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# EXPLORATORY STUDY FOR WASTEWATER TREATMENT TECHNIQUES AND THE EUROPEAN WATER FRAMEWORK DIRECTIVE

RAPPORT

2005
34

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FRONTCOVER
WWTP of Deventer near the river IJssel, picture is property of the Water Board Groot Salland

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# PREFACE

In order to implement the European Water Framework Directive (WFD) water authorities and policy officers need up to date information on water treatment techniques that can be used to improve the quality of WWTP-effluent. Based on this information measures can be formulated for the river basin management plans, leading to the required water quality improvements. Apart from that, it is desirable to timely identify possible gaps in available knowledge and practical experience, hindering implementation of the WFD.

STOWA, RIZA and The Urban Water Cycle (European funding Interreg IIIB; North Sea Programme ) commissioned an exploratory study to obtain insight in the mentioned needs, resulting in this report.

This report presents an overview of the substances relevant for WWTPs in view of the WFD. Next to that, the report provides insight in the available treatment techniques for the substances to be removed and determines gaps in knowledge. The report may be used as input for the integral assessment of measures to be taken by water authorities. In order to reduce the contribution of WWTP effluents to the load of surface waters, point-source reduction measures in the water cycle should also be considered, for example measures in the sewer system (e.g. reducing run-off area), reducing industrial and diffuse discharges, moving the WWTP-outlet and implementation of other possible sanitation methods.

Utrecht, September 2005
The Director of STOWA, ir. J.M.J. Leenen

“Urban Water Cycle” is part of the INTERREG III North Sea Programme. The INTERREG III Programmes are an initiative of the European Union aiming at fostering of transnational cooperation in the EU between 2000 and 2006. In the North Sea Programme 7 countries are cooperating to concertedly solve problems in the field of spatial planning, like environmental care, improvement of transport, creating chances for rural areas, instructing how to cope with natural disasters. The aim of Urban Water Cycle is to show how the water cycle in urban areas can be optimised, taking into account the existing environment. For more information, see www.interregnorthsea.org

# SUMMARY

## THE EUROPEAN WATER FRAMEWORK DIRECTIVE (WFD)

The European Water Framework Directive recently became effective in December 2000. The WFD aims to achieve and maintain European water bodies in a “good status”. The European Commission identified priority substances for which community legislation is likely to be implemented. These priority substances are considered to be dangerous enough that their levels need to be systematically reduced in all European countries, in order to achieve a “good chemical status”. For some of these priority substances zero-discharge will be aimed for by the year 2021. In addition to the priority substances, new discharge limits will also be established for “relevant river basin” substances. Meanwhile, the environmental standards for surface water specified in the 4th Article on Water Quality Management still apply, as well as the European Bathing Water- and Dangerous Substances Directives.

After an initial national screening of the effluent produced by wastewater treatment plants (WWTPs) in The Netherlands, it appeared that a certain number of priority substances are regularly measured in WWTP-effluent, forming a significant emission source of priority substances into regional surface water. The Exploratory Study of Wastewater Treatment Techniques and the European Water Framework Directive provides basic information about the WFD-relevant substances in WWTP-effluent and treatment techniques that can be applied now or in the near future to reduce the load of these substances emitted from WWTPs.

## SUBSTANCES

A list of substances is set up in this report which includes important and relevant substances for surface water in The Netherlands, in the light of the WFD. These are substances which are present in WWTP-effluent and which have been shown in area-specific reports to be present in higher concentrations than is specified in the surface water legislation. It is assumed that point-source reduction of these substances will be insufficient to reduce levels. To achieve the not yet fully established discharge limits for these substances before 2015, extra treatment steps will be required. The following substances need to be considered:

- the nutrients nitrogen and phosphorous;
- certain polyaromatic hydrocarbons;
- the pesticides hexachlorocyclohexane, atrazine and diuron;
- the metal ions cadmium, copper, zinc, lead and nickel;
- a plasticising agent DEHP (diethylhexylpthalate).

There has been no testing of brominated diphenyl ethers or octyl-/nonylphenol compounds, since at this moment no limits are available yet. However based on the general occurrence of these substances in WWTP-effluent and the low concentrations at which they cause adverse effects on aquatic organisms, these substances are also considered as being relevant to WWTPs.

## TECHNIQUES

The WFD dictates that plans for the required measures shall be in place by 2009, such that the desired water quality can be obtained by 2015. This time schedule requires a choice of techniques that can be operational at WWTPs within a period of three to five years. Further selection criteria used for an inventory of treatment techniques are:

- the tec hniques will be capable of removing the selected substances from wwtp-effluent to the standards of surface water;
- the techniques will be capable of handling large flow rates;
- the techniques will preferably be capable of removing a broad spectrum of substances;
- the techniques preferably consume minimal energy, additional chemicals and building space.

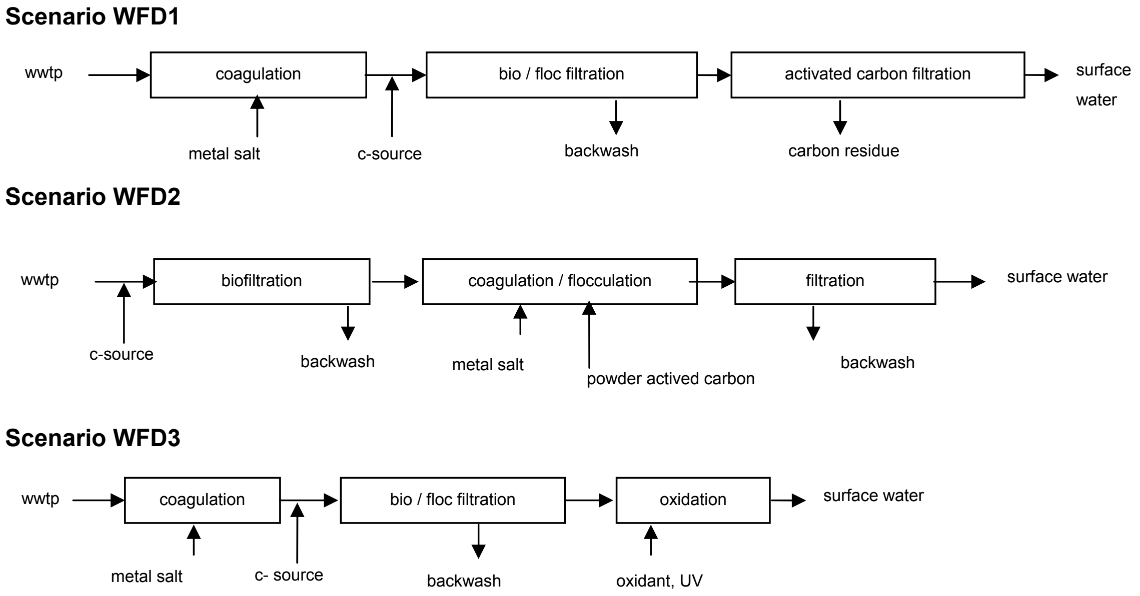
Current techniques for treatment of domestic wastewater are not designed to remove the selected substances from wastewater. Applicable treatment techniques have been selected based on their treatment principle and their estimated effectiveness for treating WWTP-effluent. This estimation is partly based on results from pilot-scale tests and/or full-scale applications for the advanced treatment of WWTP-effluent. Where inadequate information is available over certain techniques the potential effectiveness of the technique was estimated from other applications such as drinking water production or industrial water treatment. In addition to end-of-pipe techniques for post-treatment of WWTP-effluent, attention is also paid to integrated techniques, amongst which the Membrane Bioreactor. For quality-improvement within the WFD the Membrane Bioreactor is considered as an activated sludge system followed by an ultra- or microfiltration membrane.

## TREATMENT SCENARIOS

Many of the WFD-substances are more or less present in suspended or colloidal particles. Removal of suspended solids from the effluent as a first step therefore leads to improvement of the quality of the effluent. The extra advantage is that disturbing effects on the end-of-pipe techniques are avoided.

The treatment scenarios for removal of WFD-substances are largely based on systems in which advanced removal of suspended solids, nutrients, dissolved organic macromolecules and metals can be achieved, in combination with adsorptive or oxidative techniques for the removal of organic micro-contaminants and pesticides. With the techniques applicable for organic micro-contaminants, also the hormone disrupting substances and medicinal substances are removed. The applicable treatment scenarios for complete removal of all WWTP-relevant WFD-substances are shown in the figure.

FIGURE APPLICABLE TREATMENT SCENARIOS FOR THE REMOVAL OF ALL WWTP-RELEVANT WFD-SUBSTANCES



It is necessary to mention that the removal of heavy metals in these scenarios has not yet been confirmed. It is expected however that the advanced removal of suspended solids and the (partial) removal of dissolved complex organic metal complexes will lead to an effective overall removal of heavy metals. Due to the presence of high concentrations of interfering macro-ions (Ca, Mg) in WWTP-effluent it seems likely that the application of ion exchange techniques will be difficult. This would require the development of specific resins that are capable of achieving the required removal efficiency of priority substances that are present at the ppb level, in the presence of other interfering and competing substances in higher concentrations. In addition to this, treatment of the brine solution produced during ion exchange is required.

## COSTS

For each technique or combination of techniques a cost estimate has been set up, comprising the investment costs and the total yearly costs. The cost estimates have been calculated for two plant sizes, namely 20,000 P.E. and 100,000 P.E. The average dry weather flow (DWF) rate is calculated based on an average daily flow of 200 l/P.E. during 16 hours per day. The treatment units have been designed for a hydraulic flow of 1.5 x DWF. Using this hydraulic flow, the capacity of the combination of techniques is lower than the maximal flow during wet weather flow. At the chosen capacity about 75% - 85% of the annual hydraulic flow of the wwtp will be treated.

The specific treatment costs vary from 18 - 43 EUR-ct/m$^3$ (13 -31 EUR/P.E./year) at a plant size of 20,000 P.E. and from 6 - 24 EUR-ct/m$^3$ (5 - 18 EUR/P.E./year) at a plant size of 100,000 P.E. A scale-up from 20,000 to 100,000 P.E. results in a decrease in the specific treatment costs by a factor of 2 to 3. This effect is mainly caused by the costs for adjustment of the existing infrastructure, application of an effluent pumping station and pre-treatment (removal of large particles) and extra facilities such as chemical storage and dosing systems (for coagulant, carbon source). These items are approximately the same price over the considered scale-range from 20,000 to 100,000 P.E.

Nutrient removal in a single-stage filter configuration combining coagulation and filtration with denitrification in one process unit, results in the lowest treatment costs. The highest costs are incurred when coagulation and filtration are used in combination with advanced oxidation (UV/H2O2). Biofiltration with powdered activated carbon dosage combined with coagulation and filtration or biofiltration with activated carbon filtration, leads to the lowest costs for the “WFD-scenario”.

## GAPS IN KNOWLEDGE

The implementation of the WFD policy will lead The Netherlands and Europe into a new phase of domestic wastewater treatment. This will lead to a new focus in wastewater treatment in which the number of relevant substances to be removed will be largely expanded, leading to the application of new techniques and the introduction of new cost factors. Each of these aspects still contain several gaps in the knowledge and further research is necessary before 2009 in order to implement adequate measures to cope with the new legislation.

For some WFD-substances, especially organic micro-contaminants, pesticides, hormone disrupters and medicinal substances, there is little or no data available for WWTP-effluent. More information regarding the distribution of these components between the water phase and the suspended material phase is required to enable an appropriate choice of treatment.

The different treatment scenarios have been compiled based on the expectation that the required treatment standards for the relevant WFD-substances will be achieved with these techniques. This expectation is partially based on results from pilot scale research results and/or full-scale applications. In cases where insufficient information was available the potential removal efficiencies have been derived from other applications such as drinking water production or industrial wastewater treatment. This means that further research is needed in order to establish the exact removal efficiencies of these treatment techniques for a number of substances, including pesticides, organic micro contaminants, heavy metals, hormone disrupters and medicinal substances.

The estimated costs for a number of techniques (especially microfiltration / ultrafiltration, activated carbon treatment and oxidation) have been extrapolated from applications in the drinking water sector in cases where no information is available on WWTP-effluent. A risk in this approach is that the actual costs may be higher or lower depending on the development of the construction costs (e.g. if a more economical construction is developed), or on the development of the operational costs (e.g. if the required chemical dosage is higher than thought). The applicability of these techniques to WWTPs in practice will depend on the costs. It is therefore important to test these cost estimates again as soon as further insight is available in effluent treatment (laboratory → pilot → demonstration scale), and adjust them where necessary.

# STOWA IN BRIEF

The Institute of Applied Water Research (in short, STOWA) is a research platform for Dutch water controllers. STOWA participants are ground and surface water managers in rural and urban areas, managers of domestic wastewater purification installations and dam inspectors. In 2002 that includes all the country's water boards, the provinces and the State.
These water controllers avail themselves of STOWA's facilities for the realisation of all kinds of applied technological, scientific, administrative-legal and social-scientific research activities that may be of communal importance. Research programmes are developed on the basis of requirement reports generated by the institute's participants. Research suggestions proposed by third parties such as centres of learning and consultancy bureaux, are more than welcome. After having received such suggestions STOWA then consults its participants in order to verify the need for such proposed research.

STOWA does not conduct any research itself, instead it commissions specialised bodies to do the required research. All the studies are supervised by supervisory boards composed of staff from the various participating organisations and, where necessary, experts are brought in.

All the money required for research, development, information and other services is raised by the various participating parties. At the moment, this amounts to an annual budget of some six million euro.

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# EXPLORATORY STUDY FOR WASTEWATER TREATMENT TECHNIQUES AND THE EUROPEAN WATER FRAMEWORK DIRECTIVE

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# 1

# INTRODUCTION

This is the Exploratory Study for Wastewater Treatment Techniques and the European Water Framework Directive. This report supplies information about water treatment techniques that will be applied in practice now or in the near future to reduce the emission of hazardous substances from the effluent of wastewater treatment plants (WWTPs).

The set up of this Exploratory Study was prompted by the recent implementation of the European WFD in December 2000. The WFD specifies (among others) that surface water should achieve a “good” ecological and chemical condition by the year 2015. Except for substances that probably have influence on the ecological status, such as nutrients, hormone disrupters and medicinal substances, neither the good ecological status nor the targets for groundwater are discussed in this report. The WFD defines priority hazardous substances, for which the load in surface water must be reduced, including via WWTP-effluent.

The techniques that are currently used for the treatment of domestic wastewater are not designed to remove the selected hazardous substances from wastewater. In many cases the techniques are inadequate to achieve the future desired surface water quality.
In order to achieve the specified emission reduction it is necessary to apply extra treatment techniques in the form of end-of-pipe treatment (quaternary treatment) or in the form of integrated treatment techniques. Such treatment techniques are not yet widely applied and there is consequently little practical experience with these techniques. In order to set up appropriate measures to achieve the WFD-objectives, water quality managers need more information to assess whether emission reduction of certain substances via WWTP-effluent is necessary. If measures are necessary then water engineers need to know which kind of techniques are available and what the estimated costs are likely to be with such a technique.

The Water Framework Directive dictates that plans for the required measures shall be ready by 2009 and that the required water quality must be reached by 2015. This time schedule requires the implementation of techniques that can be operational at WWTPs within a period of 5 years. Applicable techniques need to be capable of handling large flow rates and to remove substances under process conditions typical of WWTP-effluent (i.e. neutral pH, low temperature etc) and preferably consume minimal energy and additional chemicals and with an as small as possible environmental load. As the composition of effluent fluctuates largely in practice it is also important that the techniques are capable of removing a broad range of substances.

### PREPARATION OF THIS REPORT

The following report is the result of a desk study. The presented information has been obtained from literature research, discussions with knowledge institutes, surveys at national and international level and input from the Supervisory Committee.

The approach used in setting up the report is one of converging information streams: starting with a very broad topic, information was sifted through and converged along the way, leading in the end to the set up of an overview that is practical for the user. To achieve this choices were made, which are outlined in each chapter.

The research focuses in parallel on the one hand on (hazardous) substances, groups of substances and characteristics of substances, and on the other hand on the treatment techniques capable of removing them from water. For the selection of techniques it was chosen to investigate "broad spectrum" techniques. After all, the chance that only one specific substance will be present in the effluent is minimal. In practically all cases there will be a mixture of substances, which above all will likely change in the course of time.

The estimated costs calculated for combinations of techniques in chapter 5 are based on typical ballpark figures obtained from practical experience. They provide an indication of the expected costs per cubic metre treated water in relation to the plant size, however they should not be used for estimation of investment costs.

## READER'S GUIDE

The report is structured as follows:
In chapter 2 the background and framework of the WFD is explained together with the possible consequences for WWTP-effluent. In chapter 3 the hazardous substances for which emission will probably need to be reduced are outlined and presented in a List of Priority Substances. The set up of this list is based on the list of priority hazardous substances and the list of "Rhine and Muese relevant substances". Groups of substances were selected from the total (complete) list and the treatment techniques are aimed at removing one or more of these groups of substances.

Chapter 4 begins with the selection of treatment techniques that can be considered applicable to WWTP-effluent. These techniques are detailed further in the attached Fact Sheets, which contain a description of the techniques, required conditions for application and achievable removal efficiencies.

In chapter 5 the techniques that are described as unit operations in chapter 4 are combined into integrated treatment configurations. These configurations are considered the most promising for achieving the WFD-objectives and are set up with the aim of removing the most commonly occurring hazardous substances form waste streams. Attention is not only paid to the water stream (removal of substances from effluent) but also to the treatment and disposal of residual products (brine, flush water, sludge). The estimated costs for these treatment configurations are calculated for two plant sizes.

In chapter 6 the gaps in the knowledge that may form a barrier to the implementation of the WFD are described. This may involve gaps in the available information that make it difficult to draw solid conclusions regarding the applicability of certain techniques, but may also involve practical observations for which there are as yet no solutions. Recommendations are provided for these problems.

Finally, there are two comments that need to be made regarding the use of this report:

The composition of effluent varies from treatment plant to treatment plant, as does the condition of the receiving surface water. To move from the current situation to the desired situation, certain specific measures are necessary. This report provides indications and possible solutions but is not intended to generate area-specific solutions.

This report is a snapshot in time. The current available knowledge and state-of-the-art is unravelled and presented. In addition to this the current gaps in the knowledge are highlighted. In a few years time the amount of available knowledge will inevitably increase, technologies will change and the costs will change.

# 2

# BACKGROUND

On the 22nd December 2000 the European Water Framework Directive (WFD) became effective. The WFD aims to achieve and maintain European water bodies in a "good status". In 2004 water quality managers began with an analysis and drafting of reports on the "current status of surface water". In these reports the current situation for each specific water body is described, including the significant loads, current geography and type of water body, as well as an estimate of the feasibility for achieving the WFD-objectives by 2015. These reports provide a better insight into the significant emission sources for each region and/or the dispersion routes of the EU-defined priority substances (2000/60/EG, appendix X), for which EU legislation is likely to be implemented (the "good chemical surface water status"). The priority substances are considered to be hazardous enough for the environment that their levels need to be systematically reduced in all EU states. For some particularly hazardous substances, new zero-discharge standards will be introduced in 2021. The reduction of the load of hazardous substances in surface water will gain high priority. Aside from the 33 priority substances, new discharge limits will also be implemented for other "relevant area-specific" substances. Meanwhile, the environmental standards for surface water in The Netherlands specified in the 4th Article on Water Quality Management, the European Bathing Water directives (76/160/EEG) and Hazardous Substances directives (76/464/EEG) still apply. Depending on the desired biological condition of surface water it is likely that region-specific standards will also be developed for nitrogen and phosphorous concentrations.

In several studies over the last few years it has become clear that WWTP-effluent forms a significant emission source for priority substances in regional surface water. In an initial national screening of the effluent produced by WWTPs it appeared that a certain number of the priority substances are regularly measured in WWTP-effluent. Emitted substances in WWTP-effluent can be reduced in a "point source" approach and/or "end-of-pipe" approach. Important principles in these approaches are for example "the polluter pays", "chance of success upon realisation of the desired objective within the required time-frame", "cost effectiveness" etc. National screenings of these principles have been carried out in the light of the Water Surveys (RIZA, 1999).

To what extent these measures will actually have a visible effect on the receiving surface water depends on other emission sources that influence the quality of the water bodies. This is location-specific and should be expressed in area-specific analyses that provide insight into the useful effect and the associated costs. Whatever the case, it is inevitable that measures will need to be taken at several wastewater treatment plants. This is discussed in the article "Pragmatic implementation of the WFD" (V&W, 2004).
In 2001 The Netherlands operated 389 WWTPs with a total capacity of 25.3 million population equivalents (P.E.), which altogether were loaded with approximately 18 million P.E. [CBS, 2004]. A relatively large number of these WWTPs release effluent into small regional water bodies; approximately 40 % of WWTP-effluent is released into brooks, lakes, small rivers and polders (see table 1). It has been calculated that in the case of 20 % of the WWTPs, the WWTP-

effluent constitutes more than 30 % of the receiving surface water flow. During the summer this percentage rises to 40 % of the WWTPs [Van der Horst, 2004]. For these locations the quality of the discharged WWTP-effluent will need to approach the WFD-standards to achieve the desired surface water quality. This concerns mainly the small- and medium-scale WWTPs with a design capacity of 10,000 – 100,000 P.E., but also a number of large WWTPs.

Whether investments in extra treatment steps will actually be required at WWTPs depends of course on future developments. This will depend initially on the quality of the receiving water body and subsequently (in case of inadequate quality) on the answer to the question as to which sources have an adverse effect on the surface water quality.

It will then be established which mix of point source approach and extra treatment of WWTP-effluent ("end-of-pipe" approach) will be applied to each water body. The final choice of the various measures will be specified in the River Basin Management Plans in 2009.

**TABLE 1** **DISTRIBUTION OF WWTP EMISSION INTO SURFACE WATER IN THE NETHERLANDS IN 2001 [CBS, 2004]**

| **Type of Water** | **Number of WWTPs** | **Actual load in 2001** | |
|---|---|---|---|
| | | **P.E. *1000 *)** | **% WWTP-load per water type** |
| Brooks | 55 | 2,361 | 14 |
| Canals | 68 | 2,962 | 15 |
| Small rivers | 33 | 2,400 | 14 |
| Lakes | 5 | 77 | 0.4 |
| Polder water | 111 | 2,208 | 12 |
| Rivers | 12 | 707 | 3 |
| Other | 2 | 36 | 0.2 |
| *Total regional water bodies* | *286* | *10,751* | *59* |
| | | | |
| Large rivers | 63 | 3,918 | 23 |
| Canals | 22 | 1,764 | 9 |
| Lakes | 7 | 330 | 2 |
| Salt water bodies managed by the State | 11 | 1,268 | 7 |
| *Total water bodies of the State* | *103* | *7,280* | *41* |
| *Total number of WWTPs* | *389* | *18,031* | *100* |

*) Population equivalents based on 54 g BOD/P.E./day

# 3

# RELEVANT SUBSTANCES

## 3.1 INTRODUCTION

One of the objectives of the Water Framework Directive is the achievement of a good chemical condition of all surface water bodies in 2015 (article 4, Directive 2000/60/EG). The good chemical condition is relevant for all substances for which environmental objectives have been formulated at EU level. This includes substances reported in the list of priority substances as well as substances included in the earlier European environmental directives (Appendix IX, directive 2000/60/EG), and for substances included in directives that may still be established in the near future. Based on article 4 and Appendix V of the WFD, European States should derive their own directives for all polluting substances that are important for a Member State or water body, based on the WFD-approach. Substances are considered “important” if they are released in significant amounts into the specific water bodies.

In this chapter the substances that is relevant for WWTPs and therefore also for the Exploratory Study for Wastewater Treatment Techniques and the European Water Framework Directive, are presented in a “list of substances”. This concerns substances that are present in WWTP-effluent and which have been shown in river basin characterisation reports to be present in levels higher than those specified in the standards for surface water. To achieve the not yet fully established discharge limits for these substances before 2015, extra treatment steps at the WWTP will be required, besides point source reduction measures.

## 3.2 LIST OF SUBSTANCES

For the set up of the List of Substances, European directives were used. Documents were also consulted regarding substances which adversely affect the environmental state upon release into the surface water, and for which the government has not yet set standards.

In this paragraph the directives and lists of substances derived from these directives will first be discussed. Finally, substances that influence the ecological condition of the water will be considered. The list of substances established in this chapter consists of 77 substances and is presented in Appendix I.

### DIRECTIVES

For the set up of the list of substances that are relevant for the WFD, the following substance directives were used:

- The list of priority and priority hazardous substances of the European Water Framework Directive (2000/60/EG).
  This list contains substances that are considered to be hazardous enough that their levels need to be systematically reduced in all European Member States. All priority and priority hazardous WFD-substances are included in the List of Substances in this report.

For priority substances, the measures are aimed at achieving a progressive reduction of emissions. The measures for priority hazardous substances are aimed at ceasing all emissions within 20 years (zero-discharge).

- The substances in List I of the Dangerous Substances Directive (76/464/EEG).
  The so-called "black" substances in List I of the Dangerous Substances Directive are included in the Basic Substances List in this report. The candidate substances in the "black list" are not included.
  For the specified "black" substances of the Dangerous Substances Directive the same required measures apply as for the priority and priority dangerous substances.
- The "relevant area-specific substances" of the International Commission for Protection of the Rhine and the Meuse.
  In The Netherlands the relevant river basin management district in the WFD are the Eems, Meuse, Schelde en Rhine. At the time of writing this report the lists of relevant substances were only available for the Rhine- and Meuse river basins. These substances are also included in the List of Substances.
- The biological parameters of the future European Bathing Water Directive
  (Com(2002) 581).
  Based on the new Bathing Water Directive, the microorganisms included under the Intestinal Enterococci and the strain of bacteria Escherichia coli have been included in the List.
  Although viruses are not yet included in the new EU Bathing Water Directive, it is expected that they will be included in future stricter directives. For this reason viruses have been included in the List of Substances.

### HORMONE DISRUPTERS AND MEDICINAL SUBSTANCES

Hormone disrupters negatively influence the ecology of water bodies and medicinal substances are also suspected of having a negative influence. There are as yet however no legal standards established for these substances in surface water. In the STOWA report 2004-W04, it is recommended to monitor certain hormone disrupters and medicinal substances due to their potential risk for water quality. From these lists, 9 substances have been selected for inclusion in the List of Substances, presented in Table 2

**TABLE 2** **SELECTED HORMONE DISRUPTERS AND MEDICINAL SUBSTANCES**

| Category | Substances |
|---|---|
| Hormone disrupters | 17 α-ethinyloestradiol<br>bisphenol A<br>oestrogen |
| Medicinal substances | ibuprofen<br>anhydro-erythromycine<br>sulphamethoxazol<br>carbamazepine<br>sotalol<br>amidotrizoic acid |

## 3.3 WWTP-EFFLUENT AND THE LIST OF SUBSTANCES

The List of Substances is shown in Appendix I. The list is divided into blue, yellow and purple columns:

- In the blue columns the surface water standards are reported for each substance (NB: these standards are therefore not applicable to WWTP-effluent). For each substance and each standard a colour code is allocated to indicate whether (according to expectations) the water quality standards in surface water will be exceeded.

- In the yellow columns it is indicated how frequently and in which concentration range the substances have been detected in WWTP effluent, up until the present day.
- In the purple columns an indication is given as to whether the substance is considered relevant for WWTP. The level of relevance is divided into three levels (orange, yellow or green):
  - If the substance occurs in WWTP-effluent and exceeds the discharge standard for surface water, the substance is marked with orange.
  - Substances that have been detected in WWTP-effluent but which do not exceed allowed levels in surface water are marked as yellow (restricted relevance).
  - If the substance is measured in less than 5% of the measurements of WWTP-effluent it is marked with green, regardless of whether the substance exceeds the surface water standards or not.

The data presented in the table come from a data file of RIZA. In this file (Watson) the research results over the period 2000 – 2004 are given for a large number of substances. This file is supplemented with inventories from certain regional water quality managers and forms the basis for the given concentration range, within which the various substances in WWTP-effluent have been shown to be present in WWTP effluent.

Based on the current available information, the following WWTP-relevant substances are important:

- the nutrients nitrogen and phosphorous;
- certain polyaromatic hydrocarbons;
- the pesticides hexachlorocyclohexane, atrazine and diuron;
- the metal ions cadmium, copper, zinc, lead and nickel;
- a plasticising additive DEHP (diethylhexylpthalate).

As yet there has been no testing of brominated diphenyl ethers or octyl-/nonylphenol compounds, however based on the general occurrence of these substances in WWTP-effluent and the low concentrations at which they cause adverse effects on aquatic organisms, these substances are also considered as being relevant to WWTPs.

This selection is a snapshot in time based on the current available information. As more information becomes available it is possible that the information shown in the table changes.

# 4

# TREATMENT TECHNIQUES

## 4.1 INTRODUCTION

In order to achieve the required ecological and chemical quality of surface water in 2015, extra discharge treatment steps will have to be implemented at WWTPs. This may require a different approach for each WWTP, depending on the occurrence of substances in the effluent, the configuration of the WWTP, the nature of the receiving water body and the contribution of the effluent load of contaminants to the total loading of the surface water.

This chapter discusses water treatment techniques that can potentially be applied to WWTPs to achieve the new effluent standards The selection of techniques is based on literature, inventory studies by water authorities and knowledge institutes and expert judgement. In this case special attention is given to documented full-scale applications, pilot-scale studies and estimated feasibility.
The selection of techniques for the Short List is based on literature, inventory studies by water authorities and knowledge institutes, and expert judgement. In this case special attention is given to documented full-scale applications, pilot-scale studies and estimated feasibility.

For each applicable technique a Fact Sheet has been created, in which the technical background, treatment principle, design guidelines and costs are presented (see Appendix III). Before the techniques are described, the nature of WWTP-effluent is discussed in relation to the consequences for treatment techniques. At the end of this chapter a summary table is presented in which potential techniques for the removal of the problem substances from effluent is presented.

## 4.2 CHARACTERISTICS OF EFFLUENT IN RELATION TO WATER TREATMENT TECHNIQUES

The efficiency of treatment techniques for the removal of priority substances, which occur typically in extremely low concentrations, is strongly influenced by the characteristics of the effluent as a whole and the presence of other components. It is therefore useful to first consider the relationship between the effluent characteristics and the influence of these characteristics on the techniques.

Table 3 indicates the typical composition of the effluent of modern WWTPs that achieve the discharge standards specified in the Urban WasteWater Directive (see STOWA 2001-14).

