Quality of Domestic Water Supplies

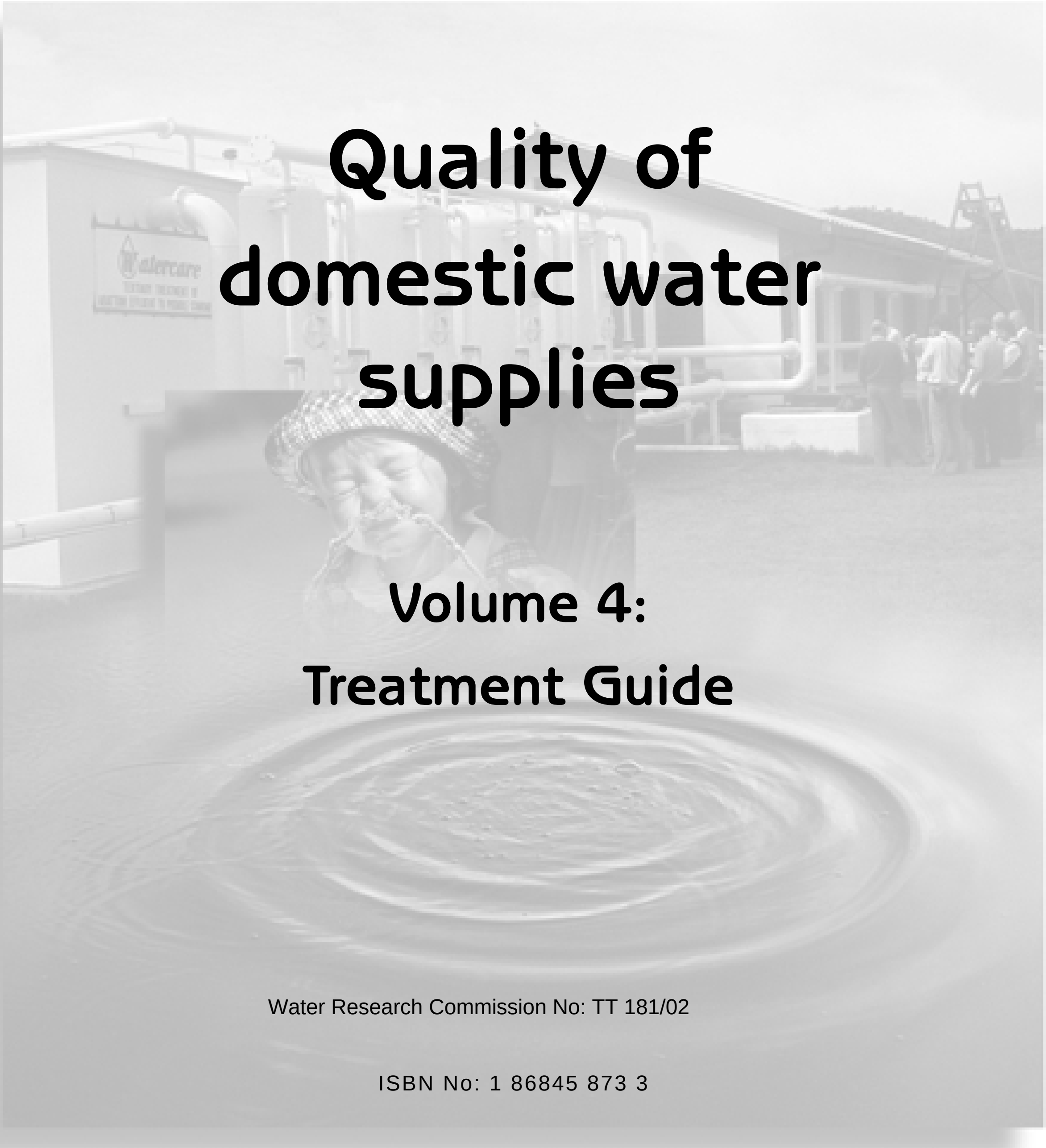
Volume 4: Treatment Guide

First Edition 2002

The Department of Water Affairs and Forestry

The Department of Health

Water Research Commission



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Volume 4: Treatment Guide

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OTHER REPORTS IN THIS SERIES

This Guide forms part of a series, which is intended to provide water supply agencies, water resource managers, workers in health-related fields, as well as communities throughout South Africa with guidance on domestic water quality with regard to:

- planning a new domestic water supply scheme
- implementation of a domestic water supply scheme, and
- actions that can or should be taken if something goes wrong at selected points in the domestic water supply scheme.

The following documents form the series:

Quality of domestic water supplies -
Volume 1 Assessment Guide

Quality of domestic water supplies -
Volume 2 Sampling Guide

Quality of domestic water supplies -
Volume 3 Analysis Guide

Quality of domestic water supplies -
Volume 4 Treatment Guide

Quality of domestic water supplies -
Volume 5 Management Guide

THIS GUIDE IS AVAILABLE FROM:

Director: Institute for Water Quality Studies
Department of Water Affairs and Forestry
Private Bag X313
Pretoria
0001
Tel: 012 808 0374
Fax: 012 808 0338

Director: Water Services Planning
Department of Water Affairs and Forestry
Private Bag X313
Pretoria
0001
Tel: 012 336 7500
Tel: 012 324 3659

Director: Environmental Health
Department of Health
Private Bag X828
Pretoria
0001
Tel: 012 312 0802
Fax: 012 323 0796

Water Research Commission
Private Bag X03
Gezina, 0031
South Africa
Tel: 012 330 0340
Fax: 012 331 2565

FOREWORD

In search of a better quality of life for all South Africa's people, the three objectives of water resource management, waste treatment and a safe water supply are of primary importance. These objectives are corner-stones in the South African Constitution, supported by a sound legal framework in terms of the National Water Act (Act No 36 0f 1998), the Water Services Act (Act No 108 of 1997), as well as the Health Act (Act No 63 of 1997).

The laudable goal of ensuring that all citizens have access to a safe supply of potable water is only achievable with reliable and timely training material being made available to capacitate the upcoming generation, so that water supply systems may be effectively managed on a sustainable basis.

With this aim in mind the Department of Water Affairs and Forestry and the Department of Health in partnership with the Water Research Commission, have embarked on a venture to produce a series of user-friendly guidelines. The aim of these guidelines is to enable water supply agencies, water resource managers, workers in health-related fields, as well as consumers, with the information they need to sample, analyse, optimise treatment, assess and manage the domestic water supplies.

This particular guide is the fourth in the series and is focused on explaining the principles of sound water treatment and the processes by which a safe potable water supply is produced. As was the case with the earlier documents in the series, particular attention been paid to the user-friendliness of the document.

It is our vision and hope that this guide will contribute substantially to assist the building of the necessary capacity in South Africa to effectively treat the resource waters available, so that the people may be ensured of a safe potable water supply.

Ronnie Kasrils.

Mr Ronnie Kasrils
Minister of Water Affairs & Forestry

M Tshabalala

Dr ME Tshabalala-Msimang
Minister of Health

PROJECT TEAM

Project Management

Dr AL Kühn	Department of Water Affairs and Forestry
Dr IM Msibi	Water Research Commission
Mr JA Pule	Department of Health

Technical Team

Mr CS Crawford	Department of Water Affairs and Forestry
Mr GH de Villiers	University of Pretoria
Dr PL Kempster	Department of Water Affairs and Forestry
Dr AL Kühn	Department of Water Affairs and Forestry
Mr O Langenegger	Bigen Africa
Dr IM Msibi	Water Research Commission
Mr TA Pule	Department of Health
Mr P Thompson	Umgeni Water

Author

Prof CF Schutte	University of Pretoria

Contributors

Mr R Holden	Mvula Trust
Mr B Aleobua	Department of Water Affairs and Forestry
Mr A Barnes	Department of Health
Mrs ND Basson	Sedibeng Water
Mr D Esterhuizen	BKS (Pty) Ltd
Ms S Hohne	Department of Water Affairs and Forestry - Bloemfontein
Mr G Hough	Department of Water Affairs and Forestry - Bloemfontein
Mr P Kotze	Technikon Pretoria
Mr FA Lems	Rand Water
Mr M Makwena	Department of Health
Mr G McConkey	Department of Water Affairs and Forestry - Western Cape
Mr R Nay	Johannesburg Water
Mr T Pieterse	TNG
Mr J Pietersen	Midvaal Water
Mr J Taljaard	Water Research Commission
Mr M van Veelen	BKS (Pty) Ltd
Mr F van Zyl	Department of Water Affairs and Forestry

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PURPOSE OF THE GUIDE

What is the purpose of the Treatment Guide?

The purpose of this guide is to provide general information on the treatment of water for domestic use. The purpose is not to go into the technical details of the different treatment methods, but rather to provide general information on aspects such as the suitability of processes for different types of water and the limitations and relative costs of different processes.

The main objective is to empower people in developing and rural areas to make informed decisions about the selection of treatment processes and the management of treatment plants under their control in order to ensure sustainability of their water supplies. A further objective of this Guide is to enable a better understanding by treatment plant operators and managers about individual treatment processes and combinations of processes.

NOTE: This Guide is the fourth in a series of *Guides on the Quality of Domestic Water Supplies*. It should therefore be used in conjunction with the other Guides: *Volume 1 - Assessment Guide; Volume 2 – Sampling Guide; Volume 3 - Analysis Guide;* and *Volume 5 – Management Guide.*

NOTE: For more detailed technical information the Department of Water Affairs and Forestry document: *Technical Guide for the Treatment of Water for Domestic Use*, could be consulted.

Who should use the Treatment Guide?

