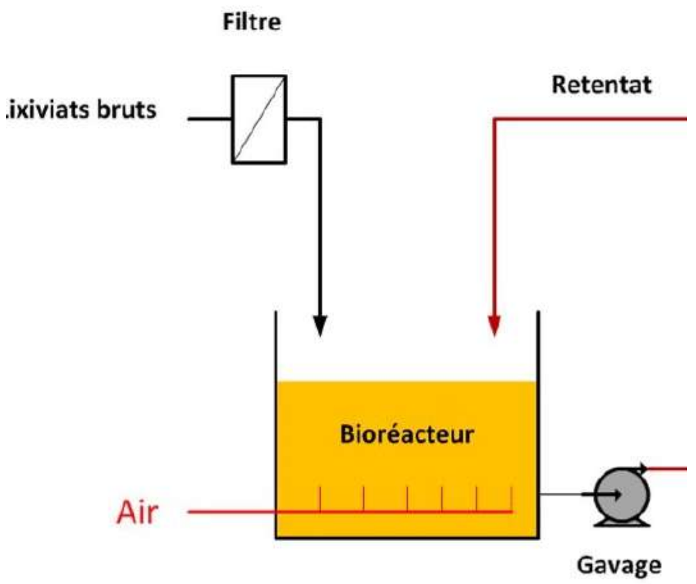


(a) Setup with the membrane module placed inside the reactor.
(b) Setup with the membrane module placed outside the reactor.
M –membrane module; B – bioreactor.

Illustration of Membrane Biologic Reactor (MBR) full scheme



Activated sludge followed by membrane filtration



+

Ultra-Filtration

Or

Decanter

BRM : Synergy between Biological and Filtration technologies

Example for process combination

+

barrier for the separation of
Suspended mater and purified water

Upflow Anaerobic Sludge Blanket Reactor (UASB)

UASB is a single tank process: Wastewater enters the reactor from the bottom, and flows upward → A suspended sludge blanket filters and treats the wastewater as the wastewater flows through it

Advantages

1. High reduction of BOD
2. Can withstand high organic and hydraulic loading rates
3. Low sludge production (and, thus, infrequent desludging required)
4. Biogas can be used for energy (but usually first requires scrubbing)
5. No aeration system required (thus little energy consumption)
6. Effluent is rich in nutrients and can be used for agricultural irrigation
7. Low land demand, can be constructed underground and with locally available material
8. Reduction of CH4 and CO2 emissions

Disadvantages

1. Treatment may be unstable with variable hydraulic and organic loads
2. Requires operation and maintenance by skilled personnel; difficult to maintain proper hydraulic conditions (upflow and settling rates must be balanced)
3. Long start-up time to work at full capacity
4. A constant source of electricity is required
5. Not all parts and materials may be locally available
6. Requires expert design and construction
7. Effluent and sludge require further treatment and/or appropriate discharge