TABLE 3 COMPOSITION OF WWTP-EFFLUENT

| Parameter | Unit | Minimum | Average | Maximum |
|---|---|---|---|---|
| temperature | °C | 5 | 12-15 | 25 |
| pH | - | 7.1 | 7.8 | 8.2 |
| total hardness | mmol/l | - | 1-2.5 | - |
| suspended solids | mg/l | 1 | 5-8 | 20 |
| COD | mg/l | 15 | 30-40 | 70 |
| BOD | mg/l | 1 | 2-4 | 16 |
| chloride | mg/l | 24 | 70-110 | 165 |
| sulphate | mg/l | 30 | 60-110 | 180 |
| electrical conductivity | mS/m | 30 | 60-80 | 120 |

For the effectiveness of treatment techniques aimed at advanced removal of substances, the following aspects are important:

### TEMPERATURE

The temperature influences the efficiency of biological treatment processes. In addition, the viscosity of the water is temperature dependent. At low temperatures the viscosity of the water increases, resulting in slower filtration processes. These effects are important for the design of treatment systems, especially if the treatment objectives need to be achieved at temperatures lower than 10 °C.

### NEUTRAL PH

Effluent has a relatively neutral pH and is buffered by bicarbonate in mmol/l concentrations. The removal of metals or phosphate by increasing the pH therefore requires the addition of large amounts of hydroxide and results in the precipitation of calcium carbonate as a side effect. To prevent this, bicarbonate would first need to be removed by acidification and $CO_2$-stripping. Altogether adjustment of the pH requires high chemical consumption.

### SUSPENDED SOLIDS

The suspended solids in the effluent can clog filter systems (sand filters, activated carbon filters, membranes). Sand filters, micro- and ultrafiltration membranes can be backwashed to remove the accumulated solids. Backwashing is not possible with activated carbon filters as the adsorption process cannot be disturbed. Spiral nano- and hyperfiltration membranes also cannot be backwashed. To prevent accumulation of solids in these systems a pre-treatment step is necessary for removal of suspended solids.

Suspended solids contain relatively high concentrations of hydrophobic organic pollutants (characterised by a highoctanol/water distribution coefficient). Heavy metal salts with low solubility are also dispersed within organic suspended solids. This explains why the removal of suspended solids also removes a significant fraction of metals and organic micro-pollutants.

### ORGANIC MACRO-MOLECULES

During the degradation processes in activated sludge, dissolved organic macro-molecules are released, such as humic and fulvic acids, components of the bacterial cell wall and cellular nucleic acids. These cause the presence of COD (in low mg/l concentrations), organic nitrogen (0.5 – 1.5 mg/l) and phosphate (< 0.5 mg/l) in the effluent. The dissolved organic compounds contain active groups that can bond with metal ions. This means on the one hand that metal ions can be protected from removal by adsorption/bonding to the dissolved solids and on the other hand it can enhance their removal during removal of dissolved organic solids.

The presence of dissolved organic material can interfere with treatment techniques such as adsorption or advanced oxidation, which are focused on the removal of micro-pollutants. This is due to the fact that a fraction of the adsorptive surface or oxidative compound is consumed due to reaction with the dissolved organic compounds, leaving less surface area available for the adsorption of micro-contaminants. It is important to realise here that the concentration of dissolved organic material is present in concentrations that are a factor 100 – 1000 times higher than the concentration of the micro-pollutants that need to be removed. Another effect is the colour of the organic material. The application of UV for disinfection or advanced oxidation colour removal requires a high radiation intensity.

### DEGRADABLE ORGANICE MATTER

The remaining degradable organic material, expressed as the BOD content of the effluent, can result in biofouling of membrane systems. Biological treatment systems aimed at removal of micro-pollutants by specialised biomass can fail because they become overgrown by general BOD-consuming heterotrophic biomass. The general BOD-consuming biomass has a much larger available substrate supply (milligrams instead of micrograms per litre) than the biomass growing specifically on micro-pollutants.

### DISSOLVED SALTS

Effluent contains several hundred mg/l dissolved salts, expressed as the parameters electrical conductivity, residue after evaporation or concentrations of chloride and sulphate. During the application of nanofiltration or reverse osmosis as treatment techniques, a fraction of the dissolved salts is retained. This can result in salt accumulation in the treatment system, with subsequent precipitation as a result and other undesired effects. Macro-ions such as calcium and magnesium can compete with the heavy metals that need to be removed during the application of ion exchange. This requires the application of selective ion exchange resins that remove specific heavy metals.

From this overview it appears that treatment techniques cannot be selected purely based on their ability to remove micro-pollutants. Other effluent characteristics can strongly influence their efficiency. It is therefore necessary to practice caution when using the results of other treatment applications for the treatment of WWTP-effluent. Industrial waste streams are often concentrated and small, while WWTP-effluent is very dilute with a large volume. For the application of drinking water techniques on WWTP-effluent special attention should be paid to the high concentrations of suspended solids and dissolved organic material. For a well-founded assessment of a certain technique it should at least first be tested on WWTP-effluent at semi-full scale.

## 4.3 APPLICABLE TREATMENT TECHNIQUES

From the broad range of potential treatment techniques, a selection has been made of applicable techniques in the light of the WFD. Applicable treatment techniques should fulfil the following criteria:

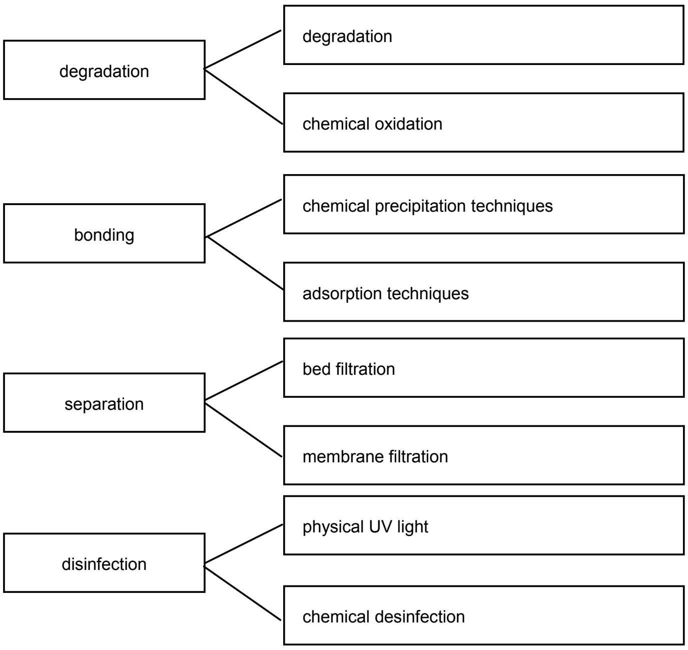
- (potentially) capable of removing the described problematic substances to the levels presented in the standards in Appendix I;
- applicable at full-scale by 2009;
- capable of treating large flows;
- preferably capable of removing a broad range of substances;
- preferably require little energy, space and additives.

In addition to well-known techniques for wastewater treatment, techniques from other water treatment areas are also applicable, such as industrial water treatment and drinking water production. In all cases it is assumed that the WWTP consists of an activated sludge system, such as is the case in The Netherlands, to which extra techniques can be added/integrated. This may include end-of-pipe techniques located after the activated sludge system, or integrated techniques that be incorporated into the activated sludge system itself.

The additional treatment steps can be divided according to their treatment principle:
- degradation techniques: break down substances at the molecular level;
- bonding techniques: remove substances from a waste stream by precipitation (chemical bonding) or adsorption (physical bonding);
- separation techniques: separate the effluent into a clean main stream that is released into surface water and a residue stream in which the pollutants are concentrated;
- disinfection techniques: kill microorganisms to achieve satisfactory disinfection.

Some techniques combine more than one of these principles.

**FIGURE 1** DIVISION OF TECHNIQUES INTO TREATMENT PRINCIPLE



According to the selection criterion “applicable in 2009”, a number of techniques have been excluded from this report. This concerns techniques that are not yet ready for application or which are not appropriate for treatment of large waste streams with low concentrations of pollutants. It also concerns techniques that consume relatively large amounts of energy, chemicals and/or building space, where other alternative techniques are available that do not have these disadvantages.

In appendix II an overview is given of the selected techniques and the techniques that, based on the above-mentioned criteria, will not be considered further.

Under the term separation techniques, sedimentation and flotation techniques will not be considered further. In comparison to filtration these techniques have a lower efficiency and require more building space, while the advantage of the high solids handling capacity of these techniques does not play a decisive role in the WFD-scenario.
In the following paragraphs the techniques that are considered applicable for further treatment of WWTP-effluent are described. Essentially it is also possible to apply techniques that are integrated into the activated sludge treatment process. These treatment techniques are considered in more detail in paragraph 4.3.8.

### 4.3.1 BIOLOGICAL TECHNIQUES

#### LIMITATIONS OF THE CONVENTIONAL ACTIVATED SLUDGE SYSTEM

Since the implementation of the environmental standard Urban Wastewater Directive, most of the Dutch WWTPs achieve an effluent quality of maximum 10 mg Ntotal/l and 1 – 2 mg Ptotal/l. In many upgraded WWTPs it appears that effluent concentrations of 4 – 6 mg Ntoaal/l and 0.3 – 0.7 mg Ptotal/l are achievable, due to the combination of a favorable wastewater composition, very low sludge loading rates, optimised biological N- and P-processes and an adequate process control. Although this surpasses the effluent quality specified in the Urban Wastewater Directive, the MTR-standards for surface water (2.2 mg Ntotal/l, 0.15 mg Ptotal/l) are not attainable in existing activated sludge systems. This study focuses therefore on additional techniques that have a relatively high probability of being able to achieve the WFD-water quality goals, assuming the WWTP fulfills the requirements of the Urban Wastewater Directive (10 mg Ntotal/l, 1 mg Ptotal/l). The upgrading of existing activated sludge systems from the Urban Wastewater Directive standard to the improved effluent quality is not within the scope of this report.

#### MEMBRANE BIOREACTOR (MBR)

The MBR is an activated sludge system in which the sludge/water separation step takes place via micro- or ultrafiltration membranes, instead of in secondary clarifiers. The activated sludge process works in the same manner as a conventional WWTP, except that the higher applicable sludge concentration enables a larger volume of biomass to be contained within the same activated sludge volume, providing a higher intensity of the biological processes. If comparing the MBR with a conventional system containing the same sludge concentration, similar partitioning (number of compartments) and process conditions, the MBR behaves biologically in exactly the same manner as a conventional WWTP. Where the effluent quality and the removal of problematic substances is concerned, the most relevant advantage of the MBR is the complete removal of fine suspended solids and colloidal substances (and the pollutants attached to these) by the micro- or ultrafiltration membranes, instead of secondary clarification. In addition, the higher sludge concentration in the MBR enables an improved biological treatment in situations where space is limited.

In several Dutch pilot-scale research projects it has been shown that the MTR-quality for nitrogen and phosphate is achievable in an MBR, provided extra measures are taken such as dosage of a C-source for denitrification and extra chemical dosage for phosphate removal.

### ADVANCED NITROGEN REMOVAL

Biological removal of nitrogen molecules by nitrification and/or denitrification is an important technique in effluent treatment. The required biomass is generally in the form of a biofilm in a bed of granular material with 1 to several millimetres diameter. In nitrification systems the incoming water is aerated; in denitrification systems a C-source is added (usually methanol or acetate) in an anoxic environment. Depending on the mode of operation the granular bed can consist of different types of material, the water can flow upwards or downwards and the bacterial growth and retained suspended solids can be removed by different modes of backwashing. In the case of the application of a nitrification filter for the removal of excess ammonium, a denitrification filter needs to follow the nitrification filter, so that the final step can be dedicated to nitrate removal. A typical design construction of this post-treatment principle is the continuous upflow sand filter with preceding methanol dosage

### ADVANCED REMOVAL OF ORGANIC CONTAMINANTS

Biological removal of organic components from WWTP-effluent can involve the following processes:

1. physical/chemical bonding of particles or macro-molecules to biomass, followed (possibly) by hydrolysis to smaller dissolved molecules;
2. active uptake of dissolved molecules through the cell wall of the bacterial cell;
3. degradation within the cell.

NB 1. The physical-chemical bonding, a non-specific process, is the most important process for the removal of micro-pollutants in the main activated sludge process. The pollutants are removed (without further degradation) with the removed surplus sludge.

NB 2. The biological removal of remaining organic pollutants that have passed through the activated sludge process requires a large population of specialised bacteria that use these substances as substrate. An important problem with this is that their substrate is present in very small concentrations (maximum a few dozen μg/l), making it impossible to enrich and maintain biomass on these substrates. The total remaining BOD in the effluent (3 – 5 mg/l) is already insufficient to maintain any kind of bacterial population.

> **EXAMPLE CALCULATION**
>
> Consider a filter or post-MBR system with a sludge concentration of 10 g/l, contact time of 0.5 h and an incoming BOD-concentration of 5 mg BOD/l. The sludge-loading rate is 0.024 kg BOD/kg MLSS.d. At a biological yield of 0.5 kg MLSS/kg BOD, the sludge age is approximately 80 days. This is extremely long for maintenance of biological ac-tivated sludge. Because organic micro-pollutants occur in concentrations of a factor 50 – 100 lower, the growth of a bacterial population on these substances is extremely difficult, if not impossible. Biological techniques are therefore only applicable for concentrated waste streams in which no degradable components are present in concentrations much higher than the contaminants to be removed.

NB 3. Organic macro-pollutants and nutrients (in the mg/l range) can be removed by systems in which sufficient biomass is retained in the system (for example biofilm reactors, MBR or wetland systems), provided the contaminants do not have to be removed down to the μg/l level.

In the last few decades a large amount of research has been conducted into the biological breakdown of specific contaminants in industrial wastewater and polluted groundwater. There is still little information available regarding the biological oxidation and/or removal of contaminants from WWTP-effluent. Research conducted by the Water Board of Wetterskip Fryslân showed that an MBR post-treatment system was capable of removing hormones and medicinal residues from WWTP-effluent. Pesticides (e.g. simazine) were however not effectively removed.

### POND TREATMENT SYSTEMS

Pond systems or helophyte filters have been applied at several locations in The Netherlands for the treatment of raw wastewater or for effluent polishing. In small-scale (individual) applications, vertical flow systems have also been used, in which the wastewater passes a root zone; for the treatment of WWTP-effluent, from a practical viewpoint only pond systems or horizontal flow helophyte filters are applicable. In these systems certain types of reed are planted whose stalks and roots have a filtering effect on suspended solids, and upon which biofilms can easily grow for the removal of nutrients and remaining organic compounds. In comparison to bioreactors, the concentration of biomass in pond systems is limited, the effectiveness of the process is strongly dependent on the season and it is impossible to influence the process conditions. The treatment efficiencies for total nitrogen and phosphorous are generally not higher than 30 – 50 %. A large surface area is also required.

To systematically achieve the WFD-standards, pond systems are not considered applicable. The technique does have useful side effects; after several days of contact time pathogenic bacteria die off. An advantage is also that the character of the water changes (becomes more “natural”) because algae and water fleas replace the presence of flushed-out activated sludge flocs. Within in the WFD the chemical standards serve the ecological standards. From this point of view helophyte filters could contribute in the sense that they have an ‘ecology-enhancing’ effect on the effluent.

For the following biological treatment techniques Fact Sheets have been set up:
- membrane bioreactors (fact sheet no.1);
- (de)nitrifying sand filters (fact sheet no.2).

### CONCLUSIONS

From a biological viewpoint the MBR is comparable to an optimised conventional activated sludge system with a post-treatment step by MF- or UF-membrane filtration; the difference in effluent quality is determined by the separation efficiency of the membrane system in comparison to a secondary clarifier. In several full-scale research projects in The Netherlands it has been shown that the MTR-effluent quality for nitrogen and phosphorous is attainable with the MBR, provided extra measures are implemented such as dosage of a C-source and extra chemical dosage for phosphate removal. Biological techniques are effective for the removal of nutrients in the concentration range of a few mg/l. They are however not effective for the removal of organic contaminants to the level of µg/l concentrations, because these concentrations are too low to enable the growth of a biomass population, due to competition with the higher numbers of general heterotrophic bacteria.

Pond systems can effectively remove pathogenic organisms at a sufficiently long contact time. Due to the low density of biomass and the sensitivity of this technique to disturbances, the efficiency of the biological degradation processes is limited. On the other hand, pond systems may contribute to achieving the ecological standards.

### 4.3.2 OXIDATIVE TECHNIQUES

Oxidative techniques are used to “crack” organic compounds with the aid of strong oxidants such as ozone or hydrogen peroxide. They are applied for the oxidation of organic contaminants. Some oxidants can also be applied for disinfection. The treatment principle involves a non-specific reaction of the oxidant with the organic compounds, which are oxidised and partially degraded to smaller molecules. The extent to which the process proceeds depends directly on the nature of the organic compounds, the nature and the concentration of dosed oxidant and the contact time.

A specific branch of oxidation processes is the Advanced Oxidation Processes (AOP). By combining oxidation techniques, free radicals can be formed which cause the oxidation processes to proceed by a factor of 10 to several thousand times faster. Applicable combinations are ozone/hydrogen peroxide, ozone/UV and UV/hydrogen peroxide.

An important advantage of chemical oxidation is that it is effective for contaminants in extremely low concentrations (μg/l). Especially with advanced oxidation (e.g. UV/$H_2O_2$), it has been shown that high removal efficiencies are possible, even in some cases for the treatment of WWTP-effluent. High UV-intensities are however required. A particular point of importance is the required UV-dosage in relation to the transmission (turbidity) of the effluent, which is negatively influenced by dissolved and suspended organic material. Removal of these components in an effective pre-treatment step is essential.

More information is available concerning the removal of micro-contaminants from effluent using conventional oxidation than for advanced oxidation. The capital and energy costs of oxidation with UV are relatively high. Possibly, these costs are lower for oxidative techniques without UV-light, such as ozone/$H_2O_2$, which makes them more promising for full-scale application to WWTP-effluent. However, the efficiency and formation of by-products of these processes will have to be investigated.

One advantage of oxidation in comparison to other treatment techniques is that no waste streams are produced. It is however possible during oxidation that undesirable by-products may be produced that are suspected of having carcinogenic properties, such as bromates which may be formed when using ozone. Another drawback is that during incomplete oxidation to $CO_2$ and $H_2O$, unknown degradation products are formed. In drinking water production it has been shown that the degradation products are in general less toxic than the original compounds; this is however not guaranteed for all types of problematic substances. Before discharging the effluent, residues of the oxidant will have to be removed from the treated water, for example by dosing a reducing agent or a (short) treatment in an activated carbon filter.
The use of chlorine to reach the WFD-standards is not desirable due to the production of chlorinated by-products.

For the advanced oxidation processes (AOP: UV / $H_2O_2$, ozone / $H_2O_2$, ozone / UV) a fact sheet has been set up (fact sheet no. 3).

**CONCLUSIONS**

Oxidative techniques (specifically advanced oxidation) are potentially applicable for the removal of organic micro-contaminants from WWTP-effluent in the required concentration range. The effectiveness for treatment of WWTP-effluent has however not yet been clearly demonstrated. The relatively high concentrations of organic compounds in WWTP-effluent require an effective pre-treatment. Due to the high costs of advanced oxidation in combination with UV, alternative combinations without UV are recommended to improve the feasibility of advanced oxidation for effluent treatment. The formation of by-products and their possible toxicity is a point requiring particular attention during application of oxidation.

### 4.3.3 CHEMICAL PRECIPITATION TECHNIQUES

Chemical precipitation is the addition of chemicals to water that bind with other substances in the form of a precipitate, which is subsequently removed. Examples of techniques that form a so-called “precipitate” are precipitation, coagulation and flocculation.

**PRECIPITATION**

is the most direct form of chemical bonding, as the substances to be removed form an insoluble product with the dosed chemicals, which precipitate out of solution. In the treatment of WWTP-effluent, precipitation of phosphate with iron or aluminum salts is a commonly applied technique.

Other insoluble products can also be formed between heavy metals and hydroxide or sulphate ions. This principle is applied in the treatment of industrial waste streams. To reduce the metal ion concentrations to the required levels, however, high pH values or sulphide concentrations are necessary. A significant practical problem with pH-correction before and after treatment is that large quantities of chemicals are necessary. High sulphide concentrations in the treated water are also undesirable. Due to these disadvantages the use of this form of precipitation for treatment of WWTP-effluent is not considered feasible.

**COAGULATION/FLOCCULATION**

Coagulation/flocculation is based on the idea that contaminants are retained in a network of flocs, which are then removed in a subsequent settling or filtration step. The process begins with the dosage of a coagulant (usually Fe- or Al-salts) which polymerises in water to form a network of positively charged groups. Due to the attraction between opposite charges, the flocculent attaches to dissolved organic molecules, whose charge is then neutralised, causing them to floc out of solution. Colloidal and fine particles become retained in the growing network and metal ions become incorporated into the crystal lattice. After an initial intensive mixing phase, gentle mixing conditions are provided in which the growing flocs gradually form larger flocs that settle efficiently out of solution.

**FLOC REMOVAL**

The precipitate produced can essentially be removed by settling, flotation or filtration. Aside from an effective precipitate formation, the efficiency of the coagulation/flocculation process is also determined by the separation of flocs from solution. Filtration is typically the preferred separation technique used in effluent treatment due to the compact construction and effective separation efficiency. In the following paragraphs the different types of available filter configurations will be discussed.

### RESIDUE PRODUCTS

The dosed coagulant and flocculent emerge in the residual waste stream as a chemical sludge. If high dosage concentrations are necessary to achieve the required removal efficiency, the amount of chemical sludge produced can be many times higher than the amount of contaminants removed. The residual waste stream will typically be mixed with the backwash water of the filtration system and subsequently be removed together with the surplus sludge generated in the activated sludge process.

### COAGULATION/FLOCCULATION IN COMBINATION WITH SUSPENDED SOLIDS REMOVAL

Since direct filtration of effluent typically has a limited ability to remove very fine suspended particles (except in the case of nano- and hyperfiltration), filtration is typically combined with coagulation/flocculation. This is especially the case with sand filtration and to a lesser extent for micro/ultrafiltration. In the latter technique, however, it appears that coagulant dosage can effectively improve the filtration process and extend the production time between backwash steps.

In different treatment scenarios the combination of coagulation, floc-formation (flocculation) and filtration are typically applied for the removal of suspended particles, phosphate and a fraction of the dissolved macromolecules. A distinction can be made hereby between the application of in-line coagulation followed by filtration in which the floc formation and floc separation are performed in the filter bed (*flocking filtration*), and application of a separate coagulation and floc forming step followed by filtration for floc separation (*floc filtration*). Due to the simplicity and low costs, flocking filtration is preferred. In the case where the water quality leads to an unstable or incomplete floc formation, floc filtration is preferred, since the floc forming process can be optimised and better controlled.

Fact Sheets have been created for the following techniques:
- Precipitation, coagulation and flocculation (fact sheet no. 5).

### CONCLUSION

Coagulation/flocculation is a suitable technique for the removal of suspended solids and colloidal material, to which micro-contaminants and heavy metals are often attached. The application of coagulation/flocculation in combination with filtration techniques can result in very effective removal of suspended solids. The technique is not suited to the removal of specific dissolved substances in the μg/l range. Disadvantages are the chemical consumption and subsequent chemical sludge production. The extra sludge can be treated together with the surplus sludge stream in the main process.

Precipitation techniques are suitable for the reduction of phosphate levels to a few mg/l. WWTP effluent, without further treatment, contains a few μg/l of metals, depending on the specific metal. It is questionable whether precipitation techniques can further decrease these concentrations.

### 4.3.4 ADSORPTION TECHNIQUES

Adsorption refers to the attachment of substances in the water phase to a fixed surface. For the treatment of effluent the following types of adsorbents are available:

- activated carbon: the bonding of non-polar organic compounds due to Van der Waals forces;
- ion exchange: bonding of ions to specific charged groups on the surface of a synthetic resin;
- other adsorptive surfaces with some kind of affinity for organic and/or inorganic components.

Important criteria for the adsorbent material (regardless of the type of treatment principle) are:

- a high specificity for the contaminant, such that low concentrations are attained and other components are not adsorbed;
- the surface area is as large as possible such that the maximum amount of adsorption occurs per unit adsorptive material;
- preferably capable of releasing the adsorbed components under controlled conditions via a technically and economically acceptable discharge route and the possibility to reuse the resin (less preferable alternative: discharge of adsorbent complete with contaminants as waste residue).

#### ACTIVATED CARBON

Activated carbon is a commonly used and reliable technique for the removal of non-polar organic contaminants to very low concentrations. In activated carbon filtration the effluent is led over a fixed bed of granular activated carbon. Essentially all organic compounds presented in the List of Substances can be removed from WWTP-effluent. The standing time of the filter bed varies per substance. Humic-type of dissolved organic macro-molecules are also removed; in practice it appears however that humic substances do not interfere with the removal of the contaminants: the removal of contaminants continues when humic substances have already reached breakthrough point. Several filters are typically used in series, such that the first filter can be regenerated once it becomes saturated. The most commonly used granule types can be regenerated by the manufacturer. The removed adsorbed organic contaminants are then incinerated.

To maintain a clearly discernible adsorption front in the carbon column, backwashing is generally not desirable. Pre-treatment for the removal of suspended solids is therefore necessary to prevent clogging of the column.

One possible financially interesting alternative is the use of powdered activated carbon (PAC) in combination with a filtration technique (e.g. flocking filtration or denitrification filter). In this manner removal of organic contaminants can take place without investing in an extra filter step. One practical limitation is however that powdered activated carbon dosage should not lead to overloading of the filter. This application is only interesting if treatment objectives can be achieved with a low dosage (maximum dosage concentration 20 mg/l), since powdered activated carbon is more expensive than granular activated carbon per ton and it cannot be regenerated. The carbon is removed with the rest of the filter surplus sludge and treated in the sludge line of the WWTP.

#### ION EXCHANGE

Ion exchange resins are capable of bonding with dissolved heavy metals. A problem in the treatment of WWTP-effluent is however the competition between the heavy metals (in concentrations in the μg/l range) with the ions Ca and Mg (mg/l range). To remove heavy metals, ion exchange resins require a high specificity for heavy metals. The regeneration of ion exchange resins produces a residue stream in which the heavy metals are concentrated (residue stream volume: less than 1 % of the main stream).

There is very little experience with the application of ion exchange for the removal of heavy metals from WWTP-effluent. Full-scale experience with ion exchange is mainly available in the industrial wastewater treatment sector and to a limited extent in the drinking water production industry. It has been shown in laboratory research that specific resins can remove heavy metals in the μg/l range from surface water [Stetter et al. 2002].

Fact Sheets are available for the following techniques:
- activated carbon (fact sheet no. 6)
- ion exchange (fact sheet no. 7)

#### CONCLUSION

Activated carbon filtration is a suitable technique for the removal of almost all-organic micro-contaminants and pesticides included in the WFD List of Priority Substances. The removal of suspended solids is necessary before activated carbon filtration. Granular activated carbon can be regenerated and reused, whereby no difficult waste products are produced.
The application of powdered activated carbon, followed by filtration, has potential if treatment objectives can be achieved with a low dosage. Further research is necessary in this area.

Once its suitability is proven, ion exchange is an interesting technique. An economically and technically feasible solution should be available for the treatment of the produced residue stream after regeneration of ion exchange resins.

### 4.3.5 BED FILTRATION

Bed filtration relies on the separation of particles from the water phase, while water flows through the pores in between the filter bed medium granules. The particles are removed by sieving, adsorption to the filter bed medium and settling onto the medium. The irregular pore size/structure and the different removal mechanisms in bed filtration means there is no clear specific granule size above which all particles are removed (in contrast to membrane filtration in which filtration occurs through a membrane with a certain nominal pore size). As an indication, it can be assumed that bed filtration is not capable of removing particles smaller than 1 – 1.5 μm, and above this particle size 100 % removal of particles cannot be guaranteed. To achieve the desired removal of fine particles and their attached contaminants it is generally necessary to combine filtration with pre-coagulation and flocculation (see paragraph 4.3.3).

Since the pore volume in the filter bed is large, there is significant room for precipitate formation and biological processes in the filter bed. Especially due to the growth of microorganisms in the pores, remaining substances, such as nitrate, can be removed. This technique is discussed in more detail in paragraph 4.3.1. and the corresponding Fact Sheet.

The most important types of bed filtration are the downflow and upflow fast(better: rapid?) filters. The downflow types need to be stopped regularly and backwashed in order to remove the retained solids and contaminants. In contrast, in the upflow configuration the filter bed medium is continuously removed from the bottom of the bed, washed and deposited back onto the top of the filter bed. The efficiency of both filter types increases with a decreasing medium granule size; on the other hand a fine granule bed cannot retain such high sludge concentrations. From experience it appears that downflow filters can achieve a better removal of suspended solids, while upflow filters can retain more sludge (and biomass), which is an advantage in the application of biofilm processes and/or high filter suspended solids and (if applicable) powdered activated carbon loading rates.

Slow sand filtration with fine sand and low loading rates (0.1 – 0.3 $m^3/m^2.h$) are used in the drinking water world for the removal of low concentrations of organic contaminants and for disinfection. Due to the large surface area required and the labour intensive cleaning process involving scraping off of the top layer, slow sand filtration is not considered feasible for the treatment of WWTP-effluent.

#### FACT SHEETS

- rapid bed filtration: continuous sand filtration, fixed bed filtration, multi media filtration (fact sheet no.8).

#### CONCLUSION

Bed filtration is a proven technique for particle removal from water. In order to obtain a high removal efficiency of suspended solids, the application of coagulation is generally necessary. Different chemicals can be added for different purposes, such as the addition of iron salts for phosphate removal or carbon source addition for nitrate removal.