The level of presentation in this Guide is not highly technical since it is aimed at different groups of people involved in water supply. It is accepted that people in some of the groups may have only limited training and/or experience in water treatment and water supply. The groups who may find the Guide useful include:

- Water treatment plant operators and managers
- Members of water committees or local authorities responsible for water supply
- Environmental health officers who have to assess water quality for domestic use
- Water supply agencies
- Educators and students.

STRUCTURE OF THE GUIDE

This guide consists of six parts and each part consists of a number of sections. The pages of each section are marked in the top right hand corner with the icon corresponding to that section.

Part 1

Provides general information on water treatment processes and the substances of concern in water for domestic purposes.

Part 2

Deals with conventional water treatment processes, i.e. processes for the removal of suspended and colloidal material, for disinfection, and for chemical stabilisation of water.

Part 3

Focuses on point-of-use treatment processes and equipment. These processes can be used for home treatment and to provide water in emergency situations.

Part 4

Deals with package plants. These are relatively small, self-contained units that can be installed within a short period of time to provide water.

Part 5

Gives information on advanced/specialised processes such as processes for the desalination of water or the removal of nitrate and fluoride from water.

Part 6

Deals with specific issues in water treatment, including management aspects, handling of treatment problems, safety, fluoridation and waste disposal.

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Section 1a: General water treatment concepts

Why is it necessary to treat water for domestic use?

Water must meet certain basic requirements to make it fit for domestic use. The most important requirement is that it must be ***safe to drink****. Many water sources contain harmful micro-organisms or other substances in concentrations that make the water unsafe to drink or in other ways unfit for domestic use. These organisms and substances must therefore be removed from the water by means of treatment processes to make the water fit for domestic use.*

Most surface water sources and many underground sources contain harmful micro-organisms and other harmful substances (contaminants) that must be removed from the water to acceptable levels to make the water fit for domestic use. There are many different types of micro-organisms and other substances that may have health effects on consumers who drink untreated water. These are called substances of concern and they are discussed in detail in the *Assessment Guide* (Volume 1 in the series *Quality of Domestic Water Supplies*). The reader is referred to Sections 1A – 1D in the *Assessment Guide* for information on these substances. A summary of these substances is also given below.

Are there other reasons why water for domestic use must be treated?

In addition to the requirement that water must be safe to drink, water for domestic use must also have a pleasing (clean) appearance, and it must furthermore be chemically stable (i.e. it must not cause corrosion or deposits in pipes or fixtures such as geysers).

Clean water has a pleasing appearance and gives the impression of good and wholesome water. However, clean water is not necessarily always safe to drink, because the water may contain harmful substances that do not affect the appearance of the water. On the other hand, water that is murky or coloured is not pleasing to drink, even though the water may be safe.

A further requirement for treatment is that water for domestic use must be **chemically stable**. This is an important requirement to protect pipes and fixtures in distribution systems. Water that is not chemically stable may cause corrosion (rust) in pipes or may result in the formation of a layer of chemical deposit (scale) on heating elements of kettles and geysers. Both corrosion and scale formation is detrimental to the system. Corrosion may result in leaks in pipes and loss of water and large costs for the lost water and eventual replacement of pipes. Scale formation causes higher electricity costs to heat water and may also result in the need for early replacement of elements.

How and where does water treatment fit into a water supply system?

Water treatment is an essential element in any water supply system in order to make the water fit for domestic use. In a conventional treatment system raw water is abstracted from the source (dam, river or borehole), the raw water is then conveyed to the treatment plant where it is treated in different treatment process. After treatment the water is stored and then distributed to individual users (see Figure 1 for a diagrammatic representation).

There are different variations to the conventional system shown above.

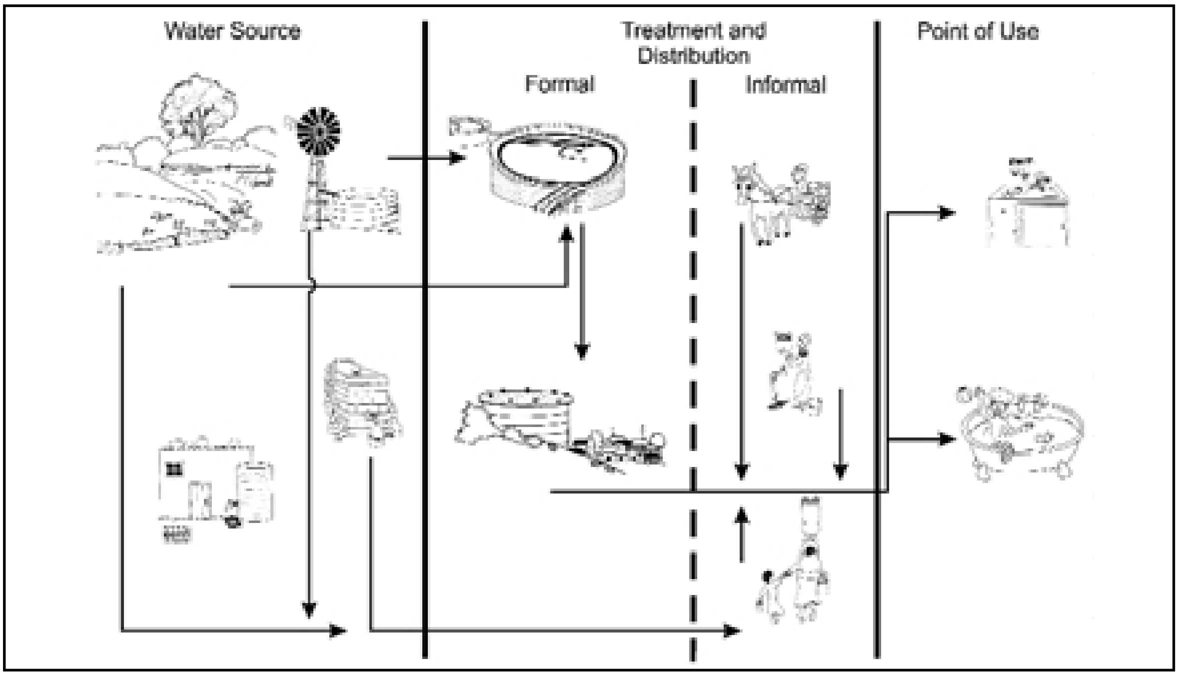

Figure 1. Diagram of typical Water Supply Scheme

- In some cases water that is treated at a central treatment plant and distributed to individual users may receive further treatment at the point of use. This may include, for example softening of hard water by means of a home ion exchanger or treatment by some other home treatment device.

- **In some areas rainwater is collected from rooftops and stored in tanks before use. The water may be treated by means of a filter or used without any treatment. Provision is often made that the first water collected from the roof is diverted from the tank in order to prevent dirt and debris from entering the tank.**

- In some systems water is supplied without any treatment at all. For example, where water is fetched directly from a source by the individual user or by vendors, the water is often consumed without any treatment.

NOTE: Consuming surface water without treatment is a dangerous practice that may result in the user contracting diseases such as cholera or dysentery if the water source is contaminated by pathogens (disease-causing organisms).

What are the substances of concern that must be removed during water treatment?

*The **types of contaminants or substances of concern** that may occur in water sources vary over a wide spectrum and are discussed in detail in the Assessment Guide. For the purpose of this Guide substances of concern with similar characteristics that can be treated by the same type of treatment process are grouped in a number of categories and are discussed below.*

The following general categories of substances are normally taken into account when a water treatment plant is designed. When water has to be treated, it is normally not possible to consider each substance of concern individually. There are exceptions, however, for example the removal of a toxic substance from water is often specific for the particular substance.

- **Suspended particles** occur generally in surface water and give water a turbid or murky appearance. Suspended material varies widely in nature and includes clay particles, algae, micro-organisms, decaying plant material and other organic and inorganic substances. In addition to the large variety of suspended particles that can be present in water, these substances also vary over a wide size range. The larger suspended particles can be easily removed from water simply by means of settling (i.e. by allowing the water to stand for a short period and then decanting the clear water). Very small particles (called colloidal particles) are very difficult to remove from water because they do not settle readily and can therefore not be removed by simple settling. The very small colloidal particles in the water have to be destabilised chemically before the particles can be removed. These aspects are discussed in more detail in Part 2 of this Guide.

- **Micro-organisms** including bacteria, viruses and other organisms may also be present in water as colloidal particles. Most micro-organisms in water are harmless, but disease-causing organisms (called pathogens) may enter water sources as a result of pollution by human and animal wastes and by untreated or poorly treated waste waters discharged into the water source. These organisms may cause diseases such as cholera and dysentery if they are present in water that is consumed without treatment. The water therefore has to be disinfected (i.e. the micro-organisms have to be removed or destroyed) to make the water fit for domestic use. **Note Box 1** gives a list of disease-causing organisms, the disease each group causes and the typical source (there are also other routes of contamination possible).

