WasteWaterConnectors: a Nature Based Solutions (NBS) Toolkit

KB 34 Circular and climate Neutral; KB 35 Food and water security
Project: Nature-based Solutions for Climate Resilient and Circular Food Systems

Intrinsic, Inspired and Hybrid NBS for re-using waste water

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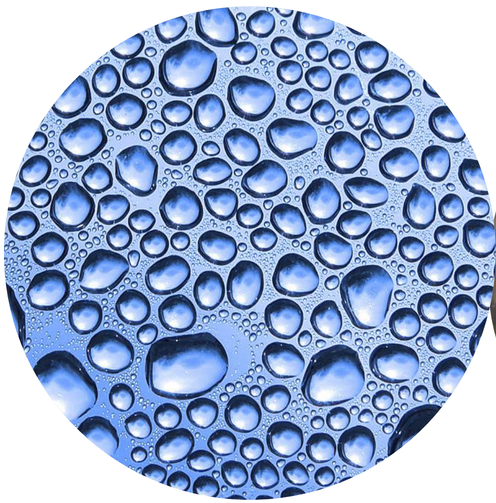

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Acknowledgements

- *This portfolio is part of the project:* Nature-based Solutions for Climate Resilient and Circular Food Systems

Content

- How to use the toolkit
- NBS, state of the art
- NBS evaluation

How to use the toolkit?

- This portfolio is aiming to help decision makers with background information to identify and select technologies and practices based on nature based solutions (NBS) to set up water re-use projects
- Information in toolkit is indicative and guiding
- Developments foreseen for 2022:
    - Using and extending the toolkit together with stakeholders from, a.o.:
        - Consultancy on water technology
        - Agri-Food industry
        - Government and water boards

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Nature Based Solutions, state of the art

State of the art are intrinsic solutions, like:

- Water Quality, constructed wetlands
- Water buffering, rain water harvesting, ASR etc..

Beyond state of the art are

- Hybrids, using inspired combinations of inspired/intrinsic

Which mix of casestudies/inter ventions in cat 2 -5 is most ***climate resilient*** with win-win for food and nature?

Valuation Nature-based (1 low, 5 high)

1 =	Inspired by nature, natural processes optimized for food production (human use), no significant improvement of abiotic environment or biodiversity
2=	Inspired, with significant improvement of abiotic environment (water, nutrients, etc.)
3=	The measure can be intrinsic or inspired depending on the way how the NBS is designed.
4=	Intrinsic, based upon natural process where by abiotic conditions greatly improve food production and nature, with local impact on biodiversity
5 =	Intrinsic, based upon natural processes with profit for food production AND Nature (in and outside the case study in biotic AND abiotic sense)

Factsheets

- Provide essential information on NBS irt Food Systems
- Connector/ rekenregels
  - Economie
  - kwaliteit

Factsheet content

1. Used for
2. Applications in which it is used
3. Description of the technology
   1. Purpose/aim of the technology
   2. Working Principle of operation
   3. Operational conditions
   4. Cost data
4. Technological bottlenecks
5. Benefit for the agro- food industries
6. Supporting systems needed
7. Development phase
8. Who provides the technology
9. Intellectual property (Patented or not?)
10. Which technologies compete with this one
11. Is the technology transferable to other applications/climates?
12. Description of the regulatory bottlenecks
13. Brief description of the socio-economic bottlenecks
14. Techniques resulting from this technology
15. References for more information

Main sources (see refences):
EU FERTINNOWA project
EMIS WASS

NBS options –intrinsics/inspired hybrids?

NBS	Type of NBS
Managed aquifer recharge (MAR)	intrinsic
Inland Shore Concepts	intrinsic
Constructed Wetlands Water / Sludge Treatment Systems	intrinsic
Nature-Based Nutrient Recovery	intrinsic
Agricultural Rainwater Harvesting	intrinsic
Zero Discharge Natural Wastewater Treatment	inspired
(Slow) sand filtration	inspired
Thermal disinfection	inspired
Photocatalytic oxidation	inspired
Reversed Osmosis	inspired
Forward Osmosis	inspired
Membrane destillation	inspired
Electrodialysis	inspired
Iron Removal	inspired
Membrane Filtration (UF/MF/NF)	inspired
Ion Exchange (using natural beds - resins)	inspired
Coagulation/precipitation	inspired
pH change / adjustment	inspired
Algae control (NBS, chemicals, liming, Daphnia spp, straw, bacteria, fish, water movement, aquatic plants, ultrasonic, blue food dey)	hybrid
Biofiltration desinfection	inspired
UV desinfection	inspired