Source: Beta, https://www.sswm.info/node/8211

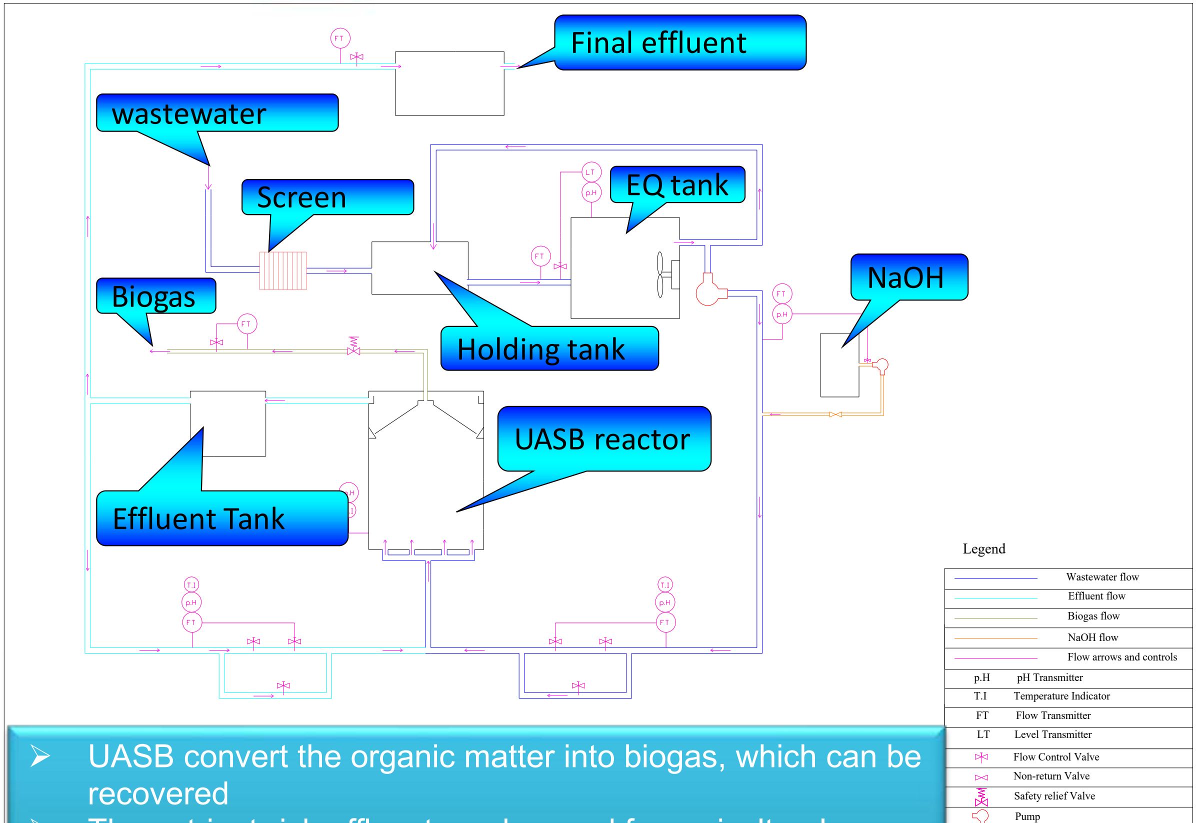
Upflow Anaerobic Sludge Blanket Reactor (UASB)

In

1. Blackwater
2. Faecal Sludge
3. Brownwater
4. Faeces
5. Excreta
6. Leachate

Out

1. Digested Faecal Sludge
2. Fertigation Water



- UASB convert the organic matter into biogas, which can be recovered
- The nutrient-rich effluent can be used for agricultural irrigation
- Sludge, even is partly stabilized (mineralized) and can be used as an organic soil fertilizer after composting

Source: Beta, https://www.sswm.info/node/8211

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Upflow Anaerobic Sludge Blanket Reactor (UASB)

Design Considerations

Primary settling is usually not required before the UASB

pH Value	✓ The pH-value needs to be between 6.3 and 7.85 to allow bacteria responsible for anaerobic digestion to grow. ✓ The pH-value is also important because at high pH-values, ammoniac (NH_4+) dissociates to NH_3 which inhibits the growth of the methane producing bacteria.
Temperature	✓ For an optimal growth of these bacteria and thus a optimal anaerobic digestion, the temperature should lie between 35 to 38°C. ✓ Below this range, the digestion rate decreases by about 11% for each 1°C temperature decrease and below 15°C the process is no longer efficient.
COD Loads	✓ Influents should have concentrations of above 250 mg COD/L, as for lower rates, anaerobic digestion is not beneficial. ✓ Optimum influent concentrations are above 400 mg COD/L and an upper limit is not known.
Hydraulic Retention Time (HRT)	✓ The HRT should not be less than 2 hours. Anaerobic microorganisms, especially methane producing bacteria, have a slow growth rate. ✓ At lower HRTs, the possibility of washout of biomass is more prominent. ✓ The optimal HRT generally lies within 2 to 20 hours.
Upflow Velocity	✓ The upflow velocity in UASB is an important design parameter as the process plays with the balance of sedimentation and upflow. ✓ An upflow velocity of 0.7 to 1 m/h must be maintained to keep the sludge blanket in suspension.

Source: Beta, https://www.sswm.info/node/8211

Upflow Anaerobic Sludge Blanket Reactor (UASB)

Cost Consideration/Operation & Maintenance

Cost Consideration

- The significantly lower level of technology required by the UASB process in comparison with conventional advanced aerobic processes means that they are also cheaper in construction and maintenance.
- Capital costs for construction can be estimated as low to medium and comparable to baffled reactors.
- Operation costs are low, as usually no costs arise other than desludging costs and the operation of feeding pump.

