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Guidelines for treated wastewater use for irrigation projects —

Part 5:
Treated wastewater disinfection and equivalent treatments

Lignes directrices pour l'utilisation des eaux usées traitées dans les projets d'irrigation —

Partie 5: Désinfection des eaux usées traitées et traitements équivalents

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Contents

Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 282, *Water reuse*, Subcommittee SC 1, *Treated wastewater reuse for irrigation*.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Disinfection of treated wastewater (TWW) is a critical phase in the process of TWW use. Its purpose is to reduce or eliminate major health risks to the wastewater treatment plant's operators and to anybody who may come in contact with TWW or with crops that were irrigated with TWW.

This document provides a guideline for the available methods of disinfection, their effectiveness and the factors impacting those methods, along with their advantages and disadvantages, regarding technical and environmental aspects and effective inactivation or removal of various pathogens in wastewater and TWW for use in irrigation.

Guidelines for treated wastewater use for irrigation projects —

Part 5:
Treated wastewater disinfection and equivalent treatments

1 Scope

This document provides a guideline for the application of various available methods of treated wastewater (TWW) disinfection for an effective inactivation or removal of pathogens from TWW, which is intended for irrigation purposes.

This document deals with:

- chemical and physical technologies, principles of operation, and establishment of effective doses to be applied, possible interferences, and technical guidance for design and monitoring;
- comparison of the advantages and disadvantages of various disinfection methods suitable for TWW;
- potential environmental effects of the disinfection methodologies and ways to minimize those impacts;
- disinfection at different locations in the TWW use system, including in the wastewater treatment plant, within the distribution system and at the point of use.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 20670, *Water reuse — Vocabulary*

3 Terms, definitions, and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 20670 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at https://www.iso.org/obp
- IEC Electropedia: available at http://www.electropedia.org/

3.1.1
advanced oxidation process
AOP
process that generates hydroxyl radicals in sufficient quantity to remove organics by oxidation

3.1.2
ballast

unit inserted between the supply and one or more discharge lamps, which by means of inductance, capacitance, or a combination of inductance and capacitance, serves mainly to limit the current of the lamp(s) to the required value so as to convert and regulate incoming power to UV lamps to produce UV light

Note 1 to entry: The ballast provides the proper voltage and current required to initiate and generate UV photons.

3.1.3
fouling

process leading to deterioration of membrane flux due to surface or internal blockage of the membrane

Note 1 to entry: See AWWA B130-13[1].

3.1.4
pore size

size of the opening in a porous membrane

Note 1 to entry: Pore sizes are expressed either as nominal (average) or absolute (maximum), typically in terms of µm.

Note 2 to entry: See in AWWA B130-13[1].

3.1.5
reduction equivalent dose

RED

dose of UV in a given device which is determined by biodosimetry

Note 1 to entry: See *UV dose* (3.1.9) and "biodosimetry"

Note 2 to entry: This *UV dose* (3.1.9) is determined by measuring the inactivation of a challenge microorganism after exposure to UV light in a UV unit and comparing the results to the known UV dose response curve of the same challenge organism determined via Bench scale collimated beam testing.

3.1.6
ultrafiltration

UF

Note 1 to entry: pressure driven process employing semipermeable membrane under hydraulic pressure gradient for the separation components in a solution

Note 2 to entry: The pores of the membrane are of a size smaller than 0.1µm, which allows passage of the solvent(s) but will retain non-ionic solutes based primarily on physical size, not chemical potential.

Note 3 to entry: See in ASTM D6161-10.

3.1.7
UV disinfection system

combination of *UV disinfection units* (3.1.8) with associated controls and instrumentation

3.1.8
UV disinfection unit

independent combination of single or multiple bank(s) in series with a common mode of failure (e.g., electrical, cooling, cleaning system, etc.)

3.1.9
UV dose

UV fluence

amount of UV energy given as the time integral of the fluence rate or irradiance (W/m^2)

Note 1 to entry: This is given in units of mJ/cm^2 or J/m^2

3.1.10
UV intensity sensor
UV irradiance meter or radiometer instrument to measure UV irradiance

3.1.11
UV transmittance
fraction of photons in the UV spectrum transmitted through a material such as water or quartz

Note 1 to entry: It is preferable that an online UVT sensor be installed and used to verify UVT.

Note 2 to entry: The wavelength of the UVT (%) should be specified, often using a path length of 1 cm. The measurement is calibrated compared to ultra pure water (ISO 3696 grade 1 or equivalent).

Note 3 to entry: UVT is related to the UV absorbance (A) by the following formula (for a 1 cm path length): % UVT = 100×10^{-A}.

3.2 Abbreviated terms

A254	absorbance at 254
CT	product of the total residual chlorine and contact time
DBP	disinfection by-products
EPA	Environmental protection agency
DOC	dissolved organic carbon
DVGM	German Technical and Scientific Association for Gas and Water (deutsher verien des gas- und wasserfaches e.v.)
LP	low pressure
LPHO	low pressure high output
LRV	log removal value
MF	microfiltration
MP	medium pressure
MWCO	molecular weight cut off
NOM	natural organic matter
ONORM	Austrian Standard (*Österreichisches Normungsinstitut*)
QA/QC	quality assurance/quality control
RED	reduction equivalent dose
RO	reverse osmosis
TDS	total dissolved solids
THM	trihalomethanes
TMP	trans membrane pressure
TOC	total organic carbon

TWW	treated wastewater
UF	ultra-filtration
UV	ultraviolet
UVT	ultraviolet transmittance
WW	wastewater

4 Wastewater pathogenic contaminants and their inactivation or removal

4.1 General

The most critical objective in a TWW reuse programme should be public health.

To achieve the main objective, other equally important objectives should be considered, including:

- environmental protection,
- aesthetics (odour and colour); and
- ability to meet irrigation requirements.

To protect public health and prevent environmental degradation, the TWW quality characteristics and pathogenic microorganisms contained in the wastewater should be assessed and consideration given to appropriate treatment to reduce the risk of negative impacts.

There are a wide range of technology options available to meet the water quality goals and to reduce the risk of disease transmission from pathogenic microorganisms that can be present in TWW and to meet the water quality goals.

In regular wastewater treatment plants, the two main processes that reduce the concentrations of pathogenic microorganisms in the water should be:

- the wastewater treatment process itself, which is intended mainly to reduce concentrations of suspended and dissolved organic matter;
- the process of disinfection of the TWW.

4.2 Type and occurrence of pathogens in wastewater

Urban wastewater intended for agricultural irrigation or for other purposes contains a variety of pathogenic microbial contaminants that can pose a risk to public health.

The type and number of pathogenic microorganisms in urban wastewater varies between countries and cities and with time/season (wet and dry), epidemics etc. When selecting disinfection method(s) the range of microorganisms that can be present should be considered, including parasites eggs, bacteria, amoebas and other protozoa, *Giardia* and viruses. Common infectious agents, associated diseases, and potential numbers of microorganisms found in domestic wastewater are shown in Table 1[2] (for the complete table see Table A.1).

Table 1 — Infectious agents potentially present in untreated (raw) wastewater[2]

Pathogen	Disease	Numbers in raw wastewater (per litre)
Shigella`	Shigellosis (bacillary dysentery)	Up to 10^4

Table 1 *(continued)*

Pathogen	**Disease**	**Numbers in raw wastewater (per litre)**
Salmonella	Salmonellosis, gastroenteritis (diarrhoea, vomiting, fever), reactive arthritis, typhoid fever	Up to 10^5
Vibro cholera	Cholera	Up to 10^5
Campylobacter	Gastroenteritis, reactive arthritis, Guillain-Barré syndrome	Up to 10^4
Enteroviruses (polio, echo, coxsackie, new enteroviruses, serotype 68 to 71)	Gastroenteritis, heart anomalies, meningitis, respiratory illness, nervous disorders, others	Up to 10^6
Adenovirus	Respiratory disease, eye infections, gastroenteritis (serotype 40 and 41)	Up to 10^6
Rotavirus	Gastroenteritis	Up to 10^5
Entamoeba	Amebiasis (amebic dysentery)	Up to 10^2
Giardia	Giardiasis (gastroenteritis)	Up to 10^5
Cryptosporidium	Cryptosporidiosis, diarrhoea, fever	Up to 10^4
Ascaris	Ascariasis (roundworm infection)	Up to 10^3
Ancylostoma	Ancylostomiasis (hookworm infection)	Up to 10^3
Trichuris	Trichuriasis (whipworm infection)	Up to 10^2

The practical measurement of all pathogenic pollutants in TWW is almost impossible.

The main reasons are:

- low concentrations of the pathogenic contaminants in the TWW;
- limitation of present technology, to detect pathogens when they are present in low numbers;
- testing for pathogenic contaminants in the laboratory is lengthy and expensive.

Consequently, the control and monitoring of pathogenic microorganisms should be done by testing for indicator microorganisms, which are feasible and simple to measure as a result of their much larger numbers, and based on the premise that factors and treatment affecting their removal similarly affect the pathogens of interest.

4.3 covers the effect of the first process (WW treatment and the reduction of the concentration of contaminants). 4.4 covers the effects of the disinfection of the TWW.

4.3 Reduction of pathogenic microorganisms in various stages of wastewater treatment

Although wastewater treatment is mainly intended to eliminate suspended and dissolved organic matter, independent of disinfection, the treatment process can reduce the number of pathogenic and indicator microorganisms present in the wastewater. The degree of removal can depend (in part) on the type of treatment process, as illustrated in Table 2[2].