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Evalution criteria NBS

- NBS: name of the nature based solutions
- Type: technology can either be physical (filtration, radiation etc..), chemical (oxididation), biological or hybrids
- BOD/COD: Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD)
- SS: effect of the NBS on the removal of suspended solids
- EC: Electric Conductivity, effect of the NBS on the removal salts (general measure for salt content in water)
- Path.: pathogens: effect of the NBS on the inactivation of pathogens, > log 3-5 is +, below, -
- **HM:**
- **micro-pollutants**, effect of the NBS on the removal of all kind of recalcitrant chemical components, like crop-protecting agents, pharmaceutics, PFAS etc..
- micro-plastics, effect of the NBS on the removal of microplastics
- P: phosporous compounds: effect of the NBS on the removal of phosporous compounds
- N : nitrogen compounds: effect of the NBS on the removal of nitrogen compounds (NH_4, NO_3)

Evaluation of NBS by technology

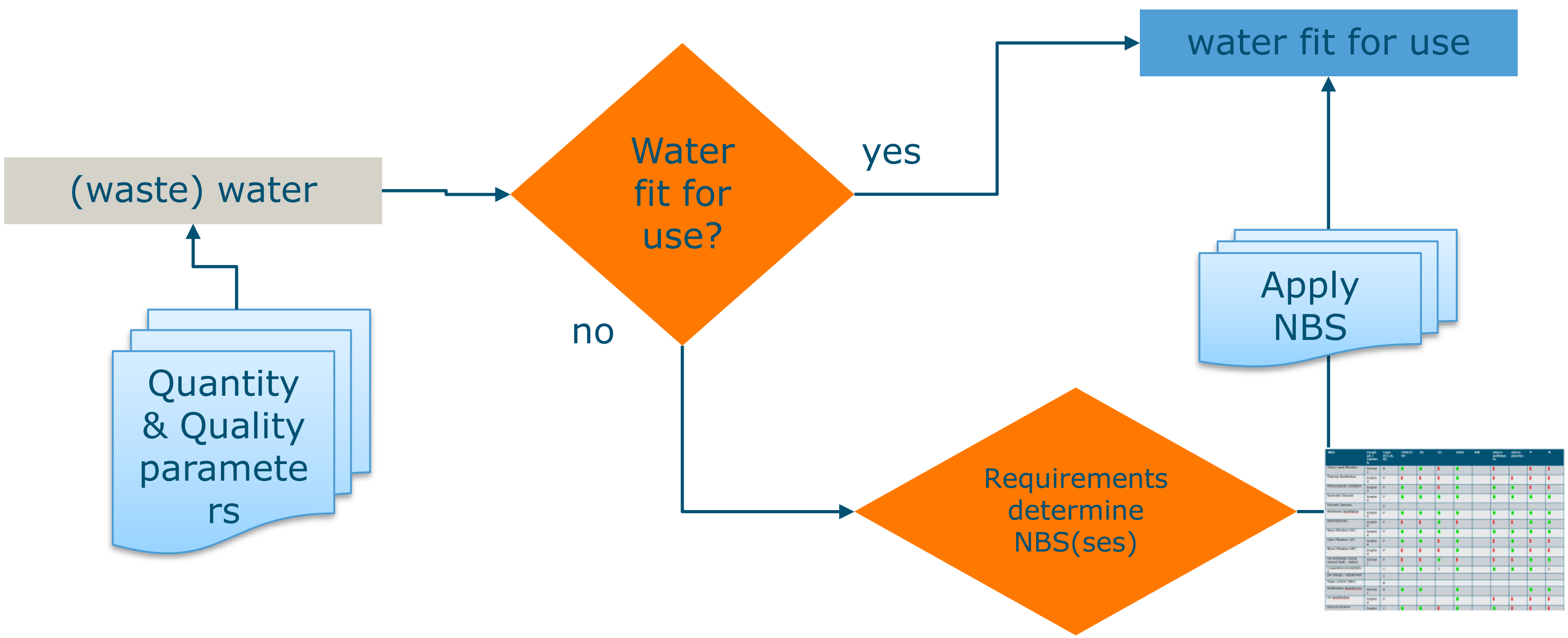
NBS	Inspired / Intrinsic	Type (P,C,B, H)	COD/DOC	SS	EC	Path.	HM	micro-pollutants	micro-plastics	P	N
(Slow) sand filtration	Intrinsic	B	+	+	-	+		-		-	-
Thermal disinfection	Inspired	P	-	-	-	+		-	-	-	-
Photocatalytic oxidation	Inspired	P	+	+	-	+		+	+	-	-
Reversed Osmosis	Inspired	P	+	+	+	+		+	+	+	+
Forward Osmosis		P									
Membrane destillation	Inspired	P	+	+	+	+		+	+	+	+
Electrodialysis	Inspired	P	-	-	+	-		-	-	+	+
Nano Filtration (NF)	Inspired	P	+	+	+	+		+	+	+	+
Ultra Filtration (UF)	Inspired	P	+	+	-	+		-	+	-	-
Micro Filtration (MF)	Inspired	P	-	-	-	+		-	+	-	-
Ion Exchange (using natural beds - resins)	Intrinsic	P	-	-	+	-		-	-	+	+