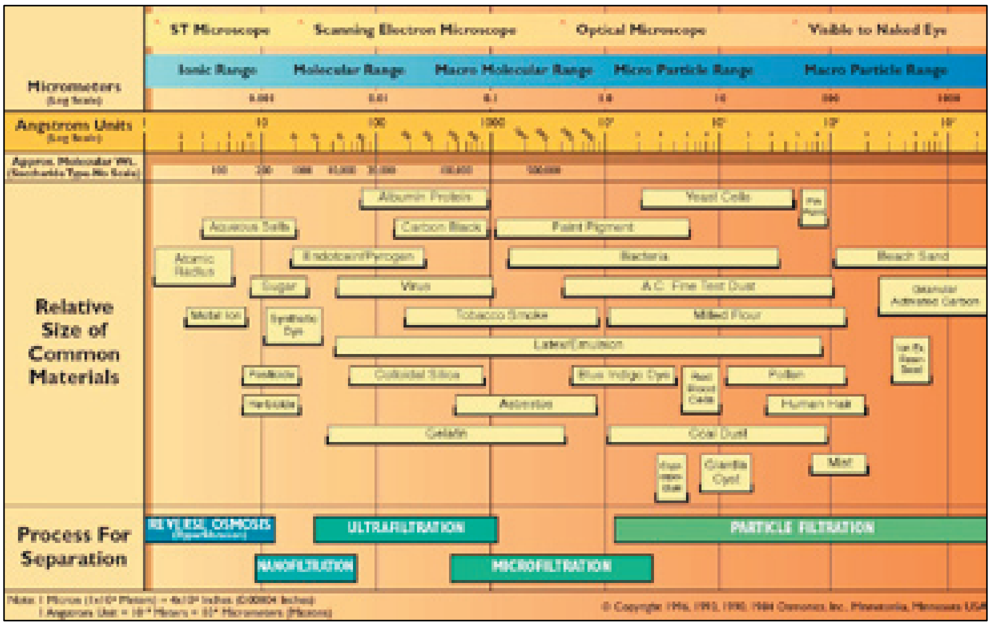
Bed filtration results in the production of an extra sludge stream, the size of which is dependent on the coagulant dosage and the pollutant removal efficiency. The produced sludge can be treated together with the surplus sludge from the activated sludge system.

### 4.3.6 SCREEN- AND MEMBRANE FILTRATION

This type of filtration works by passing water through a filter of a defined pore size. Only particles and molecules that are smaller than the pore size can pass through the filter. In contrast to bed filtration, these filter techniques do not contain spaces between the pores in which precipitates can form or in which biological degradation can take place.

Filtration processes can be divided into groups, based on their separation of respective particle diameters. Figure 2. presents an overview of the diameter application range for the different filtration techniques. In general, a distinction can be made between particle-related membrane filtration (micro- and ultrafiltration, separation diameter > 10 nm) and molecule-related membrane filtration (nano- and hyperfiltration, molecular weight cut off; removal efficiencies up to log 5).

**FIGURE 2** **DIAMETER APPLICATION RANGE OF DIFFERENT FILTRATION TECHNIQUES (OSMONICS LTD.)**



The removal of particles and colloidal components that are achieved, with micro- and ultrafiltration without addition of flocking agents, are higher than with bed filtration. This is illustrated in the removal of colloidal silica and gelatine by ultrafiltration in figure 2, while these substances cannot be removed with bed filtration (referred to here as 'particle filtration'). In contrast to the limited degree of disinfection achievable with rapid sand filters, ultrafiltration can achieve almost complete removal of bacteria and viruses.

During research into a conventional activated sludge system with post-flocking filtration and an MBR system at the Maasbommel WWTP, it appeared that both systems could achieve an effective removal of nutrients and micro-contaminants. The removal of microorganisms and viruses was clearly more effective in the MBR. This underlined the more efficient removal of very small particles by UF/MF in comparison to bed filtration.

Since half way through the nineteen nineties, several pilot-scale studies have been conducted at different WWTPs in the Netherlands, in which the recycling of effluent for reuse in different purposes has been investigated (including process water, boiler feed water, half-product drinking water). In these pilot studies both bed filtration and membrane filtration techniques were investigated. The eventual choice for bed filtration of membrane filtration techniques will be determined by the discharge standards imposed on the end water product. Micro- and ultrafiltration are typically used as "superior" pre-treatment for nano- or hyperfiltration. When the effluent standards are not as strict, financial considerations generally lead to the choice of bed filtration followed by a disinfection step.

In nanofiltration (NF) and hyperfiltration (HF) techniques, salts and dissolved organic (macro-)molecules are retained. The production of a concentrated brine solution requires special attention in this form of filtration. In NF/HF the brine stream produced constitutes 10 – 20 % of the main stream. The removed substances in the brine are concentrated to a factor of 5 or 10 higher than in the feed effluent. The integral evaporation of brine or the transport of brine for external treatment are not feasible. Unless substances can be selectively removed from the brine solution and the remaining solution can be released into the surface water, NF/HF is not an adequate technique for the production of high enough quality. At this point in time there is not enough information or practical experience available with this technique. Based on current insight, the application of nanofiltration with a separate concentrate treatment step is not considered feasible for the improvement of WWTP-effluent quality.

Different applications of membranes for effluent treatment are being investigated at pilot scale. Particular points requiring attention are the design (flux) in relation to operation, cleaning, energy consumption etc.

Fact Sheets:
- microfiltration, ultrafiltration (fact sheet no.9).

**CONCLUSION**

MF/UF are proven techniques for the removal of insoluble particles and pathogenic microorganisms. These membrane techniques can achieve a higher removal efficiency than sand filtration.

Molecular filtration (NF/HF) is only an applicable technique if a cost- and environmentally effective solution is available for treatment or disposal of brine.

### 4.3.7 DISINFECTION

Destruction of micro-organisms and the removal of viruses are applied if disinfection of the effluent is required, for example if extra standards apply due to the use of the water body for bathing purposes or as a livestock water source.

Effective disinfection can be achieved by:
1. filtration;
2. physical disinfection;
3. chemical disinfection.

NB 1. With the aid of micro- and ultrafiltration, bacteria can be retained (see paragraph 4.3.6.) With ultra-filtration an almost complete removal of viruses is possible.

NB 2. The best known physical form of disinfection is UV light (fact sheet no. 4). UV radiation affects the genetic material of microorganisms and viruses, preventing them from reproducing. The effectiveness of UV radiation is negatively affected by the presence of suspended solids in the water (provides protection for microbes against UV light) or by colour in the water (faster extinction of light). Pre-treatment aimed at the removal of suspended solids is therefore required in many cases.

NB 3. Chemical disinfection relies on the degradation of microorganisms by the oxidation of their cell and genetic material, preventing them from being able to reproduce. A commonly used form of disinfection is the use of chlorine (also in the form of sodium hypochlorite or chlorine dioxide). Although chlorine is a relatively cheap and manageable technique, its use is undesirable due to the formation of chlorinated by-products which are then released into surface water; this is contradictory to the objectives of the WFD. Chemical disinfection is also possible with ozone (see par. 4.3.2.) or with an advanced oxidation technique, which is aimed at removal of micro-contaminants (see par. 4.3.2.).

### 4.3.8 INTEGRATED TREATMENT TECHNIQUES

Integrated treatment techniques are techniques that are added to or combined with conventional activated sludge systems so that a better effluent quality can be achieved. These techniques usually achieve a better removal of specific substances or components from effluent. To achieve all objectives outlined in the WFD, extra treatment steps must be added. The following integrated treatment options are possible:

- membrane bioreactor; see paragraph 4.3.1.;
- dosage of powdered activated carbon (PAC) in the activated sludge process; the dosage of PAC during biological treatment of wastewater is a proven technique for the treatment of industrial wastewater that is (heavily) polluted with organic micro-pollutants and/or pesticides. For the application of PAC in communal wastewater treatment the same considerations apply as those described for adsorption techniques in paragraph 4.3.4. Due to the competition with humus like macromolecules and the growth of biomass on the activated carbon, the efficiency of this integrated technique is limited. In addition to this, the lowering of the sludge age due to the addition of PAC is a risk, resulting in a negative influence on other biological processes (such as the nitrogen removal). Based on these considerations, separate treatment of WWTP effluent with powder activated carbon is deemed more effective than dosage of powder activated carbon in the activated sludge process. Therefore the application of powdered activated carbon in the activated sludge process for obtaining the WFD-objectives will not be considered further.
- treatment of high ammonium-containing streams such as sludge digester rejection water; these techniques (including Sharon, Anammox, CANON, Babe) are aimed at reducing the nitrogen load to the main process, leading to an improvement in the effluent quality, especially in highly loaded systems. For the actual realisation of the WFD-treatment objectives however, combination with a post-treatment step is necessary. Bio-augmentation is a technique where a specific bioculture is seeded in the activated sludge system, where this bioculture cannot survive for a longer period of time. The application of this technique is therefore not a sustainable solution for the removal of WFD-substances with a continuous flow. For peak loads this technique may be considered, if the arrival time of the concentration peak is known early enough. For a WWTP this technique is therefore less suitable.

### 4.3.9 TECHNIQUES AND SUBSTANCES

Based on the List of Substances and the characteristics of the described techniques, an overview is presented in table 4 of the applicable techniques for the removal of the different substances and groups of substances. Whether or not a substance in the List of Substances will actually be removed with a specific technique depends not only on the physical-chemical characteristics of the substance to be removed, but also on the characteristics that are required by the specific technique, in order to be removed.

For the evaluation of the applicability of adsorption techniques the *polarity* (expressed as *log Kow* or *log P*) is the most important parameter used. For the molecular removal techniques the *molecular weight (Mw)* is used as an indication of the molecule size. The log Kow values and the molecular weights of the WFD substances are shown in table 4.

The removal efficiencies predicted for the different techniques for the treatment of WWTP-effluent are primarily based on the efficiencies experienced with these techniques in other branches of the water industry, under other conditions. For the interpretation of these results for application to effluent polishing, the authors have used their practical experience and knowledge in the fields of effluent polishing, industrial wastewater treatment and the production of drinking water. It is recommended to test the new configurations in cases where very low discharge standards are defined. This also applies to cases where changes in the composition and characteristics of the water can have a large effect on the efficiency of new configurations (e.g. during interference by dissolved and particle forming organic substances).

**TABLE 4** **EFFECTIVENESS OF TREATMENT TECHNIQUES PER SUBSTANCE**

| | | | | Degradation | | | | Bonding | | Separation | | | Disinfection | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Molecular weight | Log Kow | Relevant substance for WWTP & WFD | > Pond Systems | > (De)nitrifying filters | > MBR | > Advanced Oxidation (e.g. UV / $H_2O_2$) | > Coagulation/flocculation (+ filtration) | > Activated carbon | > Microfiltration/Ultrafiltration | > Nanofiltration | > Sand filtration (without coagulation) | > UV | > Ozone |
| **Nutrients** | | | | | | | | | | | | | | |
| Total - Phosphorous | - | - | + | o | o | + | - | + | - | - | + | o | - | - |
| Total - Nitrogen | - | - | + | o | + | + | - | - | - | - | - | - | - | - |
| **Micro-organisms & Viruses** | | | | | | | | | | | | | | |
| Intestinal enterococci | - | - | + | o | - | + | + | o | - | + | + | o | + | + |
| Escherichia coli | - | - | + | o | - | + | + | o | - | + | + | o | + | + |
| Viruses | - | - | + | o | - | + | + | - | - | o | + | - | o/+ | + |
| **Organic Micro Pollutants** | | | | | | | | | | | | | | |
| 4-chloro-anilin | 128 | 1.83 | o | - | - | - | + | - | + | - | +/? | - | - | - |
| Octylphenols | 206 | >4 | + | - | o? | o? | + | -? | + | -? | + | - | - | - |
| Nonylphenols | 220 | 3.7 | + | - | o? | o? | + | -? | + | -? | + | - | - | - |
| Bis(2-ethylexyl)phtalate (DEHP) | 390 | 6.2 | + | - | - | - | + | o? | + | o? | + | - | - | - |
| Benzene | 78 | 2.13 | - | - | - | - | + | - | + | - | +/? | - | - | - |
| Benzo-a-pyrene | 252 | 6.2 | + | o? | o? | o? | + | o? | + | o? | + | - | - | - |
| Fluoranthene | 128 | 5.07 | + | o? | o? | o? | + | o? | + | o? | +/? | - | - | - |
| Benzo-b-fluoranthene | 252 | 6.57 | + | o? | o? | o? | + | o? | + | o? | + | - | - | - |
| Benzo-k-fluoranthene | 252 | 6.84 | + | o? | o? | o? | + | o? | + | o? | + | - | - | - |
| Benzo(g,h,i)perylene | 276 | 6.9 | o | o? | o? | o? | + | o? | + | o? | + | - | - | - |
| Indeno(1,2,3-cd)pyrene | 276 | 6,65 | + | o? | o? | o? | + | o? | + | o? | + | - | - | - |
| Antracene | 178 | 4.5 | + | o? | o? | o? | + | o? | + | o? | +/? | - | - | - |
| Naphtalene | 128 | 3.3 | + | - | - | o? | + | - | + | - | +/? | - | - | - |
| Dichloromethane | 85 | 1.25 | - | - | - | o? | + | - | - | - | +/? | - | - | - |
| Trichloromethane | 120 | 1.97 | o | - | - | o? | + | - | - | - | +/? | - | - | - |
| Tetrachloromethane | 154 | 2.64 | - | - | - | o? | + | - | - | - | +/? | - | - | - |
| 1,2-dichloroethane | 99 | 1.48 | - | - | - | o? | + | - | - | - | +/? | - | - | - |
| Trichloroethene | 132 | 2.42 | - | - | - | o? | + | - | - | - | +/? | - | - | - |
| Tetrachloroethene | 166 | 2.6 | - | - | - | o? | + | - | - | - | +/? | - | - | - |
| Hexachlorobutadiene | 261 | 4.78 | - | - | - | o? | + | - | + | - | + | - | - | - |
| C10-13 - chloroalkanes | - | >4.39 | o | - | - | o? | + | - | + | - | +/? | - | - | - |
| Trichlorobenzenes | 182 | 4 | - | - | - | o? | + | - | + | - | +/? | - | - | - |
| Hexachlorobenzene | 285 | 5.47 | - | - | - | o? | + | - | + | - | + | - | - | - |
| PCB-28 | 258 | 5.62 | - | o? | o? | o? | + | o? | + | o? | + | - | - | - |
| PCB-52 | 292 | 6.1 | - | o? | o? | o? | + | o? | + | o? | + | - | - | - |
| PCB-101 | 292 | 6.4 | - | o? | o? | o? | + | o? | + | o? | + | - | - | - |
| PCB-118 | 327 | > 6 | - | o? | o? | o? | + | o? | + | o? | + | - | - | - |
| PCB-138 | 361 | 6.83 | - | o? | o? | o? | + | o? | + | o? | + | - | - | - |
| PCB-153 | 361 | 6.82 | - | o? | o? | o? | + | o? | + | o? | + | - | - | - |
| PCB-180 | 396 | >7 | - | o? | o? | o? | + | o? | + | o? | + | - | - | - |
| Brominated diphenylethers (BDPEs) | - | >8 | + | o? | o? | o? | + | o? | + | o? | + | - | - | - |
| **Pesticides** | | | | | | | | | | | | | | |
| Dibutyltin compounds | - | - | - | - | - | o? | + | - | + | - | + | - | - | - |
| Tributyltin compounds (TBT) | - | - | - | - | - | o? | + | - | + | - | + | - | - | - |
| Hexachlorocyclohexane / HCH / Lindane | 291 | 3.7 | + | - | - | o? | + | - | + | - | + | - | - | - |
| Pentachlorobenzene | 251 | 5.03 | - | - | - | o? | + | - | + | - | + | - | - | - |
| DDT | 355 | 6.53 | - | - | - | o? | + | - | + | - | + | - | - | - |
| Pentachlorophenol (PCP) | 267 | 5.07 | o | - | - | o? | + | - | + | - | + | - | - | - |
| DRINS | - | >5 | - | - | - | o? | + | o? | + | o? | + | - | - | - |
| Simazine | 202 | 1.96 | - | - | - | o? | + | - | + | - | + | - | - | - |
| Atrazine | 216 | 2.34 | + | - | - | o? | + | - | + | - | + | - | - | - |
| Dichlorprop | 235 | ? | - | - | - | o? | + | - | + | - | + | - | - | - |
| MCPA | 201 | 3.13 | o | - | - | o? | + | - | + | - | + | - | - | - |
| Mecoprop (MCPP) | 215 | 3.25 | o | - | - | o? | + | - | + | - | + | - | - | - |
| Diuron | 233 | 2.55 | + | - | - | o? | + | - | + | - | + | - | - | - |
| Chlorotoluron | 213 | 2.29 | - | - | - | o? | + | - | + | - | + | - | - | - |
| Isoproturon | 206 | 2.25 | - | - | - | o? | + | - | + | - | + | - | - | - |
| Chlorpyrifos | 351 | 3.81 | - | - | - | o? | + | - | + | - | + | - | - | - |
| Dimethoaat | 229 | 0.7 | - | - | - | o? | + | - | + | - | + | - | - | - |
| Chlorfenvinphos | 360 | 3.12 | - | - | - | o? | + | - | + | - | + | - | - | - |
| Dichloorvos | 221 | 1.47 | - | - | - | o? | + | - | + | - | + | - | - | - |
| Bentazon | 240 | -0.6 | o | - | - | - | + | - | - | - | + | - | - | - |
| Pyrazon / chloridazon | 222 | 2.2 | o | - | - | o? | + | - | + | - | + | - | - | - |
| Trifluraline | 336 | .,07 | - | - | - | o? | + | o? | + | o? | + | - | - | - |
| Alachlor | 270 | 2.27 | - | - | - | o? | + | - | + | - | + | - | - | - |
| Endosulfan | 407 | 3.04 | - | - | - | o? | + | - | + | - | + | - | - | - |
| **Heavy metals & Others** | | | | | | | | | | | | | | |
| Arsene | 74.9 | 0.68 | - | - | +? | +? | - | + | o? | o | +/? | - | - | - |
| Cadmium | 112 | -0.07 | + | - | - | o? | - | + | - | o | +/? | - | - | - |
| Chromium | 52 | ? | - | - | - | o? | - | + | - | o | +/? | - | - | - |
| Lead | 207 | ? | + | - | - | o? | - | + | - | o | +/? | - | - | - |
| Mercury | 201 | ? | - | - | - | o? | - | o/+ | - | o | +/? | - | - | - |
| Nickel | 58.7 | ? | + | - | - | o? | - | o/+ | - | o | +/? | - | - | - |
| Copper | 63.5 | -0.57 | + | - | - | o? | - | + | - | o | +/? | - | - | - |
| Zinc | 65.4 | -0.47 | + | - | - | o? | - | + | - | o | +/? | - | - | - |
| **Hormone disrupters & medicinal substances** | | | | | | | | | | | | | | |
| 17alfa-ethinyloestradiol | ? | 3.67 | - | - | o? | + | + | -? | + | -? | + | - | - | - |
| Bisphenol A | ? | >2.2 | - | - | o? | o? | + | -? | + | -? | + | - | - | - |
| Oestrone | ? | ? | - | - | o? | o? | + | -? | + | -? | + | - | - | - |
| Ibuprofen | 206 | 3.97 | - | - | o | + | + | -? | + | -? | + | - | - | - |
| Anhydro-erythromycine | ? | ? | - | - | o | +/? | + | -? | ? | -? | + | - | - | - |
| Sulfamethoxazol | ? | ? | - | - | o | ? | + | -? | + | -? | + | - | - | - |
| Carbamazepine | ? | ? | - | - | - | - | + | -? | + | -? | + | - | - | - |
| Sotalol | ? | ? | - | - | o? | +/? | + | -? | + | -? | + | - | - | - |
| Amidotrizoic acid | ? | ? | - | - | o? | +/? | + | -? | o | -? | + | - | - | - |

**LEGENDA**

| | Efficiency of technique per substance |
|---|---|
| + | Removable |
| o | Partially Removable |
| - | Not removable |
| ? | Uncertain due to limited data of effluent treatment |

| Relevance of substance WWTP & WFD |
|---|
| 🟧 Exceeding surface water standards and present in WWTP-effluent |
| 🟨 No exceeding of surface water standards, presen in WWTP-effluent |
| Not or rarely found in WWTP-effluent |

# 5

# TREATMENT SCENARIOS

## 5.1 BASIC ASSUMPTIONS

In chapter 4 the potentially applicable treatment techniques are described. For many techniques a pre-treatment step is necessary for the effective removal of contaminants. In addition it should be mentioned that not all substances in the List of Substances would actually be a problem during treatment of WWTP-effluent. This will be strongly dependent on the location of the particular area, the defined qualitative objectives for the relevant surface water and the specific contribution of the WWTP-effluent to the presence of the critical components in the water. It is expected that one or more substances in the List of Substances will be critical to the receiving surface water. It is also important to acknowledge that a large number of treatment techniques can remove a broad range of substances, whereby less critical substances will also be removed. An example of this is the application of activated carbon. In this technique a large range of dissolved organic compounds are removed.

The applicable treatment techniques combined in the different wastewater treatment scenarios are expected to attain the desired removal efficiencies for the relevant WFD substances. This expectation is partly based upon results from full-scale research and / or full-scale application for WWTP-effluent treatment. When insufficient data are available for application in WWTP, removal efficiencies are deduced from other domains such as drinking water production and industrial (waste)water treatment.

### WWTP-EFFLUENT

The current generation of activated sludge treatment systems was developed for the removal of nitrogen and phosphorous to levels specified in the Urban Wastewater Directive. Although further optimisation of the activated sludge process is possible by optimising process configurations and/or advanced process control, the MTR-standards for nitrogen and phosphorous cannot (yet) be achieved with conventional activated sludge processes. Additional treatment steps such as the addition of a carbon source for nitrate removal and chemical dosage for phosphate removal, in combination with suspended solids removal by micro/ultrafiltration, have been investigated in various pilot studies with membrane bioreactors (e.g. Maasbommel and Hilversum WWTPs). In these research studies it was shown that an MBR with additional measures can achieve the MTR-quality for nitrogen and phosphorous.

Treatment scenarios aimed at post-treatment of WWTP-effluent are based on the assumption that the effluent is produced in a current generation activated sludge treatment plant, in which a “state of the art” optimisation has been applied for advanced nitrogen and phosphorous removal (see table 5). An important assumption in this case is that ammonium removal in the activated sludge process is almost complete (N-NH4 < 1.0 mg/l) and that nitrogen is present in the WWTP-effluent predominantly as nitrate and organic nitrogen.

**TABLE 5** **NITROGEN, PHOSPHOROUS AND SUSPENDED SOLIDS IN WWTP-EFFLUENT**

| | current generation WWTPs in The Netherlands | Membrane Bioreactor | Membrane Bioreactor with additional measures*) |
|---|---|---|---|
| Nitrogen (mg N/l)**) | 4 –10 | 3 – 10 | 2 –3 |
| Phosphorous (mg P/l)**) | 0.5 – 2.0 | 0.3 – 2.0 | 0.1 – 0.3 |
| Suspended solids (mg/l) | 5 – 15 | < 1 | < 1 |

*) with C-source dosage and extra chemical phosphate removal in addition to biological phosphate removal

**) MTR-standards: for nitrogen – 2,2 mg N/l ; for phosphorous – 0,15 mg P/l.

### INTEGRATED TREATMENT OPTIONS

Possible integrated treatment options have been described already, including the membrane bioreactor and the addition of adsorbing media to activated sludge, such as powdered activated carbon. The latter option is considered less applicable for urban wastewater treatment (see paragraph 4.3.8). In the membrane bioreactor a complete removal of suspended solids can be achieved. Pathogenic microorganisms are also removed. For advanced removal of nutrients and other selected WFD substances during MBR treatment, extra post-treatment is required. The effluent quality achieved with the MBR is similar to the effluent quality achieved with a similarly designed and loaded conventional activated sludge system, with additional post-treatment by micro- or ultrafiltration.

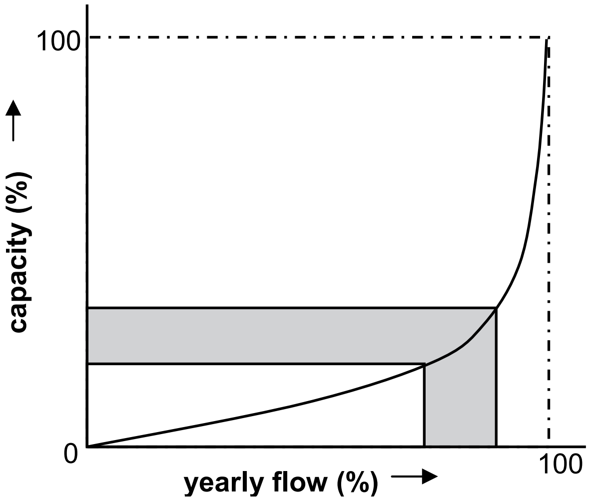
### PARTICLE REMOVAL

Almost all of the contaminants are to some extent present in suspended solids in the effluent. Removal of these solids therefore produces a significant improvement in the effluent quality. The presence of suspended solids also interferes with adsorptive, oxidative and filtration techniques, in which dissolved compounds are removed (nano- and hyperfiltration). Based on these considerations it can be concluded that in all possible treatment scenarios aimed at post-treatment, an initial particleremoval step is necessary. The filtration techniques presented in chapter 4 are relevant for particle removal.

### HYDRAULIC CAPACITY

Location-specific factors are important when establishing the hydraulic capacity to be installed for treatment techniques. Investment costs can be lowered by installing a lower hydraulic capacity than the maximum wet weather flow rate (WWF), whilst treating the majority of the flow. For the set up of the treatment scenarios a hydraulic capacity of approximately 300 l/P.E. during 16 hours per day has been assumed. This is equal to about 1.5 times the dry weather flow (DWF) rate. Using this capacity about 85% of the yearly volume flow will be treated, assuming that an average WWTP has a maximal hydraulic capacity of 3 to 4 times DWF. In figure 3 the relationship between the treatment percentage of the yearly flow and the hydraulic capacity to be installed of the post-treatment techniques is presented.

FIGURE 3 INSTALLED HYDRAULIC CAPACITY (%)*) OF THE EFFLUENT POLISHING UNIT AT DIFFERENT TREATMENT PERCENTAGES OF THE TOTAL YEARLY FLOW (%)



***) 100% capacity is the WWF rate of the WWTP**

Where treatment of the entire yearly flow is required, the hydraulic capacity to be installed will be equal to the WWF-capacity of the WWTP. This requires a significant increase in required capacity and thus costs for the treatment of a relatively small portion of the yearly flow. A sensitivity analysis has been carried out for this situation in the cost calculations in paragraph 5.7.

In the situation where complete treatment of the WWF is required, other options may be considered, such as the temporary buffering of a fraction of the effluent during WWF conditions or the advanced uncoupling of paved surfaces in the WWTP-area.

Advanced uncoupling of paved surfaces in the WWTP-area results in a lower WWF/DWF ratio. A lower WWF/DWF ratio in turn results in the treatment of a larger part of the yearly flow if 1.5 times DWF is installed as hydraulic capacity of the installation. However, attention has to be paid to the fact that some WFD-relevant substances are in particular present in stormwater runoff (e.g. zinc, polyaromatic hydrocarbons), which will thus end up diffusely in surface water with increasing uncoupled paved surfaces.

**EXAMPLE CALCULATION**

Using an installed capacity of 1.5 times DWF about 85% of the yearly volume flow is treated. The WFD standards apply for the total yearly volume flow. This implies that a mixture of treated (90%) and untreated (10%) WWTP-effluent should satisfy the standards for all WFD-relevant substances. The treatment-efficiency of the techniques should therefore be sufficiently large to compensate the extra load of a certain substance in an untreated discharge. In the table below a number of examples are presented.

| **Substance** | **WWTP-effluent average*)** (µg/l) | **WFD-Standard **)** (µg/l) | **After post-treatment***)** (µg/l) | **Needed efficiency** (%) |
|---|---|---|---|---|
| Copper | 11.2 | 3.8 | 2.5 | > 78 |
| Benzo(a)pyrene | 0.110 | 0.050 | 0.040 | > 64 |
| Total Nitrogen | 10,000 | 2,200 | 850 | > 91 |

*) The average concentrations in WWTP-effluent for copper and benzo(a)pyrene come from a survey carried out amongst all water boards in The Netherlands for this report (number of data respectively 963 and 17). The average concentration for total Nitrogen corresponds to the standards of the Urban Wastewater Treatment Directive.

**) Proposition of FHI, see appendix I.

***) Post-treatment of 85% of the total yearly volume flow.

Based on the considerations presented in the above paragraph, a number of promising scenarios have been established for each group of substances. In paragraphs 5.2 – 5.6 the corresponding treatment scenarios are presented. The costs are calculated in paragraph 5.7.

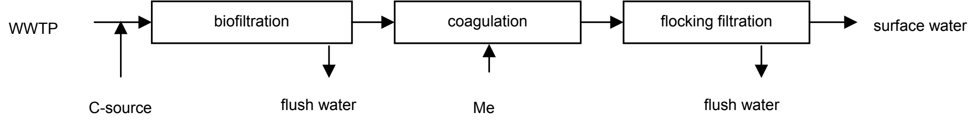
## 5.2 NUTRIENTS

For the removal of nitrogen it is assumed that biofiltration (denitrification) takes place in a post-treatment filter. For an effective removal of phosphate, chemical precipitation is applicable.

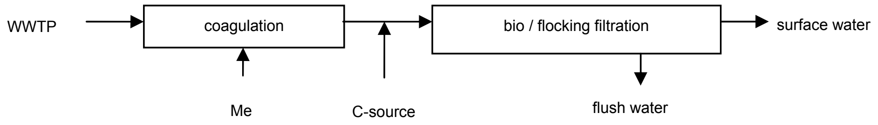
In scenario NP1 the biofilter is followed by flocking filtration. The alternative to this is micro/ultrafiltration with in-line coagulation (see Fact Sheets no. 5 and 9). Scenario NP2 combines denitrification and phosphate precipitation in one filter. This scenario has not yet been implemented at full-scale and is therefore not a proven technique. However, this configuration will be tested intensively at full-scale by the Water Board of Rijnland over the coming years.

TABLE 6 TREATMENT SCENARIO'S NP1 AND NP2 FOR THE REMOVAL OF NUTRIENTS

| | **treatment techniques [no. fact sheet]** | **explanation** | **cost** | |
|---|---|---|---|---|
| | | | **20,000 P.E.** | **100,000 P.E.** |
| **NP1** | biofiltration **[2]** (denitrification) | Dosage of a C-source (Methanol, Acetate etc.) for dephosphating and denitrification. Treatment of flush water via sludge treatment in WWTP. | | |
| | in line coagulation **[5]** | Dosage of metal salts (Fe/Al) | | |
| | flocking filtration **[8]** (P-precipitation) | Treatment of flush water via sludge treatment in WWTP. | | |
| | | **EUR-ct /m$^3$** | 27 | 10 |
| | | **EUR / P.E/ y** | 20 | 7 |



| | **treatment techniques [no. fact sheet]** | **explanation** | **cost** | |
|---|---|---|---|---|
| | | | **20,000 P.E.** | **100,000 P.E.** |
| **NP2** | in line coagulation **[5]** | Dosage of metal salts (Fe/Al), dosage of C-source (Methanol, Acetate) for dephosphating and denitrification. | | |
| | bio / flocking filtration **[2]** (P-precipitation, denitrification) | Simultaneous P- en N-removal<br>Flush water via sludge treatment at WWTP | | |
| | | **EUR-ct /m$^3$** | 20 | 8 |
| | | **EUR / P.E /y** | 14 | 5 |



The application of helophyte filers is not considered due to the low removal of nitrogen and phosphorous and the inability to achieve MTR-quality of effluent. The application of this system would require additional measures in the main process or extra pre-treatment (such as C-source addition in the main process or implementation of biofiltration or flocking filtration. The ecological effects are not taken into account in this report.