Table 2 — Indicative log removals of indicator microorganisms and enteric pathogens during various stages of wastewater treatment[2]

	Indicator microorganisms			**Pathogenic microorganisms**				
	***Escherichia coli* (indicator bacteria)**	***Clostridium perfringens***	***Phage* (indicator virus)**	**Enteric bacteria *(e.g., Campylobacter)***	**Enteric viruses**	***Giardia lamblia***	***Cryptosporidium parvum***	**Helminths**
Bacteria	X	X		X				
Protozoa and helminths						X	X	X
Viruses			X		X			
Indicative log reductions in various stages of wastewater treatment								
Secondary treatment	1 to 3	0,5 to 1	0,5 to 2,5	1 to 3	0,5 to 2	0,5 to 1,5	0,5 to 1	0 to 2
Dual media filtration[a]	0 to1	0 to 1	1 to 4	0 to 1	0,5 to 3	1 to 3	1,5 to 2,5	2 to 3
Reservoir storage	1 to 5	N/A	1 to 4	1 to 5	1 to 4	3 to 4	1 to 3,5	1,5 to >3

Key

N/A not available

NOTE 1 Reduction rates depend on specific operating conditions, such as retention time, contact time and concentrations of chemicals used, pore size, filter depths, pretreatment, and other factors. Ranges given should not be used as design or regulatory bases—they are meant to show relative comparisons only.

NOTE 2 See Table 3.

[a] Including coagulation.

As the reduction presented in the table for each type of treatment is only indicative, the exact values of pathogen reduction should be determined for each situation taking into account both the type of treatment and the environmental and operating conditions such as temperature, organic matter, turbidity, pH, ammonia, alkalinity, of each system.

4.4 Reduction of pathogenic microorganisms by different disinfection methods

The purpose of disinfecting TWW should be to remove or inactivate pathogenic microorganisms that remain in the TWW at the end of the standard treatment process. As complete inactivation is not always feasible or involves investment in methods which could make the required treatment unpractical, pathogenic microorganisms should be brought to low levels that will not cause significant health damage when the wastewater is used for irrigation. Reduction of pathogenic microorganism concentrations may be integrated with additional control strategies that can prevent health impact such as setting limitations to irrigation with TWW based on the quality achieved.

The practical measurement of all pathogenic microorganisms in TWW is almost impossible for reasons, and indicator microorganisms are used (see 4.2).

The reduction of indicator and pathogenic microorganisms in TWW by different disinfection methods is indicated in Table 3[2].

Table 3 — Indicative log reductions of indicator microorganisms and enteric pathogens by various methods of disinfecting TWW[2]

	Indicator microorganisms			**Pathogenic microorganisms**				
	***Escherichia coli* (indicator bacteria)**	***Clostridium perfringens***	***Phage* (indicator virus)**	**Enteric bacteria (*e.g., Campylobacter*)**	**Enteric viruses**	***Giardia lamblia***	***Cryptosporidium parvum***	**Helminths**
Bacteria	X	X		X				
Protozoa and helminths						X	X	X
Viruses			X		X			
Indicative log reductions by various disinfection methods[a]								
Membrane filtration (UF, NF, and RO)[b]	4 > 6	> 6	2 > 6	> 6	2 > 6	> 6	4 > 6	> 6
Ozonation	2 to 6	0 to 0,5	2 to 6	2 to 6	3 to 6	2 to 4	1 to 2	N/A
UV disinfection	2 > 6	N/A	3 > 6	2 > 6	1 > 6	3 > 6	3 > 6	N/A
Advanced oxidation	> 6	N/A	> 6	> 6	> 6	> 6	> 6	N/A
Chlorination	2 > 6	1 to 2	0 to 2,5	2 > 6	1 to 3	0,5 to 1,5	0 to 0,5	0 to 1

Key

N/A not available

[a] Reduction rates depend on specific operating conditions, such as retention times, contact times and concentrations of chemicals used, pore size, filter depths, pretreatment, and other factors. Ranges given should not be used as design or regulatory bases—they are meant to show relative comparisons only.

[b] Removal rates vary dramatically depending on the installation and maintenance of the membranes.

5 Disinfection

A partial removal of microorganisms may be obtained in various treatment stages, while disinfection is the main process for microorganisms' inactivation or removal from the TWW.

A TWW reuse for irrigation scheme should include disinfection to reduce pathogenic microorganisms; it is one of the main barriers, compulsory for some uses and an option for others.

NOTE the process of disinfection reduces the number of microorganisms to the analytical detection limit but does not eliminate them. Complete destruction can only be done by the process of sterilization.

Disinfection of TWW may be achieved with the use of a variety of methods presented in Clauses 6 to 8, including:

- chemical disinfection,
- ultraviolet light, and
- membrane filtration.

The action of disinfectants on microorganisms is a result of various mechanisms occurring simultaneously or separately[3]:

- changes in DNA structure that thwart reproduction and thus infectivity,
- damage to cell wall,

- alteration of cell permeability,
- alteration of the colloidal nature of the protoplasm, and
- inhibition of enzyme activity.

An exception is the use of membrane methods; in this case, none of the mechanisms detailed in the previous bullets work. In this case the membrane separates the microorganisms from the TWW and concentrates in the reject brine.

When applied, the chemicals used as disinfectants should be available in large quantities, reasonably priced, noncorrosive and non-staining. However, equipment used in chemical disinfectant application should be resistant and/or adapted to these chemicals – when concentrated or diluted.

The scheme may also include some types of disinfection as a means to prevent the formation of biofouling in the water distribution pipelines and irrigation equipment.

6 Chemical disinfection

6.1 General

The function of disinfectants in the use of TWW for irrigation is well described in ISO 16075-2[4].The use of halogenated chemicals in water transportation and distribution systems has the purpose of protecting irrigation systems from biofouling which means slime growing in pipes and tubes[5].

Various chemicals may be used for disinfection of TWW. The two most common are halogenated oxidizing chemicals (chlorine and bromine and its compounds) and ozone, as described in 6.2 and 6.3.

TWW chemical disinfectant should have the following characteristics[3]:

- effective with minimum alteration of the water characteristics such as increasing the total dissolved solids (TDS) or changing the pH,
- uniform in composition and low loss of germicidal action during storage or idle periods,
- soluble in water and pass through cell tissues,
- having a capacity to penetrate through particle surfaces,
- unadsorbable by organic matter other than bacterial cells,
- nontoxic to humans and other animals and safe to transport, store, handle, and use,
- toxic to target microorganisms and effective at high dilutions in the ambient temperature range.

6.2 Disinfection by chlorine/bromine compounds

6.2.1 General

The disinfection of water and TWW by halogenated based chemicals is extensively used and is considered to be an effective as well as an easy to use method for disinfection. The addition of these types of chemicals into water results with 2 reactions: hydrolysis forming hypohalous acid Formula 1 and dissociation to hypohalite ion Formula 2,[6] while X= Cl, Br.

$$X_2 + H_2O \rightarrow HOX + H^+ + X^- \qquad (1)$$

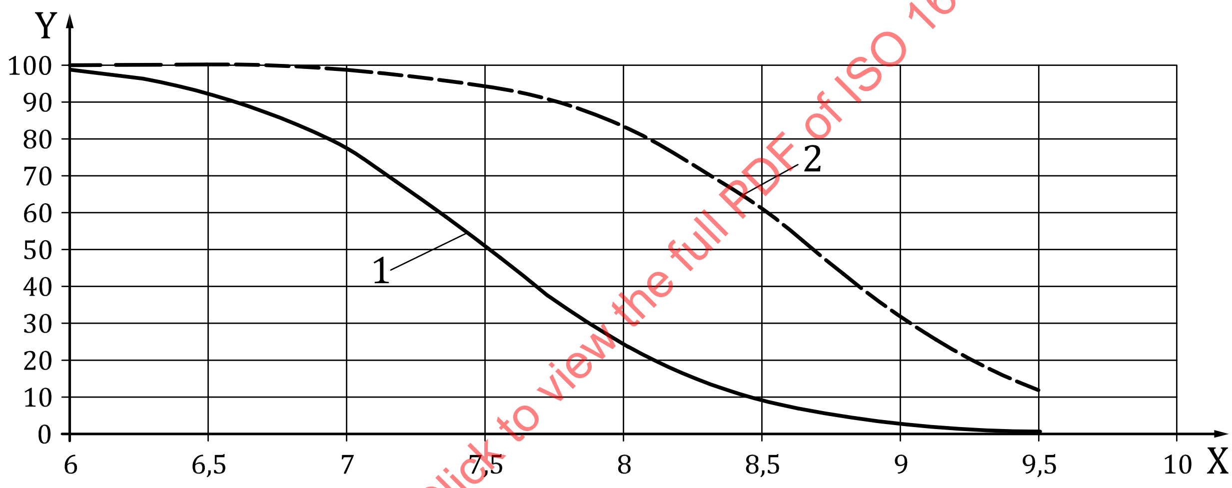
$$HOX \leftrightarrow H^{+} + OX^{-} \qquad (2)$$

Dissociation of the hypohalous acids is a function of pH, as shown in Table 4 and Figure 1. Hypohalite anions are up to 2 orders of magnitude less effective biocides than the acid form [6].

Table 4 — Distribution between hypohalous acid and hypohalite anions as a function of pH [6]

pH	Chlorine		Bromine	
	% HOCl	% OCl^{-}	% HOBr	% OBr^{-}
7,5	50	50	94	6
8,0	24	76	83	17
8,5	9	91	60	40
9,0	3	97	33	67

The dissociation curve of the hypohalous acids is given in Figure 1:



Key

X pH

Y % of active acid

1 HOCl

2 HOBr

Figure 1 — Dissociation curves of the hypohalous acids

6.2.2 Reactions of chlorine/bromine with ammonia

Untreated WW and TWW contain different concentrations of ammonia that cause difficulties in water disinfection. The reaction of the ammonia with the added chlorine or bromine creates compounds with a much lower disinfectant ability than free chlorine or bromine.

The possible reactions between HOX and ammonia are presented in Formula 3 to Formula 5,[3] while X=Cl or Br.

$$NH_3 + HOX \quad H_2O + NH_2X \rightarrow \text{(Monochloramine/bromamine)} \qquad (3)$$

$$NH_3 + 2HOX \quad 2H_2O + NHX_2 \rightarrow \text{(Dichloramine/bromamine)} \qquad (4)$$

$$NH_3 + 3HOX \quad 3H_2O + NX_3 \rightarrow \text{(Nitrogen Trichloride/Tribromide)} \tag{5}$$

These reactions occur essentially instantaneously and are pH dependent. For instance, for chlorine compounds at pH levels above 8,5, only monochloramine is formed; below this level mixtures of mono and dichloramine exist; and below pH 4,2 only nitrogen trichloride exists.