Note Box 1: Disease-causing organisms

Name of organism	Major disease	Sources
Bacteria		
Salmonella typhi	Typhoid fever	Human faeces
Salmonella paratyphi	Parathypoid fever	Human faeces
Other *Salmonella*	Salmonellosis	Human and animal faeces
Shigella	Bacillary dysentery	Human faeces
Vibrio cholera	Cholera	Human faeces
Enteropathogenic *E. Coli*	Gastroenteritis	Human faeces
Yersinia enterocolitica	Gastroenteritis	Human and animal faeces
Campylobacter jejeni	Gastroenteritis	Human faeces
Legionella pneumophila	Legionellosis	Thermally enriched water
Mycobacterium tuberculosis	Tuberculosis	Human respiratory exudates
Enteric viruses		
Polioviruses	Poliomyelitis	Human faeces
Coxsackie viruses A & B	Aseptic meningitis	Human faeces

Echoviruses	Aseptic meningitis	Human faeces
Other enteroviruses	Encephalitis	Human faeces
Reoviruses	Upper respiratory and gastrointestinal illness	Human faeces
Rotaviruses	Gastroenteritis	Human faeces
Adenoviruses	Upper respiratory and gastrointestinal illness	Human faeces
Hepatitis A virus	Infectious hepatitis	Human faeces
Norwalk & related viruses	Gastroenteritis	Human faeces
Protozoans		
Giardia lamblia	Giardiasis (dysentery)	Human and animal faeces
Cryptosporidium	Cryptosporidiosis	Human and animal faeces
Entamoeba hystolytica	Amoebic dysentry	Human faeces
Balantidium coli	Balantidosis (dysentery)	Human faeces
Algae (blue-green)		
Anabaena flos-aqua	Gastroenteritis, skin rash	Nutrient enriched water
Microcystis aeruginosa	Gastroenteritis	Nutrient enriched water

- **Dissolved inorganic substances** normally do not affect the appearance of the water, but may cause the water to have a brackish or salty taste. Some dissolved substances may also cause the water to be toxic at very low concentrations e.g. arsenic and mercury. Most of the naturally occurring substances such as sodium chloride (NaCl, table salt) and calcium sulphate ($CaSO_4$, gypsum) are harmless in water for domestic use at the concentrations at which they normally occur. Other dissolved inorganic substances may be harmful if they are present at concentrations exceeding certain limits, e.g. fluoride (see *Assessment Guide*). The presence of other inorganic substances may have different effects, e.g. high concentrations of calcium and magnesium cause excessive hardness in the water. Iron and manganese on the other hand, may cause staining of clothes by the water, while other substances (or a lack of substances) may cause the water to be corrosive or to form layers of scale in pipes.

- **Dissolved organic substances** are generally present in most surface waters. Most dissolved organic substances are harmless, e.g. dissolved substances (called humic acids) from decaying plant matter. However, there may also be harmful organic substances in water, such as pesticides and herbicides that find their way into water sources. Another category of dissolved organic substances is the so-called disinfection by-products. These are chlorinated organic compounds that form during disinfection of water with chlorine. These chlorinated compounds are called trihalomethanes, THM's (chloroform is one of the compounds in this group).

Different treatment processes are used to remove the different types of contaminants.

When is it necessary to treat water for domestic use?

It is normally not possible to tell if water from a particular source has to be treated (or not) simply by visual inspection of the water. The reason is that the water may contain substances that are not visible but can make the water unfit for domestic use. It is therefore essential to have a screening analysis done of the water that is to be used as a source for domestic use. An assessment must then be done of the analysis in order to determine whether the water is fit for domestic use as it is, or whether certain contaminants have to be removed and what treatment processes are available to remove these substances (Assessment Guide).

Normally surface water sources contain substances that affect the appearance of the water, e.g. silt or algae so that the need for treatment is obvious. Many underground sources however, are free from visual contamination and it may therefore appear not to be necessary to treat the water. However, even sources that do not appear to be contaminated may contain harmful substances leached from the soil and rock formations through which the water moves during infiltration. The water may also be contaminated by infiltration of polluted water into the groundwater (e.g. from pit latrines). The treatment needs could therefore only be determined from an analysis of the water.

Which aspects have to be considered to determine whether a water source has to be treated to make it fit for domestic use?

Samples from the water source have to be analysed for the constituents of concern in water for domestic use and an assessment then has to be made of the water as is described in the Assessment Guide. All those constituents of concern that exceed the recommended values for domestic use (see Assessment Guide for South African specifications) must be considered for removal. Decisions about treatment processes and the design of the processes are based on the substances that exceed recommended values. Substances that affect the health of consumers are the most important in the evaluation of treatment requirements.

If none of the constituents of concern in the water source exceed the recommended values given in the *Assessment Guide*, the water may be used for domestic purposes without any treatment provided the water source is adequately protected against all possible sources of pollution. In many cases water from protected underground sources may not need treatment at all or only limited treatment, while water from surface sources will in most cases need treatment to make it fit for domestic use.

NOTE:

- water that is fit for domestic use may become contaminated and unfit for domestic use during distribution to consumers or during transport in a container to the point of use;
- contamination can be prevented by keeping containers clean and by preventing growth of organisms in pipelines and reservoirs; preventing growth of organisms can be done by addition of a small amount of chlorine to the water and maintaining the chlorine concentration at a low concentration in the distribution system.

Are there processes available to treat water from highly polluted sources to make it fit for domestic use?

Water treatment technology is highly developed and there are processes available to produce drinking water from just about any source of water no matter how polluted it is. Examples include water reclamation processes that produce drinking water from sewage, e.g. water reclamation in Windhoek, and desalination processes that produce drinking water from seawater.

It is evident that the more polluted a water source, the more sophisticated the treatment required to produce high quality drinking water from it and the higher the treatment cost would be.

- The cost of treating water normally increases in accordance with the number of processes required in a treatment plant to produce water of the required quality
- The cost of water treatment also increases with the complexity of the processes.
- The size (capacity) of a treatment plant also plays a major role in determining the treatment costs. The larger the capacity of a plant the lower the unit treatment costs (cost per unit volume) of water and conversely, the smaller a plant the higher the unit treatment cost.
- The more sophisticated a plant is, normally the higher would be the treatment costs.

Section 1B: General methods of water treatment

What are the general methods that can be used for water treatment?

There are many different water treatment methods (generally referred to as treatment processes) that can be used, each on its own, or in combination with others to treat water for domestic use. Normally a series of processes is used rather than only one process.

In general, water treatment processes can be classified into the following categories corresponding to the types of contaminants listed above:

- **clarification processes** that are used to remove suspended material from water. These processes include coagulation, flocculation, sedimentation, flotation, filtration (discussed in more detail in Part 2).
- **disinfection processes** including chemical treatment with chlorine and chlorine compounds (Part 2), and advanced processes such as the use of ozone as well as physical processes such as ultra violet irradiation (Part 5).
- **advanced/specialised processes** for the removal of dissolved inorganic substances including reverse osmosis, ion exchange and electrodialysis. Advanced processes are also used for the removal of dissolved organic substances, e.g. activated carbon adsorption (Part 5).
- **relatively simple processes** that can be used for home treatment or during emergency situations (Part 3).

These processes can be selectively combined in process trains to produce water of the required quality. They can be applied on very large scale such as the treatment plants of Rand Water and Umgeni Water, but they can also be used on small scale, such as package plants for small communities, or even on home treatment scale.

After it has been decided that water from a particular source has to be treated, what are the main aspects that must be taken into account when considering different treatment options?

The main aspects that must be taken into account are:

(i) the quality of the water source (raw water quality) and its variability;

(ii) the quality of the treated water to be produced;

(iii) the volume of water to be treated (capacity of the plant);

(iv) the cost limitations (the water cost/price that is considered to be acceptable to the consumers);

(v) the level of sophistication that is acceptable taking into account plant locality and level of expertise available to control and operate the plan;

(vi) the support services available to assist with plant optimisation, trouble shooting and maintenance and repair problems.

The raw water quality determines the processes that must be considered for inclusion in the treatment process. For example, in the case of water from a borehole there will normally be very little or no suspended material in the water, but the water may be very brackish (contain high concentrations of dissolved inorganic substances). In this case it may not be necessary to incorporate any clarification process such as filtration in the treatment train, but it may be necessary to include a desalination process. On the other hand most surface waters will require some clarification process to remove suspended material.

> The most important consideration in the design of treatment processes is that the water must be safe for human consumption after treatment. This means that the water has to be disinfected to ensure that there are no harmful micro-organisms in the water. Furthermore, it must also be ensure that there are no chemical substances in the water at concentrations at which they may be harmful to human health.

The quality of the raw water from which drinking water has to be produced plays a major role in determining the treatment processes and treatment costs. The poorer the quality the more sophisticated the plant because normally a series of processes will be required with a high level of control. This will normally result in a relatively high treatment cost of the water. On the other hand, a relatively simple process at low cost is required to treat good quality raw water requiring only disinfection. In between, there is a wide spectrum of combinations of processes to treat waters of a range of qualities at a wide range of costs. Most treatment plants in South Africa employ what is known as a series of conventional treatment processes.

How does process selection take place for a plant to treat water from a particular source?

The process of designing a treatment plant goes through a number of steps before the design is finalised.

Step 1 entails a **detailed evaluation of the raw water quality**. This includes evaluation of all the constituents and groups of constituents that must be removed from the water and the alternative processes and combinations that can be used for their removal.

Step 2 involves a **conceptual process design** in which alternative processes and combinations are evaluated to determine the performance of each combination in terms of efficiencies and product water quality as well as possible problems. At this point laboratory and bench scale testing is done to determine the best coagulants and other chemicals to be used and their dosages. If problems are evident at this point further tests and pilot scale studies may be necessary.

Step 3. In this phase a **preliminary design** is made which allows estimates of the treatment costs for the different options to be made. The projected treatment costs of the different options and process efficiencies are evaluated in selecting combinations for inclusion in the final design.

Step 4. The final **process design** comprises of detailed drawings of the different process units, sizes, chemicals, pumps, other equipment together with instructions for the operation and maintenance of the equipment.

Which process combinations are commonly used for the treatment of water for domestic use?

Treatment processes vary from relatively simple treatment methods to complex and sophisticated processes. Examples of different process combinations are given below to treat water from typical raw water sources.