## 5.3 ORGANIC MICRO-CONTAMINANTS, PESTICIDES, HORMONE DISRUPTERS AND MEDICINAL SUBSTANCES

For the removal of organic micro-contaminants, pesticides, hormone disrupters and medicinal substances, the adsorption techniques, advanced oxidation and nano- or hyperfiltration techniques are potentially applicable. In each of these techniques the WWTP-effluent must first be pre-treated for the removal of suspended solids and soluble organic compounds (e.g. humic acids).

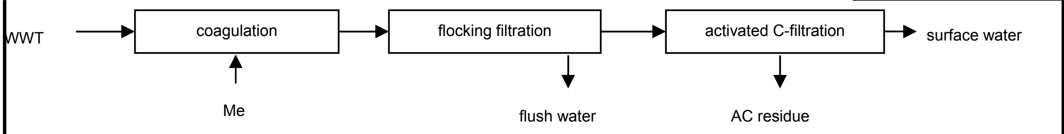
For the removal (separation) of organic micro-contaminants, pesticides, hormone disrupters and medicinal substances from WWTP-effluent, nanofiltration is in theory applicable. In this technique a concentrated waste stream is produced in which polyvalent ions and the retained contaminants are present. This waste stream needs to be treated separately to remove the organic contaminants before releasing into surface water. To achieve removal of organic contaminants, the techniques shown in scenarios OS2 and OS3 are applicable (activated carbon filtration and oxidation). Recycling of the waste stream back into the main activated sludge process is not an option as this would lead to accumulation of salts and persistent pollutants. Given the large volume (minimum 10% of the main stream), evaporation of the concentrate is not a feasible option either.

The positive effect of nanofiltration is that pollutants are concentrated into a small stream, requiring a small hydraulic capacity of an eventual treatment step, in comparison to the application of the technique in the main stream. The cost savings achieved by this concentration step before activated carbon filtration or oxidation is however not nearly high enough to cover the costs of the nanofiltration step, which results in substantially higher costs for this scenario in comparison to the other scenarios. For this reason the application of nanofiltration is not considered further.

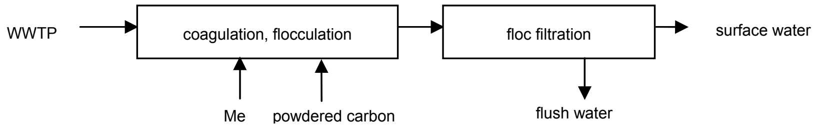
In scenarios OS1 and OS3, flocking filtration is applied. In OS2 flocculation and the contact between powdered activated carbon and the effluent (for the necessary contact time with the carbon) takes place in a separate reactor, followed by separation in a flocfilter. The alternative to this is micro/ultrafiltration in combination with in line coagulation (see Fact Sheets no. 5 and 9).

**TABLE 7** **TREATMENT SCENARIOS OS1, OS2 AND OS3 FOR ORGANIC MICRO POLLUTANTS, PESTICIDES, HORMONE DISRUPTERS AND MEDICINAL SUBSTANCES**

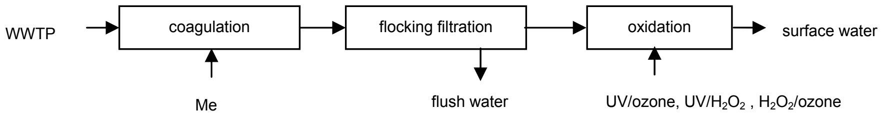
| | **treatment techniques [no. fact sheet]** | **explanation** | **cost** | |
|---|---|---|---|---|
| | | | **20,000 P.E.** | **100,000 P.E.** |
| **OS1** | in line coagulation **[5]** | Dosage of metal salt (Fe/Al) | | |
| | flocking filtration **[8]** | (partial) removal of phosphate and dissolved (colour) compounds | | |
| | activated carbon filtration **[6]** | stand time activated carbon depends on loading with competitive dissolved organic compounds.<br>external reactivation of activated carbon. | | |
| | | **EUR-ct /m$^3$** | 35 | 17 |
| | | **EUR / P.E./ y** | 26 | 12 |



| | **treatment techniques [no. fact sheet]** | **explanation** | **cost** | |
|---|---|---|---|---|
| | | | **20,000 P.E.** | **100,000 P.E.** |
| **OS2** | coagulation, flocculation **[5]** | Dosage of metal salts (Fe/Al), powdered activated carbon dosage (10-20 mg); floc formation, adsorption of pollutants to powdered activated carbon (20-30 min.) | | |
| | floc filtration **[8]** (P-precipitation) | Partial removal of phosphate and dissolved (colour)components and powdered activated carbon with adsorbed contaminants | | |
| | | **EUR-ct /m$^3$** | 25 | 11 |
| | | **EUR / P.E. / y.** | 18 | 8 |



| | **treatment techniques [no. fact sheet]** | **explanation** | **cost** | |
|---|---|---|---|---|
| | | | **20,000 P.E.** | **100,000 P.E.** |
| **OS3** | in line coagulation **[5]** | Dosage of metal salts (Fe/Al) | | |
| | flocking filtration **[9]** | (partial) removal of phosphate and dissolved (colour) compounds | | |
| | (advanced) oxidation **[3]** | UV / ozone, UV / $H_2O_2$, ozone / $H_2O_2$ | | |
| | | **EUR-ct /m$^3$** | 43 | 24 |
| | | **EUR / P.E./ y.** | 31 | 18 |

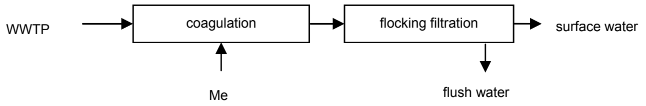


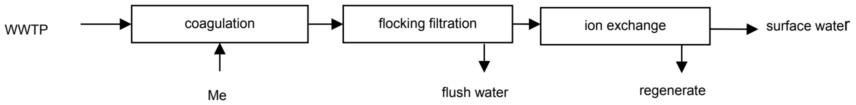
## 5.4 HEAVY METALS AND METALLOIDS

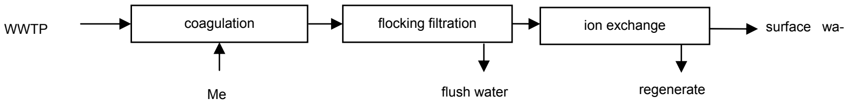
Heavy metals may be present as dissolved metal ions or adsorbed to suspended solids. By applying treatment techniques aimed at suspended solids removal from effluent, a number of critical metals can be removed to the levels required in the discharge standards (see appendix I, List of Substances). Extra removal of dissolved metals and metalloids requires a separate and selective treatment step. The applicable technique for this purpose is ion exchange. Because the concentration of heavy metals in WWTP-effluent is too low for an effective functioning of ion exchange in a conventional set up, specific ion exchange resins need to be developed. There is a large amount of uncertainty regarding the effectiveness of ion exchange due to the presence of interfering metals and organic macromolecules in relatively high concentrations, in relation to the concentrations of the heavy metals to be removed (see also paragraph 4.3.3). The strongly concentrated waste residue stream produced after regeneration (constituting 0.01% volume of the main stream) should be dealt with as well..
Nano- en hyperfiltration are in theory capable of retaining and separating metals into a separate concentrated residue stream. The critical heavy metals and other hazardous substances can then be removed from the concentrate (approximately 10 % of the treated effluent volume) before release into the surface water together with the WWTP-effluent. Treatment of the concentrate requires a significant and complex treatment step, leading to high costs. Based on the current available techniques, the application of nanofiltration with separate concentrate treatment is not considered financially feasible, for the same reasons as described in paragraph 5.3. This technique is therefore not considered further for the removal of heavy metals and metalloids.

The potentially applicable treatment scenarios (M1 and M3) are based on coagulation and separation of particles and dissolved organic macromolecules (metal complexes). In this case the flocking or floc filtration techniques are possible and (probably more efficient) micro/ultrafiltration techniques. Whether or not these scenarios can achieve the required removal of heavy metals without the application of ion exchange (scenario M2) remains however to be seen.

TABLE 8 TREATMENT SCENARIOS M1, M2 AND M3 FOR REMOVAL OF HEAVY METALS AND METALLOIDS

| | **treatment techniques [no. fact sheet]** | **explanation** | **cost** | |
|---|---|---|---|---|
| | | | **20,000 P.E.** | **100,000 P.E** |
| **M1** | in line coagulation **[5]** | Dosage of metal salts (Fe/Al) | | |
| | flocking filtration **[8]** | (partial) removal of phosphate particles and dissolved (colour) compounds | | |
| | | **EUR-ct /m$^3$**<br>**EUR / P.E./ y.** | 18<br>13 | 6<br>5 |
| |  | | | |

| | **treatment techniques [no. fact sheet]** | **explanation** | **cost** | |
|---|---|---|---|---|
| | | | **20,000 P.E.** | **100,000 P.E.** |
| **M2** | in line coagulation **[5]** | Dosage of metal salts (Fe/Al) | | |
| | flocking filtration **[8]** | (partial) removal of phosphate particles and dissolved (colour) compounds | | |
| | ion exchange **[7]** | | | |
| | | **EUR-ct /m$^3$**<br>**EUR / P.E./ y.** | 35<br>26 | 17<br>13 |
| |  | | | |

| | **treatment techniques [no. fact sheet]** | **explanation** | **cost** | |
|---|---|---|---|---|
| | | | **20,000 P.E.** | **100,000 P.E** |
| **M3** | in line coagulation **[5]** | Dosage of metal salts (Fe/Al), partial precipitation of particles and dissolved organic macro-molecules including (colour) components, dissolved metal complexes | | |
| | micro/ultrafiltration **[9]** | Removal of bound P and (complete) removal of suspended solids, flush water treated in existing sludge treatment of head process | | |
| | | **EUR-ct /m$^3$**<br>**EUR / P.E./ y.** | 36<br>26 | 15<br>11 |
| |  | | | |

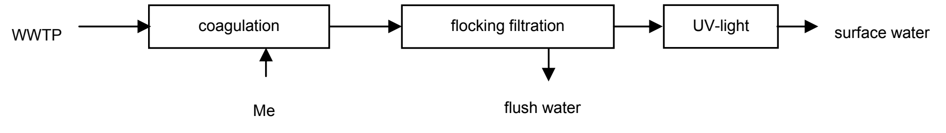
## 5.5 MICRO-ORGANISMS AND VIRUSES

Pathogens can be removed by chlorine or ozone dosage, UV-radiation and ultrafiltration. They can also be removed via natural death processes in halophyte systems, wetlands and effluent pond systems, provided a long enough hydraulic retention time is maintained. Due to the formation of hazardous by-products, chlorine dosage is not considered further. Due to extra costs of on-site safety aspects, the dosage of ozone is less applicable for small and medium scale WWTPs. UV-radiation does not have any of these disadvantages.

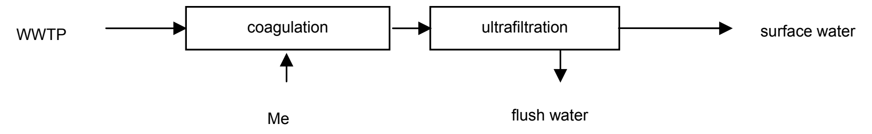
The effectiveness of UV increases with an increasing removal of suspended solids and dissolved (colour) components in a preceding treatment step. In practice these techniques are applied both with and without pre-treatment. For the set up of the treatment scenarios it has been assumed that UV-radiation will be applied with a pre-treatment step.

TABLE 9 TREATMENT SCENARIOS MV1 AND MV2 FOR THE REMOVAL OF MICRO ORGANISMS AND VIRUSES

| | **treatment techniques [no. fact sheet]** | **explanation** | **cost** | |
|---|---|---|---|---|
| | | | **20,000 P.E.** | **100,000 P.E.** |
| **MV1** | in line coagulation **[7]** | Dosage of metal salts (Fe/Al) | | |
| | flocking filtration **[9]** | Dosage of metal salts (Fe/Al), partial removal of suspended solids and dissolved (colour) components and phosphate.<br>Treatment of flush water in main sludge treatment process. | | |
| | UV light **[4]** | | | |
| | | **EUR-ct /m$^3$**<br>**EUR / P.E./ y** | 21<br>15 | 9<br>6 |



| | **treatment techniques [no. fact sheet]** | **explanation** | **cost** | |
|---|---|---|---|---|
| | | | **20,000 P.E.** | **100,000 P.E.** |
| **MV1** | in line coagulation **[7]** | Dosage of metal salts (Fe/Al) | | |
| | ultrafiltration **[9]** | Dosage of metal salts (Fe/Al), removal of suspended solids and dissolved (colour) components and phosphate.<br>Treatment of flush water in main sludge treatment process. | | |
| | | **EUR-ct /m$^3$**<br>**EUR / P.E./ y** | 36<br>26 | 15<br>11 |



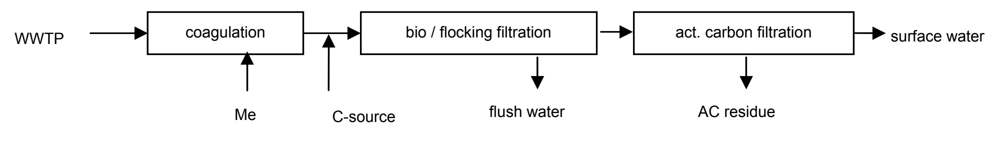
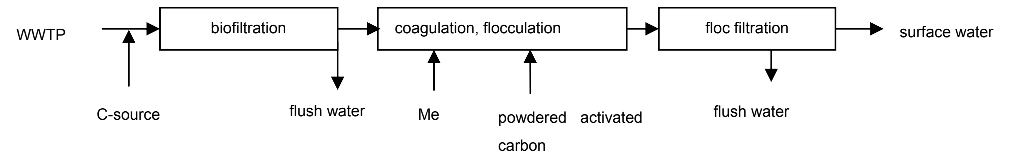
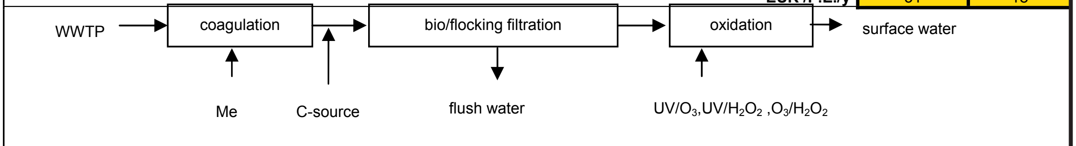
## 5.6 WFD TREATMENT SCENARIOS

In paragraphs 5.2 – 5.5, the different treatment scenarios are developed for the removal of specific substances and compounds from WWTP-effluent. For the removal of all WFD-substances, a combination of these scenarios is necessary. The most important applicable treatment steps for the “WFD-scenario” are summarised in the table below. For these combinations the current state of the art techniques have been used.

TABLE 10 OVERVIEW OF THE APPLICABLE TREATMENT TECHNIQUES FOR THE “WFD-SCENARIO”

| **Techniques** | **Substances (removal)** |
|---|---|
| coagulation, flocculation, filtration | Suspended and colloidal particles, heavy metals (organically bound or adsorbed to particles), nitrogen and phosphorous (organically bound), hydrophobic organic micro-contaminants and pesticides (adsorbed to particles), phosphate. |
| biofiltration | Nitrate removal |
| activated carbon adsorption | Organic micro-contaminants / pesticides, medicinal and hormonal substances |
| (advanced) oxidation | Organic micro-contaminants / pesticides, medicinal and hormonal substances, bacteria and viruses |

TABLE 11 TREATMENT SCENARIOS WFD1, WFD2 AND WFD3 FOR ALL WFD SUBSTANCES

| | **treatment techniques [no. fact sheet]** | **explanation** | **cost** | |
|---|---|---|---|---|
| | | | **20,000 P.E.** | **100,000 P.E.** |
| **WFD1** | in line coagulation **[6]** | Dosage of metal salts (Fe/Al) | | |
| | bio / flocking filtration **[2]** | Dosage of metal salts (Fe/Al)<br>Partial precipitation/bonding of particles and dissolved organic macro-molecules including (colour) components, dissolved metal complexes | | |
| | activated carbon filtration **[6]** | Stand time activated carbon dependent on loading with competing dissolved organic compounds.<br>external reactivation of activated carbon. | | |
| | | **EUR-ct /m$^3$** | 35 | 17 |
| | | **EUR / P.E./ y.** | 26 | 12 |
| |  | | | |
| | **treatment techniques [no. fact sheet]** | **explanation** | **cost** | |
| | | | **20,000 P.E.** | **100,000 P.E.** |
| **WFD2** | biofiltration **[2]** (denitrification) | Dosage of C-source (Methanol, Acetate etc)<br>Treatment of flush water in main sludge treatment process. | | |
| | coagulation, flocculation **[5]** | Dosage of metal salts (Fe/Al), powdered activated carbon (PAC) dosage (10 – 20 mg/l) with 20 min contact time floc, florming, adsorption of contaminants to PAC | | |
| | flocking filtration **[8]**<br>(P-precipitation, adsorption) | Treatment of flush water in main sludge treatment process. | | |
| | | **EUR-ct /m$^3$** | 34 | 15 |
| | | **EUR / P.E./y.** | 25 | 11 |
| |  | | | |
| | **treatment techniques [no. fact sheet]** | **explanation** | **cost** | |
| | | | **20,000 P.E.** | **100,000 P.E.** |
| **WFD3** | in line coagulation **[5]** | Dosage of metal salts (Fe/Al), dosage of C-source (Methanol, Acetate) | | |
| | flocking filtration **[8]** | (partial) removal of phosphate particles and dissolved (colour) components. Treatment of flushed water in sludge treatment of main process. | | |
| | (advanced) oxidation **[3]** | UV/ozone, UV/ $H_2O_2$ , ozone/ $H_2O_2$ | | |
| | | **EUR-ct /m$^3$** | 43 | 24 |
| | | **EUR /P.E./y** | 31 | 18 |
| |  | | | |

The standards for disinfection of WWTP-effluent are derived from the Bathing Water Directive. In cases where the Bathing Water Directive applies in addition to the WFD water quality standards, extra disinfection by UV-radiation is necessary in scenarios WFD1 and WFD2.

## 5.7 COSTS

For each scenario, a cost estimate has been set up, containing the investment costs and the total yearly costs. The cost estimates have been calculated for two plant sizes, namely 20,000 P.E. and 100,000 P.E. (P.E. – polution equivalent 136 g TOD/d)

The average dry weather flow (DWF) rate is calculated based on an average daily flow of 200 l/P.E. during 16 hours per day = 12.5 l/P.E./h. For the cost estimates the treatment units have been designed for a hydraulic flow of 1.5 x DWF = 18.75 l/P.E./h.

The basic assumptions used in the costs calculations are presented in appendix IV. In this appendix also the dimensions of the main treatment techniques and the needed surface per scenario are presented.

TABLE 12 COSTS OF TREATMENT SCENARIOS WITH A HYDRAULIC CAPACITY OF 375 M$^3$/H (20,000 P.E.) AND 1,875 M$^3$/H (100,000 P.E.)

| | biofiltration flocking filtration (two stage) | denitrification flocking filtration (one stage) | flocking filtration activated carbon | powdered activated carbon flocking filtration | UV/H2O2 flocking filtration | flocking filtration | in line coagulation; micro/ ultrafiltration | flocking filtration UV-desinfection | biofiltration powdered carbon flocking filtration | flocking filtration ion exchange **) |
|---|---|---|---|---|---|---|---|---|---|---|
| **scenario** | **NP1** | **NP2** | **OS1, WFD1** | **OS2** | **OS3, WFD3** | **M1** | **M3, MV2** | **MV1** | **WFD2** | **M2** |
| P.E. | 20,000 | 20,000 | 20,000 | 20,000 | 20,000 | 20,000 | 20,000 | 20,000 | 20,000 | 20,000 |
| $Q_{max}$ (m³/h) | 375 | 375 | 375 | 375 | 375 | 375 | 375 | 375 | 375 | 375 |
| Costs (Euro) | | | | | | | | | | |
| investment | 3,221,330 | 2,214,590 | 3,422,440 | 2,550,170 | 4,596,970 | 2,080,120 | 4,867,000 | 2,415,700 | 3,749,690 | 4,228,070 |
| capital costs | 304,000 | 207,000 | 322,000 | 327,000 | 435,000 | 194,000 | 395,000 | 227,000 | 354,000 | 392,000 |
| operational[1] | 95,691 | 78,891 | 188,854 | 122,254 | 191,354 | 62,754 | 129,454 | 79,654 | 149,391 | 122,700 |
| yearly costs | 399,691 | 285,891 | 510,854 | 359,254 | 626,354 | 256,754 | 524,454 | 306,654 | 503,391 | 514,700 |
| Eur/m³ | 0.27 | 0.20 | 0.35 | 0.25 | 0.43 | 0.18 | 0.36 | 0.21 | 0.34 | 0.35 |
| Eur/P.E./y | 20 | 14 | 26 | 18 | 31 | 13 | 26 | 15 | 25 | 26 |
| P.E. | 100,000 | 100,000 | 100,000 | 100,000 | 100,000 | 100,000 | 100,000 | 100,000 | 100,000 | 100,000 |
| $Q_{max}$ (m³/h) | 1,875 | 1,875 | 1,875 | 1,875 | 1,875 | 1,875 | 1,875 | 1,875 | 1,875 | 1,875 |
| Costs (Euro) | | | | | | | | | | |
| investment | 5,385,940 | 3,641,400 | 5,847,660 | 4,505,340 | 11,015,830 | 3,430,770 | 9,471,000 | 4,354,210 | 6,510,490 | 9,691,360 |
| capital costs | 480,000 | 325,000 | 514,000 | 397,000 | 1,033,000 | 303,000 | 752,000 | 394,000 | 579,000 | 888,000 |
| operational *) | 251,056 | 223,056 | 708,169 | 426,769 | 727,769 | 163,569 | 367,369 | 227,869 | 495,656 | 381,100 |
| yearly costs | 731,056 | 548,056 | 1,222,169 | 823,769 | 1,760,769 | 466,569 | 1,119,369 | 621,869 | 1,074,656 | 1,269,100 |
| Eur/m³ | 0.10 | 0.08 | 0.17 | 0.11 | 0.24 | 0.06 | 0.15 | 0.09 | 0.15 | 0.17 |
| Eur/P.E./y | 7 | 5 | 12 | 8 | 18 | 5 | 11 | 6 | 11 | 13 |

*) Costs include: maintenance, personnel, energy, chemical consumption and replacements costs (activated carbon, UV-lamps, membranes), sludge and flush water treatment, operational costs and on-line measurement

**) with the provision of brine disposal

Observations in table 12:

- from the cost estimate it appears that specific treatment costs are strongly dependent on the size of the treatment plant. An increase in the scale from 20,000 to 100,000 P.E. results in a decrease in the specific treatment costs by a factor of 2 – 3.
- the capital costs consist of general costs (including connection to the existing infrastructure, foundational work), additional equipment (pre-treatment, pumping station, electrical provisions, chemical dosage pumps and storage tanks) and costs for the supply of the treatment technique. The total of the general costs and additional equipment comprises 30 – 40% of the total investment costs. These costs do not increase considerably with an increase in capacity, which is the (largest) reason why larger installations have lower costs per P.E.
- the percentage capital costs of the total yearly costs varies between 64 – 79 % and is dependent on the number of process treatment steps per scenario and the size of the plant.
- scenario NP2, nutrient removal in a single stage filter configuration is the treatment option with the lowest costs. The highest treatment costs are found with flocking filtration in combination with advanced oxidation (UV/H2O2). Scenario WFD2, biofiltration with powdered activated carbon dosage and flocking filtration, leads to the lowest costs for the "WFD-scenario".
- based upon indications on efficiencies and residue production the extra costs of ion exchange after flocking filtration is about 0.17 Eur/m³ at 20,000 P.E. and 0.11 Eur/m³ at 100,000 P.E.

In paragraph 5.1 the choice of the hydraulic capacity of the post-treatment unit is discussed in relation to the DWF and WWF conditions and the percentage of the yearly effluent volume that can be treated. In table 12 the costs for a system with a capacity of 1.5 x DWF are presented, which is capable of treating approximately 85 % of the yearly volume. As a comparison, the costs are also calculated for a system in which the total water volume is treated at a hydraulic capacity of 3 times the DWF (2 times bigger than the base capacity). In table 13 the costs for a capacity with double the hydraulic capacity are shown, in contrast to the costs presented in table 12.

**TABLE 13** **RELATIVE TREATMENT COSTS AT A DOUBLING OF THE HYDRAULIC CAPACITY (%)**

| scenario | NP1 | NP2 | OS1, WFD1 | OS2 | OS3, WFD3 | M1 | M2, MV2 | MV1 | WFD2 | M2 |
|---|---|---|---|---|---|---|---|---|---|---|
| P.E. | 20,000 | | | | | | | | | |
| Qmax (m³/h) | 750 (= 3x DWF) | | | | | | | | | |
| investment | 164% | 158% | 168% | 164% | 170% | 162% | 168% | 164% | 166% | 163% |
| total cost | 159% | 152% | 155% | 153% | 160% | 156% | 164% | 158% | 157% | 147% |
| P.E. | 100,000 | | | | | | | | | |
| Qmax (m³/h) | 3,750 (= 3x DWF) | | | | | | | | | |
| investment | 162% | 157% | 166% | 164% | 172% | 160% | 167% | 165% | 165% | 164% |
| total cost | 151% | 144% | 141% | 143% | 155% | 149% | 158% | 152% | 146% | 140% |

From these calculations it appears that a doubling of the hydraulic capacity leads to 40 – 60 % higher costs, depending on the scenario and size of plant. Cost savings are possible if filter systems are developed that can handle a temporarily higher load, without a substantial decrease in the effluent quality, or solution that can reduce the peak flows (such as buffering of WWTP-effluent and/or advanced uncoupling of paved surfaces from WWTP).

# 6

# GAPS IN THE KNOWLEDGE

## 6.1 SUBSTANCES

For some WFD-substances, especially organic micro-contaminants, pesticides, hormone disrupters and medicinal substances, there is little or no data available for WWTP-effluent. For some WFD-substances, the presence in the effluent is also related to the type of supply. An example thereof is zinc. This metal is more present in the effluent during WWF than during DWF.
More insight into the presence of WFD-substances in WWTP-effluent, surface water and other emission sources is necessary in order to establish the required measures that must be incorporated into the River Basin Management Plans in 2009.

The suspended solids in WWTP-effluent contain relatively high concentrations of hydrophobic organic contaminants (characterised by a high octanol/water distribution coefficient). The availability of more information regarding the distribution of these components between the water phase and the suspended material phase will make an appropriate choice of treatment possible.
Also heavy metals are partitioned between the different phases. A part of the heavy metals is present in suspended solids. Another part is present in dissolved form, on the one hand in ionic form, on the other hand in complex organic substances. More information regarding the distribution of heavy metal (forms) in WWTP-effluent will make a well-founded choice of treatment technique possible.

The presence of dissolved, slowly degradable organic nitrogen compounds in WWTP-effluent (in concentrations > 1.5 g/l) can be a problem for achieving the MTR-limit for nitrogen (=2.2 mg Ntotaal/l). More knowledge is desirable regarding the concentrations of dissolved, slowly degradable organic nitrogen compounds and the factors that can have an influence on these concentrations.

The WFD aims for reaching a good water status for surface water. At this moment it is not clear whether a good ecological status can be reached with a good chemical composition of WWTP-effluent, which fulfills all defined standards of the WFD-substances. Not only removal efficiencies for substances have to kept in mind, also the reduction of environmental load has to be studied through ecotoxicity tests.

## 6.2 TECHNIQUES

The different treatment scenarios have been compiled based on the expectation that the required treatment standards for the relevant WFD substances will be achieved with these techniques. This expectation is partially based on results from pilot scale research results and/or full-scale applications. In cases where insufficient information was available the potential removal efficiencies have been derived from other applications such as drinking water production or industrial wastewater treatment. This means that further research is necessary in order to establish the exact removal efficiencies of these treatment techniques for WFD-substances, including pesticides, organic micro-contaminants, heavy metals, hormone disrupters and medicinal substances.

Suspended solids and dissolved organic (coloured) compounds influence the functioning of specific treatment techniques for the removal of WFD substances. The application of coagulation and flocculation followed by a filtration technique can remove suspended solids, colloidal particles, a fraction of the dissolved negatively charged organic complexes and heavy metals. Whether heavy metals are sufficiently removed using coagulation and flocculation is unclear. The removal of these components is also important as a pre-treatment step prior to other treatment techniques (for example activated carbon filtration, advanced oxidation, UV disinfection).

The optimal configuration of coagulation and flocculation in combination with filtration needs to be further developed. An important question in this development is whether or not a portion of the organic metal complexes and other contaminants are removed in an optimised coagulation process, such that the discharge standards for these compounds can be achieved. A significant question is whether the simple set up of in line coagulation followed by floc forming in the filter bed is sufficient, or whether a separated coagulation and flocculation reactor is necessary prior to the filter. Another question is whether the required removal efficiencies can be obtained with sand filtration (in upwards or downwards configuration) or if membrane filtration is necessary (micro- or ultrafiltration).

Due to the large pore size in the filter bed, sand filters can also be used as flocking filters for phosphate removal (with dosage of flocculent) or as a biofilter for denitrification (with dosage of a carbon-source). The combination of both techniques, in which both flocculent and a carbon-source are added to the influent, has been tried with varying success. As this technique could provide an interesting saving in costs, further research into the possibilities and operational aspects is necessary.

Advanced oxidation processes (AOP) are applicable for the removal of a large number of WFD substances. The combination of UV-radiation with either hydrogen peroxide or ozone results in the formation of free radicals, which have a stronger oxidative effect than hydrogen peroxide or ozone. The investment costs for an AOP installation are higher than for an ozone unit alone. The energy consumption is also higher than that for the production of ozone. Further research is desired into the optimisation of the oxidative technique, especially the need for UV-application and the possibility for pre-treatment (to increase transmission) to improve the efficiency.