6.2.3 Definition of the halogenated disinfection residuals

The chlorine in chloramine compounds is defined as combined available chlorine. Combined available chlorine has a lower disinfection capacity than free chlorine, however the combination of free chlorine and combined available chlorine (chloramines) that are present in the water create the ability to disinfect the water.

The residual chlorine is available in three forms:

- chloramines: a form of combined chlorine,
- chloro-organic compounds: a weak form of combined chlorine, and
- free chlorine: the strongest form of residual for disinfection.

Chlorine demand should be calculated as the difference between total chlorine added into the water and residual chlorine. It is the amount that reacts with the substances in water, leaving behind an inactive form of chlorine.

The sum of the chlorine demand and the residual chlorine should determine the chlorine injected into the water.

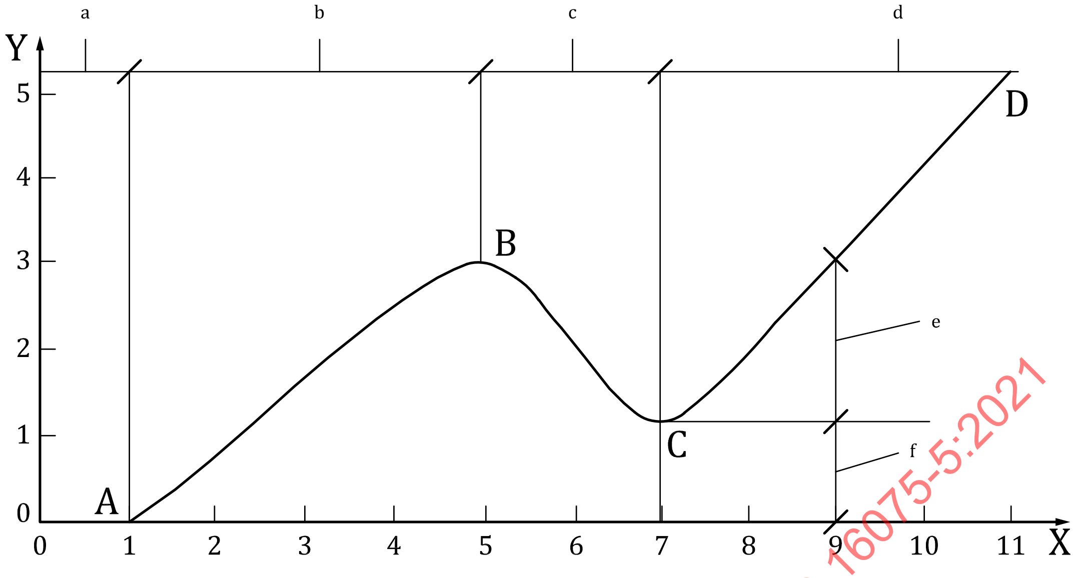
Added Chlorine = Chlorine Demand + Residual Chlorine

Residual Chlorine = Combined Available Chlorine + Free Chlorine

The same applies to bromide.

6.2.4 Breakpoint reaction

A reaction between chlorine and ammonia causes a unique phenomenon, which has a great effect on chlorine disinfection process. When chlorine is added to TWW (that contains ammonia) a stepwise reaction occurs, as described below (Figure 2).



Key

X	Chlorine dose, mg/l
Y	Chlorine residual, mg/l
A to B	Combined residual
C	Breakpoint
C to D	Free and combined residual
A	Destruction of chlorine residuals by reducing compounds
B	Formation of chloro-organic and chloramine compounds
C	Destruction of chloramines and chloro-organic compounds
D	Formation of free chlorine and presence of chloro-organic compounds not destroyed
E	free residual
F	Combined residual

Figure 2 — Breakpoint chlorination[3]

- **Step one:** destruction of residual chlorine by reducing compounds. Inorganic reducing materials commonly found in wastewater that take precedence in reacting with chlorine can be: hydrogen sulfide (H_2S), ferrous iron (Fe^{2+}), manganese (Mn^{2+}), nitrite (NO_2^-). These reducing materials consume at the first step the residual chlorine added to the water, up to point A.

- **Step two:** formation of chloro-organic and chloramine compounds. As described in 6.1 ammonia (NH_3) is found in wastewater and is the second level of reaction with chlorine. It combines with chlorine to form one of three forms of chloramine. Organic compounds are the last to react with available chlorine in the wastewater and form chlororganic compounds (chlorine demand between points A to B). In this range, the mole ratio of chlorine to ammonia is equal to 1, and increases toward point B.

- **Step three:** destruction of chloro-organic and chloramines compounds. Between point B and the breakpoint (point C), some chloramines will be converted to nitrogen trichloride, the remaining chloramines will be oxidized to nitrous oxide (N_2O) and nitrogen (N_2), and the chlorine will be reduced to the chloride ion. The mole ratio at the breakpoint is equal to 1,5 to 1.

- **Step four:** formation of free chlorine and presence of chloro-organic compounds not destroyed. Continued addition of chlorine past the breakpoint (C), resulting in a directly proportional increase in the free chlorine. At this stage, combined and free chlorine (residual chlorine) are present in the water.

The breakpoint can be described as the point at which the demand for chlorine has been fully satisfied (i.e. the chlorine has reacted with all of the reducing agents, organics and ammonia). Ammonia nitrogen can disappear completely at the breakpoint, or be reduced to only a trace, especially at neutral pH values; but in practice an "irreducible minimum" residual chlorine (also referred to as a "nuisance residual") remains, typically a few tenths of a milligram per litre as Cl_2.

6.2.5 CT values of chlorine/bromide and their compounds

The factors that determine the efficiency of disinfection include the type of disinfectant, its concentration in water and the time it acts on the pathogens in water.

The disinfection efficiency for each type of disinfectant is calculated by CT value. CT value is obtained by multiplying the residual concentration of the disinfectant (C) after a given contact time (T) by the contact time. CT values should be used for the calculation of disinfectant dose needed for the disinfection of TWW, and be expressed in units of mg.min/l.

6.2.6 Chlorinated compounds for TWW disinfection

6.2.6.1 Chlorine (Cl_2)[3]

Chlorine disinfection is the most common method for disinfection of water and TWW due to the simplicity of the method, equipment and operation.

Chlorine (Cl_2) can be present as a gas or a liquid (in pressure tanks). When added to water, two reactions take place, as explained generically in 6.2.1 for halogenated oxidants: hydrolysis to form hypochlorous acid (HOCl) Formula 6 and ionization to hypochlorite ion (OCl^-) Formula 7:

$$Cl_2 + H_2O \rightarrow HOCl + H^+ + Cl^- \quad (6)$$

$$HOCl \rightarrow H^+ + OCl^- \quad (7)$$

The two reactions can decrease the pH of the water and change the solubility of salts affected by the water's pH. These can cause problems when the ions concentration of the ion is close to the solubility limit in the water.

The relatively distribution in the water of the two species (Formula 6 and 7) is important as the germicide efficiency of HOCl is significantly higher than that of OCl^-.

Dissociation of HOCl in water has been shown to be temperature dependent, and the pKa (dissociation constant) for HOCl is in the range of 7,49 to 7,82 between 0 ºC to 30 ºC. At 20 ºC and pH = 7,58 there is 50 % of each species (see Figure 1 and Table 4).

The OCl^- and HOCl compounds are commonly referred to as free chlorine, (see 6.2.3), which is extremely reactive with numerous components of the bacterial cell.

6.2.6.2 Sodium and calcium disinfection agent hypochlorite ("liquid bleach" and "chlorine powder")

Sodium hypochlorite and calcium hypochlorite are chlorine compounds formed by the reaction of chlorine with hydroxides. The application of hypochlorite to water systems produces the hypochlorite ion and hypochlorous acid, Formula 8 to Formula 11:

$$NaOCl \rightarrow OCl^- + Na^+ \quad (8)$$

$$OCl^- + Na^+ + H_2O \rightarrow HOCl + Na^+ + OH^- \quad (9)$$

$$Ca(OCl)_2 \rightarrow 2\, OCl^- + Ca^{2+} \quad (10)$$

$$2\ OCl^- + Ca^{2+} + 2\ H_2O \rightarrow 2\ HOCl + Ca^{2+} + 2OH^- \qquad (11)$$

While a slight contribution of alkali when a hypochlorite is added cannot make a big difference in the final pH of the water, due of the buffering capacity of the TWW, some pH increase could contribute to the precipitation of insoluble salts.

6.2.6.3 Chlorine dioxide (ClO_2)

Chlorine dioxide is an efficient disinfection agent. Its advantages include efficiency in a wide range of pH values and elevated temperatures. It is effective against a wide range of organisms (including cysts and protozoa) and virus.

Another advantage of the use of chlorine dioxide, compared to chlorine, is that chlorine dioxide does not form compounds with ammonia, which reduces the chlorine disinfection efficiency.

Chlorine dioxide is an unstable and explosive gas and should be generated on site by reacting sodium chlorite ($NaClO_2$), Formula 12:

$$2\ NaClO_2 + 2\ Cl_2 \rightarrow 2\ ClO_2 + 2\ NaCl \qquad (12)$$

6.2.6.4 Chlorine production on site

When small quantities of wastewater are to be disinfected in remote areas, the transportation costs of the disinfectants sometimes exceed the price of the disinfectant.

In this case solid chlorine tablets may be used or several methods exist to produce relatively small amounts of active chlorine (sodium hypochlorite) on site, such as chlorine production from salt or from solution of salty water.