Evaluation of NBS – conclusions

Technology	COD/DOC	Suspend Solids	EC (salts)	Pathogens	Heavy Metals	Micro-pollutants	Micro-plastics	Nutrients P& N	Reliability
NBS (inspired)	+	+	-		-	-	-	+ nutrients are "destroyed"	-
Hybrids	+	+	+	+	+	+	+	+	+

Waster Water treatment based on
Intrinsic NBS: requires little maintenance,
Hybrids: best of both worlds, robust but intensified process technologies, energy requirement

Using the NBS evaluation matrix



NBS Factsheet: ***Constructed wetlands***

NBS type: intrinsic

Used for: Preparation of irrigation water / Minimising the impact to the environment by nutrient discharge

Description: an artificial wetland (engineered ecosystem) created to treat anthropogenic discharge such as municipal or industrial wastewater, or stormwater runoff.

Working Principle: using natural functions of vegetation, soil, and organisms to treat different water streams. Depending on the type of wastewater the system has to be adjusted accordingly, which means that pre- or post-treatment may be necessary. Constructed wetlands can be designed to emulate the features of natural wetlands, such as acting as a biofilter or removing sediments and pollutants such as heavy metals from the water.

Benefits for the agro- food industries

Development phase: commercial

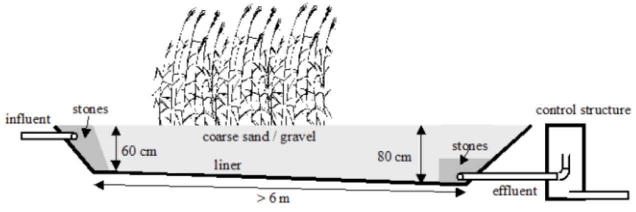
Technology transferable: Yes, dependent on climate

Operational conditions: If the wetland is used for P extraction, calcium-rich sand should be used for the sand filter. For water reuse, calcium-poor sand should be added. Can process 60 L sewage water/m² wetland/day or about 100 L of drainwater/m² wetland/day. Nitrification requirements: temperature preferably above 15°C (>12°C is also still efficient). Level of oxygen in the water > 4 mg/L. Acidity: 5,5 < pH < 9. The wetland has a guaranteed effect from June until August, at other times of the year, the effectiveness depends on the weather.

Cost data: Prices depend on region and surface area. Examples, a large flow wetland costs about 25 €/m², while small, aerated wetlands can cost up to 1000 €/m².

Socio-economic bottlenecks: less efficient than other biological technologies for disinfection of water, such as biofiltration. Constructed wetlands are used to remove excess nutrients such as N and P from drain water before releasing water into the environment. The surface area requirement of a constructed wetland may inhibit the adoption.

References for more information: Fertinnowa



NBS Factsheet: ***Ultraviolet disinfection***

NBS type: inspired

Used for: disinfection of water

Description: UV disinfection is a well-known technology from the drinking water industry. For horticultural purposes, ultraviolet disinfection (UV) is used to disinfect water sources like a drain, surface or rainwater. Pathogens like fungi, bacteria, nematodes or even viruses can be made harmless to allow water usage in a safe way.

