REMOVAL OF MICROPOLLUTANTS IN WASTEWATER TREATMENT PLANTS

EVERYTHING YOU NEED TO KNOW ABOUT RESOURCE-EFFICIENT REMOVAL OF MICROPOLLUTANTS

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This guideline is a short version of the report B2288 "Handbook for treatment of micropollutants at wastewater treatment plants - Planning and installation of treatment systems for pharmaceuticals and other micropollutants" that can be downloaded at www.ivl.se or www.hammarbysjostadsverk.se.

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WHY WE SHOULD RAMP UP TREATMENT PROCEDURES

Today, more than a thousand active substances are used in medicines in Sweden, and many of these can be detected in wastewater. Even at present levels, environmental impact has been demonstrated for a number of these substances. For example, gender change and sterility in fish and germs when exposed to hormones commonly found in birth control pills, which may be sufficient motive for introducing an additional treatment. Another example is the altered behaviour of perchants upon exposure to the anxiolytic agent oxazepam. Substances like metoprolol, fluoxetine and carbamazepine have also shown effects on fish at levels relevant to Swedish wastewater treatment plants (WWTPs).

In addition to pharmaceutical residues, there are a number of other contaminants and effects. Bacteria, parasites and human faecal viruses can present a risk of disease spread. Flame retardants, phenols and dioxins are other contaminants that should be targeted. All these substances are commonly grouped as micropollutants.

The fact that many of these substances should not be released into nature is largely uncontested, though there is a great deal of disagreement about when and to what extent WWTPs should be tasked with removing micropollutants. A crucial problem is that nature is an extremely heterogeneous and complex system and it is almost impossible to link an effect with a particular substance or a specific concentration. This also means that it is difficult to introduce legislative interventions as economic (and thus political) interests are involved. Which of the thousands of pollutants should be prioritized? Which removal goals should be set up? How should they be followed up?

Which pollutants should be prioritized and which treatment goals defined?

Thus it might appear that there is great uncertainty surrounding micropollution and its removal. However, we believe that we should strive to remove micropollutants to the degree attainable and to reduce concentrations as far as possible, as long as this can be carried out in a resource-efficient and sustainable way. Sustainable both in terms of cost, overall environmental impact and flexibility for future challenges. Read more about this on the following pages.

WHICH CONTAMINANTS SHOULD BE TARGETED?

In addition to pharmaceutical residues, there are a number of non-organic and other persistent organic contaminants and effects that can be subsumed under the micropollutant label.

- **Pharmaceutical residues:** Includes both antibacterial, anti-inflammatory and antidepressants, neuroleptics and sedatives, anaesthetics, cardiac medications, sex hormones, blood thinners, cytostatics, etc. Properties may vary greatly between different substances, which excludes a universal treatment technology. It is expected that 50% of these substances will be removed in today's WWTPs and upstream activities are complicated due to unintentional release (excretion via urine and faeces). 17β-estradiol, 17α-ethinyl estradiol, azithromycin, clarithromycin, erythromycin and diclofenac are included in the monitoring list of the EU Water Framework Directive.

- **Disease spreading:** Pathogens are common in Swedish wastewater flows and include bacteria, parasites and viruses from human faeces. Pathogens may present a risk of disease spreading.

- **Antibiotic resistance:** The WHO classifies antibiotic resistance as one of the greatest threats to world health. It is almost impossible to locate the particular nexus where the development of resistance takes place, but the removal of bacteria in WWTPs is more germane to the issue than the removal of antibiotic residues. Resistance is not only transmitted directly between bacteria but also via the DNA of dead cells. The presence of antibiotics accelerates resistance and this resistance may persist for long periods of time even if antibiotic residues have been removed.

- **Total toxicity:** As we will never have full knowledge of the substances present in the effluent of WWTPs, total toxicity serves as an important measure of the "cocktail effect". Toxicity is assessed at the three trophic levels in the food chain primarily affected by emissions, usually algae, crustacean and fish. If possible, through long-term tests to exclude effects on recipients over time.

- **Flame retardants:** Includes a large number of dissimilar types of chemicals with different physical and chemical properties. Many flame retardants are persistent, bioaccumulative and hormone-destructive. Defined as a priority substance by the EU Water Framework Directive.

- **Softeners:** Previously commonly used in PVC and older products, now partially replaced by newer alternatives due to proven adverse health effects such as their role as cancerogenic triggers and lowering sperm counts in men.

- **Phenols:** Many phenols are hormone-destructive, which has been shown to affect fish that live downstream of WWTPs. Use has decreased, especially of nonylphenols, bisphenol-A and triclosan. Nonylphenol and octylphenol are both classified as priority substances in the EU Water Framework Directive.

- **Per- and polyfluorinated alkyl substances (PFAS):** Includes a large group of substances that have historically been used in technical products and which, due to their extreme persistence, will be present in wastewater flows for a long time to come, although some are now being phased out. The EU Water Framework Directive classifies certain substances such as PFOS as substances to be monitored.

- **Dioxins and PCB:** Despite being banned, these are prevalent in wastewater flows, due to extensive historic use and they do not break down easily. Low water solubility provides good separation in today's treatment plants, but also means that some of them end up in sewage sludge. A number of dioxins are labelled as priority substances in the EU Water Framework Directive.

- **Heavy metals:** Most metals are strongly particle-bound, which implies that more than 80-90% of all of these metals end up in the sewage sludge. Sewer overflows are expected to be the largest emission source of metals to recipients.

- **Microplastics:** Have been identified in many aquatic species, and increased concentrations have been found, especially in untreated wastewater emission areas. The current state of knowledge about the effects in the environment is still inadequate – however, up to 99% can be removed already in today's WWTPs. Issues surrounding the presence of microplastics in the sea have been raised in the EU's Marine Environment Directive (2008/56/EC).