This process is based on the production of hypochlorite by running an electric current through salt water. When this happens, sodium hypochlorite, as well as hydrogen gas (H_2), are produced on site. Only sodium chloride (NaCl) is added to the water, or sea or saline water are used.

The reaction is described in Formula 13:

$$NaCl + H_2O + \text{Electric current} \rightarrow NaOCl + H_2 \qquad (13)$$

For efficient operation the system should be fed with softened water.

For safety operating reasons, a dedicated system should be operated to control and treat the hydrogen gas concentration.

Chlorine can also be produced by on site electrochlorination (OSEC) of sodium hypochlorite solution at concentration of 0,8 % to 1 %. Hypochlorite solution is always available at stable concentration and avoids the need for handling dangerous chemicals.

One of these methods should be used especially in areas where TWW is used for irrigation in a location remote from the wastewater treatment facility, for example when it is necessary to disinfect the TWW at the point of use.

6.2.7 Advantages, disadvantages and technical considerations of chlorine biocides-based disinfection method

Chlorine is a powerful oxidizing agent and therefore presents a higher rate of microorganism removal in the water. Chlorination is a well-established technology, easily accessed all over the world with the ability to maintain residual chlorine in treated waters. However, the use of chlorine and its compounds may increase the chloride content of the TWW; chlorine residuals are unstable in the presence of high concentrations of chlorine-demanding materials, thus requiring higher doses to achieve the prerequired level of disinfection; and some parasitic species have shown resistance to practical doses of chlorine, including oocysts of *Cryptosporidium parvum*, cysts of *Entamoeba histolytica* and *Giardia lamblia*, and eggs of parasitic worms.

Chlorine compounds can react with constituents in the treated water to produce carcinogenic by-products.

The handling and storage of chlorine and its compounds may be challenging, as summarised in Table 5.

Table 5 — Advantages, disadvantages and technical considerations of chlorine and its compounds

Compound	**Advantages**	**Technical considerations and/or Disadvantages**
Chlorine (Cl_2) Stored as a liquid in pressure containers	— Gas storage in pressure tanks enables the storage of a large quantity in a relatively small area. — Gas in containers does not change its properties over time and therefore can be stored for a long period. — Concentration of chlorine in solution is 100 % and therefore its use is economical. — Equipment needed for water chlorination and dosage is relatively cheap and simple to operate.	— The gas is poisonous to humans and animals, to both skin and breathing. — As leakage of tankered gas creates a high environmental risk, tanks areas need to be scrubbed or need to be stored away from residential areas and concentrations of people. — Disinfection by-products, such as THM, may be hazardous for environment, and may bioaccumulate on crops.
Sodium Hypochlorite (liquid bleach) (NaOCl) Formed by the dilution of chlorine in water	— Storage of the solution at acceptable concentrations for disinfection of water and TWW (11 % to 12 %) is not dangerous and therefore does not require distancing from population. — Material price is relatively cheap. — Equipment needed for water chlorination and dosage is relatively cheap and simple to operate.	— Considered a hazardous oxidizer at high concentrations (over 40 % chlorine). — Considered a moderate hazardous oxidizer at low concentrations. — Supplied for domestic use at a concentration of about 3 %. — Storage requires greater volumes than those required for chlorine gases (depending on the concentration of the material in water). — Solution in water loses its strength over time, and therefore should be stored before use for no longer than a week or two. — Solution is transported multiple times from its production site. — Disinfection by-products, such as THM, may be hazardous for environment, and may bioaccumulate on crops.

Table 5 *(continued)*

Compound	Advantages	Technical considerations and/or Disadvantages
Calcium Hypochlorite (chlorine powder) ($Ca(OCl)_2$)	— Can be applied for specific uses. — Can be used in areas where TWW is used for irrigation in a distance far from the location of the wastewater treatment facility, for example when it is necessary to disinfect the TWW at the point of use. — With additives of stabilizing materials, long storage is possible. In storage in a dry, cool place, it is almost non-disintegrating.	— Contains only 68 % chlorine. — More expensive than the other two forms of chlorine (gaseous chlorine and sodium hypochlorite) — Low solubility in water, therefore use as a disinfectant is more difficult than in the other two forms of chlorine.
Chlorine Dioxide (ClO_2)	— Stronger oxidizer than chlorine. — Greater disinfectant efficiency with respect to the destruction of viruses and parasites compared with disinfection by chlorine. — Less affected by changes in pH and temperature compared to chlorine disinfection. — Creates fewer harmful side compounds compared to chlorine disinfection.	— Needs to be produced at the disinfection site. Large amounts of material cannot be stored. — Production of Chlorine Dioxide (ClO_2) is more expensive than that of chlorine. — Disinfection by-products, such as THM, may be hazardous for environment, and may bioaccumulate on crops.

6.2.8 Chlorination process

To be efficient, the chlorination process should have two elementary conditions: a rapid mixing of the chlorine in the applied form with the TWW and a sufficient contact time (retention time) of the Chlorine with the TWW, as follows:

- **Initial mixing:** rapid initial mixing of the chlorine and the TWW should be accomplished practically immediately (in seconds). Different mixers for the addition of Chlorine may be used[3]: in-line turbine mixer, injector pump type, pumped flash mixing and in-line static mixer.
- **Contact time:** the time elapsed between the injections of the disinfectant to the TWW and until the TWW is used (or entered a reservoir with no disinfectant residue[4]). To ensure sufficient contact time, one or both of the following ways should be used:
    1) Flowing the TWW with the disinfectant through a container of suitable volume, according to the disinfected TWW's rate of flow. The container could be built in a serpentine fashion to improve the actual retention time.
    2) Flowing the TWW with the disinfectant through a pipeline of suitable volume. The flow time of the TWW in the pipeline should not be less than the required contact time, given the diameter of the pipe, the length of the pipe and the flow velocity of the TWW in the pipeline.

6.2.9 Brominated compounds for TWW disinfection

6.2.9.1 Sodium Bromide activated with hypochlorite

Sodium bromide (NaBr) after activation with hypoclorite (12 %) is an efficient disinfectant used in formulating liquid sodium bromide microbiocides for the control of algal, bacterial and fungal slimes in industrial water treatment as well as for TWW disinfection. It is a fast-acting biocide, efficient over a wide pH range. NaBr can be stored and transported as a non-hazardous material – either as solid or as a water based formulation. The active disinfection material is produced onsite following a reaction with hypoclorite (12 %), as described in Formula 14:

$$NaBr + NaOCl \rightarrow Na^{+}\ OBr^{-} + NaCl \tag{14}$$

The presence of water results with the following equilibrium of hypobromous acid partially dissociates to give hydrogen ions and hypobromite ions, as described in Formula 15:

$$HOBr \leftrightarrow H+ + OBr \tag{15}$$

The ratio of hypobromous acid to hypobromite ions is dependent upon the temperature, pH and alkalinity of the water.

When acting as a disinfectant, hypobromous acid functions by oxidizing the organic matter in living organisms and in doing so it is reduced to the bromide ion as described in Formula 16:

$$HOBr + L_{m} \rightarrow Br^{-} + D_{m} \tag{16}$$

Where

L_{m} is live microorganisms

D_{m} is dead microorganisms

6.2.9.2 Ammonium bromide activated with hypochlorite

Ammonium bromide (AmBr; 35 % solution) activated with hypochlorite (12 %) is a technology for water disinfection treatment with excellent biocidal and anti-biofilm properties. The production of the biocide made on site by using proprietary dosing machines, mixing ammonium bromide in the required conditions and appropriate oxidizer (bleach) leading to the formation of a unique disinfectant – BAC (bromide activated chloramine). The reaction with bleach is described in Formula 17:

$$NH_{4}Br + NaOCl \rightarrow Br^{-}\ [NH_{4}Cl] + + NaOH \tag{17}$$

6.2.9.3 Stabilized bromine solution

Stabilized bromine solution (~16 % as Br_{2}) is a single component solution. It is a biocide based on the oxidizing behaviour of bromine with improved results in alkaline water systems especially compared to sodium hypopchlorite. It controls the microbiological growth and eliminates existing micro-organisms, like bacteria, fungi, and algae. Once dosed into the water it releases the active bromine for efficient disinfection of the water. It needs a single dosing pump and is easy to use. The stabilized brominated solution is a strong oxidative solution and therefore should be handled with caution.

6.2.9.4 Bactebrom

Bactebrom (aq. solution of Urea+HBr) activated with hypochlorite (12 %) is a technology for industrial water disinfection, wastewater delivery systems and TWW. An effective biocidal treatment against biofilm accumulation. The active biocide is produced on site following the reaction with bleach at the proper ratio Formula 18:

$$[CO\ (NH_{2})_{2} + HBr] + NaOCl \rightarrow [H_{2}NCONHBr \leftrightarrow HOBr] + NaCl + (CO\ (NH_{2})_{2} + HBr) \tag{18}$$

Bactebrom is effective against all types of biofouling caused by bacteria, fungi and algae, with excellent activity against biofilm prevention and removal. A mild oxidizer that is able to work in highly loaded systems (TOC and organics) and across a wide pH range (pH 6-9). It is an acidic product that will not contribute to scale. Equipment for dosing is simple to use.

A further bromine compounds advantages and disadvantages is given in Annex C and Table C.1.

6.2.10 Advantages, disadvantages and technical considerations of brominated biocides-based disinfection method

Bromine based biocides belong to the class of halogenated biocides and are extensively used as disinfection agents for water and wastewater treatment. Brominated biocides are fast - acting broad spectrum biocides for control of algae, bacteria and fungi. Some are also highly effective against biofilm. An additional advantage of the brominated biocides is their high efficiency at both neutral and alkaline pH.

Nevertheless, it should be taken into account that brominated biocides and biocidal precursors should be handled with caution while avoiding direct contact with the skin. The storage of such compounds should be in well ventilated places. At elevated temperatures some compounds might have the risk of releasing bromine – which is a toxic highly irritating gas. The application of any halogenated biocide including brominated biocides could lead to the formation of hazardous compounds that might be toxic to the environment or even carcinogenic by-products.