Working Principle: UV-C light is produced by a lamp and fitted in a quartz tube in the middle of a cylindrical UV chamber. The water to be disinfected flows through the UV chamber. There are 3 systems of UV disinfection: low pressure (LP), mid pressure (MP) and high pressure (HP) (Table 6-6). The difference is the wavelength of radiation produced. In LP and MP systems, the wavelength is fixed at 254 nm whereas, in HP system, wavelengths are available between 200 nm and 300 nm. LP UV lamps are less powerful than HP lamps.

Benefits for the agro- food industries, Efficient, reliable, Fully automated solution, Effectiveness is not pH dependent

Development phase: commercial

Technology transferable: Yes, highly

Operational conditions: A minimum UV transmittance is given by the supplier of the equipment. UV treatment is highly dependent on water clarity (T10 value). Particulate matter suspended in the water causes shadows, while the particles can also carry pathogens. Therefore, pre-filtration with for example sand- or screen filtration is necessary. Particles should not be bigger than 25 µm and the maximum quantity of particles should not exceed 5 mg/L.

Cost data: Costs are dependent on 1) the volume of water to be treated and the required UV-C dose (usually between 80-250 mJ/cm2) to effectively remove potential pathogens. 2) the transmittance (T10) of the water to be treated. Cost per m3 are between 0,10€/m3 and 0,50 €/m3.

Socio-economic bottlenecks: Investments costs are high but have an earn back time of around 2-3 years. The system needs a good support from retailers to be operative. The investment should be optimised based on the amount of water to be treated, the required UV dose and the transmittance (T10) of the water.

References for more information: Fertinnowa

NBS Factsheet: ***Electrodialysis (ED)***

NBS type: insprired

Used for: Preparation of irrigation water, More efficient use of water, Minimising the impact to the environment by nutrient discharge

Description: Electrodialysis (ED) is a membrane process that is used to remove ions from solutions

Working Principle: Electrodialysis is used to transport salt ions from one solute, through ion-exchange membranes, to another solute under the influence of an applied electric potential difference. Electrodialysis processes are different from distillation techniques and other membrane-based processes (such as reverse osmosis (RO)) in that dissolved particles are moved away from the feed stream rather than the reverse. Because the quantity of dissolved particles in the feed stream is far less than that of the fluid, ED offers the practical advantage of much higher feed recovery in many applications

Benefits for the agro- food industries

Development phase: commercial

Technology transferable: Yes, highly

Operational conditions: Although ED is a known process in the industry, there is little knowledge of full-scale implementations, with most current installations being smaller in scale. Due to the specificity of each application, extensive testing will be needed for a full-scale implementation.

Cost data: The major costs in ED are the membrane and electricity costs. The limiting current density determines the price of the ED process. Cost prices may vary greatly depending on the type of wastewater. For an ED installation of the scale of 1-10 m3/h (3500-50000 m3/year), the CAPEX varies from 9-64 k€/year with an OPEX from 2-15 k€/year increasing with the size of the installation. Typical treatment costs (€/m3) decrease with the size from 2,6 to 1,3 (€/m^3).

Socio-economic bottlenecks: The use of ED in (semi) closed horticultural growing systems can eliminate the need to purge the water when sodium concentrations build up. In countries like The Netherlands where companies that purge are required to have treatment technologies to remove crop protecting agents, the use of ED may avoid the need to invest in those treatment technologies. However, then growers lose the possibility to purge water for other reasons.

References for more information: Fertinnowa

NBS: ***Subsurface water storage (ASR)***

NBS type: intrinsic

Used for: Preparation of irrigation water, More efficient use of water

Description: The aim of subsurface water solutions is to protect, enlarge and utilise fresh groundwater resources through advanced groundwater management and freshwater supply.