- **Other pollutants:** Anionic surfactants (constituents of cleaning products), synthetic sweeteners (e.g., sucralose), pesticides, trichlorobenzene, chloralkanes, siloxanes, etc.

- **Don't forget the sludge handling!** Removing micropollutants from wastewater means that they often end up in the sludge instead. Some of today's sludge-handling procedures can thus lead to an increased spread of these pollutants in the environment, making it difficult to implement effective mitigation measures.

TREATMENT PRINCIPLES

There are various basic treatment mechanisms that determine how efficient removal will be and what will happen to the micropollutants. Based on these mechanisms, several technologies are now available and some of these are on the brink of full-scale implementation within a foreseeable time frame. Realistic implementation refers only to resource-efficient processes that add value to the purification process.

The current technology development will affect which treatment technologies that will be most attractive and an implementation should therefore take into account this development as well as any future requirements. In this folder you can find out what technology can be integrated into the main treatment, i.e., conventional activated sludge (CAS) in most cases, and what technology can complement the existing main treatment process.

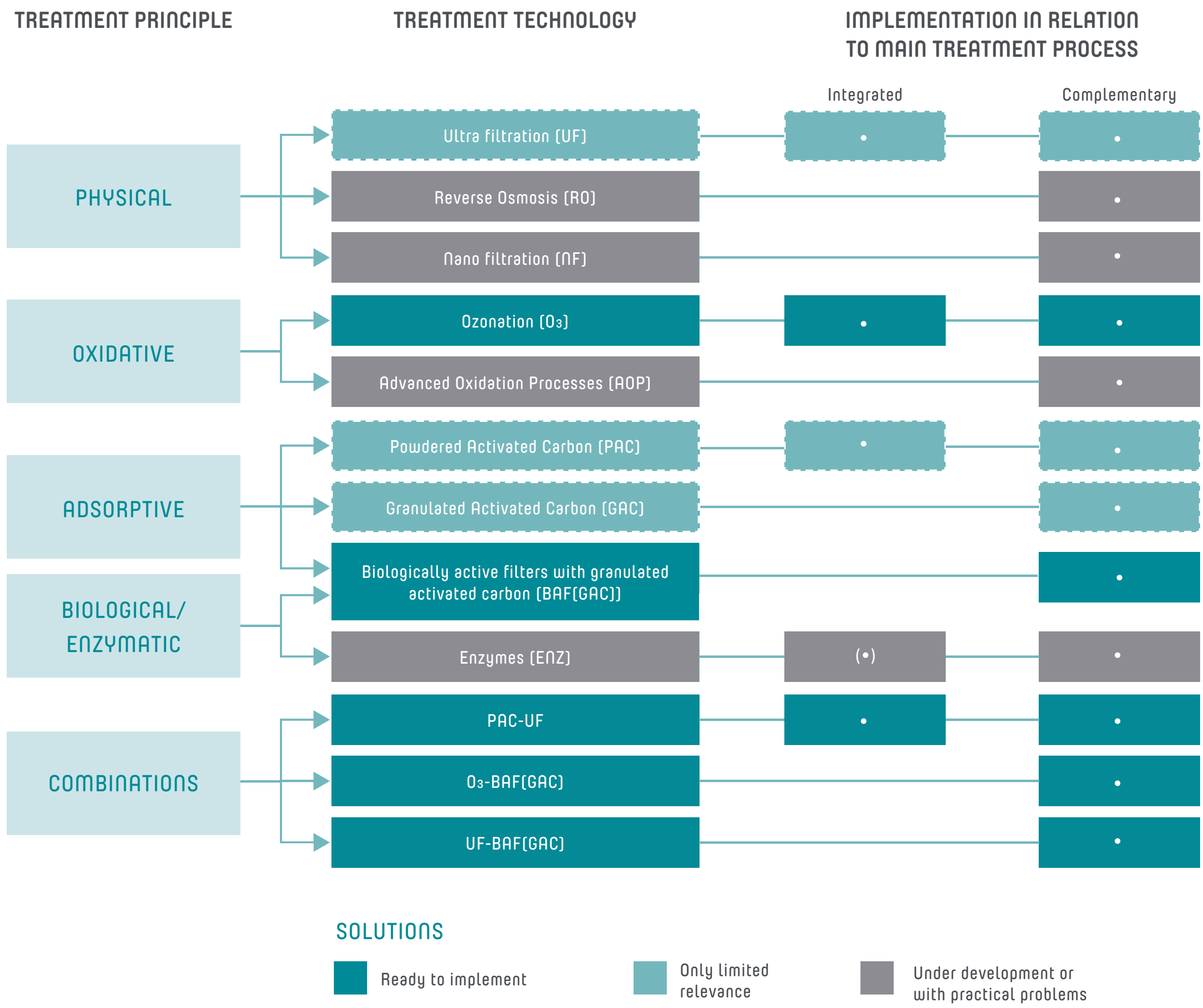
- **Physical:** Micropollutants are separated from wastewater and end up either in the sludge or need to be taken care of separately. Ultrafiltration after the main process or integrated as an MBR - Membrane BioReactor delivers the most effective physical separation technology available today. Decreasing prices and technology development also open for more advanced filter technologies.

- **Oxidation:** Micropollutants are transformed into decomposition products which are largely unknown and can be more harmful than the original substance. Most common is ozonation, but even hydrogen peroxide (H_2O_2), chlorine dioxide (ClO_2) or other advanced oxidation technologies may become relevant to certain micropollutants with increasing demands and technology development.