In the use of oxidation techniques, organic compounds are degraded into (largely unidentified) degradation products. These by-products usually seem to have a low or no toxic effect on organisms. In drinking water production activated carbon filtration is generally applied after oxidation in order to remove degradation by-products. In the case of effluent treatment it is not known whether (expensive) activated carbon treatment is necessary after oxidation techniques, or whether the release of the oxidised water into surface water does not present a risk for the ecosystem. To answer these questions more information is required regarding the formation of degradation by-products and their toxicity.

In Europe, little long-term continuing research has been performed looking at the application of granular activated carbon filtration (GAC) for the removal of organic contaminants, pesticides, hormone disrupters and medicinal substances from WWTP-effluent. The stand time of carbon has been estimated conservatively in the cost estimates (0.6 – 0.7 years). Further experience with stand times obtained in practice is necessary, especially in relation to the applied pre-treatment.

In small-scale installations good results have been achieved with biological activated carbon filtration, in which denitrification takes place in the carbon filter. An important question arising from these results is how can the biomass be retained and regularly discharged without interrupting the optimal process conditions of the adsorption process?

An interesting alternative for activated carbon filtration is the application of powdered carbon in (floc) filtration. This option is especially interesting if a low dosage can be applied to achieve the required removal of organic contaminants. Further research is necessary into the efficiency, technical and financial feasibility of this technique in its application to WWTP-effluent.

Due to the more than 1000 times lower concentration of the metals to be removed (Cd, Cu, Ni, Zn in ppb/l) in relation to the macro-ions Ca and Mg present (> 10 mg/l), the application of ion exchange to WWTP-effluent is not considered promising. However, in a pilot study looking at the removal of metals during drinking water production with specific ion exchange resins, good results have been obtained at similar concentration levels of the macro-ions and metals, at long operating times. A similar problem may arise during the biological removal of organic contaminants (at ppb level), in which the contaminants compete with the remaining BOD and COD (mg/l). The development of specific biomass that can degrade the micro-contaminants in this environment is considered difficult and not very promising. Verification of this technique is necessary, given the potential importance of these techniques for effluent treatment.

## 6.3 RESIDUAL WASTE STREAMS

When choosing a treatment system for the removal of WFD-substances, a complete solution should be chosen including treatment of the waste streams produced. Due to the fact that a feasible treatment step has not (yet) been found for treatment of the relatively large volume of concentrated salt solution, nano- and hyperfiltration are at this stage not considered applicable for complete treatment of effluent. In all other filtration systems it is assumed that the backflush water containing the removed contaminants can be recycled back to the main activated sludge process. Particular points requiring attention in the recycling of flush water back to the main plant are: the acceptable hydraulic loading rate of the plant receiving the extra load, the influence on the sludge treatment and the prevention of breakthrough of fine particles into the effluent.

## 6.4 COSTS

The estimated costs for a number of techniques (especially MF/UF, activated carbon treatment and oxidation) have been extrapolated from applications in the drinking water sector, in cases where no information is available on WWTP-effluent. A risk in this approach is that the actual costs may be higher or lower depending on the development of the construction costs (e.g. if a more economical construction is developed), or on the development of the operational costs (e.g. if the required chemical dosage is higher than thought). The applicability of these techniques to WWTPs in practice will depend on the costs. It is therefore important to test these cost estimates again as soon as further insight is available in effluent treatment (laboratory → pilot → demonstration scale), and adjust them where necessary.

In the cost estimates it appears that a doubling of the installed hydraulic capacity of the treatment technique (from 1.5 to 3.0 times the dry weather flow) results in a 40 – 60 % increase in the yearly costs. The extra water treatment that is achieved is however limited (10 – 15 % of the yearly flow). Cost savings are possible by developing filtration systems that can handle temporarily higher peak flows without a substantial decrease in effluent quality, or the development of systems or solutions that reduce the peak flow to the treatment unit (such as buffering of WWTP-effluent and/or advanced uncoupling of paved surfaces in the area of the WWTP).

# 7

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## APPENDIX I

# LIST OF SUBSTANCES

### READER´S GUIDE TO THE LIST OF SUBSTANCES

In the following table, hazardous substances are presented for which WWTPs are considered to be a relevant emission source. This has been established by studies into the presence of these substances in WWTP-effluent (over the period 2000 – 2004) and in tests that have shown that these substances are detected in surface water at concentrations higher than the required levels. The list of substances is derived from the list of priority substances of the European Water Framework Directive, the River Basin Management Plans for the Rhine and the Meuse (ICBR and ICBM), substances of list of the dangerous substances directive (76/464/EEC) and the future EU Bathing Water Directive (Com 2002 581).

In cases where a substance has been detected in WWTP-effluent and the concentration in the surface water is above the allowed level, they are marked as relevant for the WWTP (orange). In cases where the substance has not been detected in WWTP-effluent and the allowed level in surface water is not exceeded, the substance is marked as not relevant to wwtps (green). In case the surface water limit is not exceeded but the substance has been detected in WWTP-effluent, this is marked as possibly locally relevant (yellow).

The table also presents the concentration range and the frequency of the presence in WWTP-effluent.
This table has been established based upon currently available monitoring data. The expectation is that when more monitoring data become available this will lead to changes in the table.

# LIST OF SUBSTANCES

| | Casnr. | Origin | Bathing water Directive | MTR (4th NW) | FHI avg (WFD) | FHI max (WFD) | Present in WWTP effluent 2000-2004 | WWTP Effluent concentrations 2000-200 (µg/l) | | Relevant substance WWTP and WFD |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | (µg/l) | | | | | min | max | |
| **Nutrients** | | | | | | | | | | |
| 1 Total Phosphorous | | ICBM/R | | 150 | | | +++ | 120 | 29000 | 🟧 |
| 2 Total Nitrogen | | ICBM/R | | 2200 | | | +++ | 1400 | 61000 | 🟧 |
| **Biological parameters** | | | | | | | | | | |
| 3 Intestinal enterococci | | BATH | 100 | cfu/0,1l | | | +++ | ~ $10^5$ cfu/l | | 🟧 |
| 4 Escherichia coli | | BATH | 250 | cfu/0,1l | | | +++ | ~ $2*10^5$ cfu/l | | 🟧 |
| 5 Viruses | | BATH | absent | per 10 l | | | +++ | 1 - $10^3$ cfu/l | | 🟧 |
| **Organic Micro Pollutants** | | | | | | | | | | |
| 6 4-chloro-anilin | 106-47-8 | ICBM/R | | 2 | | | ? | ? | ? | *2 |
| 7 Octylphenols | 9036-19-5 | WFD | | | | | ++ | 0,00 | 1,58 | *5,*6 |
| 8 Nonylphenols | 25154-52-3 | WFD | | | | | + | 0,00 | 0,60 | *5,*6 |
| 9 Bis(2-ethylexyl)phtalate (DEHP) | 117-81-7 | WFD | | | 0,33 | | +++ | 0,00 | 20,00 | *5 |
| 10 Benzene | 71-43-2 | WFD | | | 16 | 40 | o | 0,00 | 0,00 | 🟩 |
| 11 Benzo-a-pyrene | 50-32-8 | WFD | | | 0,05 | 0,05 | ++ | 0,00 | 0,08 | *5 |
| 12 Fluoranthene | 206-44-0 | WFD | | | 0,12 | 0,9 | ++ | 0,00 | 0,12 | *5 |
| 13 Benzo-b-fluoranthene | 205-99-2 | WFD | | | 🟥 | | ++ | 0,00 | 0,07 | *5 |
| 14 Benzo-k-fluoranthene | 207-08-9 | WFD | | | 0,005 | | ++ | 0,00 | 0,04 | *5 |
| 15 Benzo(g,h,i)perylene | 191-24-2 | WFD | | | 🟩 | | ++ | 0,00 | 0,06 | *1,*5 |
| 16 Indeno(1,2,3-cd)pyrene | 193-39-5 | WFD | | | 🟥 | | ++ | 0,00 | 0,06 | *5 |
| 17 Antracene | 120-12-7 | WFD | | | 0,063 | 0,1 | ++ | 0,00 | 0,07 | *5 |
| 18 Naphtalene | 91-20-3 | WFD | | | 2,4 | 80 | ++ | 0,00 | 0,20 | *5 |
| 19 Dichloromethane | 75-09-2 | WFD | | | 8,2 | 162 | o | 0,00 | 0,00 | 🟩 |
| 20 Trichloromethane | 67-66-3 | WFD | | | 3,85 | 38,5 | + | 0,80 | 1,10 | *1 |
| 21 Tetrachloromethane | 56-23-5 | BL | | 1100 | | | o | 0,00 | 0,00 | 🟩 |
| 22 1,2-dichloroethane | 107-06-2 | WFD | | | 🟩 | 1080 | o | 0,00 | 0,00 | 🟩 |
| 23 Trichloroethene | 79-01-6 | BL | | 2400 | | | o | 0,00 | 0,00 | 🟩 |
| 24 Tetrachloroethene | 127-18-4 | BL | | 330 | | | o | 0,00 | 0,00 | 🟩 |
| 25 Hexachlorobutadiene | 87-68-3 | WFD | | | 0,003 | 0,59 | o | 0,00 | 0,00 | *5 |
| 26 C10-13 - chloroalkanes | 85535-84-8 | WFD | | | | | ? | ? | ? | *4 |
| 27 Trichlorobenzenes | 12002-48-1 | WFD | | | 1,8 | 50 | o | 0,00 | 0,00 | 🟩 |
| 28 Hexachlorobenzene | 118-74-1 | WFD | | | 0,03 | 0,05 | o | 0,00 | 0,00 | *5 |
| 29 PCB-28 | 7012-37-5 | ICBM/R | | 🟥 | | | o | 0,00 | 0,00 | *5 |
| 30 PCB-52 | 35639-99-3 | ICBM/R | | 🟥 | | | o | 0,00 | 0,00 | *5 |
| 31 PCB-101 | 37680-73-2 | ICBM/R | | 🟥 | | | o | 0,00 | 0,00 | *5 |
| 32 PCB-118 | 31508-00-6 | ICBM/R | | 🟥 | | | o | 0,00 | 0,00 | *5 |
| 33 PCB-138 | 35065-28-2 | ICBM/R | | 🟥 | | | o | 0,00 | 0,00 | *5 |
| 34 PCB-153 | 35065-27-1 | ICBM/R | | 🟥 | | | o | 0,00 | 0,00 | *5 |
| 35 PCB-180 | 35065-29-3 | ICBM/R | | 🟥 | | | o | 0,00 | 0,00 | *5 |
| 36 Brominated diphenylethers (BDPEs) | | WFD | | | | | ? | ? | ? | *3,*5 |
| **Pesticides** | | | | | | | | | | |
| 37 Dibutyltin compounds | 1002-53-5 | ICBM/R | | 0,02 | | | o | 0,00 | 0,00 | *5 |
| 38 Tributyltin compounds (TBT) | 688-73-3 | WFD | | | 1E-04 | 0,002 | o | 0,00 | 0,00 | *5 |
| 39 Hexachlorocyclohexane / HCH / Lindane | 58-89-9 | WFD | | | 0,042 | 0,9 | + | 0,00 | 0,012 | *5 |
| 40 Pentachlorobenzene | 608-93-5 | WFD | | | 0,05 | 1 | o | 0,00 | 0,00 | *5 |
| 41 DDT | 50-29-3 | BL | | 9E-04 | | | o | 0,00 | 0,00 | *5 |
| 42 Pentachlorophenol (PCP) | 87-86-5 | WFD | | | 0,1 | 1 | o | 0,00 | 0,02 | *1,*5 |
| 43 DRINS | | BL | | 0,01 | | | o | 0,00 | 0,00 | *5 |
| 44 Simazine | 122-34-9 | WFD | | | 🟩 | 4,2 | + | 0,00 | 0,11 | *1 |
| 45 Atrazine | 1912-24-9 | WFD | | | 🟥 | 2 | + | 0,00 | 0,12 | 🟧 |
| 46 Dichlorprop | 120-36-5 | ICBM/R | | 40 | | | o | 0,00 | 0,00 | 🟩 |
| 47 MCPA | 94-74-6 | ICBM/R | | 2 | | | + | 0,00 | 0,73 | *1 |
| 48 Mecoprop (MCPP) | 7085-19-0 | ICBM/R | | 380 | | | + | 0,00 | 0,34 | *1 |
| 49 Diuron | 330-54-1 | WFD | | | 0,046 | 1,1 | + | 0,00 | 1,40 | 🟧 |
| 50 Chlorotoluron | 15545-48-9 | ICBM/R | | 0,22 | | | o | 0,00 | 0,00 | 🟩 |
| 51 Isoproturon | 34123-59-6 | WFD | | | 0,32 | 1,3 | o | 0,00 | 0,00 | 🟩 |
| 52 Chlorpyrifos | 2921-88-2 | WFD | | | 5E-04 | 0,001 | o | 0,00 | 0,00 | 🟩 |
| 53 Dimethoaat | 60-51-5 | ICBM/R | | 23 | | | o | 0,00 | 0,00 | 🟩 |
| 54 Chlorfenvinphos | 470-90-6 | WFD | | | 0,01 | 0,01 | o | 0,00 | 0,00 | *5 |
| 55 Dichloorvos | 62-73-7 | ICBM/R | | 0,7 | | | o | 0,00 | 0,00 | *5 |
| 56 Bentazon | 25057-89-0 | ICBM/R | | 64 | | | ? | ? | ? | *2 |
| 57 Pyrazon / chloridazon | 1698-60-8 | ICBM/R | | 73 | | | ? | ? | ? | *2 |
| 58 Trifluraline | 1582-09-8 | WFD | | | 0,03 | 0,42 | o | 0,00 | 0,00 | *5 |
| 59 Alachlor | 15972-60-8 | WFD | | | 0,035 | 1,15 | o | 0,00 | 0,00 | 🟩 |
| 60 Endosulfan | 959-98-8 | WFD | | | 0,004 | 0,004 | o | 0,00 | 0,00 | *5 |

# LIST OF SUBSTANCES

| | Casnr. | Origin | Bathing water Directive | MTR (4th NW) (µg/l) | FHI avg (WFD) (µg/l) | FHI max (WFD) (µg/l) | Present in WWTP effluent 2000-2004 | WWTP Effluent concentrations 2000-200 (µg/l) min | WWTP Effluent concentrations 2000-200 (µg/l) max | Relevant substance WWTP and WFD |
|---|---|---|---|---|---|---|---|---|---|---|
| **Heavy metals & Others** | | | | | | | | | | |
| 61 Arsene | 7440-38-2 | ICBM/R | | 🟩 32 | | | +++ | 0,00 | <11 | 🟨 *1,*5 |
| 62 Cadmium | 7440-43-9 | WFD | | | 🟥 0,72 | 🟥 | +++ | 0,00 | 0,99 | 🟧 *5 |
| 63 Chromium | 79440-77-3 | ICBM/R | | 🟩 84 | | | +++ | 0,00 | 43 | 🟨 *1,*5 |
| 64 Lead | 7439-92-1 | WFD | | | 🟥 25,7 | 🟥 2 | +++ | 0,00 | 50,00 | 🟧 *5 |
| 65 Mercury | 7439-97-6 | WFD | | | NA | 🟩 0,07 | +++ | 0,00 | 0,14 | 🟨 *1,*5 |
| 66 Nickel | 7440-02-0 | WFD | | | 🟥 1,5 | 🟥 1,3 | +++ | 0,00 | 36,60 | 🟧 *5 |
| 67 Copper | 7440-50-8 | ICBM/R | | 🟥 3,8 | | | +++ | 0,00 | 95 | 🟧 *5 |
| 68 Zinc | 7440-66-6 | ICBM/R | | 🟥 40 | | | +++ | 0,00 | 210 | 🟧 *5 |
| **Hormone disrupters & medicinal substances** | | | | | | | | | | |
| 69 17alfa-ethinyloestradiol | 57-63-6 | EJ | | | | | + | 0,00 | <0,01 | |
| 70 Bisphenol A | 80-05-7 | EJ | | | | | ++ | 0,04 | 4,09 | |
| 71 Oestrone | 53-16-7 | EJ | | | | | ++ | 0,00 | 0,01 | |
| 72 Ibuprofen | 15687-27-1 | EJ | | | | | +++ | 0,12 | 0,76 | |
| 73 Anhydro-erythromycine | 114-07-8 | EJ | | | | | +++ | 0,15 | 0,52 | |
| 74 Sulfamethoxazol | 723-46-6 | EJ | | | | | +++ | 0,06 | 0,13 | |
| 75 Carbamazepine | 298-46-4 | EJ | | | | | +++ | 0,33 | 1,00 | |
| 76 Sotalol | 3930-20-9 | EJ | | | | | +++ | 0,97 | 1,60 | |
| 77 Amidotrizoic acid | 117-96-4 | EJ | | | | | +++ | 0,23 | 1,20 | |

| LEGENDA | |
|---|---|
| MTR - Maximum Allowable Risk, minimal quality for surface water; 4th National (Dutch) policy document on water management | |
| FHI avg - Yearly average standard for surface water as proposed by Fraunhofer Institute | |
| FHI max - Maximum standard for surface water as proposed by the Fraunhofer Institute | |
| WFD - Substance of App. X of the European Water Framework Directive (2000/60/EC) | |
| ICBM/R - Substance of the list of substances as set up by the International River Basin Management Committees for Meuse and Rhine | |
| BL - Substances from the Black List (76/464/EEG) | |
| BATH - Parameters from the old and new Bathing Water Directive (76/160/EEG; Com 2002/581) | |
| EJ - Expert Judgment. Substances from 'Prioritering hormoonverstorende stoffen / prioritaire geneesmiddelen voor waterbeheerders' (Stowa2004-W04) | |
| 🟩 | No exceeding of the standards for surface water |
| 🟥 | Exceeding of the standards for surface water |
| NA | No Analysis |
| ? | Never analysed |
| o | Substance is encountered in <5% of the effluent |
| + | Substance is encounterd in >5% and <50% of all analyses in the effluent |
| ++ | Substance is encounterd in >50% and <95% of all analyses in the effluent |
| +++ | Substance is encountered in >95% of the cases |
| 🟩 | Substance not relevant for WWTP (for definition see Reader's Guide) (for definition see Reader's Guide) |
| 🟨 | Not clear whether the substance is, or is not, relevant for the WWTP (for definition see Reader's Guide) |
| 🟧 | Substance relevant for WWTP(for definition see Reader's Guide) |
| *1 | Substance is encountered in WWTP effluent but nationally the standard is not exceeded. Locally it may be a problem. |
| *2 | Substance was never measured in WWTP effluent. Relevance is not clear. |
| *3 | Substance was not measured in water. Substance was demonstrated in Suspended Solids of WWTP effluent |
| *4 | There is no analysis method available to measure this substance in WWTP effluent |
| *5 | Apart from measured dissolved concentrations also suspended solids in the effluent play a role in the load of the surface water; log Kow>3.0 |
| *6 | No measurements available in the surface water to check |

## APPENDIX II

# OVERVIEW OF TREATMENT TECHNIQUES

## LIST OF TECHNIQUES

| | nr. fact sheet (see App. III) |
|---|---|
| **INTEGRAL TECHNIQUES** | |
| > MBR | 1 |
| > Dosage of Powder Activated Carbon to Activated Sludge System | |
| > Bioaugmentation | |
| **ADVANCED TREATMENT TECHNIQUES** | |
| **Degradation Techniques** | |
| **Biological Degradation** | |
| > Helophyte Systems | |
| > Pond Systems | |
| > Denitrifying Sand Filters | 2 |
| > Biological Activated Carbon Filtration | |
| **Oxidation Techniques** | |
| Advanced Oxidation Processes | |
| > H2O2 | |
| > UV / H2O2 | 3 |
| > Ozone | |
| > Ozone/ H2O2 (peroxone) | 3 |
| > Ozone / UV | 3 |
| > Fe2+ / H2O2 (Fenton proces; solar fenton)) | |
| **Disinfection** | |
| **Physical Disinfection** | |
| > UV | 4 |
| **Chemical Disinfection** | |
| > Ozone | |
| **Bonding Techniques** | |
| **Chemical Precipitation Techniques** | |
| > Precipitation | 5 |
| - Pellet Reactor | |
| - Polymer Dosing | |
| > Coagulation and Flocculation | 5 |
| **Adsorption Techniques** | |
| > Activated Carbon | 6 |
| - Granular Activated Carbon Filtration | |
| - BBA filter (TNO) | |
| > Molecular Sieves | |
| - Zeolytes | |
| - Carbon molecular sieve | |
| > Ion exchange | 7 |
| > Precoat vacuumfilter | |
| **Separation Techniques** | |
| **Bed Filtration** | |
| > Bed Filtration | 8 |
| - Continuous Sand Filtration | |
| - Fixed Bed Filtration | |
| - Multi-media filtration | |
| - Fuzzy Filter | |
| - Slow Sand Filtration | |
| **Pore Filtration** | |
| > Micro Sieves | |
| > Membrane Filtration | |
| > Microfiltration/Ultrafiltration | 9 |
| > Nanofiltration | |
| **Remaining Techniques** | **Selection NOT based on the selection criteria from Chapter 4 Treatment Techniques** |
| > Sedimentation | |
| - Sedimentation | |
| - Lamella Sedimentation | |
| > Flotation | |
| > Memstil (membrane destillation) | |
| > Evaporation | |
| > Electro-deionisation | |
| > Extraction | |
| > Pervaporation | |
| > Pertraction | |
| > Eutectic Freezing | |
| > Magnetic Separation | |
| > Crystallisation | |

This list is based on the results obtained with a questionnaire among the Dutch Water Boards, research insitutes, consultancy firms and research institutes from countries partaking in the Urban Water Cycle (Denmark, Germany and UK)

## APPENDIX III

# FACT SHEETS

# MEMBRANE BIOREACTOR

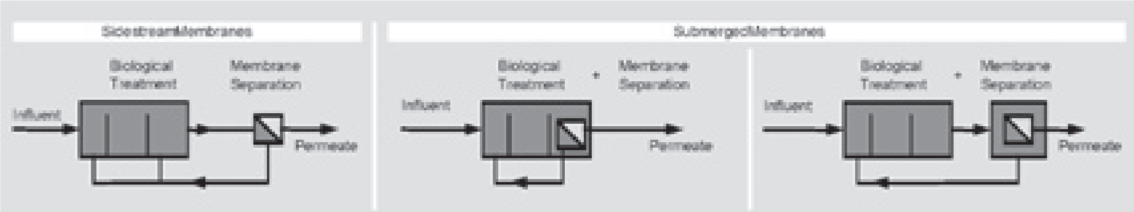
**Fact sheet nr. 01**

| | |
|---|---|
| Unit operation | Activated sludge system and membrane filtration |
| Treatment principle | Biological system and separation |
| Applicable for | Integrated treatment |
| Stage of development | full-scale |
| Process | |
| function: | degradation and conversion of COD, BOD, nitrogen and phosphporus containing substances, removal of suspended solids, pathogenic organisms, bacteria |
| feed: | WWTP effluent |
| Keywords: | Activated sludge, membrane filtration |

## A. BACKGROUND

The membrane bioreactor combines the activated sludge process with a membrane filtration step. The filtration can be in side stream configuration with pressurised membranes or with submerged membranes, either in the aeration tank or in a separate membrane tank (Figure 1). The applied membranes can be microfiltration membranes with pore sizes of 0.1 to 1 μm, or ultrafiltration membranes with pore sizes of 0.001 – 0.1 μm. Compared to the conventional activated sludge process the biological treatment can be operated with higher MLSS concentrations, leading to smaller tank volumes. A further reduction in footprint is caused by the absence of sedimentation tanks. The effluent quality is higher because the membrane forms an absolute barrier for microorganisms and particles. Operation and maintenance costs are high compared to conventional activated sludge treatment, mainly caused by the intensive pretreatment and the aeration needed for membrane air scouring. The higher MLSS concentration leads to lower oxygen transfer coefficients (α-values) of about 0.5 (-) at 15 g/l.

FIGURE 1 MBR WITH DIFFERENT MEMBRANE CONFIGURATIONS



## B. DESCRIPTION AND WORKING PRINCIPLE

*membranes*

There are several options for the membrane choice in MBR.

<u>Submerged membranes</u> (outside-in filtration):

1. hollow fibre membranes, vertically mounted
2. hollow fibre membranes, horizontally mounted
3. plate and frame membranes

<u>Side stream membranes</u> (inside-out filtration):

4. Tubular membranes

The membrane material is commonly a hydrophilised or hydrophilic organic polymer. For a more detailed description of the types of membranes available refer to Fact Sheet 10 Microfiltration/Ultrafiltration.

*required pretreatment*

Special attention should be paid to remove fats and hairs, to avoid clogging of membrane modules. Especially with submerged hollow fibre system there is a risk of sludging of the membrane modules; the characteristic size of the screen should be <1 mm for these systems. For plate and frame modules the pretreatment can be somewhat less extensive up to characteristic sizes of 3 mm.

*membrane separation step*

The membrane filtration step of the MBR can be regarded as the bottle-neck of the process: all water has to pass through the membrane, which has a restricted pore size. The maximum achievable membrane permeate flux depends on the type of membrane and ranges from 20 to 60 l/m$^2$.h. This will have implications for systems where storm weather flow has to be treated. A good option for this is the hybrid configuration where several alternatives exist. The hybrid configuration consists of a conventional activated sludge system with a secondary clarifier and a MBR in parallel or in series with this installation. In the hybrid configuration the capacity of the MBR is designed to treat dry weather flow and during storm weather events the surplus inflow is treated in the conventional lane.

*waste products*

Primary sludge (screenings) and secondary (waste) sludge

*treatment performance*

Because of the membrane step the effluent is disinfected and particle free. Depending on the type of wastewater the achievable effluent quality may vary. Some general values are listed in Table 1.

**TABLE 1** **TREATMENT EFFICIENCY OF MBR PROCESS**

| Parameter | Effluent quality | Removal efficiency (WER, 2002) |
|---|---|---|
| BOD | < 2 mg/l | > 98% |
| COD | | > 95% |
| TSS | < 1 mg/l | |
| Total N | 3 – 15[1] mg/l | |
| TKN | | 88-99% |
| Ammonium-N | | 90-99% |
| Total P | < 3 mg/l | |
| Turbidity | < 1 NTU | |
| Total Coliforms | < 100 cfu / 100 ml | |
| Fecal Coliforms | < 20 cfu / 100 ml | |

[1] Depending on season

*energy consumption*

The specific energy consumption of an MBR system is dependent on many factors, like system design, operational philosophy and plant size. Therefore a rather wide range of energy consumption figures is reported in literature. With a design flux of 20 – 30 l/m$^2$h the hollow fibre MBR requires a total amount of energy of 0.6 - 1.2 kWh/m$^3$ (Lesjean *et al.*, 2004).

*chemical demand*

Periodic chemical cleaning is required depending on the type of membrane and wastewater. Commonly applied chemicals include: NaOCl, $H_2O_2$, citric acid.

### C. DESIGN GUIDELINES / TECHNICAL DATA

- design loads
  - hydraulically: membrane step: 10 – 30 l/$m^2$h, depending on design temperature and required effluent quality
  - kinetically: 0.03 – 0.07 kg BOD / kg active biomass day

### D. OPERATIONAL STABILITY AND MAINTENANCE

The operation of the biological part of the membrane bioreactor is essentially the same as a conventional activated sludge system. If the system is designed to treat sewage from a mixed sewer system, special attention should be paid to cope with hydraulic peaks. Current practice is to keep a stable membrane permeability throughout dry weather periods by means of frequent low-dosage chemical cleaning with hollow fibre systems (once every two weeks/once per month), relaxation time (e.g. 2 minutes in 8 minutes production) and/or backwashing. For plate and frame systems the frequency of chemical cleaning is considerably lower, generally once or twice a year.

### E. REFERENCE INSTALLATIONS, SUPPLIERS / PATENTS

**TABLE 2** REFERENCE INSTALLATIONS FOR MUNICIPAL MBRS

| city, country | year | membrane system[1] | capacity | mean flow | max flow | flux mean/ max |
|---|---|---|---|---|---|---|
| | | | p.e. | $m^3$/hr | $m^3$/hr | l/$m^2$·hr |
| Varsseveld, NL | 2005 | HF, Zenon | 23,150 | 275 | 755 | 12 / 50 |
| Nordkanal, D | 2004 | HF, Zenon | 80,000 | 1,000 | 1,880 | 15 / 30 |
| Cardigan, UK | 2004 | PF, Kubota | | - | 360 | -/- |
| Schilde, B[2] | 2004 | HF, Zenon | 20,000 | 300 | 350 | - / 45 |
| Brescia, IT[2] | 2002 | HF, Zenon | 46,000 | 530 | - | -/- |
| Lowestoft, UK | 2002 | HF, Zenon | 46,000 | 300 | 590 | 26 / 31 |
| Knautnaundorf, D | 2001 | RD, Huber | 900 | - | - | -/- |
| Swanage, UK | 2000 | PF, Kubota | 23,000 | 1,580 | - | -/- |
| Rödingen, D | 1999 | HF, Zenon | 3,000 | - | 100 | - / 25.5 |
| Porlock, UK | 1998 | PF, Kubota | 3,800 | 80 | - | 16 / 31 |

[1] HF Hollow Fibre; RD Rotating Disk; PF Plate and Frame

[2] Parallel with conventional system

### MEMBRANE SUPPLIERS

Submerged hollow fibre membranes - Zenon, Puron, Mitsubishi
Plate and frame modules – Kubota, Toray
Rotating disk – Huber/VRM

Side stream
Tubular membrane – X-Flow (vertically mounted), Koch, Nadir, Berghof

## F. LITERATURE REFERENCES

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- MBR wwtp Varsseveld www.mbrvarsseveld.nl
- Zenon references http://www.zenon.com/MBR/case_studies.shtml
- Kubota references in UK http://www.copa.co.uk/products/mbr choose -sewage-
- Koch/Puron: www.puron.de
- Huber/VRM: www.huber.de choose: - solutions – Membrane Technology
- Toray: www.segherskeppel.com
- X-Flow: www.X-Flow.com

# DENITRIFYING SAND FILTERS

**Fact sheet nr. 02**

| | | |
|---|---|---|
| Unit operation | | Biological denitrification |
| Treatment principle | | Attached growth (biofilm) filtration |
| Applicable for | | Advanced effluent treatment |
| Stage of development | | Full-scale |
| Process | function: | Denitrification, suspended solids (TSS), phosphorous removal |
| | feed: | WWTP effluent |
| Keywords: | | filtration, denitrification, sand filters, fixed-bed, continuous sand filtration |

## A. BACKGROUND

Attached growth post-denitrification sand filters can be used to reduce the nitrate, nitrite and suspended solids levels in WWTP effluent. An exogenous carbon source is typically added in the influent stream to provide an electron donor for the reduction of $NO_x^-$ by denitrification. Methanol is often used as the carbon source and is dosed in the influent in proportion to the influent flow rate. In case phosphate levels must also be reduced, an iron salt can be added in the influent stream for chemical precipitation of $FePO_4$. Different types of post-denitrification processes include (1) downflow sand filters with periodic, discontinuous back-washing to prevent filter bed clogging, or (2) continuous upflow sand filtration with continuous washing of the filter material. Both types have been successfully used in many installations for post-denitrification.