Working Principle: Sophisticated new well design, configuration and management allow for maximum control over water resources, which goes far beyond the levels of control provided by standard water management techniques. This makes these solutions applicable in coastal areas, where groundwater management is a severe challenge because of the presence of saline and brackish groundwater

Benefits for the agro- food industries, Limited claim on aboveground land, Increased freshwater and available and Better water quality (preservation)

Development phase: commercial

Technology transferable: Yes, dependent on climate

Operational conditions: Typically a supply of 5000-1000000 m^3/year for individual agriculturists or agricultural clusters. Requires suitable aquifers (permeable sand layers or carbonates) in order to use wells for infiltration and recovery. Coastal areas. Infiltration can be beneficial in areas with fresh groundwater to counter declining water levels and lower the iron levels in abstracted groundwater

Cost data: For installation: 25000-500000 € (scale-dependent). Yearly maintenance or inputs needed: 2000 €/year, Approximately 0,05 €/m3

Socio-economic bottlenecks: Acceptance by the public: willingness to store water with a different quality and potential contaminants in a (normally) "clean" subsurface. Especially if this is in the vicinity of drinking water well fields. Water Framework Directive regarding groundwater quality: It should be guaranteed that infiltration does not negatively impact the groundwater quality. National regulations to verify the infiltration water quality can be strict (high-frequency of sampling and analyses), negatively impacting the business cases.

In the Netherlands, the Water Act and Soil Protection Act apply on a national scale and a Regulation by the Dutch Water Authorities (small-scale systems) and the Province (large-scale systems) applies regionally.

References for more information: Fertinnowa

NBS Factsheet: ***Fungal water treatment***

NBS type: intrinsic

Used for: white-rot fungi can be considered a very useful tool for the bioremediation of emerging contaminants of pharmaceutical origin. Their ability to degrade wide variety of recalcitrant molecules and their easy handling make them excellent biological agents to include in wastewater treatment processes

Description:

Working Principle:

Benefits for the agro- food industries

Development phase: research

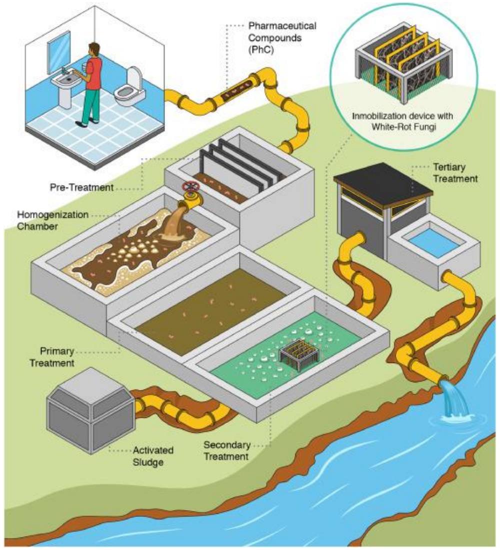
Technology transferable: Yes, dependent on climate

Operational conditions: immobilization of the fungal biomass is a crucial aspect to consider, since the dispersed growth of the mycelium can cause operational difficulties

Cost data:

Socio-economic bottlenecks:

References for more information: [Fungi for the bioremediation of pharmaceutical-derived pollutants: A bioengineering approach to water treatment – ScienceDirect]



NBS Factsheet: ***Vermifilter (worms)***

NBS type: intrinsic

Used for: sewage treatment and for agro-industrial wastewater treatment

Description: A vermifilter is an aerobic treatment system, consisting of a biological reactor containing media that filters organic material from wastewater. The media also provides a habitat for aerobic bacteria and composting earthworms that purify the wastewater by removing organic particles, pathogens and oxygen demand.

Working Principle: vermifilters provide an aerobic environment and wet substrate that facilitates microorganism growth as a biofilm. Microorganisms perform biochemical degradation of organic matter present in wastewater. Earthworms regulate microbial biomass and activity by directly or/and indirectly grazing on microorganisms.[5] Biofilm and organic matter consumed by composting earthworms is then digested into biologically inert castings (humus).[6] The vermicast is incorporated into the media substrate or vermiconpost, slowly increasing its volume. When this builds up, it can be removed and applied to soil as an amendment to improve soil fertility and structure.

Benefits Vermifilters are most commonly used for sewage treatment and for agro-industrial wastewater treatment.[1] Vermifilters can be used for primary, secondary and tertiary treatment of sewage, including blackwater and greywater in on-site systems and municipal wastewater in large centralised systems.