- **Biological (enzymatic):** Breaking down of organic pollutants using biological processes including enzymes. In principle, today's treatment mechanism in wastewater treatment plant, but more powerful or more specialized in microorganisms. Enzyme treatment intends to break down contaminants with tailor-made enzymes for a targeted removal.

- **Adsorption:** Implies that micropollutants are attached to an active surface that needs to be replaced at saturation. Granulated activated carbon (GAC) in a filter bed and powdered activated carbon (PAC) added to the process are the most common technologies that are also used in drinking water production. Biochar produced from organic residues such as sewage sludge is under development.

- **Combinations:** Combines at least two completing treatment mechanisms for inclusive and more efficient removal.



The figure shows a schematic characterization of various complementary treatment technologies.

PREREQUISITES AFFECTING THE CHOICE OF TECHNOLOGY

When selecting appropriate technologies for the treatment of various micropollutants, several aspects need to be considered as these affect how resource-efficient the implemented solution will be, both in the short and long term. These aspects are briefly described below. In general, a holistic assessment is required. For example, for a planned upgrading of the main process, the additional removal of micropollutants should be integrated in a resource efficient way and main and extra treatment should be harmonized. Other aspects such as sampling, sludge handling, site-specific conditions, etc. are of importance and described briefly below.

- Uppstream activities: Point sources that can be mitigated and possible phasing out of micropollutants should be prioritised. Removal of micropollutants at WWTPs does NOT replace upstream activities! Wastewater can be a significant part of the total emissions of micropollutants and should be considered if a resource efficient treatment is sought.
- Status of recipient: WWTP-effluent that is strongly diluted in a large recipient with high water exchange reduces the risk of adverse environmental effects, while low dilution, small recipients and low water exchange increase the risk and emission minimization should be targetet. Do not forget that the dilution factor can vary greatly over the year. In any event a dilution of less than factor 8 should be considered as critical.
- Existing treatment processes: A removal of micropollutants is justified if an advanced treatment of nutrients, organic matter and suspending substances has already been implemented. If the existing main process is expected to change in the future, the choice of technology should take this into account. E.g., an upgrade to an MBR to achieve very low nutrient concentrations and particle levels affects the choice of technology for further micropollutant treatment. A poor existing treatment process affects the choice of technology, especially with regard to whether the extra treatment should be integrated into or added to the main process.
- Working environment: Although the different technologies can lead to increased handling of chemicals and gases, and may also imply other working environment and safety aspects, there are no risks that can not be addressed through structured preventive actions.
- Sludge handling: The use of sludge on arable land or as soil improvement means that micropollutants in the sludge are dispersed in the environment. Treatment technologies that transfer micropollutants from the wastewater to the sludge increase this risk and a separate handling that takes care of micropollutants is desirable.
- Mapping of micropollutants: The progress of micropollutants through the WWTP (including the sludge) should be carried out before chossing treatment technology. Mapping will give you an idea of the micropollutants and technologies that should be prioritized. Note: Sampling, processing and analysis are particularly important. Deficiencies here can lead to erroneous conclusions and technology choices. This also applies when testing different treatment technologies! The complex composition of wastewater further implies that current standard analyses of pharmaceutical residues underestimate true concentrations (about 40% in WWTP influents and 30% in effluents, respectively). The misquantification of individual substances can be significantly higher.
- Load fluctuations: The removal of micropollutants can either target very low levels in a fixed side stream, which is then mixed with other treated wastewater, or it can treat the whole flow with load variations that need to be handled. A flow equalization and effective wastewater treatment should be aimed for.
- Facility-specific limitations: Certain specific restrictions and limitations on WWTPs may affect the choice of technology. For example, ozone treatment requires a large power supply, filter basins require more space.

TECHNOLOGIES AND DIMENSIONING

Removal efficiencies with regard to various micropollutants are given in the overview on the last page. Here, the most relevant technologies[1] are described in brief with the main pros and cons as well as the basics of design.

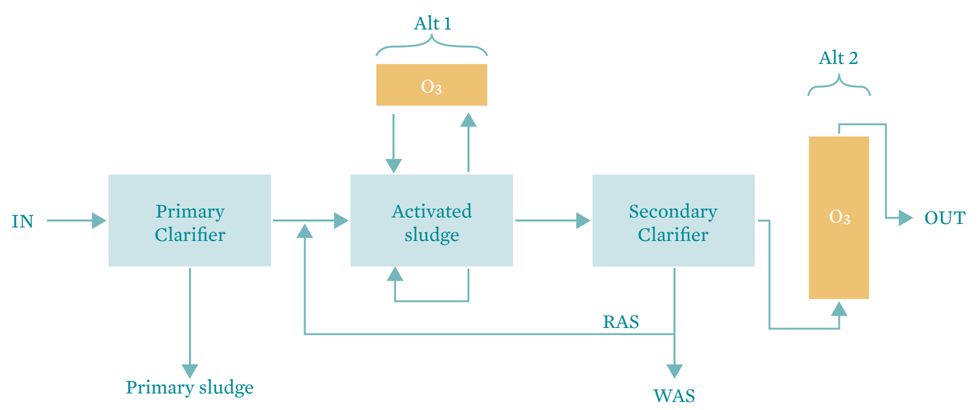
OZONATION (O_3)

Advantages

- Provides good treatment
- Known, simple and comparatively inexpensive technology (however, required polishing steps are often not accounted for!)
- Several monitoring and control concepts available with spectral absorbance at 254 nm (UVA254 or SAC254) being the most common
- Dosage can be adjusted to load and flow variations

Disadvantages

- Less effective than activated carbon on certain substances
- Requires significant amounts of energy at the treatment plant for ozone production
- Creates partially unknown degradation products and therefore an additional polishing step is recommended
- No disinfection of the wastewater at relevant ozone doses
- High ozone consuming substances (e.g., iron, nitrite) increase the ozone demand/costs
- Real-time measurement/control still requires some development/improvement