## B. DESCRIPTION AND WORKING PRINCIPLE AND PICTURE

*downflow filtration*

Downflow filters are deep bed sand or granular media filters (1,2 – 2 m) which can typically achieve TSS concentrations of < 5 mg/l. With proper control of the methanol dose total effluent N-concentrations of 1 – 3 mg/l can be achieved. During operation headloss gradually increases due to solids accumulation, biomass growth and accumulation of nitrogen gas. The filter is “bumped” periodically by a hydraulic surge to remove gas (once every 2 – 4 h) and backwashed for solids removal by air scouring followed by an air/water backwash (once every 24 – 48 h). The solids storage capacity is estimated to be about 4 kg TSS/m$^3$ before headloss occurs. A schematic diagram of a downflow filter is shown in Fact Sheet 9 Bed Filtration.

*continuous sand filtration*

A schematic diagram of a typical continuous upflow sand filter is shown in Fact Sheet 8 Bed Filtration.

*required pretreatment*

Large particles that could interfere with the effective working of the filter bed must be removed from the influent by a screen with a maximum opening of 5 mm.

*waste products*

In both systems excess biological sludge (and chemical sludge in the case of Fe-dosage) is produced. The flush water containing the excess sludge is recycled back into the main activated sludge process.

*treatment performance*

Post-denitrification is capable of achieving TSS concentrations of < 5 mg/l, nitrate-nitrogen concentrations of 0.5 mg N/l and phosphate concentrations of 0.3 mg P/l (when an iron salt is dosed). The performance is affected predominantly by the methanol and iron salt dosage concentrations. Being a biological process, the performance is also affected by the temperature.

*energy consumption*

Energy consumption for these systems is low, ranging from 0.16 kWh/m$^3$ for small-scale systems (4,000 m$^3$/d) and 0.04 kWh/m$^3$ for large-scale systems (20,000 m$^3$/d).

*chemical demand*

The major chemical demand in post-denitrification is methanol and iron salt dosage. Methanol is dosed at a ratio of 3 kg methanol/kg NO$_3$-N. This results in around 35 ton/year (approximately 9,000 EUR/year) for a medium-scale plant (4,000 m$^3$/d) and 180 ton/year (45,000 EUR/year) for a large-scale plant (20,000 m$^3$/d). When iron is simultaneously dosed for phosphate precipitation a molar ratio of 3 mol Fe/mol P is often used, or a concentration of 5 – 6 g Fe/m$^3$. This results in an average yearly consumption for a medium-scale plant of 8 ton Fe/year and 40 ton Fe/year for a large-scale plant.

## C. DESIGN GUIDELINES / TECHNICAL DATA

Some typical design parameters are shown in table 1.

**TABLE 1** **DESIGN PARAMETERS OF FIXED-BED UPFLOW/DOWNFLOW SAND FILTERS AND FLUIDISED BED CONTINUOUS SAND FILTERS**

| | | **Downflow filtration** | **Continuous sand filtration** |
|---|---|---|---|
| Packing type | - | sand or multi layer (anthracite, garnet and sand) | sand |
| Granule size | mm | 1.8 – 6.0 | 0.3 – 2.0 |
| Filter bed depth | m | 1.2 – 1.8 | 1.5 – 2.0 |
| Hydraulic loading at 20 °C | m$^3$/m$^2$.h | 2.5 – 5 | 15 – 25 |
| NO$_3$-N-loading at 20 °C | kg/m$^3$.d | 1.4 – 1.8 | 3.0 – 6.0 |
| Max TSS loading at 20 °C | g TSS/m$^2$.h | 1,000 | 2,000 |
| Empty bed contact time | min | 20 – 30 | 10 – 20 |
| Methanol:nitrate ratio | kg/kg | 3.0 – 3.5 | 3.0 – 3.5 |
| Flush water flow rate | m$^3$/m$^2$.h | - | 1.0 – 1.2 |
| Recirculation ratio | - | - | 2:1 – 5:1 |
| Backwash airflow rate | m$^3$/m$^2$.h | 90 – 120 | - |
| Backwash water flow rate | m$^3$/m$^2$.h | 15 – 25 | - |
| Backwash frequency | times per day | 1 – 2 | - |
| Backwash duration | min | 10 – 20 | |
| Effluent NO$_3$-N concentration | mg N/l | 1 – 3 | 0.5 – 2 |
| Me/P ratio for P-removal | mol Fe/mol P | 2 – 3 | 2 – 3 |

## D. OPERATIONAL STABILITY AND MAINTENANCE

Post-denitrification is a very “fail-safe” technique due to its robust set-up and few moving parts. The only major failure that can occur is clogging of the bed, which is measured as a pressure increase in the filter bed. In this case the filter bed needs to be flushed or “bumped”. Continuous sand filters rarely (if ever) need to be taken out of service for backwashing. Treatment of both the water and the filter sand take place without interruption. The filter has no moving parts, minimising the need for superintendance.

## E. REFERENCE INSTALLATIONS, SUPPLIERS/PATENTS

*Installations*

- De Groote Lucht WWTP, Vlaardingen, the Netherlands, 3.600 $m^3/h$ (Paques)
- Genk WWTP, Belgium, 1.440 $m^3/h$ (Paques)
- KA Freising, Germany, 2.200 $m^3/h$ (Nordic Water)
- KA Rietberg, Germany, 833 $m^3/h$ (Nordic Water)

*Suppliers*

- Paques Natural Solutions, P.O. Box 52, 8560 AB BALK, the Netherlands (ASTRASAND®).
- Nordic Water Benelux BV, P.O. Box 522,1940 AM Beverwijk, the Netherlands (DYNASAND®).
- Andritz Ltd, Speedwell Road, Parkhouse East, Newcastle-under-Lyme, Staffordshire, ST5 7, UK (HYDRASAND® patent).
- UNIDRO S.p.A, Via Alghero 19, 20128 Milan, Italy.

## F. LITERATURE REFERENCES

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Oesterholt FIHM, Bult BA (1993) Improving municipal waste water quality by effluent polishing – a pilot scale experiment at Winterswijk, the Netherlands. Water Science & Technology 27 (5 – 6): 277 – 286.

Hultman B, Jonsson K, Plaza E (1994) Combined nitrogen and phosphorous removal in a full-scale continuous up-flow sand filter. Water Science & Technology 29 (10 – 11): 127 – 134.

Forsell B (1994) Removal of phosphorous and nitrogen from municipal wastewater by DynaSand continuous sand filter, Polijstingsfiltratie en denitrificatie met behulp van DynaSand filtratie, Astraco Trading, Astracom, Sassenheim.

# ADVANCED OXIDATION PROCESSES
# $O_3/H_2O_2$, $UV/O_3$ and $UV/H_2O_2$

**Fact sheet nr. 03**

| | |
|---|---|
| Unit operation | Advanced oxidation |
| Treatment principle | Oxidation |
| Applicable for | Advanced effluent treatment |
| Stage of development | Full-scale development for drinking water production, not yet applied at full-scale for WWTP effluent treatment, techniques researched since 1970 |
| Process | |
| function: | Disinfection, oxidation of inorganic compounds, organic micro-pollutant oxidation (taste and colour removal, phenolic pollutants, pesticides), organic macro-pollutant oxidation, improvement of biological degradability of water. |
| feed: | WWTP effluent |
| Keywords: | advanced oxidation, UV, hydrogen peroxide, ozone |

## A. BACKGROUND

Advanced oxidation processes (AOP) are used to oxidise complex organic constituents that are difficult to degrade biologically into simpler end products. An AOP is a highly accelerated oxidation reaction that typically involves the use of the hydroxyl free radical ($OH^{\cdot}$) as a strong oxidant to destroy compounds that cannot be oxidised by conventional oxidants such as oxygen, ozone and chlorine. Free radicals can be produced from ozone ($O_3$) or hydrogen peroxide ($H_2O_2$) by means of direct reaction with each other (Eq 1) or by reaction with UV light (photolysis) (Eqs 2 – 3). The most commonly applied methods in water treatment until now are $UV/O_3$, $O_3/H_2O_2$ and $UV/H_2O_2$, although the techniques have not yet to applied widely to WWTP effluent. The free radicals react with pollutants to initiate a series of oxidative degradation reactions. When UV light is used a large fraction of organic breakdown occurs due to photolysis of organics. Until now AOPs have been mostly applied to drinking water and specific industrial (e.g. textile) wastewater. Their main treatment purpose is for removal of substances such as SOCs (Synthetic Organic Chemicals), pesticides, and odour-causing compounds, which have been of little relevance in the municipal wastewater treatment industry until now. The complexity of the chemistry of AOPs is high due to the large number of reactions that are possible. This makes it difficult to predict the products of an AOP. Disadvantages of AOPs are that the toxicity of the byproducts is not always better than the original compounds (e.g. bromate formation is a problem with $O_3/H_2O_2$ treatment), and the chemical consumption can be high due to the non-specificity of the technique. Other disadvantages are high cost, complex maintenance and the reduced effectiveness in presence of radical scavenging compounds. An important advantage of AOPs is that complete oxidation to $CO_2$ and water is possible and no sludge or concentrate is produced.

Production of $OH^{\cdot}$ from ozone and peroxide:

$$2O_3 + H_2O_2 \rightarrow 2\,{}^{\cdot}OH + 3\,O_2 \qquad \text{(Eq 1)}$$

Production of $OH^{\cdot}$ by photolysis of ozone and peroxide:

$H_2O_2 + h\nu \rightarrow 2\,OH^{\cdot}$ (Eq 2)

$O_3 + h\nu + H_2O \rightarrow O_2 + O(^1D) + H_2O \rightarrow 2\,OH^{\cdot} \rightarrow H_2O_2$ (Eq 3)

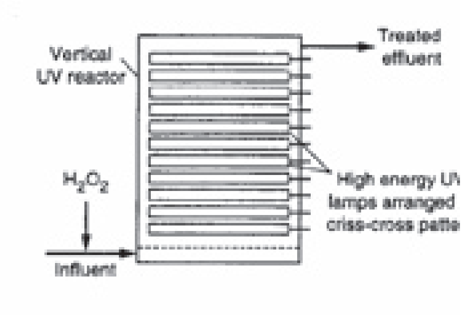
where $O(^1D)$ = excited oxygen atom. The rate of oxidation in an AOP depends on the radical concentration generated, the oxygen concentration and pollutant concentration. Many factors can affect the radical concentration such as pH, temperature, the presence of ions, the type of pollutant and the presence of radical scavengers such as bicarbonate ions.

### B. DESCRIPTION AND WORKING PRINCIPLE AND PICTURE/SCHEMA

The efficiency of AOPs requires precise design and operation of the process. In general it is important to emphasize that pilot testing is always recommended because of the specificity of each wastewater.

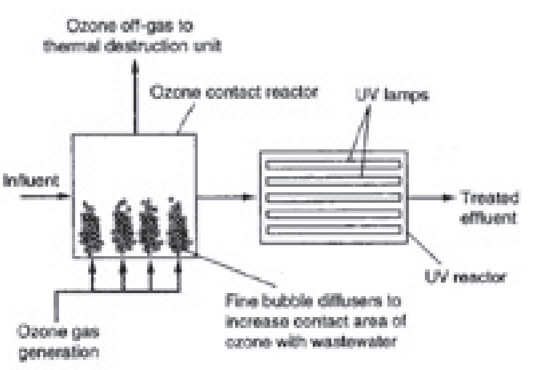
*UV/$H_2O_2$:* There is growing interest in UV-based AOPs to degrade trace organic contaminants in drinking water, however the applicability to wastewater is limited by the suspended solids concentration (UV-transmittance). UV/$H_2O_2$ is the most commonly used AOP for industrial water treatment and has been applied for the removal of N-Nitrosodimethylamine (NDMA), sex and steroidal hormones, human prescription/nonprescription drugs, antibiotics and personal care products. At the very low (usual) concentrations tested (μg/l) their oxidation appears to follow first order kinetics (Parsons, 2004). $H_2O_2$ absorbs UV light in the range 200 – 280 nm. In some cases this process is not feasible because $H_2O_2$ has a low molar extinction coefficient, requiring high concentrations of $H_2O_2$ (> 10 mg/l) and inefficient UV energy use. The extent of removal of impurities is determined by a number of factors: the UV- and $H_2O_2$-dosage, the transmission of the wastewater, the design of the UV reactor, and the choice of UV lamps. Understanding the processes requires knowledge of fundamental photochemistry and it consequences in the design of efficient UV reactors.

**FIGURE 1** **SCHEMATIC REPRESENTATION OF AOP INVOLVING PEROXIDE AND UV RADIATION**



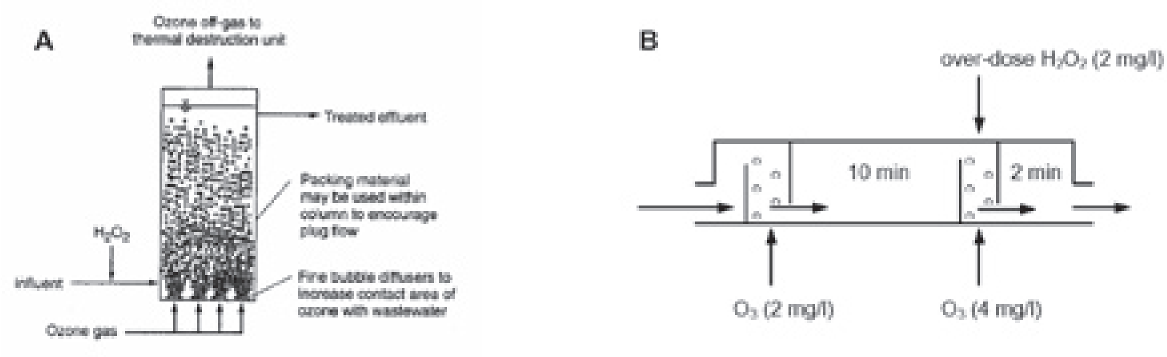
*UV/$O_3$:* As shown in equation 1 the photolysis of ozone in water leads to the formation of hydrogen peroxide, which is subsequently photolysed to form hydroxyl radicals. Essentially, the UV/$O_3$ process is an expensive way of producing $H_2O_2$, which makes the use of ozone in this application generally not cost-effective. The ozone/UV process is more effective when the compounds of interest can be degraded through the absorption of the UV irradiation as well as through the reaction with the hydroxyl radicals. Some industrial applications (e.g. treatment of TNT) require the UV/$O_3$ process. A major disadvantage with the UV/$O_3$ technique is the formation of the toxic bromate ion.

**FIGURE 2** **SCHEMATIC REPRESENTATION OF AOP INVOLVING UV/$O_3$ (METCALF & EDDY 2003)**



*$O_3/H_2O_2$:* For removal of compounds that do not absorb UV, this AOP may be more effective. Organic micropollutants such as trichloroethylene (TCE) and perchloroethylene (PCE) have been reduced significantly with this technique. The $H_2O_2$ is added to the influent before it comes into contact with the ozone (Fig 2). The performance is greatly dependent on the $H_2O_2/O_3$ ratio applied. The optimal ratio is around 0.3.

**FIGURE 3** **SCHEMATIC REPRESENTATION OF AOP INVOLVING OZONE AND PEROXIDE IN A COLUMN DIFFUSER (A) OR IN A PLUG-FLOW CONTACTOR (B)**



*required pretreatment*

Advanced oxidation (especially in combination with UV) is sensitive to the suspended solids concentration due to the reduced UV transmittance of the water. It is not economical for wastewater with high levels of suspended solids (SS), biochemical/chemical oxygen demand (> 1 g/l COD) or total organic carbon and requires pretreatment. A typical pretreatment process for suspended solids removal is (multi) media filtration and/or activated carbon.

*waste products*

In AOPs involving ozone the oxidation reaction with bromide ion produces hypobromous acid and bromate ion and precludes their usage with waters containing high concentrations of bromide ion (> 0,10 mg/l). AOPs in general produce no waste products as such, as compounds are degraded rather than concentrated or transferred into a different phase. Because secondary waste materials are not generated there is no need to dispose of or regenerate materials. However the nature of the oxidation products is difficult to predict and may include toxic products or intermediates.

*treatment performance*

Available data for removal efficiencies of various compounds vary largely in the literature. It is very difficult to predict the efficiency of pollutant removal since results vary significantly with the specific oxidant in question and the characteristics of the treated wastewater (pH, temperature etc). Moreover, the cited processes can be very effective with some compounds and almost pointless with others, especially in the case of refractory organic substances. The best approach is therefore to rely on previous experiences with wastewater similar to the one being treated and/or to conduct lab-scale and pilot tests. During UV/$H_2O_2$ treatment of drinking water at the Andijk DWTP > 80% conversion of 11 selected priority pollutants could be achieved at 0.6 kWh/$m^3$ (540 mJ/$cm^2$) and 6 mg/l $H_2O_2$.

*energy consumption*

In AOPs involving UV radiation electrical energy is the principal factor in the operating costs. The electrical energy required for the oxidation of organic compounds is expressed in EE/O units, defined as the electrical energy input per unit volume per log order of pollutant reduction. EE/O values for various pollutants such as NDMA, chlorinated alkene, 1,4-dioxane, atrazine and MTBE vary between 0,15 – 5 kWh/order/$m^3$ and 2 – 10 kWh/order/$m^3$ for benzene and its derivatives. For the new UV/$H_2O_2$ drinking water plant at Andijk the energy consumption is 0,6 kWh/$m^3$. Variations in the literature are very large and energy requirements must be established in pilot tests. Energy consumption in the $H_2O_2/O_3$ process is relatively much lower than UV based AOPs.

*chemical demand*

The principle chemical demand in AOPs is due to $H_2O_2$ and $O_3$ consumption. Ozone is typically dosed at a concentration of 4 g/$m^3$, resulting in a consumption of 6 ton/year for small-scale plants (4,000 $m^3$/d) and 30 ton ozone/year for large-scale plants (20,000 $m^3$/d). Hydrogen peroxide is typically dosed at a concentration of 1 – 2 g/$m^3$, resulting in a consumption in the order of 2 ton/year for a small-scale plant and 9 ton/year for large-scale plants.

## C. DESIGN GUIDELINES / TECHNICAL DATA

**TABLE 1** **SOME IMPORTANT PUBLISHED DESIGN PARAMETERS FOR AOPS**

| Design parameter | unit | value |
|---|---|---|
| **$H_2O_2/O_3$** | | |
| Ozone concentration | g $O_3$/$m^3$ | 2 – 4 |
| $H_2O_2/O_3$ | g $H_2O_2$/g $O_3$ | 0.3 |
| $O_3$/DOC (dissolved organic carbon) | g $O_3$/g DOC | 1 – 3 |
| **UV/$O_3$ and UV/$H_2O_2$** | | |
| CCT (concentration x contact time) | mg/l * min | > 10 |
| UV dosage | mJ/$cm^2$ | 500 – 1,000 |
| UV-lamp output | nm | 200 – 280 |
| UV power output | kWh/$m^3$ | 0.3 – 2 |
| $H_2O_2$ dosage | mg/l | 5 – 25 |

## D. OPERATIONAL STABILITY AND MAINTENANCE

Ozone and $H_2O_2$ delivery systems are complex using highly technical instruments, however the processes are highly automated and reliable, requiring only a modest degree of operator skill and time to operate them. Maintenance of ozone generators and UV systems requires skilled technicians and regular maintenance.

## E. REFERENCE INSTALLATIONS, SUPPLIERS/PATENTS

*Reference installations:*

- $H_2O_2/O_3$: Neuilly sur Marne drinking water production plant, France, 6.300 $m^3/h$, 5 mg/l ozone, 1,5 mg/l $H_2O_2$.
- UV/$H_2O_2$: Andijk drinking water production plant (4.000 $m^3/h$).
- Widely applied in textile industry for colour removal.

*Commercial-scale AOP systems:*

Calgon Carbon Corboration Peropure™ and Rayox™ UV/$H_2O_2$ systems, Magnum Water Technology Inc. CAV-OX® UV/$H_2O_2$ system, Trojan and Wedeco UV/$H_2O_2$ and UV/$O_3$ systems and US Filter/Zimpro Inc UV/$H_2O_2$/$O_3$ system.

## F. LITERATURE REFERENCES

*articles*

Aquarec Review Report on Wastewater Treatment Unit Operations EVK1-CT-2002-00130, Work package 7, Deliverable D6, edited by Viviane Miska, Aldo Ravazzini, Jaap de Koning, Delft University of Technology, April 2004.
Kruithof JC, Peer Kamp, Mike Belosevic, Mihaela Stefan (2005) UV/$H_20_2$ retrofit of PWN´s water treatment plant Andijk for primary disinfection and organic contaminant control, Water Intelligence Online © IWA Publishing 2005 (http://www.iwaponline.com/wio/2005/04/wio200504006.htm).

*books*

Parsons S (2004) Advanced oxidation processes for water and wastewater treatment, IWA Publishing, Cornwall UK.

Tchobanoglous G, Franklin L, Burton H, Stensel D (2003) Wastewater engineering, treatment and reuse, 4th edition, McGraw-Hill Publishing, New York, ISBN 0-07-112250-8 (ISE).

STOWA (2001) Compendium rwzi-effluent als bron, Deel 4 bijlagen, Utrecht, the Netherlands.

*websites*

http://www.mep.tno.nl/water/Afvalwater/afvalwater_innovatieve_technieken_advanced_oxidation_processes.html

# UV DISINFECTION

**Fact sheet nr. 04**

| | | |
|---|---|---|
| Unit operation | | Disinfection |
| Treatment principle | | UV radiation |
| Applicable for | | Advanced wastewater treatment |
| Stage of development | | full-scale |
| Process | | |
| | function: | degradation of pathogenic organisms, photoloysis of organic material, decolouring, destruction of metal complexes, partial or complete destruction of micro-pollutants (PACs, pesticides, chlorinated hydrocarbons) |
| | feed: | WWTP effluent |
| Keywords: | | UV, disinfection |

## A. BACKGROUND

Ultra violet (UV) light is the range of the electromagnetic spectrum with a wavelength between 100 – 400 nm. The range between 200 – 280 nm (UV C) has a germicidal effect. The germicidal properties of UV radiation have been used in a wide variety of applications since its use was pioneered in the early 1900s. With the proper dosage, ultraviolet radiation has proven to be an effective germicide and virucide for wastewater, without the formation of toxic by-products. The efficiency of UV radiation depends on the UV-absorbancy of the compound to be destroyed. Nucleic acids and proteins are effective absorbers of UV radiation, which is the reason UV is an effective (physical) disinfection method. UV radiation of micro-organisms causes irreversible photo-biochemical alterations in the DNA structure, causing the inability of microbes and viruses to reproduce.

## B. DESCRIPTION AND WORKING PRINCIPLE AND PICTURE

The extent of disinfection achieved with UV radiation is expressed in log units and is directly related to the UV dose[1] (Eq 1). The UV dose required for effective inactivation is determined by site-specific data relating to the water quality and log removal required. The effectiveness of the UV radiation is strongly affected by the UV transmittance of the water to be treated. The efficiency decreases with increasing turbidity. For this reason, UV disinfection is not feasible for water with a high suspended solids concentration. The presence of some dissolved or suspended matter may shield microbes from the UV radiation. Iron, sulphites, nitrites and phenols all absorb UV light. Accordingly, the absorbance coefficient of the water is an indication of this demand and is unique for each water. The UV-dose can be calculated as the specific intensity per unit surface (mW/cm$^2$) multiplied by the exposure (or contact) time (s) (Eq 1):

$$\text{Dose} = \text{UV Intensity} * \text{Exposure Time (mJ/cm}^2\text{)} \qquad \text{(Eq 1)}$$

---

[1] Reduction by 99% is a factor $10^2$ reduction and is equal to log 2 inactivation. Reduction by 99.9% is equal to log 3 units and so on.

Specific “design” parameters vary for individual waters and should be determined empirically for each application. The UV demand of water can be measured simply in a spectrophotometer set at a wavelength of 254 nm using a 1 cm thick water layer.

*UV lamps*

Almost all UV lamps are mercury arc discharge lamps in which an electric current is sent through mercury vapour, causing mercury atoms to become excited and emit light at UV wavelengths. The mercury “arc” is inherently unstable and requires specific current conditions. A ballast is used to control the current. There are 3 main types of lamps, 1) Low pressure (LP), 2) Low/pressure/high output (LPHO) and 3) Medium pressure (MP). Low-pressure lamps are generally more energy efficient, while medium pressure lamps emit up to 10 times more energy but are more expensive. The output of a UV lamp decreases during its lifetime (12 – 20 months, depending on type of lamp) and lamps need to be replaced when the output is reduced to 70%. For disinfection purposes low pressure lamps are preferred due to the specific wavelength that can be produced and the lower energy consumption. For AOP purposes medium pressure lamps are preferred due to the more intensive oxidation reactions they can produce. The broad emission spectrum and the higher intensity of medium pressure lamps is used to produce free radicals ($OH^{\cdot}$) from hydrogen peroxide and ozone, as well as disinfection.

*ballasts*

Ballasts are transformers that control the power to the UV lamps. They generally generate enough heat to supply cooling fans or air conditioning. Ballasts should be compatible with the UV lamps and must be in a waterproof remote location.

*UV reactor design*

The design of a UV reactor has a large influence on the efficiency of the process. The following factors need to be taken into account, 1) Hydraulics: direction and flow rate of the water flow through the reactor; 2) Positioning of the lamps; 3) Radiation intensity of the lamps in relation to the water flow; 4) Configuration of the reactors in series; 5) Use of space due to the lamp dimensions, and 6) Energy consumption due to the water flow. Most conventional UV reactors are available in two types: closed channel and open channel. Closed channel systems are generally applied in drinking water production plants, however they are becoming increasingly popular for WWTP effluent. Open channels are commonly used in WWTP effluent disinfection, however they are more susceptible to fouling.

*required pretreatment*

The efficiency of UV treatment is sensitive to the dissolved organics concentration and solids concentration in the water. UV radiation is generally not effective for effluent with TSS > 30 mg/l. An overview of some interfering substances to UV radiation is shown in table 1.

**TABLE 1** **DISTURBING SUBSTANCES FOR UV DISINFECTION (METCALF & EDDY 2003)**

| Constituent | Effect |
|---|---|
| BOD, COD, TOC | No, or minor effect |
| Humic material | Strong adsorbers of UV radiation |
| Oil and grease | Can accumulate on quartz sleeves of UV lamps, can absorb UV radiation |
| TSS | Absorption of UV radiation, can shield embedded bacteria |
| pH, Alkalinity, Hardness | Can impact scaling potential |

*waste products*

An important advantage of UV radiation is that no sludge or concentrate is produced. There is no residual effect that can be harmful to humans or aquatic life, which is an advantage when compared to chlorine disinfection systems. By-product formation is generally insignificant under disinfection conditions. Nitrate absorbs UV light and is reduced to nitrite in the presence of UV light, which may be a major problem if nitrate concentrations are high. An overview of possible by-product formation is shown in table 2.

**TABLE 2** **BY-PRODUCT FORMATION IN UV RADIATION FOR DISINFECTION AND AOPS**

| Compound | Disinfection conditions 40 – 120 mJ/cm$^2$ | Organic contaminant control conditions 1000 – 2000 mJ/cm$^2$ |
|---|---|---|
| Bromate | absent | absent |
| Nitrite | present | high |
| AOC | up to a few μg/l | 100 – 150 μg/l |
| Mutagenicity | insignificant | absent |

*treatment performance*

Since UV radiation is energy in the form of electromagnetic waves, its effectiveness is not limited by chemical water properties. It appears that pH, temperature, alkalinity and total inorganic carbon do not impact the overall effectiveness. The addition of oxidants ($H_2O_2$ or ozone) enhances the effectiveness. The quality of the treated water is however dependent on the extent of fouling of the lamps, the UV transmittance of the water (UVT) and the turbidity, which make this technique ineffective for WWTP effluent with a high suspended solids concentration (> 30 mg TSS/l). UVT is the most important performance parameter. As a rule of thumb, for every 5% decrease in UVT, 50% less UV is available for disinfection.

*energy consumption*

Energy consumption for disinfection purposes (UV intensity 40 – 125 mJ/cm$^2$) is in the range 0.1 – 0.2 kWh/m$^3$. For the use of UV in advanced oxidation processes (UV intensity 600 – 1,000 mJ/cm$^2$) the energy consumption is much higher (0.2 – 0.6 kWh/m$^3$).

*chemical demand*

Chemical addition is not required in UV disinfection, which is a major advantage of this technique.

## C. DESIGN GUIDELINES / TECHNICAL DATA

*design loads*

- hydraulically: UV installations have been designed for systems as small as 90 m$^3$/d to large-scale systems (1.600.000 m$^3$/d). Installation of enough hydraulic capacity is generally a question of installing more units and elements. Single UV units can treat flow rates of up to 200 m$^3$/h.
- kinetically: For adequate disinfection of most viruses and micro-organisms a UV dosage of 40 – 125 mJ/cm$^2$ is required.
- residence time: UV disinfection has a shorter contact time when compared with other disinfectants (approximately 20 to 30 seconds with low pressure lamps).

### D. OPERATIONAL STABILITY AND MAINTENANCE

UV lamps have a limited life (1 – 2 years LP lamps, 0.5 – 1 year MP lamps), meaning lamps need to be replaced regularly. A major disadvantage is the development of biofilm (fouling) on the exposed surfaces of the UV reactor. Especially open channel systems that are exposed to daylight may encounter fouling. Closed UV systems, however, can also experience fouling. Fouling occurs essentially when treating any water. Removal of biomass growth must be conducted on an as-need basis either with a mechanical wipe or by a chemical (acid) clean. In addition, UV sensors can drift over time and need to be recalibrated periodically. UV installations do not require any storage of hazardous material, neither proportioning nor handling of chemical substances is involved. Installation is relatively simple.