1. Conventional treatment processes

Figure 2 shows the layout of a typical conventional treatment plant. The raw water source for this type of plant would typically be surface water from a dam or a river. **Figure 3** shows a general photograph of a conventional treatment plant

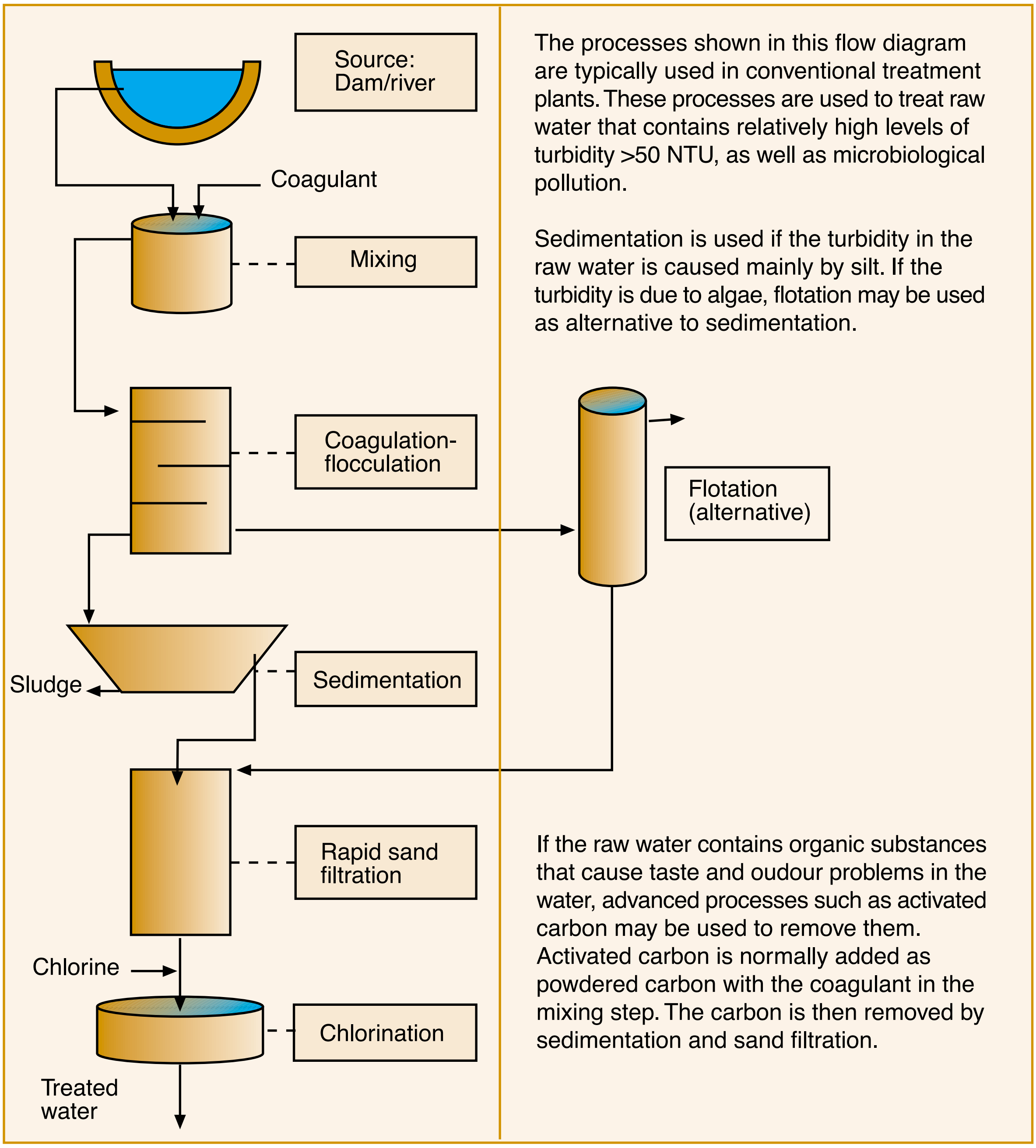

Figure 2: Flow diagram of conventional treatment processes

Figure 3: Conventional treatment plant

1. Specialised treatment processes

Figure 4 shows the layout of one type of specialised treatment process. The raw water source for this type of process would typically be ground water with a high concentration of total dissolved solids. **Figure 5** shows a general photograph of a conventional treatment plant.

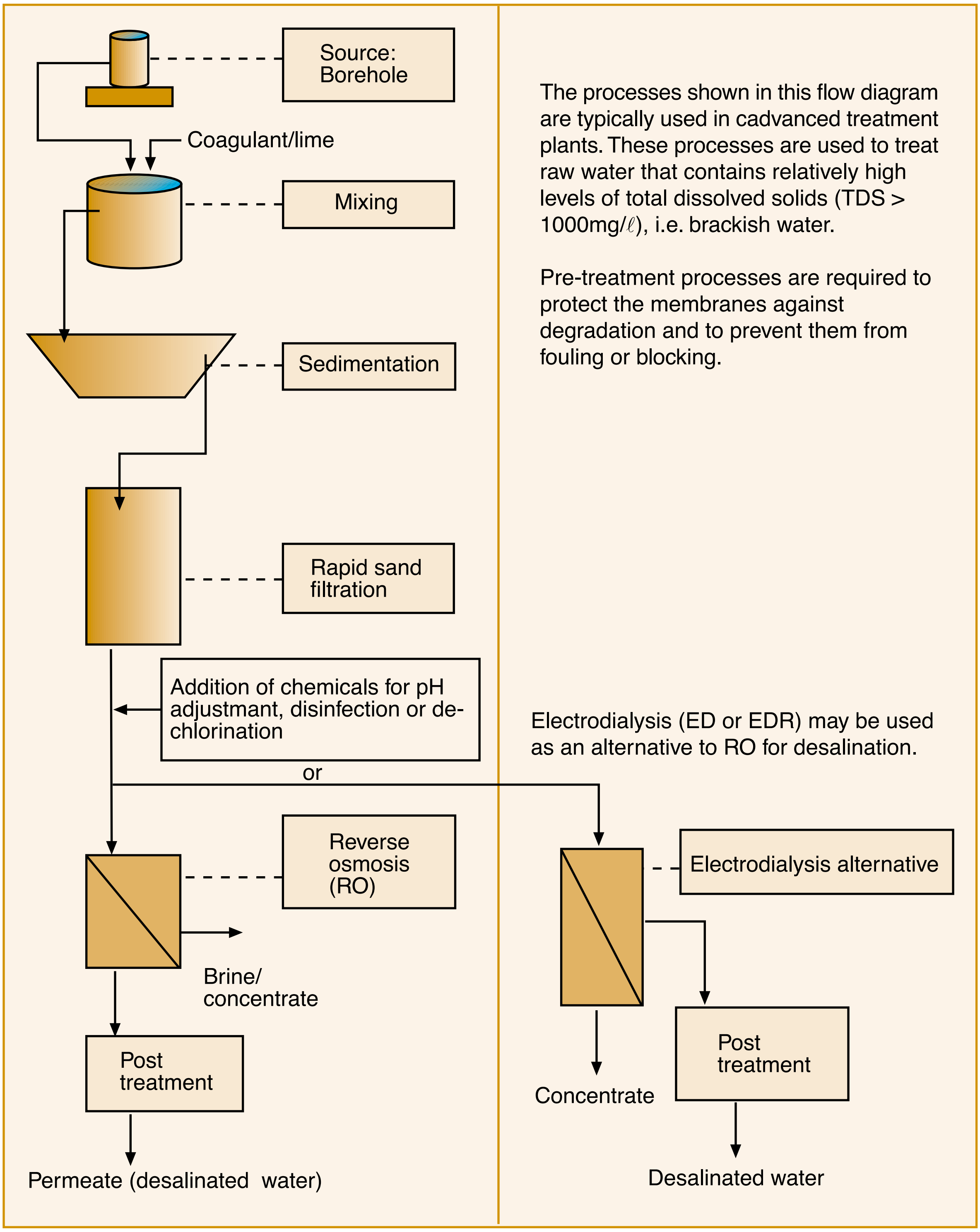

Figure 4: Flow diagram of specialised treatment processes

Figure 5: Specialised reverse osmosis desalination plant

What are the important considerations in the operation of treatment processes?

Water treatment processes make use of chemical and physical processes to treat water to the desired quality. The processes have to be operated and controlled according to design specifications by appropriately trained operators and supervisors.

Water treatment processes are similar in many respects to processes in the chemical industry. These processes therefore require the same level of supervision and control as those in the chemical industry by suitably trained operators and supervisors. Different treatment processes require different levels of operational supervision and control.

- Some processes are relatively simple to operate and not very sensitive to variations in operating conditions for example slow sand filtration.
- Certain other processes however, require very close supervision and control. Disinfection, for example is a critical process that requires close control to ensure that the water is adequately disinfected before distribution to consumers.
- All the processes where chemicals have to be added to the water require close control since the quality of the raw water may change with time and this requires that the dosages of chemicals have to be adjusted accordingly.

What simple treatment methods can be used to treat water for domestic use?

A variety of simple treatment methods can be used to treat water for domestic use. These methods include:

- boiling of water to destroy micro-organisms that may cause diseases
- adding of bleach to destroy micro-organisms
- using a chlorine pill contactor to disinfect water
- using traditional coagulants to clarify water
- exposing water to sunlight to destroy micro-organisms.

The use of simple treatment methods on small scale appears to be an attractive way of making purified water available for domestic use. Simple treatment methods also have a very important role to play during emergency situations such as during natural disasters when the normal water supply is contaminated or not functioning. These methods are discussed in more detail in Part 3.

It must be kept in mind that even simple treatment methods make use of physical or chemical processes and that there must be a certain minimum level of supervision and control to ensure that the water produced is fit for domestic use.

For example, where chemicals are added such as bleach for disinfection, the amount added must be controlled and it must be ensured that the bleach has not lost most of its disinfecting power. If this is not done people consuming the water may be under a false impression that the water is safe, while it may not be the case, or the water may be over-dosed causing it to be harmful.

PART 2A

Conventional water treatment processes

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Section 2A: Overview of conventional water treatment processes

What is conventional water treatment?