Dimensioning

- 5-7 g O_3/m^3 (or 0.5-0.7 mg O_3/mg DOC) (higher if ozone consuming substances are present e.g., 1.1 mg O_3/mg NO_2)
- Ozone production and mixing should be adapted to load dynamics
- Control by UVA254 change and O_3-residual recommended
- Contact time ~ 10 minutes

Placement

- Integrated or as finishing with postpolishing
- Low particle content and high degree of water purity reduce ozone required
- Placement affects reliability of online monitoring/control
- Cooling in ozone production is required

[1]*Baresel, C., Magnér, J., Magnusson, K., Olshammar, M. 2017. Tekniska lösningar för avancerad rening av avloppsvatten. IVL Svenska Miljöinstitutet, Rapport C235.*

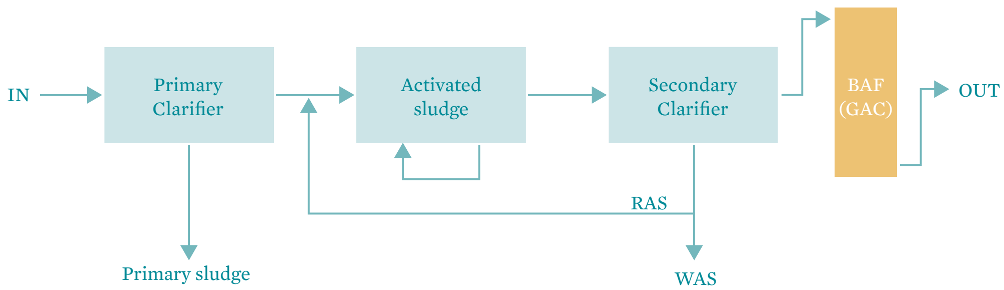
BIOLOGICALLY ACTIVE FILTER WITH ACTIVATED CARBON AS FILTER MATERIAL (BAF(GAC))

Advantages

- Provides efficient removal through adsorption and biological (enzymatic) degradation
- Known technology comparable to sand filters
- Can also be operated with other filter materials
- Integrated regeneration of filter capacity through biodegradation
- Creates no problematic decomposition products
- Micropollutants are destroyed by degradation (and at filter material destruction/regeneration)
- Can benefit in the future of biochar production
- Low energy consumption at WWTPs

Disadvantages

- Requires much energy and materials in the production/ regeneration of activated carbon
- Clogging of the filter due to biological growth needs to be monitored and controlled via backwashing
- Currently no Swedish manufacturing/regeneration
- Real-time monitoring requires continued development, spectral absorbance at 254 nm (UVA254 or SAC254) not generally applicable
- Requires space for filter basins
- Flow variations can only be handled to a limited extent
- Requires an establishment period for the biology, using GAC as filter material, however, gives an immediate treatment effect



Dimensioning

- Different filter materials affect growth and adsorption, GAC or equivalent materials are recommended
- <20 g GAC/m³ (or <2 mg GAC/mg DOC)
- Contact time ~ 10 minutes
- Gravitational flow
- Backwashing with air and water

Placement

- Only as final treatment step
- Low particle content and high degree of water purity provide an increased capacity/lifetime of the filter
- Backwash water returned to main treatment
- Two or more filters can be connected in series for significantly increased utilization of carbon capacity

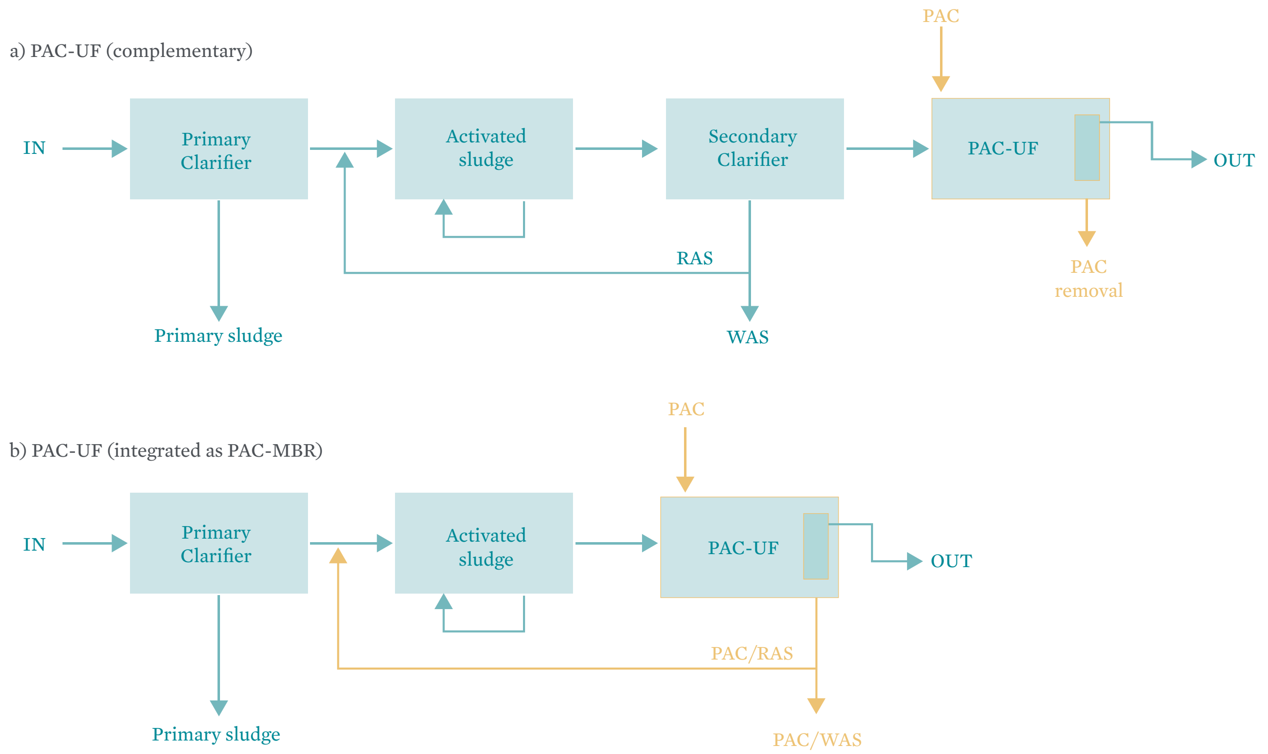
PAC-UF (INKL. PAC-MBR)