Operation & Maintenance

- The UASB is a Centralized Treatment technology that must be constructed, operated and maintained by professionals.
- A skilled operator is required to monitor the reactor and repair parts, e.g., pumps, in case of problems.
- UASB reactors require several months to start up. The sludge not only needs to form but also needs to adapt to the characteristics of the specific WW.
- To keep the blanket in proper position, the flow rate must be controlled and properly geared in accordance with fluctuation of the organic load.
- Desludging is infrequent and only excess sludge is removed every 2 to 3 years.

Source: Beta, https://www.sswm.info/node/8211

Performance of Suspended Growth Biological Nitrification Processes

Technology	Performance				Additional Comments	
	BOD	TSS	Ammonia	TP	Benefits	Drawbacks
Suspended Growth Biological Nitrification Processes						
Activated Sludge (AS)	Good	Good	Good (<1 mg/L)	Poor		■ Requires high efficiency aeration system ■ Continuous flow mode requires external clarification stage following the AS unit ■ Requires closely controlled operational conditions
Oxidation Ditch	Good	Good	Poor	Poor		■ Requires aeration system ■ Requires external clarification stage following aeration ■ Requires closely controlled operational conditions ■ Susceptible to cold climate issues
Sequencing Batch Reactor (SBR)	Good	Good	Good	Poor	■ Does not require external clarification stage	■ Requires aeration system ■ Requires closely controlled operational conditions ■ Requires skilled operator

Performance	Description
Good	High level of treatment; anticipated to meet the estimated discharge limits
Fair	Some treatment; requires further treatment to meet the estimated discharge limits
Poor	Inadequate treatment; requires separate treatment stage(s)

Source: TAGGART, Technical Support Document #10, Leachate management, December 2014

Performance of different types of biological treatment processes

Technology	Performance				Additional Comments	
	BOD	TSS	Ammonia	TP	Benefits	Drawbacks
Aerated Lagoon	Good	Good	Poor	Poor	■ Minimal operational controls	■ Requires aeration system ■ Susceptible to cold climate issues ■ Large footprint
Trickling Filter	Good	Good	Poor	Poor	■ Minimal operation and maintenance requirements	■ Requires pre-treatment (primary settling) ■ Susceptible to cold climate issues
Rotating Biological Contractor (RBC)	Good	Good	Good (<3 mg/L)	Poor		■ Requires external clarification stage following the RBC unit ■ Requires electrical supply for shaft motor ■ Requires closely controlled operational conditions ■ Susceptible to environmental conditions and fluctuations in influent quality (e.g., temperature, pH, flow, concentrations, etc.)
Aerobic Submerged Fixed Beds	Good	Good	Good (<3 mg/L)	Poor	■ Can have higher organic loading rates compared to trickling filters ■ Smaller footprint	■ Requires aeration system ■ High energy use
Aerobic Submerged Mobile Beds	Good	Good	Poor	Poor		■ Requires aeration system ■ Susceptible to cold climate issues

Source: TAGGART, Technical Support Document #10, Leachate management, December 2014

Performance ranking of three types of biological treatment (1)

Criteria	Activated Sludge (AS)	Sequencing Batch Reactor (SBR)	Rotation Biological Contactor (RBC)
Flexibility	**Ranked 3rd because:** ▪ May require adjustment to optimize treatment at different flow rates ▪ May overcome increases in peak loadings ▪ System can be expended by adding new AS units and clarifier	**Ranked 1st because:** ▪ May require adjustment to optimize treatment at different flow rates ▪ Susceptible to increases in peak loadings ▪ Easier and less costly than the AS system to add additional treatment units to handle additional flow	**Ranked 4th because:** ▪ Can handle flow changes ▪ May be susceptible to increases in peak loadings ▪ System can be expanded by adding RBC units
Reliability	**Ranked 1st (tied) because:** ▪ Aeration system and pump failure are only reliability concerns	**Ranked 2nd because:** ▪ Restart of SBR would require a skilled operator (complex process control system) ▪ Aeration system is equipped with jet aerators that allow mixing, self-cleaning, and accessibility for maintenance. Pumps and automated switch failure are concerns	**Ranked 3rd because:** ▪ Has a reputation for variable performance, sensitivity to variable inflow quality and weight imbalances causing rotating shaft damage ▪ System upset would require cleaning discs and lengthy restart
Ease of Use	**Ranked 3rd because:** ▪ Requires regular maintenance of aeration system and the chemical addition system	**Ranked 4th because:** ▪ Higher level of operation and maintenance required due to controls, aeration system, pumps, valves and automated switches	**Ranked 1st because:** ▪ Minimal operation requirements