### E. REFERENCE INSTALLATIONS, SUPPLIERS / PATENTS

- *reference installations*

| city, country | year | supplier | pretreatment | system | capacity, max m3/h | number of lamps |
|---|---|---|---|---|---|---|
| Manukau, N-Z | 2001 | wedeco | anthracite filtration | open channel, tangential, | 57 | 7,700 |
| Bad Tölz, D | 2003 | | sand filtration-TSS=5 mg/l | open channel, low pressure | 2 | 144 |
| Fairfield, Ohio, USA | 2003 | Aquionics | | medium-pressure | 56 | |

- *suppliers*

Berson, Neunen, the Netherlands, http://www.bersonuv.com
Trojan, Ontario, Canada, http://www.trojanuv.com
Wedeco, Herford, Germany, http://www.wedecouv.de
Calgon Carbon Corporation, http://www.calgoncarbon.com
Magnum Water Technology, http://www.magnumwater.com

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Parsons, S. (ed.)(2004) Advanced Oxidation Processes for Water and Wastewater Treatment.
IWA Publishing, London, UK.

*websites*

International Ultraviolet Association (IUVA): www.iuva.org

ANSI/NSF: www.nsf.org/water.html

Austrian Standards (ONORM): www.onorm.at

NWRI/AWWA Guidelines: www.awwa.org.bookstore

# PRECIPITATION, COAGULATION / FLOCCULATION

**Fact sheet nr. 05**

| | |
|---|---|
| Unit operation | Precipitation, coagulation / flocculation |
| Treatment principle | Chemical bonding |
| Applicable for | Advanced effluent treatment |
| Stage of development | full-scale |
| Process | |
| function: | removal of ions (heavy metals and nutrients) and suspended solids |
| feed: | WWTP effluent |
| Keywords: | precipitation; coagulation; flocculation |

## A. BACKGROUND

Precipitation is a method of causing ionic contaminants to settle out of solution as a solid precipitate by the addition of chemicals. Coagulation and flocculation are terms given to the irreversible agglomeration of fine particles into large particles, caused by the use of coagulants such as ferric chloride and aluminium sulphate. In general it is believed that a coagulant neutralises the electrical charges of the fine particles, causing destabilisation of the particles and consequent coagulation. Coagulation and flocculation can be used to remove undissolved particles and colloidal particles. The particle size-increase of the formed flocs caused by coagulation can be accelerated using polymers. The formed flocs and precipitates can be filtered, settled, or otherwise separated from the WWTP effluent. Different forms of coagulation/flocculation techniques include: in-line coagulation, flocculant filtration, flocculation filtration, “Actiflo” and pellet reactors.

## B. DESCRIPTION AND WORKING PRINCIPLE

In the treatment of WWTP-effluent precipitation is generally applied for the purpose of precipitating phosphate using iron or aluminium salts. The iron or aluminium ions in solution will react with phosphate to produce insoluble metal phosphates. The degree of insolubility for these compounds is pH-dependent. Theoretically, the minimum solubility of aluminium phosphate occurs at about pH 6.3, and that of iron phosphate at pH 5.3. However, practical applications have yielded efficient phosphorus removal at around pH 7.0, which is compatible with most biological treatment processes. Hydroxides or sulfides of heavy metals can also be precipitated, however for the formation of these precipitates pH corrections are necessary, which for the treatment of WWTP-effluent are not realistic due to the buffering capacity of the effluent. Since iron and aluminium salts also act as a coagulant, precipitation and coagulation cannot be considered separately. The addition of iron and aluminium ions for phosphate precipitation destabilizes fine particles in the effluent, thereby forming flocs. The types of iron and aluminium salts most commonly used are:

- $FeCl_3$
- $Al_2(SO_4)_3.14H_2O$
- PAC (polyaluminiumchloride)

*required pre-treatment*

No pre-treatment is required.

*waste products*

Inorganic sludge is produced, the quantity depending on the level of chemical dosage.

*treatment performance*

The effluent containing the formed precipitates and flocs should be treated to remove the precipitates. This treatment generally consists of a filtration step. In table 1 efficiencies of a flocculation filtration process are presented.

**TABLE 1** **TREATMENT EFFICIENCY OF FLOCCULATION FILTRATION PROCESS FOR WWTP EFFLUENT**

| parameter | influent concentration range [mg/l] | removal efficiency Fe [%] | removal efficiency Al [%] |
|---|---|---|---|
| COD | 30 – 75 | 10 – 25 | ~ 35 |
| TSS | 5.1 – 7.4 | ~ 60 | 55 – 65 |
| $P_{tot}$ | 0.1 – 0.83 | 30 – 70 | 10 – 99 |

When sedimentation is used the efficiencies given in table 2 can be obtained (STOWA, 2001).

**TABLE 2** **TREATMENT EFFICIENCY OF COAGULATION, FLOCCULATION FOLLOWED BY SEDIMENTATION**

| parameter | removal efficiency [%] |
|---|---|
| COD | 40 - 60 |
| TSS | 60 - 80 |
| Ammonia | 0 - 20 |
| Phosphate | 80 – 100 |
| Copper | 80 – 100 |
| Zinc | 60 – 80 |
| E. Coli | 40 - 60 |
| DOC | 0 - 40 |
| PCB | 60 – 80 |

*energy consumption*

Mixing energy is required in the range of 2 – 40 kW/m$^3$ (Metcalf&Eddy, 2003).

*chemical demand*

The quantity of chemicals needed depends on the concentrations to be precipitated in the incoming stream. The exact application rate is determined by onsite testing and varies with the characteristics of the wastewater and the desired removal. For precipitation, a molar ratio Me / P of 2 is normally used. For a phosphate concentration of 1 mg/l phosphate, 3.6 mg/l Fe should be dosed or 1.7 mg/l Al. Coagulation dosages are in the order of 2 – 5 mg Al/l, or 5 – 10 mg Fe/l.

### C. DESIGN GUIDELINES / TECHNICAL DATA

For precipitation and coagulation, a chemical addition step and a mixing step are required. The mixing step can be performed in a mixed tank or by creating turbulence in the stream of effluent. The flocculation is performed in a zone with less turbulence then the zone for precipitation and coagulation. The design parameters for coagulation and flocculation are determined using the G-value, the residence time and the dissipated power (for mixing). For mechanically stirred tanks this relation is as follows:

$$G = \sqrt{\frac{P}{V \cdot \mu}}$$

with:

G mean velocity gradient, $s^{-1}$
P power requirement, W
V volume, $m^3$
$\mu$ dynamic viscosity, $Ns/m^2$

For coagulation, a zone is required with $G > 1000\ s^{-1}$ and a residence time of 10 – 60 s. For flocculation, a zone is required in which the G-value is in the order of 10 – 200 $s^{-1}$ and the total residence time is in the order of 15 – 45 min.

### D. OPERATIONAL STABILITY AND MAINTENANCE

The stability of the process depends on the quality of the feed wastewater. If the quality of the feed changes in the sense that the interference of other components with the added chemicals is increased, the treatment efficiencies might be less than expected. No specific maintenance is necessary.

### E. REFERENCE INSTALLATIONS, SUPPLIERS / PATENTS

For the treatment of wwtp effluent, coagulation/flocculation is almost always followed by filtration to remove the formed aggregates. A large scale application in use until 2004 is the Water Factory 21, Orange County. Also the water reuse plant at Windhoek, Namibia, applies coagulation preceding flotation and dual media filtration.
The tertiary treament of San Diego wastewater treatment plant (California Code of Regulations 1978) consists of coagulation with lime followed by clarification in a center-fed upflow sludge bed clarifier.

### F. LITERATURE REFERENCES

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www.epa.gov/owm/mtb – Wastewater Technology Fact Sheet, Chemical Precipitation (2005)

# ACTIVATED CARBON

**Fact sheet nr. 06**

| | |
|---|---|
| Unit operation | Adsorption |
| Treatment principle | Physical bonding |
| Applicable for | Advanced effluent treatment |
| Stage of development | full scale in drinking water treatment; effluent: only pilot scale |
| Process | |
| function: | removal of organic micropollutants, pesticides, endocrine disruptors and medicinal substances |
| feed: | WWTP effluent |
| Keywords: | adsorption, activated carbon, pesticides, nutrients, medicine residue |

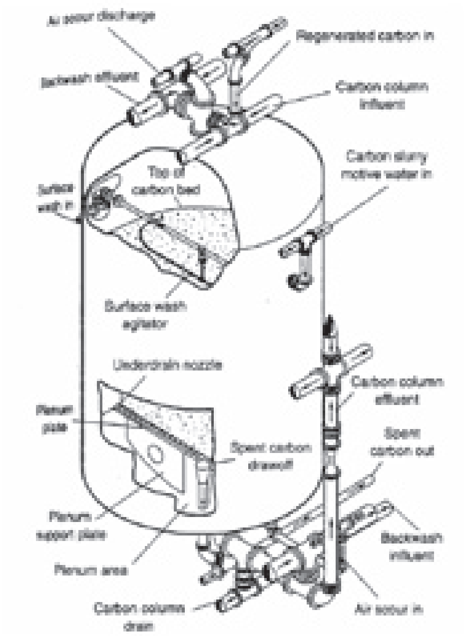
## A. BACKGROUND

Activated carbon has a broad spectrum of adsorptive activity, as most organic molecules are retained on its surface. The adsorption of substances onto activated carbon can be predicted according to their $K_{ow}$ coefficient, which is the octanol/water partition coefficient. Substances with a log $K_{ow} < 0$ are not retained by activated carbon. Activated carbon can be applied in several ways, such as in a granular activated carbon (GAC) filter, by in-line addition of powder activated carbon (PAC), in a membrane assisted affinity separator (MAAS) or a continuous moving bed adsorption system (MBA).

## B. DESCRIPTION AND WORKING PRINCIPLE AND PICTURE

Treatment with a Granular Activated Carbon (GAC) filter involves passing the WWTP-effluent through a bed of activated carbon. A typical filter is represented in Fig. 1. The GAC particles have a diameter of 0.25 – 3 mm. When the column is fully loaded with a certain organic compound this compound will not be adsorbed anymore and will break through the filter. At that moment, the GAC needs to be regenerated and reactivated. The moment of breakthrough differs per organic compound and depends (among others) on the polarity of the compound.

**FIGURE 1** **TYPICAL ACTIVATED CARBON FILTER IN A PRESSURE VESSEL (METCALF& EDDY, 2003)**



*Required pretreatment*

Special attention should be paid to remove suspended solids and easily removable organic compounds from the influent of the GAC-filter. Suspended solids can cause the filter bed to clog. Easily removable organic compounds will block the adsorption sites on the activated carbon, on which organic micropollutants or pesticides are to be adsorbed.

*Waste products*

Loaded carbon in a granular filter can be regenerated and reactivated by intensive heat treatment. Powdered activated carbon is injected as a slurry (1% w/w) and cannot be regenerated. The powdered carbon is separated from the effluent stream as sludge.

*Energy consumption*

Considering filters of the same size, the pumping costs for activated carbon filters are similar to the cost for depth filters. Regeneration of the activated carbon is an energy intensive process, consuming between 1 – 3 kWh/m$^3$ for the reactivation process alone.

*Treatment performance*

In Miska et al., 2004 removals are indicated in the range of 95 – 100% for AOC and 80 – 100% for PCB. Other examples are listed in table 1.

**TABLE 1** **REMOVAL OF ORGANIC COMPOUNDS THROUGH A TEST GAC FILTER, TREATING EFFLUENT OF A SAND FILTER AFTER CONVENTIONAL TREATMENT (MISKA ET AL., 2004)**

| Parameter compound substances | Average influent to process | Average effluent of process |
|---|---|---|
| 1,2 Dichlorethane | 0.1- 24 mg | < 1 mg/l |
| Atrazine | < 0.1- 5360 ng/l | < detection limit |
| Chlorinated hydrocarbon insecticides (CHI) | < 5 ng/l | < detection limit |

### C. DESIGN GUIDELINES / TECHNICAL DATA

The design values for a GAC filter are listed in table 2.

**TABLE 2** **TYPICAL DESIGN VALUES FOR GAC CONTACTORS (METCALF & EDDY, 2003)**

| Parameter | Unit | Value |
|---|---|---|
| Volumetric flow rate | $m^3/h$ | 50 – 400 |
| Bed volume | $m^3$ | 10 – 50 |
| Cross-section area | $m^2$ | 5 – 30 |
| Length | m | 1.8 – 4 |
| Void fraction | $m^3/m^3$ | 0.38 – 0.42 |
| GAC density | $kg/m^3$ | 350 – 550 |
| Approach velocity | m/h | 5 – 15 |
| Effective contact time | min | 2 – 10 |
| Empty bed contact time | min | 5 – 30 |
| Operation time | d | 100 – 600 |
| Throughput volume | $m^3$ | 10 – 100 |
| Specific throughput | $m^3/kg$ | 50 – 200 |
| Bed Volumes | $m^3/m^3$ | 2,000 – 20,000 |

### D. OPERATIONAL STABILITY AND MAINTENANCE

Loaded activated carbon requires regular regeneration. Upon regeneration and reactivation activated carbon is lost. After each life-cycle activated carbon has to be added to compensate this loss.

### E. REFERENCE INSTALLATIONS, SUPPLIERS / PATENTS

- No WWTP-effluent polishing references in Wester Europe
- Windhoek, Namibia

## F. LITERATURE REFERENCES

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Faust, S. D. and O.M. Aly (1987) Adsorption Processes for Water Treatment. Butterworth Pub., Stoneham, MA, USA

Miska V et al., (2004) Aquarec - Integrated Concepts for Reuse of Upgraded Wastewater, Delft University of Technology, Delft

*websites*

Chemviron carbon: www.chemvironcarbon.com

Norit: www.norit.com

# ION EXCHANGE

**Fact sheet nr. 7**

| | |
|---|---|
| Unit operation | Adsorption |
| Treatment principle | Bonding |
| Applicable for | Advanced treatment of WWTP effluent |
| Stage of development | full scale |
| Process | |
| function | removal of dissolved solids and/or organics or heavy metals |
| feed | pre-treated wwtp effluent |

Keywords: advanced treatment WWTP effluent, ion-exchange., selective removal of heavy metals, cadmium, nickel, copper, sink , selective chelating ion exchange resins

## A. BACKGROUND

In this unit process the exchangeable given species attached to an insoluble material (resin) are displaced by ions of a different species present in the solution. The displacement is mainly ruled by electromagnetic forces and/or adsorption. The ion-exchange resins can be either of natural origin or manufactured. Natural materials are better known as Zeolites, which are complex aluminosilicates with sodium as a mobile ion. Manufactured materials can also be synthetic aluminosilicates, in which case they are still called Zeolites, but more often they are resins (styrene and divinylbenzene copolymerised) or phenolic polymers.

Five types of synthetic ion-exchange resins are in use: (1) strong-acid cation, (2) weak-acid cation, (3) strong-base anion, (4) weak-base anion, and (5) heavy metal selective chelating resins. Besides, resins can be of macro-porous structure for adsorption of organic material. The relevant properties of ion-exchange resins are the following:

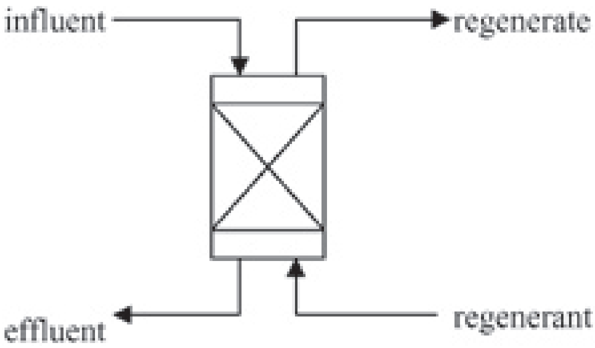
- Exchange capacity [eq/L] or [eq/kg]: quantity of exchangeable ions that the resin can take up. The “ideal” value is much higher than the actual operating capacity, which is influenced by competing ions, flow rates, temperature and regeneration level. For removal of organics, the exchange capacity is (normally) expressed in [$KMnO_4$/L].
- Particle size: important towards the hydraulics and the kinetics of the ion-exchange;
- Stability: chemical-physical resistance in the long term.
- Selectivity: the ion-exchange process is basically a chemical equilibrium where the taking up capacity of the resin towards a certain ion is specific, depending upon the nature and the valence of the ion, as well as from the operating conditions (such as saturation of the resin, ions concentrations, pH, presence of concurrent ions). The selectivity coefficient is basically the constant of the equilibrium of the ion exchange; therefore it is valid only for the conditions under which it was measured. On the basis of selectivity, a “series” of the affinity towards different ions is created for each resin. For strong acid cation exchange resins the selectivity in order of decreasing preference is: $Ba^{2+} > Pb^{2+} > Hg^{2+} > Ca^{2+} > Ni^{2+} > Cd^{2+} > Cu^{2+} > Zn^{2+} > Mg^{2+} > K^+ > NH_4^+ > Na^+$. Furthermore, especially for drinking water production, in the past years selective chelating ion exchange resins have been developed for the efficient removal of heavy metals with a high removal efficiency on a ppb level (Stetter, D., 2002).

Commercially viable ion exchange processes are often confined to dilute solution of lower than 40 eq/m$^3$ due to cost reasons (Harland C.E, 1994). For organics removal, the process is merely used for TOC/DOC containing waters in order to protect downstream anion resins becoming (irreversibly) fouled. Macroporous resins are also used for (high) colour containing waters at drinking water production. Use of cation exchange resins is also used for heavy metals removal, e.g. in the metal plating and surface finishing industry where, in some cases, recovery of valuable metals is aimed at. There is less experience with this process for effluent treatment aiming at heavy metal polishing in the ppb range.

### B. DESCRIPTION AND WORKING PRINCIPLE AND PICTURE/SCHEME

The process can be operated either in batch or continuous mode. In batch mode, the resin and the water to be treated are stirred together in a reactor. When the reaction is complete the spent resin is separated by settlement, regenerated and reused. The continuous mode is usually run in down-flow packed-bed columns; therefore the wastewater flows from the top to the bottom of the column, through the resin bed. The exhausted resins are regenerated through backwash operation (see Figure 1).

FIGURE 1 ION EXCHANGE PROCESS



Aiming at heavy metals removal the following reactions can be given as an example:

$2 (R\text{-}SO_3H) + NiSO_4 = (R\text{-}SO_3)2Ni + H_2SO_4$ (production cycle)

$(R\text{-}SO_3)2Ni + H_2SO_4 = 2(R\text{-}SO_3H) + NiSO_4$ (regeneration cycle with acid)

*Required Pretreatment*

The ion exchange process is susceptible for suspended solids (max. 2-3 mg/l, Harland, 1994) and organics and requires adequate pretreatment. A typical pretreatment process for removal of suspended solids is (multi) media filtration, and in case of presence of organics either polishing by macroporous resins is applied or activated carbon.

*Waste Products*

The waste product of the ion exchange process is a regeneration stream containing salts. Typical regeneration compounds are: Ca(Cl)2, Ca(OH)2, NaCl, NaOH. In general, regeneration with sodium salts is found to be more economic thanks to a greater throughput per cycle (de la Torre, 1999). For heavy metals removal regeneration with a strong acid (H2SO4 or HCl) is required and produces regeneration liquids comprising metal complexes next to metal salts.

*Effluent*

Applying ion exchange processes, the removal efficiency of a resin depends upon the characteristics of the feed water (concentrations and ions concurrency) and the applied process parameters (flow, regenerative level, etc.). As a consequence it is usual to design the whole process on the basis of the desired concentration value in the effluent. For heavy metals removal and/or recovery, experiences show effluent concentrations in the order of <0.1 ppm. Lower concentrations are not yet experienced and need to be pilot tested.

### C. DESIGN GUIDELINES AND TECHNICAL DATA

*design loads*

- hydraulically: 20-30 **B**ed**V**olume/h; regeneration and rinsing load: 90 g HCl per liter resin;
- kinetically: exchange capacity between 0.2 and 0.7 meq/L
- energy consumption; the energy consumption of ion exchange process is general less than 0.3 – 0.4 kWh/$m^3$.
- chemical demand; regeneration chemicals (acid and base chemicals, salts like lime or NaCl) are required at intervals. Consumption figures are much dependent on feed water composition, regeneration frequency and load. General figures cannot be given.

*treatment performance* see table 1

**TABLE 1** **TREATMENT PERFORMANCE**

| parameter component substances | average influent to process (ppm) | average effluent of process (ppm) | process parameters (research/full scale) |
|---|---|---|---|
| $NH_4$ | 50 | 1 | Zeolite exchange process, research |
| colour | > 20 ppm PtCo | < 10 ppm PtCo | full scale |
| organics | not known / limited | not known / limited | research |
| (heavy) metals | low (10 – 0,01) and high (>100) concentrations | < 0.1 – 0,001 | full scale; research |

*waste / by product production* regeneration fluids.

### D. OPERATIONAL STABILITY AND MAINTENANCE

The ion exchange process is a well-known and robust process used merely in the industry. The process can be operated fully automatic. Filter vessels are generally installed in parallel for continuous filtration of the wastewater. Maintenance is mainly required for chemical dosing facilities (especially lime) and during resin exchange after exceeding its lifetime.

### E. REFERENCE INSTALLATIONS, SUPPLIERS / PATENTS

The ion exchange process is in general a well-known and robust process and is applied worldwide, mostly for the production of demineralised water in the industry, but also for treatment and/or recovery of (heavy) metals at e.g. the galvano industry. Worldwide, numerous installations are installed at industries, from small size (several $m^3$/h) upto large size (>1000 $m^3$/h) units. For effluent polishing, reducing organics and/or trace (heavy) metals, the process is relatively new.

Suppliers of (synthetic) ion exchange resin are (a.o.): Rohm&Haas, Purolite, ResinTech, Dow Chemical, Bayer. Natural ion exchange material (Zeolite) can be extracted at several places (mountain and vulcanic areas).

*Alternative Processes*

Alternative processes for removal of soluble organic substances and/or suspended solids are: denitrifying (sand) filters, activated carbon filtration, membrane filtration and coagulation/ floccuation processes.

An alternative resin to remove heavy metal ions is the AlgaSORB® technology being a biological sorption process. This system functions as an biological ion exchange resin to bind metallic cations. The product is composed of a non-living algal biomass immobilised in a silica polymer.

A second alternative process for removal of heavy metals achieving metal effluent concentrations at ppb level would be the MAAS technology. This technology is developed by TNO-MEP specifically for the removal of heavy metals and combines the high selectivity of ion exchange resins with the continuous membrane filtration process. The MAAS technology has been tested on pilot scale level.

## F. LITERATURE REFERENCES

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Harland, C.E., (1994), Ion Exchange: theory and practice (2nd ed.), Royal Society of Chemistry, UK.

Miska V., Ravazzini A., Koning J. de, Delft University of Technology, Integrated concepts for reuse of upgraded wastewater EVK1-CT-2002-00130 Work package 7 Deliverable D6, April 2004.

Rees, D. Goltz, B. Gisch, D. (2004), Ion exchange resins can reduce nitrogen levels in water, Water and Wastewater International, November 2004.

Torre Gutierrez, L. de la, (1999), Ammonium removal from municipal wastewater by Ion Exchange, Afstudeerverslag TU-Delft (Sectie Gezondheidstechniek), DUP Science, Delft.

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# BED FILTRATION

**Fact sheet nr. 08**

| | |
|---|---|
| Unit operation | Separation |
| Treatment principle | Bed filtration with sand or multimedia |
| Applicable for | Advanced wastewater treatment |
| Stage of development | Full-scale |

| | | |
|---|---|---|
| Process | function: | removal of particles, suspended solids, pathogenic organisms, bacteria |
| | feed: | WWTP effluent |
| Keywords: | | filtration, multi media filtration, sand filtration, fixed-bed, continuous sand filtration, flocculating filtration |

## A. BACKGROUND

Different types of bed filtration are available such as rapid bed filtration, slow filtration, continuous filtration and fuzzy filtration. Rapid (sand or multi media) filtration and continuous sand filters are the most commonly used filtration techniques for effluent treatment. Slow sand filtration is an older technique that, due to its very large space requirement and maintenance-intensive operation (manual cleaning of filter bed), is less applied in recent times. Rapid bed filtration is a bed filtration technique originating from drinking water treatment where it is used to remove particle matter and turbidity. The process is very robust and has been in operation in drinking water production for more than 100 years throughout the world. Within wastewater treatment rapid filtration has been used for over 30 years for advanced effluent treatment, mainly in Germany, Switzerland, UK and the USA. Rapid sand filtration is the flow of water through a bed of granular media, normally following settling basins in conventional water treatment plants. The purpose of this filtration is to remove any particulate matter left over after flocculation and settling. The filtration mechanisms are sieving, sedimentation, adsorption, coagulation and flocculation (in case of metal salt addition). During passage of water through the granular bed, water fills the pores of the filter medium and the suspended solids and colloidal impurities are adsorbed on the surface of the grains or become trapped in the openings. The key to this process is the relative grain size of the filter medium.

Slow sand filtration is a filtration technique which generally uses fine sand (effective size 0.15 – 0.4 mm) and slow filtration rates in the range from 0.1 to 0.3 m/h. The fine media and low filtration rates encourage the surface capture of large (> 20 um) particulate material. Head loss, maximum biofilm growth and finer particle capture is usually concentrated in the top 20 – 30 mm of sand media. With rapid and slow bed filtration the filtration resistance increases over time due to accumulation of retained material. This requires periodical backwashing. The time interval between cleaning operations is called ‘run time’. The types of available filtration techniques can be separated into discontinuous and continuous filtration techniques.

## B. DESCRIPTION AND WORKING PRINCIPLE

*discontinuous downflow/upflow filtration*

Downflow filters are deep bed sand or multi-media filters (1.0 – 2.0 m) which can typically achieve TSS concentrations of < 1 mg/l. During operation head loss gradually increases due to solids accumulation. The filter is backwashed for solids removal by air scouring followed by an air/water backwash (once every 24 – 48 h). The solids storage capacity is estimated to be about 4 kg TSS/m$^3$ before headloss occurs. A schematic diagram of a downflow filter is shown in figure 1 (left).

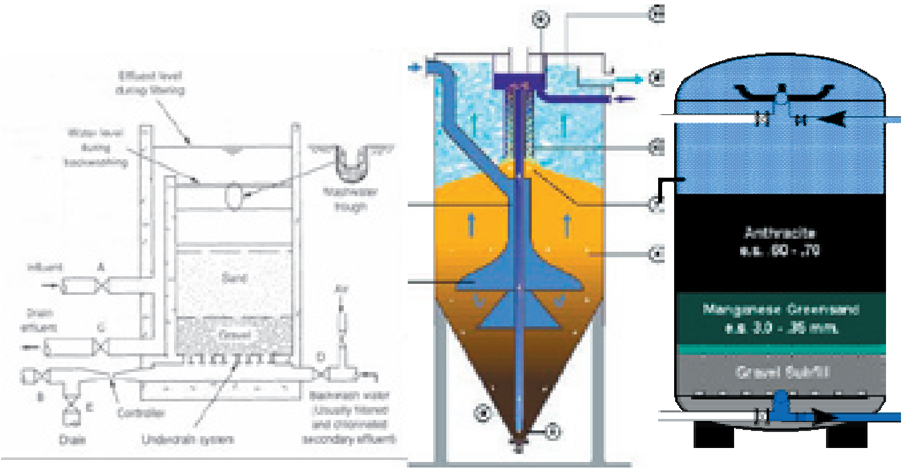
*continuous filtration*

A schematic diagram of a typical continuous sand filter is shown in middle schema of figure 1. The effluent is transported into the filter by means of the feed pipeline (1). The water enters the filter bed (4) through the supply pipe (2) and the distributors (3). The water is purified as it flows through the filter in an upward direction. The filtrate is discharged from the upper part of the filter (5). The filter bed is moving downward as the water flows up. The dirty sand (6) is continuously abstracted from the sand bed and washed, after which it is released back on the top of the sand bed (7). The sand circulation is based on the airlift principle, forcing a mixture of dirty sand and water upward through a central pipeline (8). The intensive scouring movements separate the impurities from the sand particles. At the top of the pipeline the air is released, and the dirty water is discharged (9). The sand then settles in the washer. The sand washer (10) at the top of the filtration tank washes the sand with a small amount of clean filtrate. This removes the last traces of pollutant from the sand. Flow is achieved through a difference in level between the filtrate (11) and the rinse water (9).

*pressurised filtration*

Pressurised filtration is mainly applied in smaller systems to increase surface loading rates. Within these filtration systems the inlet water is fed to a sand or multi media filtration bed under pressure. The filter system is backflushed by air and a combination of air and water.

**FIGURE 1** **LEFT: DOWNFLOW PACKED-BED FLOW CONFIGURATION. MIDDLE: UPFLOW FLUIDISED BED CONFIGURATION, RIGHT: PRESSURE FILTER**



*required pretreatment*

Generally well treated wastewater treatment plant effluent from conventional settling tanks is suitable as feedwater of rapid filtration systems. Large particles or substances that could interfere with the effective operation of the filter bed have to be removed from the feedwater by screens with a maximum mesh width of 5 mm. In practice round screen openings have been found to be the most effective.

*waste products*

In rapid filtration systems excess particulate matter (and chemical sludge in the case of metal dosages) is produced. In fixed-bed systems the sludge is partially dislodged during the backwash stage and in continuous sand filtration the biomass is separated from the sand particles by the sand-flushing step. The flush water containing the excess sludge is recycled back into the main activated sludge process.

*treatment performance*

Rapid filtration is capable of achieving TSS concentrations of < 1 mg/l. The performance is affected predominantly by the filter medium size and the applied metal salt dosage.
See table 1.

**TABLE 1** **TREATMENT EFFICIENCY OF RAPID MULTI MEDIA FILTRATION OF WWTP EFFLUENT**

| parameter | feedwater values [mg/l] | removal efficiency with rapid filtration [%] |
|---|---|---|
| BOD | 5 – 25 | 40 – 80 |
| COD | 30 – 100 | 60 – 90 |
| TSS | 5 – 25 | > 90 |
| Phosphate | 0.5 – 3.0 | 15 – 40 (without chemical addition) |
| micro-organisms | $10^3$ – $10^4$ (n/ml) | log 2 |

*energy consumption*

Energy consumption for these systems is low, ranging between 0,10 kWh/m$^3$ for small-scale systems (2.000 m$^3$/d) and 0,05 kWh/m$^3$ for large-scale systems (20.000 m$^3$/d).

*chemical demand*

Chemical demand is relevant if filtration is combined with chemical phosphorous removal by metal dosage (see Fact Sheet 03 Denitrifying Sand Filters).

## C. DESIGN GUIDELINES / TECHNICAL DATA

Typical design parameters are shown in table 2.