Advantages

- Provides efficient treatment
- Provides disinfection of the wastewater
- Produces no probematic decomposition products
- Can benefit in the future of biochar production
- Dosage of PAC can easily be adjusted to load and flow variations
- Micropollutants are destroyed at carbon destruction/regeneration

Disadvantages

- Requires significant amounts of energy and material in the production of activated carbon
- Requires much energy and chemicals for UF operation
- Micropollutants are transferred to the sludge/PAC slurry that requires separate handling
- Regeneration of PAC is usually not possible which results in higher costs and environmental impact from PAC production
- In an integrated solution, the addition of PAC implies a sludge contamination



Dimensioning

- Nominal pore size <0.02 µm (Alt a)
- Nominal pore size <0.04 µm (Alt b)
- 20-25 g PAC/m³ (or 2-2.5 mg PAC/mg DOC)
- Contact time ~ 15 minutes

Placement

- Only as final treatment step
- Integrated in the main process (becoming a MBR process) or as a polishing step
- Dosage of PAC before UF

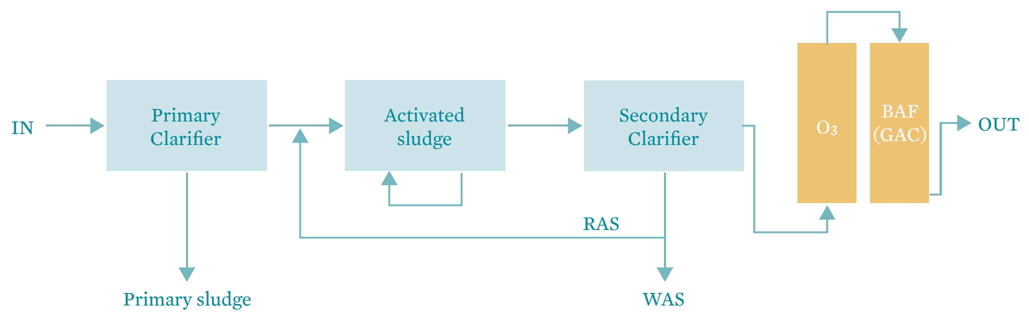
COMBINATION OF OZONATION & BIOFILTER WITH ACTIVATED CARBON O_3–BAF(GAC)

Advantages

- Provides effective treatment through ozone oxidation, adsorption and biodegradation
- Increased oxygen levels after ozonation provide favourable conditions for the biofilter
- Combination of known technologies
- Creates no problematic decomposition products in the final effluent
- Micropollutants are destroyed at carbon destruction/regeneration
- Can benefit in the future of biochar production
- Monitoring and control concepts available, spectral absorbance at 254 nm (UVA254 or SAC254) the most common
- Load/flow variations can be handled to a certain extent

Disadvantages

- Requires significant amounts of energy and material in the production of activated carbon
- Currently no Swedish manufacturing/regeneration
- Requires significant amounts of energy at the treatment plant for ozone production
- Real-time monitoring technology requires more development
- Several process steps (which can, however, be combined in one device)



Dimensioning

- <5-7 g O_3/m^3 (or <0.5-0.7 mg O_3/mg DOC) (higher if ozone consuming substances are present e.g. 1.1 mg O_3/mg NO_2) and <20 g GAK/m^3 (or < 2 mg GAK/mg DOC)
- Contact time ~ 10 minutes for each step

Placement

- Only as final treatment step
- Low particle content and high degree of water purity increase the capacity/lifetime of carbon filter and reduce ozone demand

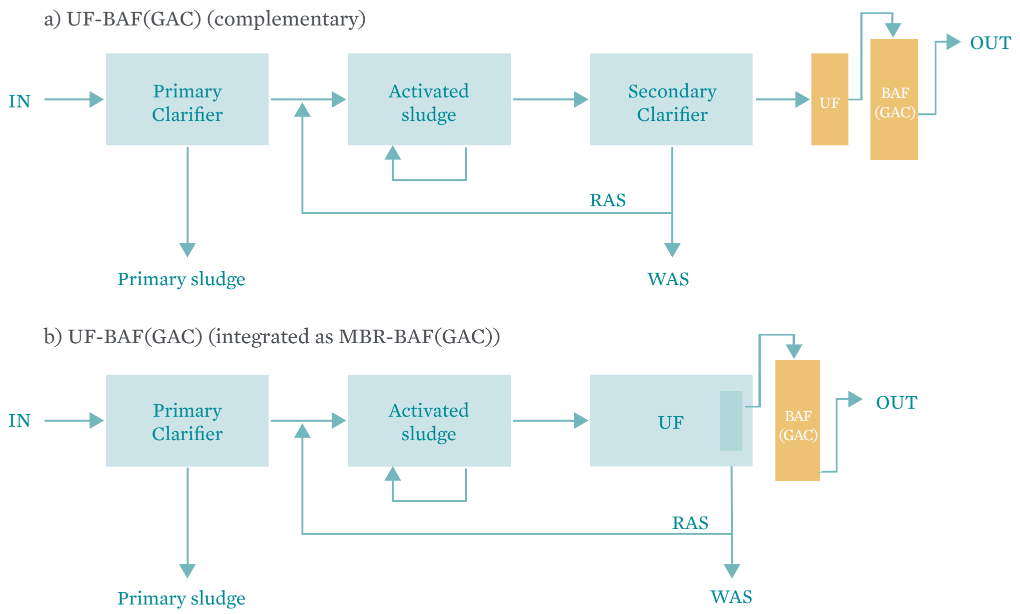
UF-BAF(GAC) (INKL. MBR-BAF(GAC))