The term conventional water treatment refers to the treatment of water from a surface water source by a series of processes aimed at removing suspended and colloidal material from the water, disinfecting the water, and stabilising the water chemically.

What does conventional water treatment involve?

Conventional treatment of water for domestic use involves a number of treatment steps aimed at achieving the following objectives:

- ***removal of suspended and colloidal matter** to an acceptable level by means of coagulation-flocculation, sedimentation and sand filtration (see Assessment Guide, for acceptable levels of turbidity);*
- ***disinfection** to produce water that is safe to drink ;*
- ***chemical stabilisation** of the water to prevent corrosion of pipelines or the formation of chemical scale in distribution systems and fixtures.*

The processes employed for the **removal of suspended and colloidal matter** include the following:

- a process to change the nature of the colloidal material in the water to facilitate its removal (coagulation);
- a process to form larger groups of particles or flocs (flocculation);
- a process to remove the flocs from the water (sedimentation or alternatively flotation); and
- a process for final clean-up of the water (sand filtration).

Disinfection involves the addition of disinfection chemicals to the water. On large-scale plants chlorine gas is normally used (but ozone or chlorine dioxide can also be used), while on small plants chlorine granules, $Ca(OCl)_2$ (commercially known as HTH) are often used for disinfection.

Chemical stabilisation is achieved by addition of different chemicals such as lime and/or carbon dioxide to the water.

Each of these processes is discussed in more detail below.

Why is it important to remove suspended and colloidal material from water?

Suspended material in water causes it to look dirty and therefore not acceptable to drink. Furthermore, suspended material may 'shield' micro-organisms against the action of disinfectants such as chlorine. A third factor is that suspended material may settle in reservoirs and distribution systems, thereby creating conditions in which micro-organisms may grow and re-contaminate the water.

What types of suspended and colloidal material can be present in water?

A variety of different types of suspended and colloidal material can be present in water. This includes:

- *inorganic silt and clay particles that occur mainly in surface water sources;*
- *algae that grow in surface waters enriched with plant nutrients;*
- *bacteria and other micro-organisms that are present in water as a result of pollution;*
- *decaying plant material as well as a variety of other types of particles.*

The most common type of colloidal particles in surface water is minute **clay or silt** particles that are washed into surface waters by runoff after rainstorms. Erosion is a major factor that contributes to the amount of silt that is washed into streams and end up in most surface waters in South Africa. The amount of silt that has to be removed adds substantially to the cost and complexity of treatment of surface water. A further negative factor is that large silt loads settle in storage dams, thereby reducing the storage capacity of such dams.

Algae are another general type of colloidal particle that occur in many surface waters. There are many different types of algae, but the most important algae type that causes problems in water treatment are very small single-cell algae which float freely in the water. Because algae are so small, they are not effectively removed by sand filtration unless they are killed by pre-chlorination and/or coagulated. Other algae types include filamentous algae and different types that are attached to surfaces. Even seaweed is a salt-water algae species. Algae grow in water that is enriched with plant nutrients, mainly nitrogen and phosphorous.

Other types of suspended material include micro-organisms, decaying organic material which can also cause colour in the water (brown coastal water), as well as a variety of industrial pollutants.

What are the main characteristics of suspended and colloidal material in water?

The nature and characteristics of suspended and colloidal material in water are important in determining the type of treatment process required for removal. The suspended material can be inorganic in nature, e.g. sand or clay particles or organic in nature such as algae or humic material from decaying plant material. The size of the particles is another very important characteristic because size determines to a large extent the type of treatment process that can be used to treat the water.

The nature of suspended material in water can vary from relatively coarse particles that can be removed simply by allowing the particles to settle and decanting the clear water. At the other end of the spectrum are very fine particles, called colloidal particles which do not settle at all even if left for a long period of time and which have to be treated chemically to remove them from the water.

Colloidal particles are very small (smaller than 0,1 micron, see Note Box 2), and since they are electrically charged they have very specific characteristics. The most important characteristic is that they form a stable colloidal suspension that do not settle readily, but remain in suspension (even for periods of days or weeks). In order for such particles to settle, they must be chemically destabilised or coagulated to neutralise the charge on them and to form larger flocs that can settle, thereby facilitating their removal from water.

Note Box 2 gives an illustration of the size of different types of particles and species that can be present in water and the types of processes that can be used for their removal.

Note Box 2: The size of particles in water

The standard (SI) unit for size or length is the metre (m). However, the particles that occur in water are extremely small and their dimensions are normally given in micro-metre (µm) or nano-metre (nm).

1 m = 1 000 mm (millimetre)

1 mm = 1 000 µm (micrometre)

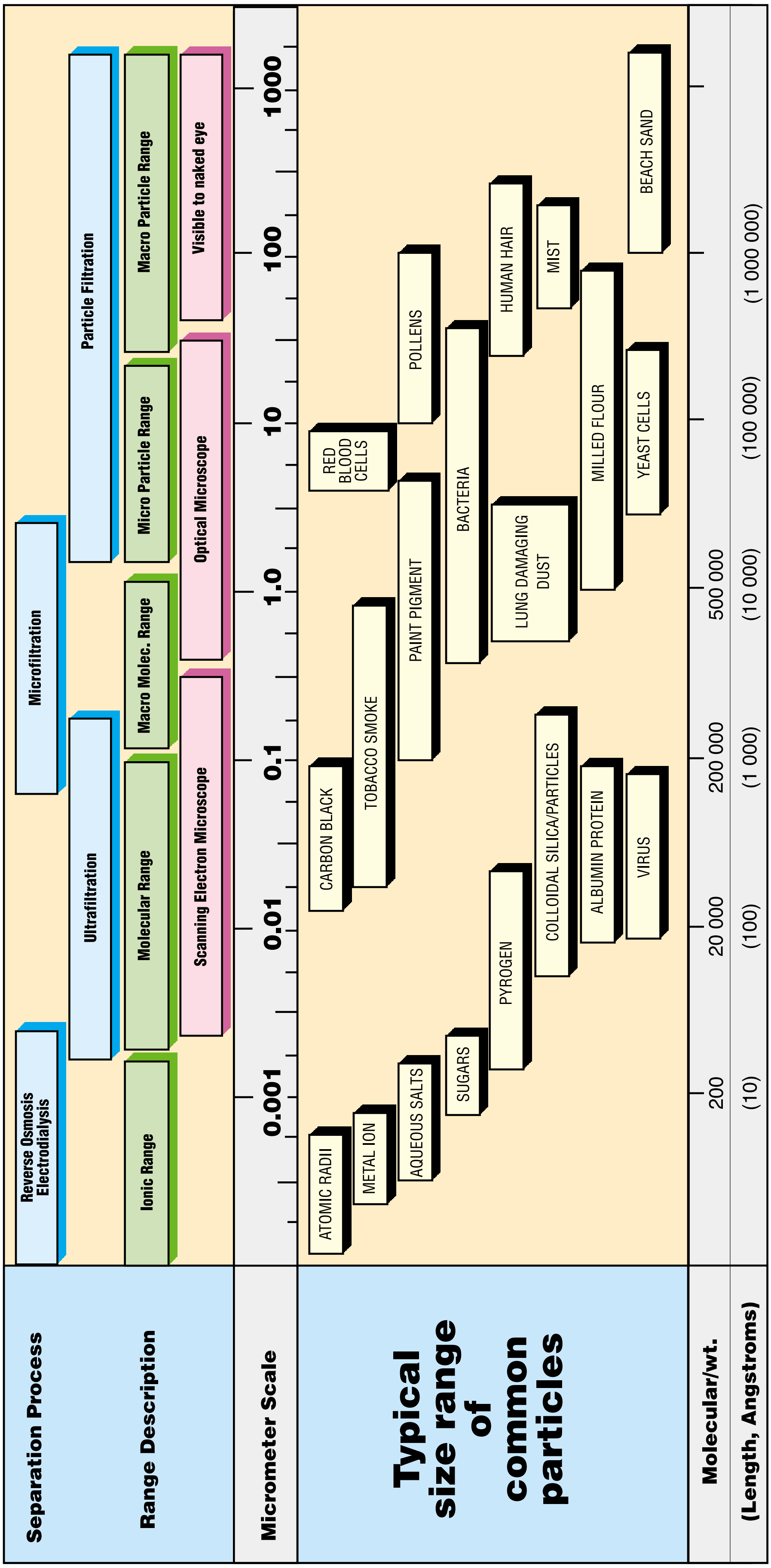
1 µm = 1 000 nm (nanometre)

This means that 1 m = 1 000 000 µm = 1 000 000 000 nm.

Figure 6 gives an illustration of the relative size of different particles and of processes that can be used for the removal of different size ranges of particles.

An important characteristic that determines the behaviour of algae in water is the fact that since algae are plants, they produce oxygen and the small gas bubbles cause the algae to float and therefore to remain in suspension. Settling of algae is therefore difficult and an alternative process, i.e. flotation is often used for their removal.

Figure 6: Size range of particles



Section 2B: Processes used in conventional water treatment for removal of suspended and colloidal matter

What methods can be used to remove suspended and colloidal material from water?

The conventional treatment methods for removal of suspended and colloidal material from water include chemical ***coagulation*** *of small colloidal particles,* ***flocculation*** *of the small particles to form larger flocs, followed by* ***sedimentation*** *and* ***sand filtration****. When the water contains a large amount of suspended material, larger suspended particles such as sand particles can be removed by means of* ***settling*** *without coagulation and flocculation.*

Other methods that can be used include slow sand filtration, flotation, micro-filtration and ultra-filtration.