**TABLE 2** **DESIGN PARAMETERS OF FIXED-BED UPFLOW/DOWNFLOW SAND FILTERS AND FLUIDISED BED CONTINUOUS SAND FILTERS**

| | | Slow sand filtration | Sand or multi-media rapid filtration | Fluidised bed continuous sand filtration |
|---|---|---|---|---|
| Packing type | - | anthracite, sand, garnet | anthracite, sand, garnet | anthracite, sand |
| Granule size | mm | 0.3 – 0.6 | 0.5 – 6.0 | 0.3 – 3.5 |
| Filter bed depth | m | 0.3 – 1.5 | 1.0 – 2.5 | 1.5 – 2.0 |
| Hydraulic loading | m$^3$/m$^2$.h | 0.1 – 0.3 | 5 – 30 | 15 – 25 |
| Max TSS loading | g TSS/m$^2$.h | 1,000 | 1,000 | 2,000 |
| Flush water flow rate | m$^3$/m$^2$.h | - | - | 1.0 – 1.2 |
| Media contact time | h | 1 – 15 | 0.07 – 2 | 0.07 – 2 |
| Recirculation ratio | - | - | - | 2:1 – 5:1 |
| Filter run length | d | 20 – 300 | 0.3 – 3 | - |
| Backwash airflow rate | m$^3$/m$^2$.h | - | 90 – 120 | - |
| Backwash water flow rate | m$^3$/m$^2$.h | - | 15 – 25 | - |
| Me/P ratio for P-removal | mol Fe/mol P | 1 – 3 | 1 – 3 | 1 – 3 |

### D. OPERATIONAL STABILITY AND MAINTENANCE

Rapid (multi media) filtration is a "fail-safe" technique due to its robust set-up and few moving parts. The only major failure that can occur is clogging of the bed, which is measured as a pressure increase in the filter bed. In this case the filter bed needs to be flushed or "bumped". Continuous sand filters rarely need to be taken out of service for backwashing. Treatment of both the water and the filter sand take place without interruption. The filter has no moving parts, minimising the need for superintendance. Slow sand filters can be labour intensive as they need to be manually cleaned up to two times per year, depending on the quality of the feed water.

### E. DIFFERENT TYPES OF RAPID SAND FILTERS

In addition to the gravity fed, other versions are available:

- Deep coarse beds employ only a single media in 2 – 3 m deep beds. These filters are best used on industrial wastewater with a known particulate matter.
- Upflow filters employ filtration from the bottom up, using coarse to fine filtration. Backwashing is accomplished in the same direction (upflow) but with a greater velocity.
- Biflow filters use a divided flow - upflow from the bottom and downflow from the top which permits filtration in opposite directions at the same time.
- Pressure filters are sand filters with the filter bed enclosed in a cylindrical steel or iron shell. The water is passed through at a pre-determined pressure. The filter can be connected directly to the water main and clean water delivered to the point of use with no additional pumping. It is most useful for smaller quantities of water.
- "Fuzzy" filters, employing nylon "sponges" to absorb suspended solids and colloidal material.

### F. SUPPLIERS

Paques Natural Solutions, P.O. Box 52, 8560 AB BALK, the Netherlands (ASTRASAND®).

Nordic Water Benelux BV, P.O. Box 522,1940 AM Beverwijk, the Netherlands (DYNASAND®).

Andritz Ltd, Speedwell Road, Parkhouse East, Newcastle-under-Lyme, Staffordshire, ST5 7,
UK(HYDRASAND® patent).

Mitsubishi Kakoki Kaisha, Ltd.

Hubert Water Technology

SAMCO Water Technology.

Bosman, Fuzzy Filter

# MICROFILTRATION / ULTRAFILTRATION

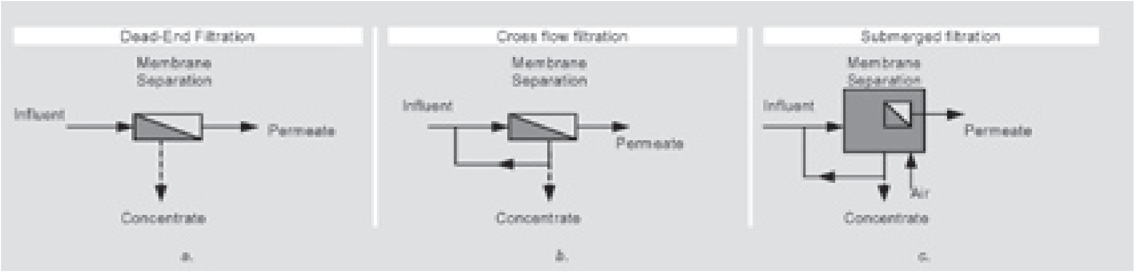
**Fact sheet nr. 09**

| | |
|---|---|
| Unit operation | Membrane filtration |
| Treatment principle | Separation |
| Applicable for | Advanced effluent treatment or in integrated treatment in MBR |
| Stage of development | full scale |
| Process | |
| function: | concentration and removal of suspended solids, bacteria |
| feed: | WWTP effluent |
| Keywords: | membrane, filtration, suspended solids, bacteria |

## A. BACKGROUND

Membrane filtration processes can be classified according to the pore size of the membrane. Microfiltration is a membrane filtration process designed to retain particles in the ‘micron’ range (0.10 μm – 5 μm). Microfiltration is used mainly as a clarification technique, separating suspended particles from dissolved substances, provided the particles meet the size requirements for microfiltration membranes (Cheryan, 1998). Ultrafiltration (UF) membranes have a pore size in the range 0.005 – 0.1 μm. Due to the smaller pore size, UF can retain macromolecules, viruses and bacteria in addition to suspended solids.

FIGURE 1 MEMBRANE FILTRATION WITH DIFFERENT CONFIGURATIONS



## B. DESCRIPTION AND WORKING PRINCIPLE

In microfiltration and ultrafiltration the separation mechanism is sieving, i.e. particles bigger than the pore size are retained by the membrane. Smaller particles pass the membrane. The membrane filtration process can be designed as a dead end system with periodic discharge of concentrate (Figure 1a). Alternatively, cross flow filtration can be used, where the concentrate is (partially) recycled back to the influent stream (Figure 1b). Because of the relatively low concentration of suspended solids in WWTP effluent, dead-end filtration is commonly applied for tertiary treatment with membranes.

*membranes*

For the application in tertiary treatment, several membrane types are available:

- hollow fibre, inside-out. The membranes are configured as hollow fibres, potted in pressure vessels. The feed flow enters the inside of the fibres and effluent permeates through the fibre wall.
- hollow fibres, outside-in. The membranes are submerged (Figure 1c) in the feed and effluent is forced to the inside of the fibres by a suction pressure. Usually, the membrane modules also have a coarse bubble aeration to provide turbulence around the membrane for fouling control.

*required pretreatment*

A fine screen is optional to remove coarse material. For an optimal operation of dead end membrane filtration of WWTP effluent, inline coagulation can be useful. Coagulants increase the filterability of the water. As coagulants iron or aluminium salts can be used in concentrations of 0.5 – 2 mg/L.

*waste products*

Concentrate is produced in the filtration step, containing suspended solids and microbes. The TSS concentration of the concentrate depends on the concentration factor of the system.

*treatment performance*

The membrane-treated effluent is disinfected and particle free. The removal of nutrients occurs by removal of nutrients within the suspended solids. Further treatment figures are presented in Table 1.

**TABLE 1** **TREATMENT EFFICIENCY OF MICROFILTRATION AND ULTRAFILTRATION PROCESS**

| Parameter | Microfiltration [%] | Ultrafiltration [%] |
|---|---|---|
| BOD | 75 – 90 | ~ 81 |
| COD | 46 – 70 | 70 – 85 |
| TSS | 95 – 98 | 97 – 99.5 |
| Total N | | ~ 12 |
| Ammonium-N | 5 – 15 | |
| Total P | ~ 14 | ~ 26 |
| Turbidity | 92 – 99 | >99 |
| Total Coliforms | 90 – 100% | 100% |
| Fecal Coliforms | 95 – 100% | 100% |
| Bacteria | 5 – 6 log removal | |

*chemical demand*

Periodical chemical cleaning is required depending on the type of membrane and feed water quality.

## C. DESIGN GUIDELINES / TECHNICAL DATA

| membrane technology | operating pressure kPa | permeate flux rate $l/m^2 \cdot hr$ | energy consumption $kWh/m^3$ |
|---|---|---|---|
| microflitration | 7 – 150 | 15 – 80 | 0.05 – 0.15 |
| ultrafiltration | 7 – 150 | 15 – 80 | 0.05 – 0.15 |

## D. OPERATIONAL STABILITY AND MAINTENANCE

Filtration performance is dependent on feed water characteristics and operational conditions. Because of the separation process, suspended matter and macromolecules will accumulate at the membrane surface. This process leads to an increase in required trans membrane pressure, commonly described by the term ‘fouling’. The amount and type of fouling that occurs is dependent on the feed flow characteristics and operation of the membrane system. Fouling can be controled by several measures, such as cleaning (backflush, forward flush, soaking in chemical solution), depending on the type of membrane system and the type of fouling.

## E. REFERENCE INSTALLATIONS, SUPPLIERS / PATENTS

**TABLE 2** **REFERENCE INSTALLATIONS FOR MICRO / ULTRAFILTRATION OF WWTP-EFFLUENT**

| city, country | year | membrane system[1] | pore size µm | max flow $m^3/hr$ | flux min/ max $l/m^2 \cdot hr$ |
|---|---|---|---|---|---|
| Tilburg, NL | 2004 | HF, Zenon | 0.020 | | |
| Torreele, B[2] | 2002 | HF, Zenon | 0.045 | 400 | |
| Windhoek, Namibia | 2002 | HF, X-flow | | 1000 | |
| Flag Fen, UK[2] | 2003 | HF, Pall | 0.1 | 65 | 24 / 37 |

[1] HF Hollow Fibre

[2] Pretreatment for Reverse Osmosis

*Membrane Suppliers*

Zenon, Pall, Memcor, X-Flow (see also Fact Sheet 01 Membrane Bioreactor)

## F. LITERATURE REFERENCES

Cheryan. M (1998) Ultrafiltration and Microfiltration Handbook. Technomic Publishing AG, Basel, Switzerland

Mulder, MN. (1996) Basic Principles of Membrane Technology. Kluwer Academic Publishers, Dordrecht, The Netherlands

*Websites*

Membrane Academia Industry Network http://www.main.wizzy.co.uk/

Zenon references http://www.zenon.com/resources/case_studies/wastewater/IWVA.shtml

X-Flow: www.X-Flow.com

Pall: www.pall.com

## APPENDIX IV

# BASIC ASSUMPTIONS FOR THE COST ESTIMATES

### GENERAL

For each technique or combination of techniques a cost estimate has been set up, containing the investment costs and the total yearly costs. The cost estimates have been calculated for two plant sizes, namely 20,000 P.E. and 100,000 P.E.

The average dry weather flow (DWF) rate is calculated based on an average daily flow of 200 l/P.E. during 16 hours per day = 12.5 l/P.E./h. The treatment units have been designed for a hydraulic flow of 1.5 x DWF = 18.75 l/P.E./h.

| | 20,000 P.E. | 100,000 P.E. | |
|---|---|---|---|
| Average daily flow | 4,000 | 20,000 | $m^3$/d |
| Average flow | 250 | 1,250 | $m^3$/h |
| Maximum flow | 375 | 1,875 | $m^3$/h |
| Yearly flow | 1,460,000 | 7,300,000 | $m^3$/year |

The total costs are presented both per cubic metre treated (m3) and as costs per P.E./year.

For estimation of the construction costs, the estimated costs have been used from the detailed design phase of a project in which denitrifying sand filter post-treatment units are being implemented for 6 different WWTPs by the Water Board of Rijnland. Both plant sizes of 20,000 and 100,000 P.E. have been applied in this project. The costs for connection to the existing facilities, elevation of water, pre-treatment, filtration and extra provisions required at the Rijnland installations are considered representative for the “typical” application at other WWTPs in The Netherlands.

### CONSTRUCTION COSTS AND INVESTMENT COSTS

The estimation of the construction costs includes:

- connection to the effluent pumping system of the existing WWTP;
- pumping station with fine screen for the elevation of effluent to the post treatment unit;
- the treatment step(s), including extra provisions (e.g. compressed air), feeding, measurement and control units and process control;
- chemical storage and dosage units;
- simple operation rooms for instruments that cannot be mounted outside.

For the application of filter installations in plants of 20,000 P.E., it has been assumed that steel filters mounted outdoors will be used; for plants of 100,000 P.E., it is assumed that filters will be built in concrete filter constructions.

For the treatment of residual waste streams, integral costs are accounted for in the operational costs (internal costs in the WWTP and transport costs of residual waste products); no extra treatment units have been calculated in the investment costs.

The investment costs presented are excluding the costs for eventual extra building space (land).

All treatment scenarios are provided with a simple cascade step as a last process step to ensure sufficient oxygen levels in the effluent (3 – 5 mg/l).

The investment costs are calculated from the construction costs. Construction costs are multiplied by a factor of 61 % for unforeseen costs, design and supervision, funding costs, permits, insurance, costs for commissioning and service goods tax (BTW in The Netherlands).

**TOTAL YEARLY COSTS (OPERATIONAL COSTS)**

In the operational costs the following aspects have been accounted for:

- capital costs are based on the method of annuity, with 6 % rent. Depreciation period civil: 30 years, mechanical, electrical and process control: 15 years. This results in annuities of 7.3 %/year and 10.3 %/year, respectively.
- maintenance costs 0.5 %/year of civil construction costs, 3 %/year of mechanical, electrical and process control construction costs.
- personnel 50,000 EUR/FTE/year, required service is dependent on the technique.
- Energy costs based on 0.07 EUR/kWh.
- Additional chemicals:

| | |
|---|---|
| 40 %FeCl3 | EUR 150/1,000 kg |
| methanol | EUR 275/1,000 kg |
| 35 % H2O2 | EUR 300/1,000 kg |
| powdered activated carbon | EUR 1,100/1,000 kg |

| | |
|---|---|
| - Replacement costs during operation time: | |
| - granular activated carbon (GAC) | EUR 600/1,000 kg (run time 0.6 – 0.7 y) |
| - UV-lamps | depending on application (advanced oxidation or disinfection) |
| - MF/UF membranes | EUR 30/$m^2$, lifetime 7 year |
| - Treatment of residual waste streams (internal & external costs): | |
| - filtration sludge, surplus sludge | EUR 500/1,000 kg ds (= thickening, dewatering, transport, end treatment together with WWTP-sludge) |
| - Brine of ion exchange | 0.01 % of main stream, 60 EUR/$m^3$ |
| - On line measurement (quality control) | EUR 3,000/y (operational costs) |

**TABLE IV-1** OVERVIEW OF MAIN TREATMENT UNITS PER TREATMENT SCENARIO

| biofiltration flocking filtration (two stage) | denitrification flocking filtration (single stage) | flocking filtration activated carbon | powdered activated carbon flocking filtration | flocking/biofiltration UV/H2O2 |
|---|---|---|---|---|
| **NP1** | **NP2** | **OS1** | **OS2** | **OS3, WFD3** |
| connection to effluent piping<br>effluent pumping station<br>pre-treatment<br>- fine screen 3 mm biofiltration (12 m/h)<br>- 4 units 8 $m^2$<br>- steel cylinders in line coagulation flocking filtration (12 m/h)<br>- 4 units 8 $m^2$<br>- steel cylinders cascade piping (supply and discharge):<br>- 2 x 50 m dosage and storage C-source (Methanol)<br>- on ground level<br>- 30 $m^3$ dosage and storage coagulant (Fe)<br>- on ground level<br>- 15 $m^3$ operations building<br>- e-installation<br>- compressor installation on line measurement<br>Total surface:<br>- 800 $m^2$, incl. safety zone for MeOH storage (400 $m^2$) | connection to effluent piping<br>effluent pumping station<br>pre-treatment<br>- fine screen 3 mm in line coagulation bio/ flocking filtration (12 m/h)<br>- 4 units 8 $m^2$<br>- steel cylinders cascade piping (supply and discharge):<br>- 2 x 50 m dosage and storage C-source (Methanol)<br>- on ground level<br>- 30 $m^3$dosage and storage coagulant (Fe)<br>- on ground level<br>- 15 $m^3$ operations building<br>- e-installation<br>- compressor installation on line measurement<br>Total surface:<br>- 700 $m^2$, incl. safety zone for MeOH storage (400 $m^2$) | connection to effluent piping<br>effluent pumping station<br>pre-treatment<br>- fine screen 3 mm in line coagulation flocking filtration (12 m/h)<br>- 4 units 8 $m^2$<br>- steel cylinders activated carbon filtration (5 m/h)<br>- EBC > 20 min<br>- 4 units 20 $m^2$<br>- steel cylinders cascade piping (supply and discharge):<br>- 2 x 50 m dosage and storage coagulant (Fe)<br>- on ground level<br>- 15 $m^3$ operations building<br>- e-installation<br>- compressor installation on line measurement<br>Total surface:<br>- 600 $m^2$ | connection to effluent piping<br>effluent pumping station<br>pre-treatment<br>- fine screen 3 mm contact reactor / coagulation<br>- contacttime 20 min<br>- volume 83 $m^3$ floc filtration (12 m/h)<br>- 4 units 8 $m^2$<br>- steel cylinders cascade piping (supply and discharge):<br>- 2 x 50 m dosage and storage coagulant (Fe)<br>- on ground level<br>- 15 $m^3$ dosage and storage PAC<br>- on ground level<br>- 15 $m^3$ operations building<br>- e-installation<br>- compressor installation on line measurement<br>Total surface:<br>- 500 $m^2$ | connection to effluent piping<br>effluent pumping station<br>pre-treatment<br>- fine screen 3 mm in line coagulation flocking filtration (12 m/h)<br>- 4 units 8 $m^2$<br>- steel cylinders<br>UV-reactor and contact reactor<br>- 2 UV-units<br>- 500-1.000 mJ/$cm^2$<br>- CT > 10 min<br>- activated carbon filter for removal of residual $H_2O_2$ (optional) cascade piping(supply and discharge):<br>- 2 x 50 m dosage and storage coagulant (Fe)<br>- on ground level<br>- 15 $m^3$ dosage and storage $H_2O_2$<br>- on ground level<br>- 30 $m^3$ operations building<br>- e-installation<br>- compressor installation on line measurement<br>Total surface:<br>- 800 $m^2$, incl. safety zone for $H_2O_2$ storage (400 $m^2$) |

| **flocking filtration** | **flocking filtration**<br>**Ion exchange** | **in line coagulation**<br>**micro/ultrafiltration** | **flocking filtration**<br>**UV-desinfection** | **flocking/biofiltration**<br>**activated carbon** | **biofiltration PAC**<br>**floc filtration** |
|---|---|---|---|---|---|
| **M1** | **M2** | **M3, MV2** | **MV1** | **WFD1** | **WFD2** |
| connection to effluent piping<br>effluent pumping station<br>pre-treatment<br>- fine screen 3 mm in line coagulation flocking filtration (12 m/h)<br>- 4 units 8 $m^2$<br>- steel cylinders cascade piping (supply and discharge):<br>- 2 x 50 m dosage and storage coagulant (Fe)<br>- on ground level<br>- 15 $m^3$ operations building<br>- e-installation<br>- compressor installation on line measurement<br>Total surface:<br>- 300 $m^2$ | connection to effluent piping<br>effluent pumping station<br>pre-treatment<br>- fine screen 3 mm in line coagulation flocking filtration (12 m/h)<br>- 4 units 8 $m^2$<br>- steel cylinders Ion exchange<br>- 2 columns 5 $m^2$<br>- steel cylinders cascade piping (supply and discharge):<br>- 2 x 50 m dosage / storage coagulant (Fe)<br>- on ground level<br>- 15 $m^3$ operations building<br>- e-installation<br>- compressor installation<br>- storage regeneration chemicals on line measurement<br>Total surface:<br>- 450 $m^2$ | connection to effluent piping<br>effluent pumping station<br>pre-treatment<br>- fine screen 3 mm in line coagulation MF/UF<br>- gross flux at $Q_{max}$ 60 $l/m^2/h$)<br>- capillary 1,5 mm<br>- 8 inch, 6 m pressure vessels<br>- 4 modules p. pressure vessel cascade piping (supply and discharge):<br>- 2 x 50 m dosage / storage coagulant (Fe)<br>- on ground level<br>- 15 $m^3$ operations building<br>- e-installation<br>- compressor installation<br>- MF / UF on line measurement<br>Total surface:<br>- 350 $m^2$ | connection to effluent piping<br>effluent pumping station<br>pre-treatment<br>- fine screen 3 mm in line coagulation flocking filtration (12 m/h)<br>- 4 units 8 $m^2$<br>- steel cylinders UV-installation and contact reactor<br>- one UV-unit<br>- UV 40 – 125 $mJ/cm^2$ cascade piping (supply and discharge):<br>- 2 x 50 m dosage / storage coagulant (Fe)<br>- on ground level<br>- 15 $m^3$ operations building<br>- e-installation<br>- compressor installation on line measurement<br>Total surface:<br>- 350 $m^2$ | connection to effluent piping<br>effluent pumping station<br>pre-treatment<br>- fine screen 3 mm in line coagulation flocking filtration (12 m/h)<br>- 4 units 8 $m^2$<br>- steel cylinders activated carbon filtration (5 m/h)<br>- EBC > 20 min<br>- 4 units 20 $m^3$<br>- steel cylinders cascade piping (supply and discharge):<br>- 2 x 50 m dosage / storage C-source (Methanol)<br>- on ground level<br>- 30 $m^3$ dosage / storage coagulant (Fe)<br>- on ground level<br>- 15 $m^3$ operations building<br>- e-installation<br>- compressor installation on line measurement<br>Total surface:<br>- 900 $m^2$, incl. safety zone for MeOH storage (400 $m^2$) | connection to effluent piping<br>effluent pumping station<br>pre-treatment<br>- fine screen 3 mm in line coagulation bio filtration (12 m/h)<br>- 4 units 8 $m^2$<br>- steel cylinders contactvolume / coagulation<br>- contacttime 20 min<br>- volume 83 $m^3$ floc filtration (12 m/h)<br>- 4 units 8 $m^2$<br>- steel cylinders cascade piping (supply and discharge):<br>- 2 x 50 m dosage / storage C-source (Methanol)<br>- on ground level<br>- 30 $m^3$ dosage / storage coagulant (Fe)<br>- on ground level<br>- 15 $m^3$ dosage / storage PAC<br>- on ground level<br>- 15 $m^3$ operations building<br>- e-installation<br>- compressor installation on line measurement<br>Total surface:<br>- 1.000 $m^2$, incl. safety zone for MeOH storage (400 $m^2$) |

**TABLE IV-2 OVERVIEW OF MAIN TREATMENT UNITS PER TREATMENT SCENARIO (100.000 P.E.)**

| biofiltration flocking filtration (two stage) | denitrification flocking filtration (single stage) | flocking filtration activated carbon | powdered activated carbon flocking filtration | flocking/biofiltration UV/H2O2 |
|---|---|---|---|---|
| **NP1** | **NP2** | **OS1** | **OS2** | **OS3, WFD3** |
| connection to effluent piping<br>effluent pumping station<br>pre-treatment<br>- fine screen 3 mm biofiltration (12 m/h)<br>- 4 units 40 $m^2$<br>- concrete cylinders in line coagulation flocking filtration (12 m/h)<br>- 4 units 40 $m^2$<br>- concrete cylinders cascade piping (supply and discharge):<br>- 2 x 50 m dosage and storage C-source (Methanol)<br>- on ground level<br>- 30 $m^3$ dosage and storage coagulant (Fe)<br>- on ground level<br>- 30 $m^3$ operations building<br>- e-installation<br>- compressor installation on line measurement<br>Total surface:<br>- 1,600 $m^2$, incl. safety zone for MeOH storage (400 $m^2$) | connection to effluent piping<br>effluent pumping station<br>pre-treatment<br>- fine screen 3 mm in line coagulation bio/flocking filtration (12 m/h)<br>- 4 units 40 $m^2$<br>- concrete cylinders cascade piping (supply and discharge):<br>- 2 x 50 m dosage and storage C-source (Methanol)<br>- on ground level<br>- 30 $m^3$ dosage and storage coagulant (Fe)<br>- on ground level<br>- 30 $m^3$operations building<br>- e-installation<br>- compressor installation on line measurement<br>Total surface:<br>- 1,300 $m^2$, incl. safety zone for MeOH storage (400 $m^2$) | connection to effluent piping<br>effluent pumping station<br>pre-treatment<br>- fine screen 3 mm in line coagulation flocking filtration (12 m/h)<br>- 4 units 40 $m^2$<br>- steel cylinders activated carbon filtration (5 m/h)<br>- EBC > 20 min<br>- 6 units 60 $m^2$<br>- concrete cylinders cascade piping (supply and discharge):<br>- 2 x 50 m dosage and storage coagulant (Fe)<br>- on ground level<br>- 30 $m^3$ operations building<br>- e-installation<br>- compressor installation on line measurement<br>Total surface:<br>- 1,400 $m^2$ | connection to effluent piping<br>effluent pumping station<br>pre-treatment<br>- fine screen 3 mm contact reactor/ coagulation<br>- contacttime 20 min<br>- volume 420 $m^3$ floc filtration (12 m/h)<br>- 4 units 40 $m^2$<br>- concrete cylinders cascade piping (supply and discharge):<br>- 2 x 50 m dosage and storage coagulant (Fe)<br>- on ground level<br>- 30 $m^3$ dosage and storage PAC<br>- on ground level<br>- 30 $m^3$ operations building<br>- e-installation<br>- compressor installation on line measurement<br>Total surface:<br>- 1,100 $m^2$ | connection to effluent piping<br>effluent pumping station<br>pre-treatment<br>- fine screen 3 mm in line coagulation flocking filtration (12 m/h)<br>- 4 units 40 $m^2$<br>- concrete cylinders UV-reactor and contact reactor<br>- 6 UV-units<br>- 500-1.000 $mJ/cm^2$<br>- CT > 10 min<br>- activated carbon filter for removal of residual $H_2O_2$ (optional) cascade piping(supply and discharge):<br>- 2 x 50 m dosage and storage coagulant (Fe)<br>- on ground level<br>- 30 $m^3$ dosage and storage $H_2O_2$<br>- on ground level<br>- 30 $m^3$ operations building<br>- e-installation<br>- compressor installation on line measurement<br>Total surface:<br>- 1,400 $m^2$, incl. safety zone for $H_2O_2$ storage (400 $m^2$) |

| **flocking filtration** | **flocking filtration Ion exchange** | **in line coagulation micro/ultrafiltration** | **flocking filtration UV-desinfection** | **flocking/biofiltration activated carbon** | **biofiltration PAC floc filtration** |
|---|---|---|---|---|---|
| **M1** | **M2** | **M3, MV2** | **MV1** | **WFD1** | **WFD2** |
| connection to effluent piping<br>effluent pumping station<br>pre-treatment<br>- fine screen 3 mm in line coagulation flocking filtration (12 m/h)<br>- 4 units 40 m$^2$<br>- concrete cylinders cascade piping (supply and discharge):<br>- 2 x 50 m dosage and storage coagulant (Fe)<br>- on ground level<br>- 30 m$^3$ operations building<br>- e-installation<br>- compressor installation on line measurement<br>Total surface:<br>- 700 m$^2$ | connection to effluent piping<br>effluent pumping station<br>pre-treatment<br>- fine screen 3 mm in line coagulation flocking filtration (12 m/h)<br>- 4 units 40 m$^2$<br>- steel cylinders Ion exchange<br>- 8 columns 8 m$^2$<br>- concrete cylinders cascade piping (supply and discharge):<br>- 2 x 50 m dosage / storage coagulant (Fe)<br>- on ground level<br>- 30 m$^3$ operations building<br>- e-installation<br>- compressor installation<br>- storage regeneration chemicals on line measurement<br>Total surface:<br>- 1,000 m$^2$ | connection to effluent piping<br>effluent pumping station<br>pre-treatment<br>- fine screen 3 mm in line coagulation MF/UF<br>- gross flux at $Q_{max}$ 60 l/m$^2$/h)<br>- capillary 1,5 mm<br>- 8 inch, 6 m pressure vessels<br>- 4 modules p. pressure vessel cascade piping (supply and discharge):<br>- 2 x 50 m dosage / storage coagulant (Fe)<br>- on ground level<br>- 15 m$^3$ operations building<br>- e-installation<br>- compressor installation<br>- MF / UF on line measurement<br>Total surface:<br>- 350 m$^2$ | connection to effluent piping<br>effluent pumping station<br>pre-treatment<br>- fine screen 3 mm in line coagulation flocking filtration (12 m/h)<br>- 4 units 40 m$^2$<br>- concrete cylinders UV-installation and contact reactor<br>- 4 UV-unit<br>- UV 40 – 125 mJ/cm$^2$ cascade piping (supply and discharge):<br>- 2 x 50 m dosage / storage coagulant (Fe)<br>- on ground level<br>- 30 m$^3$ operations building<br>- e-installation<br>- compressor installation on line measurement<br>Total surface:<br>- 900 m$^2$ | connection to effluent piping<br>effluent pumping station<br>pre-treatment<br>- fine screen 3 mm in line coagulation flocking filtration (12 m/h)<br>- 4 units 40 m$^2$<br>- concrete cylinders activated carbon filtration (5 m/h)<br>- EBC > 20 min<br>- 6 units 62 m$^3$<br>- concrete/steel cylinders cascade piping (supply and discharge):<br>- 2 x 50 m dosage / storage C-source (Methanol)<br>- on ground level<br>- 30 m$^3$ dosage / storage coagulant (Fe)<br>- on ground level<br>- 30 m$^3$ operations building<br>- e-installation<br>- compressor installation on line measurement<br>Total surface:<br>- 1,800 m$^2$, incl. safety zone for MeOH storage (400 m$^2$) | connection to effluent piping<br>effluent pumping station<br>pre-treatment<br>- fine screen 3 mm in line coagulation bio filtration (12 m/h)<br>- 4 units 40 m$^2$<br>- concrete cylinders contactvolume / coagulation<br>- contacttime 20 min<br>- volume 420 m$^3$ floc filtration (12 m/h)<br>- 4 units 40 m$^2$<br>- concrete cylinders cascade piping (supply and discharge):<br>- 2 x 50 m dosage / storage C-source (Methanol)<br>- on ground level<br>- 30 m$^3$ dosage / storage coagulant (Fe)<br>- on ground level<br>- 30 m$^3$ dosage / storage PAC<br>- on ground level<br>- 30 m$^3$ operations building<br>- e-installation<br>- compressor installation on line measurement<br>Total surface:<br>- 1.600 m$^2$, incl. safety zone for MeOH storage (400 m$^2$) |