Table 6 specifies some examples for brominated biocides including guidelines for their handling and storage.

Table 6 — Advantages, disadvantages and technical considerations of brominated biocides and its compounds

Compound	Advantages	Technical considerations and/or disadvantages
NaBr - Activated with hypochlorite (12 %)	— can be stored and transported as a non-hazardous solid. — aqueous solutions are non-hazardous having good storage stability. — Dosing equipment is relatively cheap and simple to use. — Monitoring can easily be done by Halogen sensors.	— Needs to be activated on site – using hypochlorite.
AmBr (Fuzzicide, 35 % AmBr solution)- Activated with hypochlorite (12 %)	— Superior bactericidal effect in a short time and in small concentrations. — Effective against bacteria and a wide range of microorganisms such as fungi and yeast. — Little consumption by dissolved organic matter which furthers osmosis into slime and inhibits its growth. — No rise in corrosion of metals such as stainless and carbon steels because of slight oxidation.	— Requires the installation of dedicated dosing equipment near the intended system or treatment site. — Requires to be activated with hypochlorite.
NOTE: In the past, farmers were deterred from using bromine for fear of workers safety considerations. The new materials are safer for farmers and are recommended for use in the irrigation systems for protection of the distribution system and irrigation equipment.		

Table 6 *(continued)*

Compound	Advantages	Technical considerations and/or disadvantages
Stabilized bromine solution (~16 % as Br_2)	— Controls the microbiological growth and eliminates existing micro-organisms, like bacteria, fungi, and algae. — Compared to conventional treatment for alkaline cooling systems (Sodium Bromide with Bleach) there is no need for an expensive mixing station (including two dosing pumps) but just a single dosing pump. — Monitoring can easily be done by Halogen sensors.	— It is an oxidizer and should not be stored near reducing agents or strong acids.
— Bactebrom (aq. solution of Urea+HBr) -Activated with hypochlorite (12 %)	— Excellent activity against biofilm – prevention and removal. — The presence of Urea and acidic pH can be compatible with a wide range of fertilizers. — A mild oxidizer that is able to work in highly loaded systems (organics) and across a wide pH range (pH 6-9). — An acidic product that will not contribute to scale. — Equipment for dosing is simple to use.	— The precursor Bactebrom is a concentrated acid. Considered to be a hazardous solution (corrosive liquid). — Requires the installation of the dosing equipment near the intended system. — Requires to be activated with hypochlorite. Important to make sure that the 2 concentrated precursors (Bactebrom and Hypochlorite) do not mix non diluted.
NOTE: In the past, farmers were deterred from using bromine for fear of workers safety considerations. The new materials are safer for farmers and are recommended for use in the irrigation systems for protection of the distribution system and irrigation equipment.		

6.3 Ozone

6.3.1 Chemistry of ozone disinfection

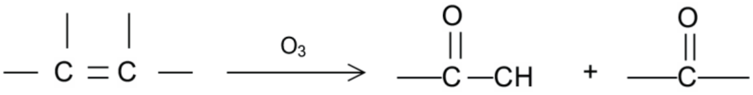
Ozone, a highly toxic, oxidizing gas, composed of three atoms of oxygen (O_3) and characterized by a strong odour, may be used in water treatment for disinfection and oxidation (e.g. odour control, discoloration, inactivation of micropollutants, etc.) or a combination of both.

Ozone is unstable in water and its reaction is not straightforward, as many chemical reactions can occur simultaneously with some water matrix components.

Ozone can react with substances in two different ways: directly with a compound, see 6.3.2, or it can produce hydroxyl radicals, which are the strongest oxidants in water that then react with a compound, see 6.3.3.

6.3.2 Direct ozone reaction

The mechanism involved in the direct ozone reaction pathway is a selective reaction where an ozone molecule reacts with an unsaturated bond due to its dipolar structure and leads to a splitting of the bond, see Formula 19:



$$-\overset{|}{C}=\overset{|}{C}- \xrightarrow{O_3} -\overset{\overset{O}{\|}}{C}-CH + -\overset{\overset{O}{\|}}{C}- \tag{19}$$

To generate $OH^\bullet$, which has a higher oxidation potential than molecular ozone and can attack organic and inorganic molecules rapidly and non-selectively, advanced oxidation processes are used.

Ozone has greater disinfection effectiveness against bacteria and viruses compared to chlorination and bromination.

Ozone is unstable, and it will degrade over a time frame ranging from a few seconds to 30 minutes. The rate of degradation is a function of water chemistry, pH and water temperature.

Due to the high level of ozone disinfection and its instability, all ozone residues should be removed from the water at the end of the disinfection process[7].

6.3.3 Indirect ozone reaction

The mechanism involved in an indirect ozone reaction can be divided into three different steps: initiation, chain propagation and termination. On the first step, ozone (O_3) in water (H—OH) reacts with hydroxyl ions (OH-, initiators), to form secondary oxidants, the hydroxyl radicals ($OH^\bullet$), described in Formula 20 and Formula 21:

$$O_3 + OH^- \rightarrow O_2^{\bullet -} + HO_2^\bullet \tag{20}$$

$$HO_2^\bullet \leftrightarrow O_2^{\bullet -} + H^+ \tag{21}$$

Typical initiators are: OH^-, H_2O_2/HO_2- or Fe^{2+}.

On the second step, the superoxide anion $O_2^{\bullet -}$ reacts with ozone to form an ozonide anion ($O_3^{\bullet -}$), described in Formula 22 to Formula 24:

$$O_3 + O_2^{\bullet -} \rightarrow O_3^{\bullet -} + O_2 \tag{22}$$

$$O_3^{\bullet -} + H^+ \leftrightarrow HO_3^{\bullet -} \tag{23}$$

$$HO_3^{\bullet -} \rightarrow OH^\bullet + O_2 \tag{24}$$

The substances that promote the chain reaction, i.e., that convert $OH^\bullet$ into superoxide radicals ($O_2^{\bullet -}$/$HO_2^\bullet$), act as chain carriers (promoters). Some organic molecules, R, can also act as promoters. The presence of certain functional groups leads to the reaction with $OH^\bullet$ and form organic radicals $R^\bullet$, described in Formula 25:

$$H_2R + OH^\bullet \rightarrow HR^\bullet + H_2O \tag{25}$$

Typical promoters are: humic acid, aryl-R or primary and secondary alcohols.

Some organic and inorganic substances react with $OH^\bullet$ to form secondary radicals that do not produce superoxide radicals, acting as inhibitors (or scavengers) that terminate the chain reaction and inhibit ozone decay. e.g. described in Formula 26 and Formula 27:

$$CO_3^{2-} + OH^\bullet \rightarrow OH^- + CO_3^{\bullet -} \tag{26}$$

$$HCO_3^- + OH^\bullet \rightarrow OH^- + HCO_3^\bullet \tag{27}$$

The chain reaction can also terminate through the reaction of two radicals, described in Formula 28:

$$HO_2^\bullet + OH^\bullet \rightarrow O_2 + H_2O \tag{28}$$

Typical scavengers are: HCO_3^-, CO_3^{2-}, PO_4^{3-}, humic acids, alkyl-R and *tert*-butyl alcohol.

Thus, the decay of ozone initiated by the hydroxide ion leads to a chain reaction, producing fast reacting and nonselective OH-radicals, which due to their reactivity have a very short half-life, thus they react as soon as they come into contact with organic compounds. The reaction combination shows that in the overall reaction three ozone molecules produce two $OH^\bullet$, described in Formula 29:

$$3O_3 + OH^- + H^+ \rightarrow 2OH^\bullet + 4O_2 \tag{29}$$

Bicarbonate and carbonate play an important role as scavengers of OH-radicals in natural systems since they can act as inhibitors in conventional ozonation[7].

6.3.4 Advantages, disadvantages and technical considerations of Ozone disinfection method

Ozonation is very efficient technique for the removal of bacteria, viruses, and protozoa (including *Giardia* and *Cryptosporidium*) and a wide variety of inorganic, organic problems and odour problems can be also eliminated.

However, other technical aspects of ozonation may be considered taking into account the characteristics of each water reuse project. For example, the formation of oxygen-rich compounds, such as aldehydes and carboxylic acids that may increase biodegradability, and therefore, in some cases a biological post-treatment step may be required after ozonation, to remove biodegradable oxidation by-products and to control biofilm growth.

For advantages, disadvantages, technical considerations of disinfection methods of ozone, see Table 7.

Table 7 — Advantages, disadvantages, technical considerations of ozone disinfection[8].

Advantages	**Technical considerations and/or disadvantages**
— Ozone is effective over a wide pH range, rapidly reacts with bacteria, viruses, and protozoa and has stronger germicidal properties than chlorination. It has a very strong oxidizing power with a short reaction time.	— Ozonation does not provide germicidal or disinfection residual to inhibit or prevent regrowth.
— The treatment process does not add chemicals to the water.	— Ozone is less soluble in water, compared to chlorine, and therefore, some gas-liquid mixing techniques are needed.
— Ozone can eliminate a wide variety of inorganic, organic and microbiological problems and odour problems. The microbiological agents include bacteria, viruses, and protozoa (such as *Giardia and Cryptosporidium*).	.

6.3.5 System configuration

Ozone can be produced in a modern ozone generator. The passage of a high voltage, alternating electric discharge (A.C.) through a gas stream containing oxygen will result in the breakdown of molecular oxygen to atomic oxygen. Ozone is produced when oxygen (O_2) molecules are dissociated by an energy source into oxygen atoms and subsequently collide with an oxygen molecule to form an unstable gas, ozone (O_3), which is used to disinfect wastewater. Most wastewater treatment plants generate ozone by imposing a high voltage alternating current (6 kV to 20 kV) across a dielectric discharge gap that contains an oxygen-bearing gas. Ozone is generated onsite because it is unstable and decomposes to elemental oxygen in a short amount of time after generation.