Development phase: commercial

Technology transferable: Yes, dependent on climate

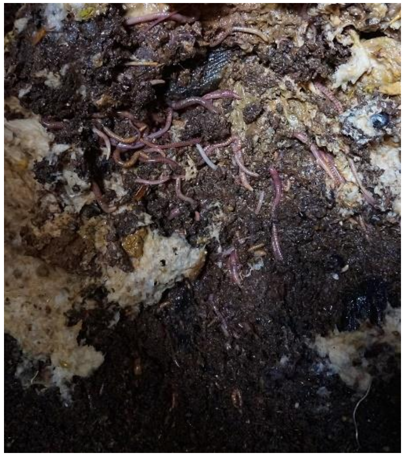
Operational conditions: low mechanical and manual maintenance requirements, and, where gravity operated, requires no energy input.

Cost data:

Socio-economic bottlenecks:

References for more information: [Vermifilter – Wikipedia]

Singh, Rajneesh & Samal, Kundan & Dash, Rajesh & Bhunia, Puspendu. (2019). Vermifiltration as a sustainable natural treatment technology for the treatment and reuse of wastewater: A review. Journal of Environmental Management. 247. 140-151. 10.1016/j.jenvman.2019.06.075.



NBS Factsheet: ***Microalgae water treatment***

NBS type: intrinsic

Used for: remove nutrients and organic compounds from agro industrial wastewaters

Description: remove nutrients from wastewater, and provide a biomass source. Additionally, when combined with the conventional activated sludge systems, the algae-bacteria symbiosis can reduce the electrical energy demands from aeration, which can represent more than 50 percent of the total energy of wastewater treatment plants.

Working Principle: through photosynthesis, the microalgae provide oxygen necessary for aerobic bacteria to biodegrade organic pollutants, consuming in turn the carbon dioxide released from the bacterial activity.

Benefits for the agro- food industries harvested biomass can be used to recover valuable products obtainable from it such as usage as feed, biogas substrate, biofuels, fertilizers and biopolymers

Development phase: not commercial

Technology transferable: Yes, dependent on climate

Operational conditions: By using LED lamps for lighting the process can made less light dependent for periods or places with lower sunlight Challenges are harvesting of the algae, due to settling characteristics and operational conditions; control of biomass composition is complicated by the selection of the desired species; while the definition of an optimal ratio of algae and bacteria biomass, micro-pollutants removal, and the possible need for external CO2 present additional obstacles

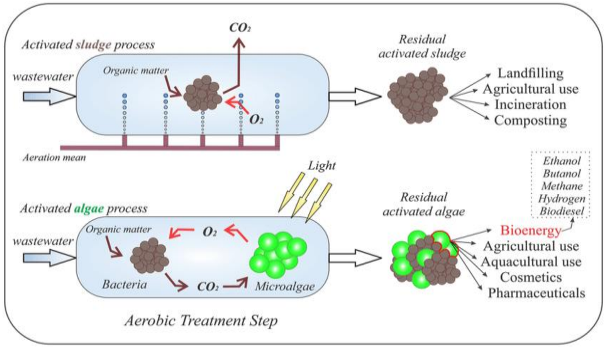
Cost data: by-products from algae are technically feasible, their economic feasibility is still under discussion

Socio-economic bottlenecks:

References for more information: van Dijk, W. , R.Y. van der Weide, A. Kroon (2016) Groen proceswater: zuivering brouwerijprocesafvalwater met microalgen PPO rapport https://edepot.wur.nl/408792

Tiron, O., Bumbac, C., Manea, E. et al. (2017) Overcoming Microalgae Harvesting Barrier by Activated Algae Granules. Nature Scientific Report 7, 4646 https://www.nature.com/articles/s41598-017-05027-3

Microalgae as a sustainable alternative for wastewater treatment - International Water Association (iwa-network.org)



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NBS Factsheet: ***Ultra-filtration (UF)***

NBS type: intrinsic

Used for: pre-treatment in the preparation of drinking water or process water

Description: Ultra-filtration (UF) is a pressure-driven membrane processes.. The pore size varies between 20 nm and 0.1 microns allowing retention for particles smaller than 20 nm and up [EMIS].

Working Principle: pressure-driven membrane processes

Benefits for the agro- food industries

Low operating pressure required (higher than MF); Lower energy consumption than nano-filtration or reverse osmosis; Good permeate yield depending on the supply water and membrane choice;

Disinfection through removal of bacteria. To a certain extent, UF allows viruses, phage, colloids and macro molecules to be removed.