The selection of the best combination of processes to treat a particular water depends on a number of factors. These factors include:

- the amount of suspended solids;
- the turbidity of the water;
- the nature of the suspended material;
- the chemical properties of the water (alkalinity and pH);
- the volume of water to be treated, and the availability of facilities, trained operators and supervisors. For example, if coagulation-flocculation is to be used, certain laboratory facilities must be available to monitor pH and alkalinity on a regular basis and to perform beaker tests to determine the optimum coagulant dosage.

> **NOTE:** Water quality characteristics, including turbidity, pH, alkalinity are discussed in detail in the *Analysis Guide*.

What does settling of water involve?

Simple settling is often used as a pre-treatment step to remove larger suspended particles from water without coagulation-flocculation. Settling requires that the water remains stagnant for a period of time to allow the larger particles to settle to the bottom of a tank or holding reservoir. After settling of the particles clear water can be decanted from the container. Settling can be performed as a batch process (filling a tank with the water, allowing sufficient time for settling, and decanting of the clear water) or as a continuous process. In a continuous process the water flows through the reservoir at a slow rate that allows time for settling while clarified water is withdrawn continuously.

Simple settling is mostly used as a pre-treatment step at a water treatment works when the raw water contains relatively course suspended material. The suspended material is removed in a large holding dam through which the water flows at a slow rate to allow sufficient time for the particles to settle. The clear water then flows to the coagulation section if further clarification is required. The sediment must be removed from the dam at regular intervals to prevent the dam from silting up.

What does coagulation-flocculation involve?

Coagulation is the process by means of which the colloidal particles in water are destabilised (i.e. the nature of the colloidal particles is changed) so that they form flocs through the process of flocculation that can be readily separated from the water. Destabilisation is achieved through the addition of chemicals (called coagulants) to the water.

Different chemicals can be used as coagulants. The most common coagulants are aluminium sulphate, ferric chloride, lime, and polyelectrolytes. Coagulant-aids are also sometimes used. These are substances added in very small quantities to improve the action of the primary coagulant. The characteristics of the different coagulants and the way in which they function are given in **Note Box 3.**

Note Box 3 : Coagulants used in water treatment

Aluminium sulphate, also known as alum $Al_2(SO_4)_3.16\ H_2O$ is commonly used as coagulant. The alum is dissolved in water and the aluminium ions, Al^{3+} that form, have a high capacity to neutralise the negative charges which are carried by the colloidal particles and which contribute to their stability. The aluminium ions hydrolyse and in the process form aluminium hydroxide, $Al(OH)_3$ which precipitates as a solid. During flocculation when the water is slowly stirred the aluminium hydroxide flocs "catch" or enmesh the small colloidal particles. The flocs settle readily and most of them can be removed in a sedimentation tank.

NOTE: Since aluminium may be harmful at high concentrations it must be allowed to precipitate completely as the hydroxide. Complete precipitation is a function of the pH of the water (see *Analysis Guide* for a detailed discussion of pH) and the pH must therefore be closely controlled between 6,0 and 7,4.

Ferric chloride, $FeCl_3$ is also commonly used as coagulant. When added to water, the iron precipitates as ferric hydroxide, $Fe(OH)_3$ and the hydroxide flocs enmesh the colloidal particles in the same way as the aluminium hydroxide flocs do. The optimum pH for precipitation of iron is not as critical as with aluminium and pH values of between 5 and 8 give good precipitation.

The reaction can be presented in a similar way as for aluminium sulphate.

Lime is also used as coagulant, but its action is different to that of alum and ferric chloride. When lime is added to water the pH increases. This results in the formation of carbonate ions from the natural alkalinity in the water. The increase in carbonate concentration together with calcium added in the lime results in the precipitation of calcium carbonate, $CaCO_3$. The calcium carbonate crystals enmesh colloidal particles in the same way as alum or ferric flocs.

When lime is used as coagulant the pH has to be lowered in order to stabilise the water chemically. Carbon dioxide is normally used for this purpose.

Polyelectrolytes are mostly used to assist in the flocculation process and are often called flocculation aids. They are polymeric organic compounds consisting of long polymer chains that act to enmesh particles in the water. The polyelectrolytes can be:

Cationic, i.e. carry a positive charge,

Anionic, i.e. carry a negative charge,

Non-ionic, i.e. have no net charge.

Other coagulants are also sometimes used in water treatment. These include:

Aluminium polymers such as poly-aluminium chloride that give rapid flocculation, efficient removal of organics, and less sludge than alum under certain conditions, but at a higher cost.

Activated silica is sometimes used as a flocculant together with alum as coagulant.

Bentonite and/or kaolin are sometimes added to water when the water to be flocculated contains too few particles for effective flocculation.

What are the most important factors to be taken into account in coagulation?

There are a number of very important aspects that must be taken into account to ensure successful coagulation:

- *The best coagulant (and coagulant-aid if required) must be identified for the specific raw water, the optimum dosage must be determined for the range of turbidities normally encountered in the plant and optimum conditions of pH and alkalinity must be determined for the different chemicals and dosages. This is normally done by means of beaker tests (see Note Box 3).*
- *The coagulant (and coagulant-aid) must be added to the water at a point and under conditions that will ensure rapid dispersion and complete mixing of the small volume of coagulant with the large body of flowing water.*
- *The pH and alkalinity of the raw water must be adjusted according to the levels identified in the beaker tests.*
- *Coagulant storage and preparation of the solution (especially for polyelectrolytes) must be done strictly according to the directions of the supplier.*
- *If there are algae present in the raw water it may be necessary to add a small amount of chlorine to the raw water (pre-chlorinate) to kill the algae before coagulation.*

What is the best way of determining the optimum coagulant type, dosage and process conditions for the clarification of water?

An indication can be obtained of chemicals, dosage and conditions from an evaluation of the water quality, i.e. the amount of suspended solids and the turbidity of the water. However, the best way of determining which chemical to use for coagulation and at what dosage (optimum amount to be used) and the optimum chemical conditions, e.g. pH is by performing so-called jar or beaker tests.

A jar test is a standardised way of determining the optimum conditions for clarification of water. It is performed on a beaker test unit. There is a variety of such test units available, but they all consist essentially of a variable drive with normally six stirrers which can be used to stir the contents of a set of beakers to which different coagulants and dosages are added, mixed and allowed to settle. Jar tests are described in Note Box 4.

Note Box 4: Jar tests

A typical jar or beaker test set is shown in **Figure 7**. A specified volume (normally 750 mℓ or 1 ℓ) of the water to be treated is measured into each beaker and pre-determined quantities, say 5, 10, 15, 20, 30, 40 mg/ℓ (depending on raw water turbidity) of a selected coagulant are added to the 6 beakers. The contents are stirred rapidly for 1 minute and then at a slow rate for about 20 minutes. The stirrer is then switched off and the formation and settling of flocs is observed. After a period of time, say 30 minutes the turbidity of the clear water (supernatant) is determined and from the visual observation and turbidity values the best dosage can be determined.

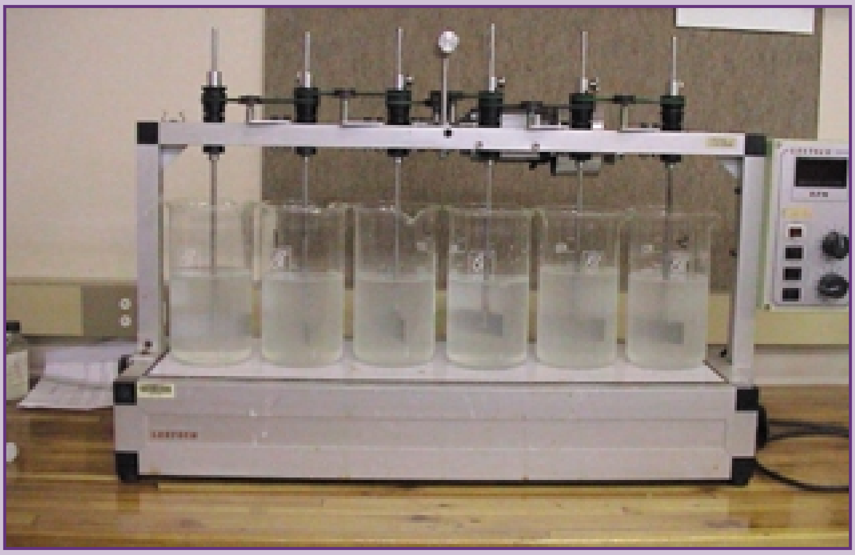


Figure 7: Jar test apparatus

This type of test has to be repeated a number of times to determine optimum dosages and conditions. The first test will give an indication of the approximate optimum dosage for the particular coagulant. If the best result is obtained by a dosage of, say 20 mg/ℓ, a second test must be performed in which the dosage is varied with smaller increments of, say 15, 17, 19, 21, 23, 25 mg/ℓ for a more precise determination of the dosage.

In addition to dosage, the optimum pH for coagulation by the particular coagulant also has to be determined. This is done by controlling the pH level at the optimum theoretical level for the first series of tests until the optimum dosage has been determined and then varying the pH by 0,5 units for the particular dosage to determine the optimum pH for the dosage.

After the optimum dosage and conditions have been determined for one coagulant the process must be repeated for other available coagulants to find the coagulant that gives the best results (turbidity and nature of floc) at the lowest cost.

What does flocculation of water involve?

The objective of the flocculation step is to cause the individual destabilised colloidal particles to collide with one another and with the precipitate formed by the coagulant in order to form larger floc particles. Flocculation involves the stirring of water to which a coagulant has been added at a slow rate, causing the individual particles to "collide" with each other and with the flocs formed by the coagulant. In this way the destabilised individual colloidal particles are agglomerated and incorporated into the larger floc particles.