Ozone produced commercially for oxidation reactions is always produced as a gas, from extremely dry air at concentrations between 1,0 % and 2,0 % by weight, or from oxygen at concentrations greater than 2 % and up to 8 % (or greater) by weight.

After generation, ozone is fed into a down-flow contact chamber containing the wastewater to be disinfected. The main purpose of the contactor is to transfer ozone from the gas bubble into the bulk liquid while providing sufficient contact time for disinfection. The commonly used contactor types are diffused bubble (co-current and counter-current), positive pressure injection, negative pressure (Venturi), mechanically agitated, and packed tower. Because ozone is consumed quickly, it should be contacted uniformly in a near plug flow contactor.

Biological nitrification being followed by ozonation should be controlled carefully since NO_2 is a good scavenger of ozone[8].

6.3.6 Monitoring of ozonation

To control the efficiency of an ozonation system the critical microbiological parameters, such as thermotolerant coliforms or other indicators (e.g., virus and protozoa) for high quality water demand systems should be monitored before and after disinfection, to assess the removal capacity and to demonstrate the compliance of the water quality with the intended use requirements, i.e., usually national standards.

To ensure that the disinfection system is running properly in terms of disinfection by-products formation control, the monitoring of the major or hazardous by-products may be performed according the system configuration.

Since ozonation is starting to be used to remove some pollutants of emerging concern, such as pharmaceutical compounds, specific monitoring programs may be displayed according the intended purposes.

For details of system monitoring and control, see ISO 20468-3[9].

6.4 Environmental impacts of chemical disinfection

6.4.1 Environmental impacts of chlorination/bromination disinfection

During water disinfection, secondary reactions can occur and disinfection by-products (DBP) can be formed. Some of these DBP can pose a threat to the environment due to their intrinsic properties, namely they can present a significant risk to -- or via the -- aquatic environment, with their toxicity, persistent characteristics, potential to bioaccumulate or to be an endocrine disruptor.

During water disinfection, chlorine and bromine are likely to react with natural organic matter (NOM) which is a heterogeneous mixture of organic macro-molecules that varies both temporally and spatially, and mainly comprising humic substances, carboxylic acids, amino acids, proteins and carbohydrates. Therefore, NOM acts as a precursor in the formation of DBP, such as trihalomethanes (THM) that include chloroform ($CHCl_3$), dichlorobromomethane ($CHBrCl_2$), dibromochloromethane ($CHBr_2Cl$), and bromoform ($CHBr_3$). In lower concentrations haloacetic acids, haloacetonitriles, haloketones and chloropicrin can also occur. Other important DBP are the *N*-nitrosamines which present toxic effects; this type of compounds is carcinogen to humans[11,12].

Trihalomethanes are the major group of DBP, namely chloroform which presents a risk to human health, risk of cancer and also present a risk to benthic communities.

NOTE The characteristics of NOM, chlorine/bromine dose, contact time, pH and temperature seem to influence the DBP formation. The determination of the chlorine/bromine demand can be used to adjust the disinfection procedures, such as chlorine/bromine dose and the reaction time, to minimize DBP formation.

6.4.2 Environmental impacts of ozonation disinfection

Similar to other chemical disinfectants for water treatment, ozone is unstable in water and undergoes reactions with some water matrix components. However, its decomposition into unselective hydroxyl radicals (OH°) has a wider range of action on the oxidation of many organic contaminants such as pesticides, pharmaceuticals and personal care products and natural and synthetic hormones. During this process some DBP can also occur, however the current knowledge on its environmental behaviour is still limited.

The DBP formation is very complex and highly dependent on water characteristics (e.g., TOC, bromide, ammonia, carbonate alkalinity) as well as on the treatment processes and operating conditions used (e.g., pH, temperature, ozone dose, contact time). Hence, seasonal variations can occur at one location. Then, ozonation DBP results in a complex mixture and can cause synergistic or antagonistic interactions with other substances, i.e., ozone treatment can either increase or decrease toxicity and mutagenicity.

The oxidation of chlorine and bromine can also lead to the formation of chlorates and bromates which present toxic effects. Bromates is a potential carcinogen.

DBP formation should be controlled using one of the following treatments:

- removing precursors that react with the disinfectants to form the unwanted DBP (reducing NOM concentration),
- optimizing the water treatment to control the DBPs formation, e.g. through the control of pH and/ or dissolved ozone concentration, and
- removing DBPs that are formed (advanced treatments).

This also applies to chlorine/bromine in 6.4.1.

7 UV disinfection

7.1 General

Microbicidal UV light is the portion of the light spectrum from 200 nm to 415 nm that penetrates and damages spores, cysts and vegetative cells. UV light has been proven effective against bacterial and protozoan pathogens, viruses and algae as well as biofilm forming microbes that are resistant to commonly used disinfectants like chlorine. It is safer in an agricultural setting because an overdose of UV on water has no effect while an overdose of chemicals in water can have a negative effect on the irrigated produce.

Different target organisms require different UV doses. UV can inactivate pathogenic microorganisms without forming carcinogenic disinfection by-products (DBPs) or leaving residuals that can have an ecological impact on receiving streams.

The mechanism of disinfection by UV light differs considerably from the mechanisms of chemical disinfectants. UV light is absorbed by the cell and inactivates microorganisms by damaging their nucleic acid and proteins, thereby preventing them from replicating or, in some cases, repairing damages. A microorganism that cannot replicate or repair cannot infect the host or spread.

Design, operation, and maintenance for UV disinfection systems also differ from those of traditional chemical disinfectants. Aspects like temperature and pH that are critical to chemical disinfection efficacy have little influence on effectiveness of UV disinfection.

As UV does not leave a residual that can be monitored to determine if the dose was provided correctly, UV disinfection systems should be validated so that they can be sized to achieve the required disinfection in each specific situation. UV systems should be validated in accordance with published protocols. A validated UV system can replace chemicals for primary disinfection of wastewater for irrigation since it can disable both typical and chemically resistant bacteria, viruses, fungi, algae, moulds and yeasts, while avoiding carcinogenic DBP formation.

Appropriate validation practices are discussed in 7.7.

Since periodic residual testing is not relevant for UV, once a UV unit has been installed, only continuous monitoring of key variables should be used to evaluate and verify UV performance. Key variables include:

- UV intensity,
- flow rate, and
- UV transmittance (UVT).

Operational variables like fouling, lamp aging and power should also be considered in UV performance evaluation [13].

7.2 UV light technologies and how they work

7.2.1 General

UV light is generated in a lamp by applying a voltage across a gas mixture, resulting in a discharge of photons. The specific wavelengths of light emitted from photon discharge depend on the elemental composition of the gas and the power to the lamp. UV lamps designed for water treatment generally use a mixture containing mercury, which emits light in germicidal wavelengths. Depending on the pressure and voltage applied, as well as the constituents and amounts of various elements inside the lamp, a different mixture of wavelengths will be generated.

The basic disinfection mechanism involves absorption of a UV photon by pyrimidine bases (principally thymine) where two pyrimidine bases are next to each other on the DNA chain. This creates a "dimer" that links the two bases together, inhibiting replication. UV light can also damage cell membranes, cell RNA and microbial proteins that can trigger repair mechanisms, particularly in viruses.

While wavelengths from 200 nm to 415 nm are germicidal, the specific response of a microbe (the “dose response”) will differ based on its sensitivity or resistance to UV. This “action spectrum” determines the dose required to inactivate an organism so that it cannot be repaired. The specific dose will be different when only one wavelength is applied (by LP or LPHO, or amalgam lamps) versus when many wavelengths are applied (by MP lamps).

Flow rate is a critical parameter that expresses how long the water is in the UV disinfection chamber and exposed to UV light. It is generally linear with dose. It also impacts the hydraulics and dose delivery inside the chamber.

UV systems should provide real time performance monitoring to document that they are operating within specified conditions. On spec performance should include the correct dose, flow rate, UV intensity as measured by a calibrated UV intensity sensor and current water quality (UVT). Reporting and recording should be used to assist the grower, in conjunction with pathogen sampling and testing, in tracing any disinfection lapses and determining whether a field can be harvested.

NOTE UV in agriculture is often used in greenhouses and growing houses for the treatment of the drainage water for reuse of this water for irrigation. Due to the concern of contamination of the water from the bacteria or other pathogens, farmers invest in disinfectant systems and UV is used as one of the important components in disinfecting water and preventing the distribution of diseases to healthy plants.

7.2.2 UV disinfection system components

A UV disinfection system may include:

- UV source,
- disinfection chamber (sometimes called the “reactor”),
- ballasts that provide the power that the lamp converts to UV photons (energy),

- sensors that measure the UV light generated by the lamp,
- sensors that measure the quality of the incoming water the UV will treat,
- lamp protection sleeves,
- cleaning/wiping mechanisms,
- software that runs the process, and
- software that tracks the process and provides verification and documentation.

An external flow measurement device or flow assumptions should be used to provide flow data for dose control.

The UV dose achieved and the amount of energy needed for disinfection is impacted by the concentration of total suspended solids (TSS), total organic carbon (TOC) and dissolved organic carbon (DOC) which interact to affect UV transmittance (UVT).

7.3 UV source

7.3.1 General

The UV light output depends on the concentration of mercury and the mercury vapor pressure inside the lamps. In low-pressure (LP) UV lamps, mercury at low vapor pressure [near vacuum; 2×10^{-5} to 2×10^{-3} pounds per square inch (psi)] and moderate temperature [40 °C] produces essentially monochromatic (one wavelength) germicidal UV light at 253,7 nm. In medium-pressure (MP) UV lamps, a higher vapor pressure [2 psi to 200 psi] and higher operating temperature (600 °C to 900 °C) are used to increase the frequency of collisions between mercury atoms, which produces UV light over a broad spectrum (polychromatic) with an overall higher intensity.