Development phase: commercial

Technology transferable: Yes

Operational conditions: Membranes must be protected against fouling and scaling (particles > 0.1 mm). Supply flows, pH conditions and temperature conditions must be compatible with the membrane material.

Cost data: A typical small scale UF installation able to process 64 m^3/day costs +/- € 56.000. Typical large UF installation (650 m^3/h) costs +/- € 2.000.000. [EMIS]

Socio-economic bottlenecks: UF concentrate consists of suspended matter and bacteria and can only be discharged if accumulated concentration does not exceed environmental limits. Rinse waters after chemical cleaning contain substances like bleach, peroxide, acid and alkali and can only be discharged to specific waste purification systems.

References for more information: EMIS-WASS
Ultrafiltration | EMIS (vito.be)

Picture: Ultrafiltration - Wikipedia

NBS Factsheet: ***Microfiltration (MF)***

NBS type: intrinsic

Used for: production of drinking and process water by removing suspended matter and bacteria as an alternative to sand filtration

Description: Micro-filtration (MF) is a pressure-driven membrane processes.. The pore size varies between 0.1 and 5 microns allowing retention for particles smaller than 0.1 microns and up [EMIS].

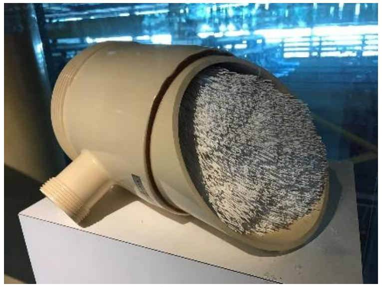
Working Principle: pressure-driven membrane processes

Benefits for the agro- food industries

Because large pores pressure needed for a micro-filter membrane is limited to 0.1 to 3 bar.

Development phase: commercial

Technology transferable: Yes, dependent on climate



Operational conditions:

Membranes must be protected against hard particles larger than 0.1 mm. They can be removed by regular pre-filtration. Further, supply flows and pH conditions must be compatible with the membrane material [EMIS].

Cost data: Typical installation costs for micro-filtration (tubular membranes, PVDF) with a volume of 25 m³/day, amount to between € 25.000 and 50.000 depending on the quality of the water supply. Difficult to treat supply water is more expensive to process due to the choice of membrane material, total membrane surface area and the special cleaning techniques needed for the membrane. For MF, one should assume an average operating costs of 0.1 to 0.15 €/m³ produced permeate. [EMIS]

Socio-economic bottlenecks: MF concentrate consists of suspended matter and bacteria and can only be discharged if accumulated concentration does not exceed environmental limits. Rinse waters after chemical cleaning contain substances like bleach, peroxide, acid and alkali and can only be discharged to specific waste purification systems [EMIS]

References for more information: EMIS-WASS
[Microfiltration | EMIS (vito.be)]

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Picture: microfiltration module with hollow fiber membranes - Wikipedia

NBS Factsheet: ***Nanofiltration (NF)***

NBS type: intrinsic

Used for:

Description: pressure-driven membrane process which, in terms of separation level, lies between ultra-filtration and reverse osmosis.

Dissolved matter (>75%);

Harmful micro-organisms, e.g. bacteria, protozoa, algae, fungi (>90%).

Persistent organic matter (50-75%);

Organic compounds (50-90%);

Nutrients (incl. phosphates);

Metals (50-90%).

Inorganic salts (e.g. sulphates).

Working Principle: pressure-driven ion-selective membrane process

Benefits for the agro- food industries

NF is effective in removal of Micro-pollutants (herbicides and insecticides, low-molecular components like colorants and sugars).

Development phase: commercial

Technology transferable: Yes, dependent on climate

Operational conditions: operating range of nano-filtration lies between that of reverse osmosis and ultra-filtration

Cost data: NF or the production of 100 m³/h permeate, approximately costs between € 300.000 and 350.000 [EMIS]

Socio-economic bottlenecks: concentrate must be discharged (after purification). When discharging, the discharge norms in the permit must be compared with the quality of the concentrate

References for more information: EMIS-WASS [Nanofiltration | EMIS (vito.be)]

References

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