Flocculation is considered to be part of coagulation, although some handbooks treat it as a separate process. Flocculation can take place in different types of equipment. A simple mechanical stirrer can be used for flocculation or a specially designed channel with baffles to create the desired flow conditions can also be used to flocculate the particles in water. The basis of the design of a flocculation channel is that the flow velocity of the water has to be reduced from a high initial value to a much lower value to enable large, strong flocs to grow. If the flow velocity is too high the flocs may break up again, causing settling of the broken flocs to be incomplete.

Flocculation is controlled through the introduction of energy into the water (through paddles or by means of baffles in the flocculation channel) to produce the right conditions (required velocity gradient) for flocs to grow to the optimum size and strength. The velocity gradient (or G-value) is an extremely important factor that determines the probability of particles to collide and form flocs. If G values are too low, the probability of collisions is low and poor floc formation results. If it is too high, shear forces become large and this may result in floc break-up.

Acceptable G-values are:

- Coagulation: 400 – 1 000 s^{-1}
- Flocculation: in the order of 100 s^{-1}

How are the flocs removed from water?

Flocs are removed from water by means of separation processes, i.e. sedimentation and sand filtration; or flotation and sand filtration.

What does sedimentation involve?

Sedimentation is the process in which the flocs that have been formed during coagulation and flocculation are allowed to settle from the water.

The flocs collect as sludge at the bottom of the sedimentation tank from where it must be removed on a regular basis. The clean water leaves the sedimentation tank through collection troughs located at the top of the tank.

There are a variety of designs for sedimentation tanks available. These include large rectangular tanks in which the water enters one side and leaves at the other end. This type is normally used at large conventional treatment works. Circular tanks with flat or cone shaped bottoms are also used, especially at smaller works. Flocculated water enters the tank at a central distribution section and clarified water leaves the tank at collection troughs at the circumference of the tank. The design and flow conditions in a sedimentation tank must be such that the minimum amount of flocs leaves with the clarified water.

NOTE: Sedimentation is a suitable process for removal of flocs formed from silt and clay particles that are relatively heavy and settle readily. However, certain flocs are relatively light and do not settle readily and a process such as flotation must be used for their removal. Light flocs are formed when algae or organic matter is flocculated.

The flocs that settle in the sedimentation tank collect at the bottom of the tank as sludge from where it must be removed on a regular basis to prevent accumulation in the tank. If sludge is not withdrawn regularly according to operating schedules, the quality of the clarified water may deteriorate due to re-entrainment of sludge.

Figure 8 shows the layout of a circular sedimentation unit and **Figure 9** shows a photograph of such a unit.

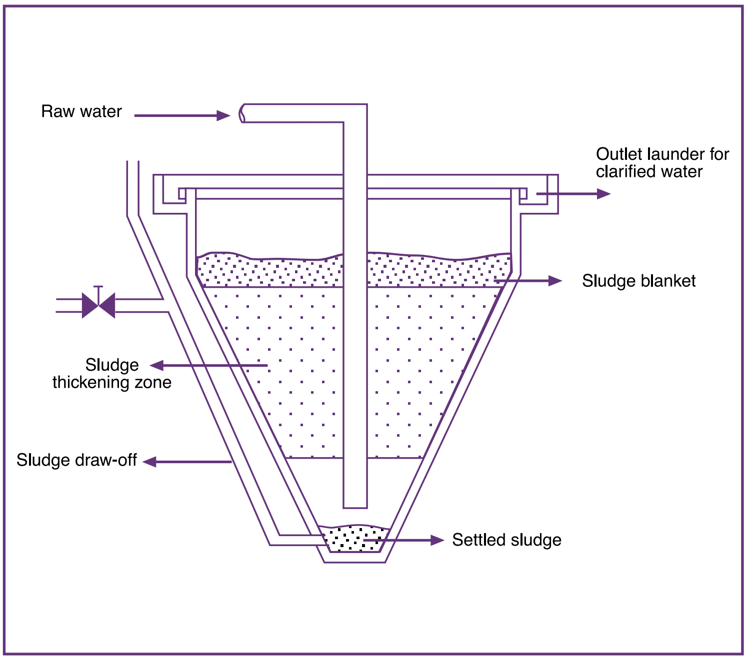


Figure 8: Layout of a sedimentation unit

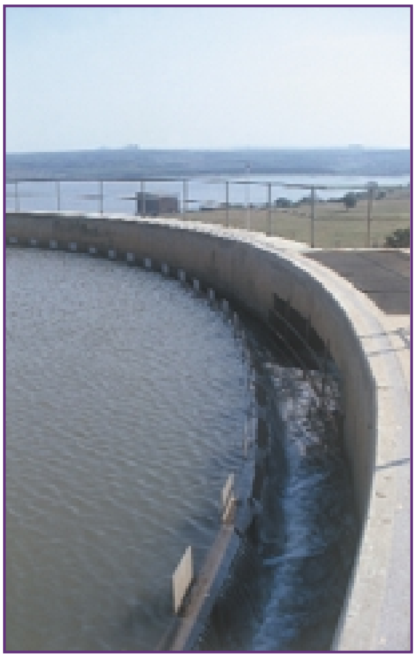


Figure 9: Photograph of sedimentation unit

How is the sludge from a water treatment plant disposed of?

Sludge from a sedimentation tank has a large pollution potential because it contains all the suspended material removed from the water together with the chemicals used for coagulation. It must therefore be disposed of in a proper manner to prevent contamination of water sources.

The sludge is withdrawn from the sedimentation tank in a diluted form (2-5% solids) and is sometimes thickened (excess water removed) before disposal. At smaller treatment works sludge is disposed of in sludge lagoons. The lagoons are large holding dams in which the sludge compacts and clear water accumulates on top of the sludge. The clear water may be recycled to the inlet of the plant. (See Section 6E Handling and disposal of wastes for more detail).

What does flotation involve?

Flotation is an effective process for removal of relatively light types of flocs. Flotation involves the formation of small air bubbles in water that has to be flocculated. The bubbles attach to the flocs causing them to rise to the surface where they are collected as a froth that is removed from the top of the flotation unit.

Air is dissolved under pressure in a small amount of water in a device called a saturator. This water that is saturated with dissolved air is added to the main stream of water that is to be treated. When the pressure is released after the saturated water is mixed with the water to be treated, the dissolved air comes out of solution in the form of very fine bubbles.

Both sedimentation and flotation remove the bulk of the flocs from the water. However, most of the time a small amount of (broken) flocs or non-flocculated colloidal material remains in the water. This material has to be removed to ensure a low enough turbidity in the water. A sufficiently low turbidity level (see *Assessment Guide*) is required for effective disinfection of the water and to remove all traces of murkiness from the water. Removal of turbidity to low levels is achieved by means of sand filtration.

Sedimentation and flotation are two processes that perform the same function. Sedimentation is normally used when the raw water contains mainly silt or clay particles, while flotation is normally used when the raw water contains algae or other types of organic material.

Figure 10 shows a photograph of the top of a flotation unit.

Figure 10: Flotation unit

What does sand filtration involve?

Sand filtration is a simple process in which the water is allowed to filter through a layer of sand in a specially constructed container. In the filtration process the small remaining floc particles are removed by the sand grains and are retained in the bed of sand, while clean water flows out from the bottom of the sand bed.

There are two types of sand filtration processes:

- rapid gravity sand filtration, and
- slow sand filtration.

What are the differences between rapid gravity sand filtration and slow sand filtration?

Rapid gravity sand filtration (or simply rapid filtration RF) *normally follows flotation or sedimentation as the final 'polishing' step in conventional water treatment. Filtration takes place at a relatively high rate, and the filter has to be back-washed at intervals of a few hours.*

Slow sand filtration (SSF) *on the other hand, has a very slow rate of filtration (compared to RF) and is a process that can be employed as stand-alone treatment process. The filter media in SSF is not back-washed at all, but the filter is cleaned by removal of the top layer of sand at long intervals (e.g. weeks).*

Rapid filtration is used in conventional water treatment following sedimentation. The filters are open to the atmosphere and flow through the filter is achieved by gravity. Flow is normally downward at rates of about 5 m/h. Some RF sand filters are not open to the atmosphere, but operate under pressure. These types of filters are often used in package treatment plants and are discussed in more detail in Part 3.

During RF operation, solids are removed from the water and accumulate within the voids and on the top surface of the filter medium. The filter medium normally consists of a layer of graded sand with a size of about 0,5 mm and a depth of about 0,6 m. Dual media filters are a variation of single-layer sand filters. In these filters a layer of anthracite is placed on top of the layer of sand. This has the advantage of longer filter runs.

The fact that flocs are retained in the RF sand bed means that the filter will become saturated or clogged with the retained flocs at some stage. The sand has then to be cleaned by means of back washing to remove the accumulated flocs in order to restore the filtering capacity of the sand. The frequency of back washing is determined by the amount of flocs that has to be removed. Backwashing can be controlled on a time basis or on the basis of the pressure drop across the filter.

The size of the RF sand grains and construction of the filter are very important to ensure effective filtration. Equally important is correct operation of the sand filter. This means the quality of the water leaving the filter as well as the increase in the operating pressure of the filter must be monitored to determine when back-washing is required. If back washing is left for too long, breakthrough will occur and the turbidity of the product water will increase and this may compromise effective disinfection.

Figure 11 shows the layout of a rapid gravity sand filter, and **Figure 12** shows a photograph of such a unit. **Figure 13** shows a small-scale pressure sand filter.