The following types of lamps are currently commercially available for UV disinfection of TWW:

- Low Pressure (LP) Lamp

  A mercury-vapor lamp that operates at an internal pressure of 0,13 Pa to 1,3 Pa (2×10^{-5} to 2×10^{-4} psi) and electrical input of 0,5 watts per centimetre (W/cm). This results in essentially monochromatic light output at 253,7 nm at a lower operating temperature with higher per watt conversion efficiency[16].

- Low-pressure high-output (LPHO) Lamp

  A low-pressure mercury-vapor lamp that operates under increased electrical input (1,5 W/cm to 10 W/cm), resulting in a higher UV intensity than low-pressure lamps. It also has essential monochromatic light output at 253,7 nm. Monochromatic lamps are also affected by influent water temperature.

- Amalgam Lamp

  An amalgam lamp is low pressure lamp based on an alloy of mercury (bismuth often) that is in blobs rather than liquid form. It is monochromatic and has a power density that is higher than other types of LP lamps. The mercury blobs act as a pressure regulator and extend the working life of the lamp. However, Amalgam lamps run much hotter than traditional LP lamps and are less stable in hot climates and where the water is not always flowing.

- Medium-pressure (MP) Lamp

  A mercury vapor lamp that operates at an internal pressure of 1,3 Pa and 13 000 Pa (2 psi to 200 psi) and electrical output of 50 to 300 W/cm. This results in a polychromatic (or broad spectrum) output of UV light at multiple wavelengths, generally between 200 nm to 400 nm, covering UVA, UVB, UVC germicidal spectrums. Medium pressure lamps are not affected by influent water temperature.

Low-pressure lamps are not as effective for secondary TWW with TSS levels above 30 mg/L. The higher these concentrations, the less UV light penetrates and can be absorbed by the organisms.

Polychromatic Medium-pressure lamps use more energy than low pressure lamps and have a lower proportional energy conversion, but they generate approximately 15 to 20 times the germicidal UV intensity of low-pressure lamps and have a smaller overall footprint. Polychromatic Medium pressure UV photons destroy the proteins that trigger repair mechanisms so that the inactivated microorganisms cannot repair downstream, overcoming dark and light repair mechanisms that can play a role particularly in irrigation water exposed to sunlight.

Water temperature affects the start-up and restart times and the UV output of low-pressure UV lamps, but not medium pressure UV lamps. Lamp temperature will affect the start-up of MP lamps.

NOTE Some systems also need a cooling process to keep the lamps at their correct operating temperature and keep the ballasts and related power devices from overheating.

7.3.2 UV source protector

UV lamps should be housed in protective lamp sleeves. Any deposits on the sleeve can absorb UV light and compromise efficiency.

Sleeves that encase and protect the lamps can be vulnerable to fractures, which can occur from internal stress and external mechanical forces such as wiper jams, water hammer, resonant vibration, and impact by objects within the flowing water.

Sleeves should be handled properly when removed for manual cleaning, to avoid fractures and consequent water leakage.

The temperature difference between the hot lamp and cooler water can cause the lamp to break. Therefore, lamp sleeves should be thick enough to decrease their vulnerability to fractures and protect the lamp. Thick sleeves should be used.

7.4 Disinfection chamber

The following factors should be considered:

- upstream and downstream impact of piping on hydraulics in the chamber,
- lamp configuration impact on hydraulics,
- short circuiting,
- dead zones, and
- other factors that compromise dose uniformity and need more energy to achieve the required dose.

UV units should be configured within an installation so that the disinfection chamber is entirely filled with water, with no air at all inside it.

7.5 Sensors

7.5.1 UV intensity sensors

UV light in a system should be measured by a dedicated sensor. UV lamp intensity is affected by lamp age and lamp sleeve fouling.

Optimally each lamp should have a UV intensity sensor to measure actual UV intensity to determine if the required dose has been achieved in the disinfection chamber. UV intensity sensors should be calibrated and checked regularly for accuracy.

NOTE Some UV systems use UV intensity sensor data to automatically adjust the power to the lamp and thus the UV intensity to compensate for lamp age and other factors affecting intensity to produce the correct dosage based on water quality and flow rate.

UV intensity sensors should comprise the following:

- optical components,
- a photodetector,
- an amplifier,
- its housing, and
- an electrical connector.

The optical components may include monitoring windows, light pipes, diffusers, apertures, and filters.

Monitoring windows and light pipes deliver light to the photodetector. Diffusers and apertures reduce the amount of UV light reaching the photodetector, thereby reducing the sensor degradation that UV light causes. Optical filters modify the spectral response such that UV intensity sensor responds only to a specific set of wavelengths (e.g., 250 nm to 280 nm).

UV intensity sensors may be classified as dry or wet, as follows:

- dry sensors monitor UV light through a monitoring window outside the flowing water, and
- wet sensors measure UV light directly in contact with the water flowing through the unit.

Monitoring windows and the wetted ends of wet sensors can foul over time and should be cleaned in a similar manner to lamp sleeves.

UV intensity sensors can serve one of two functions:

- duty UV intensity sensors: online sensors that continuously monitor UV intensity,
- reference UV intensity sensors: off-line sensors used to assess the duty UV intensity sensor performance. A reference UV intensity sensor should be calibrated at least once per year at a qualified facility (e.g., manufacturer) to confirm that it is calibrated properly[13].

Accurate UV intensity sensors should be used to verify adequate UV dose delivery during operation and should have an established calibration check regime to assure that the UV intensity sensors always report within a 20 % tolerance or less. If UV intensity is reported higher than the actual, the system will be instructed to deliver less energy and may not provide enough energy for correct disinfection.

7.5.2 UV transmittance sensors

UVT (UV transmittance) functions as an index of UV demand. It has a strong effect on the dose delivery of a UV unit. As UVT decreases, the intensity throughout the unit decreases, which reduces the dose the unit delivers. UV systems should be sized to deliver the required UV dose under specified UVT conditions.

Based on the physical and chemical constituents of the influent, the UVT measures the transmittance of specific wavelengths of UV photons through the water. Germicidal UVT sensors generally measure between 250 nm and 280 nm, focusing on 253,7 nm.

UVT should be measured as often as needed, as TWW quality fluctuates and changes the amount of UV light needed to achieve disinfection. Some units have on-line real time UVT measurement where UVT is part of the UV dose calculation, and, the lamp output changes to maintain appropriate UV dose delivery.

UVT may be measured with a bench-top spectrophotometer or continuously measured by an integrated or external on-line UVT sensors/analyzers.

UVT sensors should be calibrated regularly (according to manufacturer's instructions) and compared to values for the same water from a bench top or alternate spectrometer. Tolerance for UVT error should be ± 2 %. If UVT is reported higher than the actual, the system will be instructed to deliver less energy and will compromise disinfection.

7.6 Ballasts

The ballast should be protected from excessive heat by ventilation or air-conditioning as required by site environmental conditions.

Magnetic ballasts operate at line frequency which can vary, and only allow step adjustment of lamp intensity. Electronic ballasts operate at frequencies higher than line voltage and provide almost continuous incremental adjustment of lamp intensity.

NOTE UV lamps that are powered by magnetic ballasts tend to have more lamp end-darkening (i.e., electrode sputtering) and have shorter lives compared to lamps powered by electronic ballasts due to the higher frequencies used by electronic ballasts.

7.7 UV validation

UV unit performance should be rated through a UV validation process. Dose delivery in a continuous flow UV disinfection chamber is fairly complex. The path that an organism takes determines the amount of UV it will be exposed to before leaving the disinfection chamber and will determine inactivation. Some microorganisms travel close to the UV lamps and experience a higher dose, while others that travel close to the chamber walls can experience a lower dose. Some microorganisms move through directly, while others travel a more circuitous path. The result is that each microorganism can leave the unit having received a different UV dose. The more uniform the dose distribution, the more efficient the unit and the less energy it will consume to achieve the required dose.

To enable proper UV disinfection systems, a measured and reliable dose rating is required. It should be based on full scale validation testing with a known challenge organism that has been quantified with collimated beam dose response testing, using published and accepted protocols.

While UV validation for drinking water disinfection has a number of acceptable protocols (DVGW, ONORM, EPA), the recommended protocol to establish the reduction equivalent dose (RED) for reuse water was published in 2012[17].

UV validation can be performed by an independent 3rd party with expertise in the science of UV, to assure that the dose rating will provide reliable treatment and public health safety. UV validation should consider an operational envelope that describes ranges of flowrate, UV transmittance, Electrical supply voltage, power input to the lamps and correlates them with the microbiological results under a variety of conditions.

The basic components of the reuse validation protocol include specific procedures for:

- challenge microbe preparation,
- collimated beam testing,
- full scale unit sampling and testing, including water quality matrix,
- data analysis,
- dose calculation methods,
- specific QA/QC limits,
- instrument calibration, and

— documentation.

An equation can be developed to fit the validation data and assign the RED, and can take a similar form to Formula (30):

$$R = 10^{a} \times A254^{b} \times (S/S_0)^{c} \times (1/Q)^{d} \quad (30)$$

where

R is RED (reduction equivalent dose) *UV dose* units in mJ/cm^2;

$A254$ is the Absorbance at 254 nm;

S is the measured UV intensity sensor reading;

S_0 is the UV intensity at 100 % lamp power;

Q is the flow;

a, b, c,d are model coefficients that are obtained by fitting the equation to the validation data[16].

However, the standard MS-2 equation, developed specifically for TWW for reuse, is based on specified QA/QC parameters for MS-2 and can be used to assign the RED (14), see Formula (31):

$$x = [y\ (\log\ [i]-0{,}5464)]/0{,}0368 \quad (31)$$

where

x is UV dose

i is inactivation

Full scale and scale up parameters and implementation limits provide that while dose ratings are interpolated, they should not be extrapolated. They should be based on the highest flow tested, the lowest UVT tested, sensor criteria, accuracy, QA/QC quantification and dose response curve limits of MS-2 as the challenge testing organism.