Advantages

- Efficient treatment with known technology
- Creates no probematic decomposition products and micropollutants are destroyed during carbon destruction/regeneration
- Provides wastewater disinfection
- Can benefit in the future of biochar production
- Load/flow variations can be managed to some extent
- Simple process stability and monitoring

Disadvantages

- Requires significant amounts of energy and material in the production of activated carbon
- Currently no Swedish manufacturing/regeneration
- Requires much energy and chemicals for UF operation
- High energy consumption at WWTPs due to UF step
- Requires prefiltration (< 1-3mm)



Dimensioning

- Nominal pore size <0.02 µm (Alt a)
- Nominal pore size <0.04 µm (Alt b)
- Requires prefiltration (< 1-3mm)
- 10-25 g GAC/m³ (or 1-2.5 mg GAC/mg DOC)
- Contact time ~ 10 minutes
- Gravitational flow (or pressurized)
- Backwashing with air and water

Placement

- Only as final treatment step either integrated in main process (MBR process) or as polishing step
- Two or more filters can be connected in series for significantly increased utilization of carbon capacity

Dimensioning of the technical solution must be based on plant-specific conditions that take account of existing infrastructure that can be utilized, the scope of the construction work necessary, loads and desired redundancy, and synergies with other facilities or purification targets. However, on-site pilot studies are recommended for each individual installation. Preferably, an independent review of technology providers should be carried out to leverage the most resource-efficient solution.

THE ENVIRONMENTAL IMPACT OF DIFFERENT TECHNOLOGIES

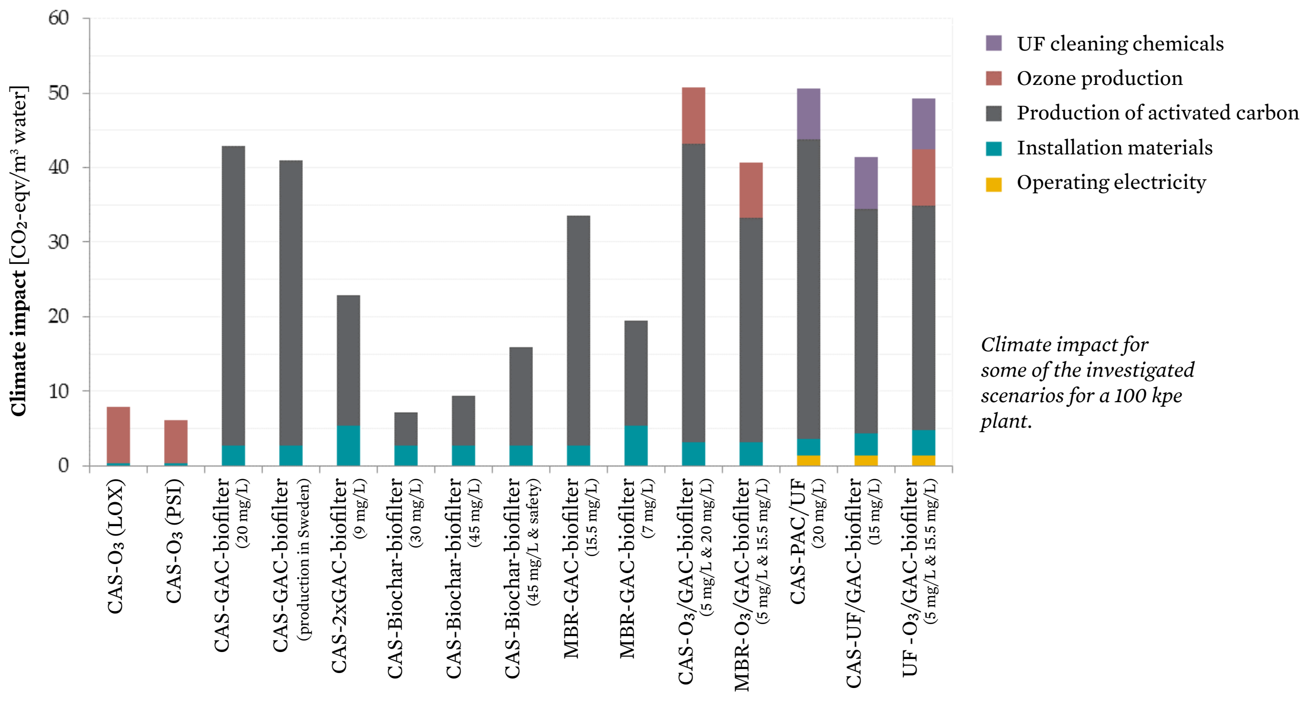
The main negative environmental impact that all treatment technologies/combinations give rise to is the climate impact due to increased energy use.