Source: TAGGART, Technical Support Document #10, Leachate management, December 2014

Performance ranking of three types of biological treatment (2)

Criteria	Activated Sludge (AS)	Sequencing Batch Reactor (SBR)	Rotation Biological Contactor (RBC)
Capital Costs	**Ranked 1st (tied) because:** ■ Requires high efficiency aeration system ■ Continuous flow mode of AS requires external clarification stage following the AS unit ■ May require pre-treatment (chemical precipitation) ■ Requires equalization pond/tank ■ Lower capital cost compared to Siemens PACT system but similar to SBR and RBC	**Ranked 1st (tied) because:** ■ Requires high efficiency aeration system ■ SBR does not require external clarification stage ■ May require pre-treatment (chemical precipitation) ■ Requires equalization pond/tank ■ Lower capital cost compared to Siemens PACT system but similar to AS and RBC	**Ranked 1st (tied) because:** ■ Does not require aeration system but requires large motors for shaft rotation ■ Requires external clarification stage ■ May require chemical precipitation treatment unit ■ Requires equalization pond/tank ■ Lower capital cost compared to Siemens PACT system but similar to AS and SBR
Operational Costs	**Ranked 2nd because:** ■ Electricity is required for aeration system and pumps operating in continuous mode ■ Chemical cost to remove metals, non-biodegradable and toxic compounds prior to AS treatment unit ■ Requires heating of the AS tank to maintain optimal temperature (10-15°C)	**Ranked 1st (tied) because:** ■ Electricity is required for pumps and blowers operating in intermittent mode (less electricity than continuous aeration systems) ■ Chemical cost to remove metals, non-biodegradable and toxic compounds prior to SBR treatment unit(s) ■ Requires heating of the SBR tank to maintain optimal temperature (10-15°C)	**Ranked 1st (tied) because:** ■ Energy requirement for pumps and the shaft ■ Regular bearing maintenance ■ Requires heating of the RBC tank to maintain optimal temperature (10-15°C)

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Source: TAGGART, Technical Support Document #10, Leachate management, December 2014

Performance ranking of three types of biological treatment (3)

Criteria	Activated Sludge (AS)	Sequencing Batch Reactor (SBR)	Rotation Biological Contactor (RBC)
Operations and Maintenance	**Ranked 2nd (tied) because:** ■ Regular pump, blower and boiler maintenance ■ Sludge removal from AS treatment unit, chemical precipitation unit and clarifier on a regular basis ■ Plate air diffusers require shutdown and removal for cleaning and replacement	**Ranked 1st because:** ■ Regular pump, blower and boiler maintenance ■ Sludge removal from SBR treatment unit(s) and chemical precipitation unit on a regular basis ■ Less sludge volume from SBR treatment unit(s) compared to other selected options ■ Jet aerators are located above water for maintenance without shutdown and are self-cleaning	**Ranked 2nd (tied) because:** ■ Regular pump, and boiler maintenance ■ Chemical cost to remove metals, non-biodegradable and toxic compounds prior to RBC ■ Sludge removal from RBC and chemical precipitation unit on a regular basis

Source: TAGGART, Technical Support Document #10, Leachate management, December 2014

Advantages of anaerobic over aerobic leachate treatment

- lower energy requirement as no oxygen is required and thus reduces the operation cost;
- low sludge production as only about 10 - 15% of organics is transformed into
- biomass;
- biogas production (85 - 90%) favors the energy balance with a low nutrient
- requirement making it appropriate for treating leachate;
- possibility to treat leachate with high organic concentration without dilution used for aerobic processes, reduces space requirements, size of the plant and capital cost;
- valuable substances such as ammonia-nitrogen can be retained;
- anaerobic microorganisms seldom reach endogenous phase, important for the
- treatment of leachate with variable volume and strength;
- destruction of pathogens at thermophilic temperature ranges if it is intended to be used as fertilizers;
- elimination of odor problems;
- anaerobic sludge is highly mineralized than aerobic sludge, which increases its value as fertilizer if toxic metals are removed; and
- anaerobic sludge tends to settle more easily than aerobic sludge where addition of flocculants is required.

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