Variability in lamp output represents a potentially serious issue for UV system scale up. UV lamps are commonly assumed to be identical, however when measurements of lamp output are conducted, substantial variations are observed. These variations can have a substantial effect on the sizing and performance of UV systems, particularly when small numbers of lamps are involved. In larger systems, it is expected that lamp output variability will have a less profound effect on process performance. These arguments point out another level of uncertainty in scaling up from pilot-scale units (where small numbers of lamps are the norm) to full-scale systems. In some cases, computational fluid dynamic (CFD) models are used to guarantee system performance where the full range of operational parameters has not been validated.

To eliminate concerns regarding scale-up, a spot-check bioassay practice should be conducted, whereby the actual performance of the full-scale facility is investigated and documented.

The system should be designed for UV dose based on regulatory requirements, type of wastewater reuse application and the maximum daily flow. The required dose will vary based on pretreatment type (e.g. porous membrane filtration, microfiltration and or semi-permeable membrane filtration). The dose achieved should be continuously reported, as well as lamp intensity, UV transmittance, and flow rate[17].

7.8 The effectiveness of a UV disinfection system

Different system configurations (e.g., open channel, closed channel, various lamp orientations, etc.) define the hydraulic profile and dose distribution. Thus, UV facilities have different scale-up, layout, and mechanical redundancy requirements, which determine the efficacy of a UV system.

A UV disinfection system's flow should be as uniform as possible, with enough motion and mixing to maximize exposure to UV. The more uniform the dose distribution the lower the energy demands to achieve disinfection. An UV unit should be designed to eliminate short-circuiting and/or dead zones, which could result in a broad dose distribution and thus poor performance[2].

The effectiveness of an installed UV disinfection system generally depends on[15]:

- the intensity of the UV light and the wavelength profile compared to the characteristics of the influent and the target organisms,
- the types and concentration of organisms in the influent and their action spectrum,
- the amount of time the microorganisms are exposed to UV,
- the UV source configuration and the hydraulic properties,
- the dose distribution/uniformity inside the unit,
- the quality of the influent water in terms of chemical characteristics, colour, dissolved solids, particles and organic content,
- the UV transmittance of the water compared to the amount of UV light in the disinfection chamber, and,
- biofouling and fouling from magnesium, iron and calcium.

7.9 Cleaning

Inadequate cleaning and deposits on lamp sleeves are the most common challenges to UV system effectiveness. Some methods prevent deposits and some remove them. Ultrasonic cleaning may be used to prevent lamp deposits. Physical lamp sleeve cleaning can remove deposits by one of several methods:

- removing the protection components and treating them with chemicals and returning them to their place;
- an off-line chemical cleaning where the unit is shut down, drained and flushed with a cleaning solution;
- on-line mechanical cleaning methods with mechanical wipers that physically remove fouling from the lamp sleeve surface and do not require draining the unit, which can remain on-line. Some just use the scraping action of the wiper and some work with food-grade chemical solutions.

Cleaning frequency should be site-specific, as some systems should be cleaned more often than others. Chemical cleaning should be done with citric acid. Other cleaning agents may include mild vinegar solutions, sodium hydrosulfite or phosphoric acid. A combination of cleaning agents may be tested to find the most suitable agent for the TWW characteristics without producing harmful or toxic by-products.

7.10 Environmental impacts of UV disinfection

While conditions vary under which UV disinfection is used, the risk for negative environmental consequences is minimal. In general, longer wavelengths are less likely to produce disinfection by-products (EPA 1997)[18]. Higher doses (over 100 mJ/cm^2) may, in nitrate-rich waters, produce some nitrites, though usually below the WHO recommended limits. The guideline value for nitrite in drinking-water is 3 mg/L as nitrite ion (equivalent to 0,9 mg/l as nitrite-nitrogen)[19]. Discharges of UV disinfected water to the environment do not pose pollution risks.

7.11 Advantages, disadvantages and technical considerations of UV disinfection method

Advantages, disadvantages, and technical considerations of disinfection methods by UV are listed in Table 8:

Table 8 — Advantages, disadvantages and technical considerations of UV disinfection

Advantages	Technical considerations and/or disadvantages
— Effective over a wide pH range, rapidly reacts with bacteria, viruses, and protozoa and has stronger germicidal properties than chlorination.	— Does not provide germicidal or disinfection residual to inhibit or prevent recontamination.
— Short reaction time.	— UV light inactivates microorganisms by damaging their nucleic acid and proteins. — Preventing them from replicating, but some damages caused by monochromatic UV can be repaired through photoreactivation and dark repair.
— The treatment process does not add chemicals to the water.	— Require high quality of TWW (appropriate UV Transmittance-UVT)).
— No formation of by-products hazardous to health	— Power consistency and reliability required.
— No ecological damage.	— There is a need to safely dispose of used lamps.
— Method with low maintenance and easy handling.	— Requires computer tracking to verify

8 Removal of pathogens by membrane methods

8.1 General

Removal of pathogens by membrane is principally performed by filtration of water through membranes of defined pore diameter which is smaller than pathogens cell size. Membrane filtration process removes pathogens and viruses from water but does not inactivate them. The concentrate that has not passed through the membrane should be safely treated or removed, as it can contain high concentrations of pathogens. Combined application of membrane process with other disinfection processes as “multi-barrier“ enables effective disinfection to achieve the most stringent standards.

8.2 Membrane system

A membrane filtration unit usually consists of screen, membrane modules, tanks, pumps, cleaning device and auxiliary equipment. MF/UF membranes are made up of polymeric or ceramic materials which have a porous structure.

MF/UF membranes are classified by pore size as shown in Table 9.

Pathogen concentrate effect is produced by the “sieve mechanism" and depends on the size of pores present in the porous structure and size of the separating substances.

NF/RO membranes are applicable for TDS and Boron removal.

Table 9 — Membrane types and targeted contaminants [21]

Type of Process	Membrane	TMP, approximate range (MPa)	Contaminants targeted for removal	MWCO (kDa)
Microfiltration membrane process	MF	< 0,2	0,05 µm to 2,0 µm diameter particle: TSS, Turbidity, at least 4-log reduction in protozoan oocysts and cysts & bacteria, but not viruses	> 5 000
Ultrafiltration membrane process	UF	0,2 to 1	0,008 µm to 0,05 µm: TSS, turbidity, macromolecules, colloids, at least 4 to 6-log reduction in protozoa and bacteria, and 1 to 6-log reduction in viruses	5 to 5 000
Nanofiltration membrane process	NF	0,5 to 3	0,001 µm to 0,02 µm: Pesticides and other macromolecules (high molecular weight), color, colloids, all pathogen groups and polyvalent cations. NF has been used in place of RO when only softening or partial deminera,lization is needed	0,1 to 5
Reverse osmosis membrane process	RO	0,5 to 7	0,0001 µm to 0,002 µm: used to remove dissolved salts and colloidal / dissolved solids, including trace organics, by means of size exclusion and solution-diffusion	< 0,1

8.3 Pathogen removal by membrane filtration

Membrane equipment and system should be designed and selected according to the certified log-reduction value (LRV) for each class of pathogen. MF systems are effective to remove protozoan oocysts and cysts, most bacteria (but not all), but not viruses, while UF systems are able to remove most protozoa, bacteria and viruses. The degree of removal for the different pathogens in the different membrane systems is presented in Table 10, Annex B and Table B.1.

Cryptosporidium oocysts are not inactivated by chlorination disinfection but can be effectively removed by membrane filtration.

NF/RO Membrane systems are less commonly applied for pathogen removal purpose, since their pathogen log removal rate does not significantly exceed those of MF/UF membranes systems in terms of LRV credit.

The advantage of membrane filtration process is the high level of pathogen removal achieved with combination of other disinfection processes as "multi-barrier".

8.4 Considerations for operation and maintenance

In the use of membrane systems, the following items should be taken into consideration:

- feedwater characteristics,
- management of concentrate,
- control of membrane fouling,
- proper monitoring of the system.

A complete description is given in Annex D.

8.5 Monitoring

Key monitoring items in membrane filtration should be water quality and membrane integrity. The performance of the membrane and integrity test are described in ISO 20468-1[20] and ISO 20468-5:2021 [21] in detail.

In relation to water quality, there are two aspects that should be controlled and monitored:

a. Quality of the feedwater (input): the first tests of the TWW quality at the entrance of the membranes are carried out in the pre-design stage. The pretreatment strategy should be determined accordingly:

   During the use of the membrane system, the factors listed in item 1 in Annex D should continue to be monitored. Unlike a natural source of water, the quality of TWW can vary temporarily or permanently, especially when wastewater of industrial origin flow to the treatment plant. The frequency of monitoring for part or all of the parameters should be in accordance with the variability found during the time.

b. Quality of the product (output): this monitoring should be performed to establish if the TWW treated in the membrane process meets the requirements required by the local regulation and for which the system was designed. The parameters that should be measured are those required by the local regulation as indicator microorganisms or some specific pathogen.

8.6 Environmental impacts of membrane systems

Special attention should be paid as concentrate with a high concentration of contaminants is produced. The concentrate can be discharged to sewer or evaporated for minimizing the concentrate amount as Zero Liquid Discharge (ZLD) system. Membrane modules/elements are composed of different types of plastic or ceramic materials which are difficult to recycle. The amount of the solid waste may be calculated based on the lifetime of membrane modules/elements. For residual chemicals and neutralized wastes generated in cleaning that require industrial waste collections, the volume/weight of the chemicals will be used for disposal evaluation.

8.7 Advantages, disadvantages and technical considerations of pathogens removal by membrane systems disinfection method

The advantages, disadvantages and technical considerations of membrane removal by filtration systems are summarized in Table 10.

Table 10 — Advantages, disadvantages and technical considerations of membrane systems

Advantages	Technical considerations and/or disadvantages
— Efficient removal of bacteria and protozoa.	— Partial removal of viruses depending on type of the membrane system.
— Removal of *Cryptosporidium* oocysts	— Requires treatment of concentrate and liquid waste.
— No bacterial regrowth.	.
— No chemical reaction.	
— No by-product.	
— Automated operation possible.	