For PAC, GAC, BAF and combinations of these technologies, it is primarily the production and regeneration of activated carbon that requires large amounts of energy. For ozone and UF technology, it is the operation itself that entails increased energy use. For one kWh produced electricity, the climate impact is greater outside the Nordic region, as energy there is produced with a larger proportion of fossil fuels. Electricity consumed at Swedish treatment plants or generally in Scandinavian countries, can therefore be considered as less environmental impactful. A possible production and regeneration of activated carbon in Sweden would thus, to a certain extent, reduce the overall environmental impact of all technologies in which activated carbon is included. This would also reduce the environmental impact due to transports. Even an increased acidification and eutrophication potential can be primarily related to increased energy consumption in additional treatments. Using new activated carbon without regeneration would imply more than fivefold the climate impact of activated carbon production.

The environmental impact of the different technologies can be ameliorated and will change over time. Generally, improved technology implementation and development lead to more resource-efficient processes. For example, the energy requirement for membrane processes has steadily declined over the past decade. Processes that can be shut down at the treatment plant when introducing new supplementary treatment steps should also be included in the calculation of environmental impacts.

New technologies that utilize biochar produced from the WWTPs own sludge or from other substrates may be especially beneficial when it comes to the environmental assessment, although exact emissions cannot currently be quantified as full-scale reference installations are lacking.

Ecotoxic effects on soil and water systems are more difficult to quantify and are for this reason usually excluded from environmental impact assessments. This can both impact not only assessment of the need for additional treatment measures and their environmental benefits , but also assessment of potential negative effects. In addition, single substances may have a non-existent toxic effect in the environment, but become toxic when mixed with other substances. This means, inter alia, that toxicity in wastewater may increase, the so-called cocktail effect. Toxicity may also be chronic, which, in contrast to acute toxicity, makes it more difficult to detect. Bioaccumulation of certain emissions can create a toxicity that, in the future, may generate an effect that is currently impossible to quantify. Thus, the assessment of the overall environmental impact and the conclusions can be drawn may be limited – an environmental impact assessment is only as good as it is formulated.



Climate impact for some of the investigated scenarios for a 100 kpe plant.

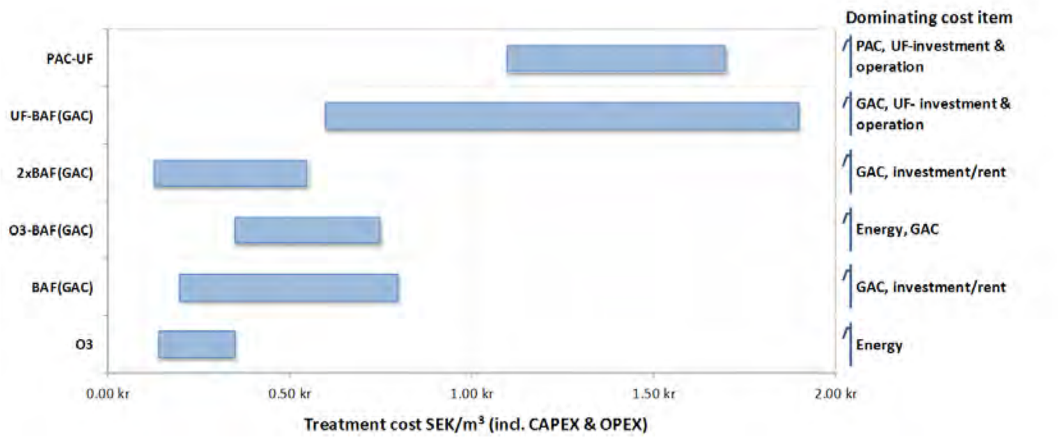
COSTS FOR DIFFERENT CLEANING TECHNOLOGIES

Below, estimated costs for both installation and operation for the various technologies/combinations are provided for a design flow of 150 m3/(pe, yr) and simplifications. The costs for different plant sizes and may be used as indications.

- DOC in wastewater: < 10 mg/L
- Nominal pore size UF: < 0.2 µm
- Dosage activated carbon (PAC, GAC, BAF(GAC): 20 mg/L
- Contact time filter bed (GAC, BAF): >10 min
- Ozone dosage ~5 mg O_3/L
- Contact time ozone: ~10 min
- Purchase price electricity: 0.80 SEK/kWh
- Activated carbon: 20 kSEK/ton; regenerated 13 kSEK/ton
- Liquid oxygen LOX: 1.70 SEK/kg
- Personnel costs: 450 SEK/hour

Costs for ground works and other engineering constructions such as concrete basins and storage silos have been assumed to be 100% of the cost of the technical components according to experience from technology suppliers. Planning and application/permit costs have not been taken into account. The lowest costs in the figure below can be achieved for large plants (> 500 kpe) and higher costs occur at smaller plants (20 kpe).

Note that the assumed water flow that requires treatment at different treatment plant sizes not only affects the costs but also gives rise to uncertainty when comparing the costs reported from other countries. The flow to which the treatment refers to may differ greatly from plant to plant. If a supplementary treatment has to be able to treat all wastewater, i.e., 100% of the treatment plant's inflow, the costs are affected to a greater extent than if only, for example, 95% of all water has to be treated. This is because the last 5% can represent extremely high peaks during extreme weather that would require extraordinarily large processes or equalization capability, which leads to higher costs and less resource efficient operation of the treatment.



WHICH TECHNOLOGY?

The choice of technology solution is a complex issue and requires careful consideration of the various aspects presented here and preconditions at individual WWTPs. The table on the next page indicates that an effective and inclusive treatment of micropollutants can only be achieved by combining different technologies. However, the following overall recommendations for technology selection are applicable to the vast majority of WWTPs. Together with common sense, an understanding of the own treatment process and the environmental impact of different technologies, these serve as a good basis for discussion and further work.

- WWTPs with an MBR process should select a biofilter with granulated activated carbon as filter material: BAF(GAC)
- WWTPs with a conventional activated sludge (CAS) process and very good N/P/C-treatment and low particle contents should choose a combination of ozone and biofilter with granulated activated carbon as filter material: O_3-BAF(GAC)
- WWTPs with a CAS process and poor N/P/C-treatment and high particle contents should choose an integrated ozonation (O_3) or ultrafiltration with subsequent biofilter with GAC as filter material: UF-BAF(GAC)
- WWTPs with poor N/P/C-treatment should not focus on an advanced treatment of micropollutants before the main treatment has been improved. When a better N/P/C treatment and advanced treatment of micropollutants must be achieved, the MBR process may be a good alternative.

TREATMENT EFFICIENCIES FOR
VARIOUS MICROPOLLUTANTS

	Priority micro pollutants and effects	Treatment technology/-combination: O_3[1]	BAF(GAC)	PAC-UF	O_3-BAF(GAC)	UF-BAF(GAC)
Pharmaceuticals	**Azithromycin** (antibiotic)	Little	Good	Good	Good	Good
Pharmaceuticals	**Ciprofloxacin** (antibiotic)	Moderate	Good	Good	Good	Good
Pharmaceuticals	**Clarithromycin** (antibiotic)	Little	Good #	Good #	Good #	Good #
Pharmaceuticals	**Diklofenac** (painkiller)	Good	Good	Good	Good	Good
Pharmaceuticals	**E2 (17β-estradiol)** (hormone)	Good	Good	Good	Good #	Good
Pharmaceuticals	**EE2 (17α-ethinylestradiol)** (synthetic hormone)	Good	Good	Good	Good #	Good
Pharmaceuticals	**Erythromycin** (antibiotic)	Little	Good #	Good #	Good #	Good #
Pharmaceuticals	**Ibuprofen** (antiinflammatory and analgesic)	Moderate	Good	Good	Good	Good
Pharmaceuticals	**Carbamazepine** (antidepressant)	Good	Good	Good	Good	Good
Pharmaceuticals	**Levonorgestrel** (synthetic hormone)	Good	Good #	Good #	Good #	Good #
Pharmaceuticals	**Metoprolol** (beta blockers, antihypertensive)	Good	Good	Good	Good	Good
Pharmaceuticals	**Oxazepam** (anti-anxiety)	Moderate	Moderate	Moderate	Moderate	Moderate
Pharmaceuticals	**Propranolol** (beta blockers, antihypertensive)	Good	Good	Good	Good	Good
Pharmaceuticals	**Sertraline** (antidepressant)	Moderate	Good	Little	Good	Good
Pharmaceuticals	**Sulfamethoxazole** (antibiotic)	Good	Good	Good	Good	Good
Pharmaceuticals	**Trimetroprim** (antibiotic)	Good	Moderate	Moderate #	Good	Good
Effects	**Risk of infection** (bacteria, pathogens)	Moderate	Little	Good	Moderate	Good
Effects	**Antibiotic resistance** (ARB)	Little	Little	Good	Moderate	Good
Effects	**Estrogenic effects** (effect of hormones)	Good	Moderate	Moderate #	Good	Moderate #
Other micropollutants	**Bisphenol A** (in plastic, hormone-destructive)	Good	Little	Little	Good	Little
Other micropollutants	**Cybutryne/Irgarol** (Herbicide)	Good	Good #	Good #	Good #	Good #
Other micropollutants	**Dioxins and PCB** (in coolants)	Moderate	Good #	Good #	Good #	Good #
Other micropollutants	**Endotoxins** (toxic bioaerosols)	Little	Good #	Good #	Good #	Good #
Other micropollutants	**Phthalates** (e.g.. DEHP) (plasticisers)	Little	Good	Good	Good	Good
Other micropollutants	**Flame retardants** (e.g. HBCD)	Little	Good	Good	Good	Good
Other micropollutants	**Chloroalkanes (C10 to C13)** (lubricants)	Little	Good #	Good #	Good #	Good #
Other micropollutants	**Linear alkyl sulfonates (LAS)** (C10 to C13)	Good	Good #	Good #	Good #	Good #
Other micropollutants	**Nonylphenol** (incl. additive in cleaning products)	Moderate	Little	Little	Moderate	Little
Other micropollutants	**Octylphenol** (incl. additives in cleaning products)	Moderate	Good	Good	Good	Good
Other micropollutants	**PFAS** (incl. PFOS) (tensid)	Little	Good	Good	Good	Good
Other micropollutants	**Sucralose** (sweetener)	Little	Good	Good	Good	Good
Other micropollutants	**Terbutryn** (Herbicide)	Good	Good #	Good #	Good #	Good #
Other micropollutants	**Tributyltenn (TBT)** (Biocid)	Little	Good #	Good #	Good #	Good #
Other micropollutants	**Trichlorobenzene** (solvents & insecticides)	Moderate	Good #	Good #	Good #	Good #
Other micropollutants	**Triclosan** (antiseptic)	Moderate	Good	Good	Good	Good
Other micropollutants	**Heavy metals**[2] (lower priority)	Non	Little #	Little #	Little #	Little #
Other micropollutants	**Microplaster 1 µm - 5 mm** (lower priority)	Non	Little	Good	Little	Good
Standard	Phosphorus	Non *	Little	Little	Little	Little
Standard	Nitrogen	Non *	Little	Little	Little	Little
Standard	Organic material COD/BOD	Non * / Little	Little	Little	Little	Little
Standard	Particle content	Non	Little	Good	Little	Good

Removal efficiency: Good | Moderate | Little | Non

Expected effect based on substance properties and technology purification mechanism
[1] For an ozone dose of between 0.5-1 mg O_3/g DOC
[2] Expected effect is based on a few measurement results for single metals and purification mechanisms
* can release hard-bound C, P and N for a subsequent biodegradation