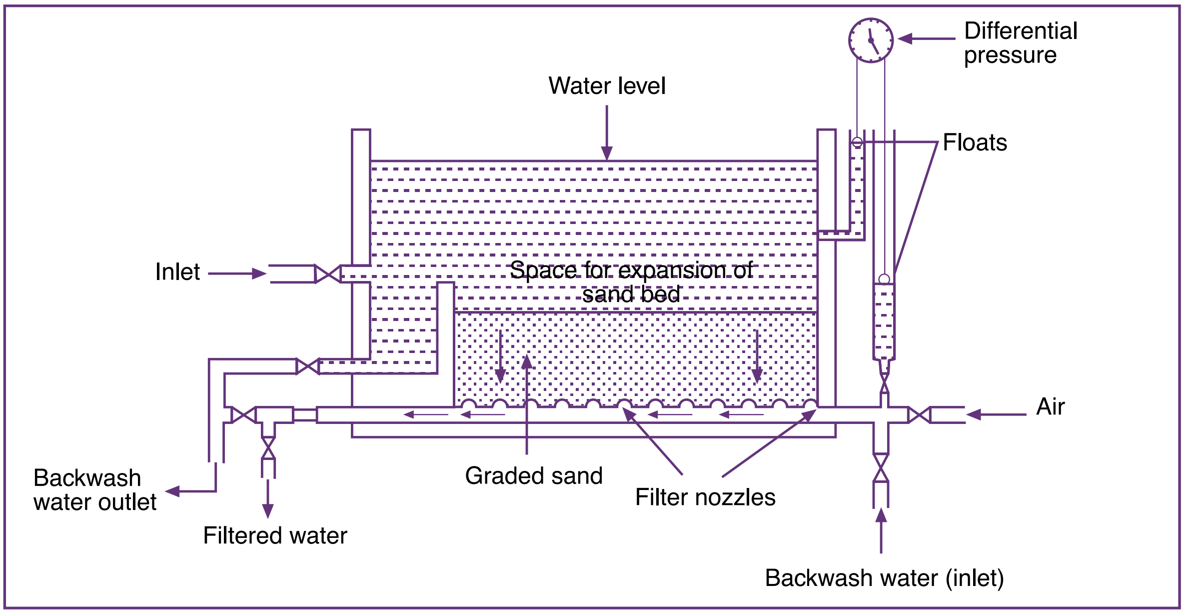


Figure 11: Layout of rapid gravity sand filter

Figure 12: Photograph of rapid gravity sand filter

Slow sand filtration also involves the filtration of water through a bed of sand. However, the operating principles of SSF are different from those of RF.

A slow sand filter (SSF) uses finer sand than a rapid sand filter, typically 0,3 mm diameter in a sand bed which is typically about 1m deep. During operation the material that is removed collects in the top layer of sand and as filtration progresses, micro-organisms and larger organisms establish in the top layer and this layer performs the actual filtration function.

During the use of a SSF the top layer becomes biologically active with different micro-organisms and larger organisms establishing in the top and lower layers of the bed. The removal of suspended and colloidal particles in a SSF is therefore a combination of physical straining and filtration as well as biological degradation processes.

Figure 13: Small-scale pressure sand filter

The rate of filtration in a SSF is much slower (about 0,1 m/h) than in a rapid sand filter and the SSF is not backwashed at all as is done to clean rapid sand filters. The SSF is operated for extended periods before cleaning, typically 1 month or up to 6 months depending on the raw water quality.

Shortly after the start of filtering, a thin layer of slime forms on the surface of the sand. This layer is known as the filter skin or Schmutzdecke (German for dirt layer) and is the most important element of the filter. It consists of a variety of micro-organisms that feed on organic matter and bacteria, and in this way functioning as a comprehensive treatment process and not only as a simple filtration process.

After several weeks of operation, the resistance of the filter skin will normally increase to such an extent that the filtration rate reduces to very low levels. At that point the filter has to be regenerated. This can be achieved by scraping off the top layer of sand including the filter skin. This will then expose clean sand on which a new filter skin will develop when water is applied to the filter. The water quality will not be acceptable until the filter skin has developed, which may take a few days.

What are the advantages of slow sand filtration?

The main advantage of SSF is that it is a relatively simple process that does not require high levels of skills and operational control to produce water for domestic use. Under many circumstances chemicals are also not required for treatment. However, it is important to note that final disinfection is required to produce microbiologically safe water.

Figure 14 shows the layout of a slow sand filter.

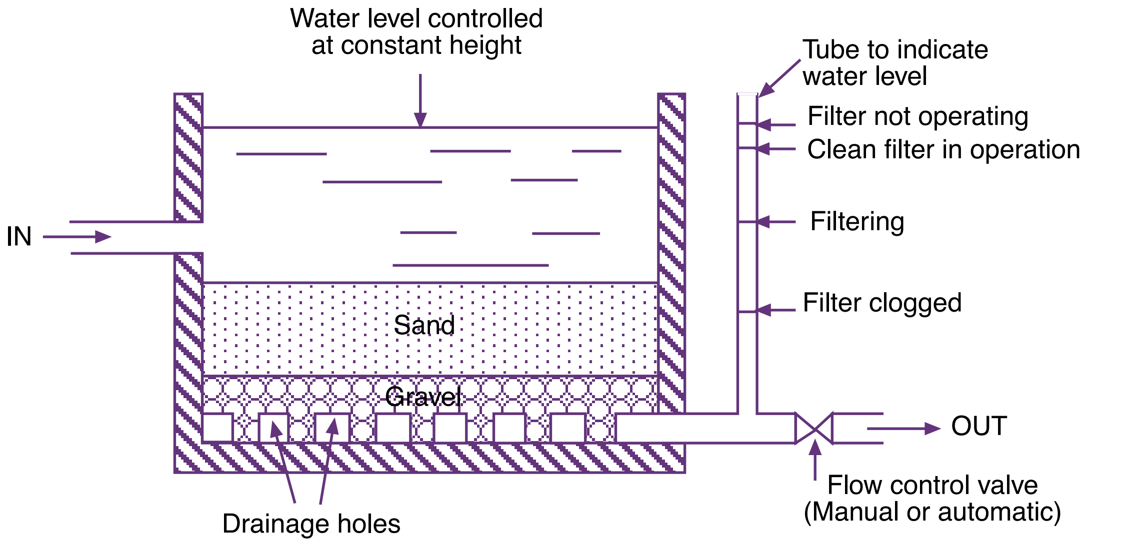


Figure 14: Layout of slow sand filter

Under which circumstances does slow sand filtration have advantages over conventional treatment processes?

SSF is normally used for relatively small-scale applications in areas where the possibility to operate a conventional treatment plant successfully, is limited. SSF normally functions well when the feed water has a low turbidity and there is not too much variability in feed water quality.

SSF cannot produce water of the same quality as that produced by conventional treatment processes. The advantages of SFF can therefore normally be realised in areas where it is difficult to use conventional treatment processes.

Furthermore, when the raw water contains high levels of turbidity, the resistance to flow of the slow sand filter increases rapidly and it has to be cleaned at frequent intervals. This means that some form of pre-treatment is required to remove the bulk of the suspended substances before SSF can be used for such water. This means that chemicals have to be used which increases level of complexity of the process, which detracts from the advantages of simplicity and no chemical use in the process.

Can these conventional processes for removal of suspended and colloidal particles also be applied on small scale?

These processes can be applied on both large and small scale. It must however, be kept in mind that the same operational control measures that are applied on large scale are also necessary on small scale. The correct dosing of coagulant, control of pH, correct flocculation conditions and control of sedimentation and sand filtration are necessary irrespective of the scale of the operation.

In large-scale plants the individual processes are normally designed as alone-standing units with levels and flow of water in such a manner as to minimise the energy requirements for pumping. Small-scale units are often designed as so-called package plants where all the units are mounted on a common base and housed in a container or small room (package plants are discussed in detail in Part 4).

NOTE: It is rather difficult to apply conventional clarification process on home-treatment scale. In some areas traditional coagulants (e.g. crushed seeds of trees, or ash) are used to achieve coagulation. (See Part 3 for a discussion on home treatment methods).

Section 2C: Conventional water disinfection processes

Why is it necessary to disinfect water when suspended and colloidal matter has already been removed?

A large fraction of bacteria and larger micro-organisms are removed during clarification processes, especially by sand filtration. However, many bacteria and viruses still remain in clarified water even at low turbidity levels. It is therefore, essential to disinfect water to prevent the possibility that water-borne diseases are spread by pathogens (disease-causing micro-organisms) in water.

Waterborne diseases are caused by pathogenic micro-organisms which enter water supplies as a result of pollution by human and animal wastes. A large variety of diseases are transmitted by pathogens in water as is discussed in Part 1.

The provision of microbiologically safe drinking water must include a **series of barriers** aimed at preventing pathogens from infecting the consumer.

The **first barrier** is aimed at preventing pathogens from entering water sources. This is achieved by protection of the water source from pollution by human or animal wastes or other wastes that may be carriers of pathogens.

The **second barrier** comprises clarification processes to remove the maximum number of micro-organisms from the water. Only the final step in this multi-barrier approach is disinfection of the water.

Since it is not possible to determine the presence or absence of all the possible pathogens that may be present in water, certain indicator organisms are used to give an indication of whether disinfection was effective or not - see *Analysis Guide* for a detailed discussion of indicator organisms.

> **Note:** Emergency and home treatment disinfection methods are discussed in Part 3.

What does disinfection of water entail?

Disinfection of water entails the addition of the required amount of a chemical agent (disinfectant) to the water and allowing contact between the water and disinfectant for a pre-determined period of time (under specified conditions of pH and temperature). Other methods of disinfection of water include boiling of the water or irradiation with ultra-violet light.

The term **disinfection** of water refers to the destruction of harmful micro-organisms in water to make it fit for domestic use. Sterilisation on the other hand refers to the destruction of all organisms and applies only to specific applications such as the production of water for sterile intravenous drips, etc. Water that is disinfected is safe to drink but it may still contain harmless micro-organisms.

The most commonly used disinfectant is chlorine gas, Cl_2 that is dissolved in the water at a certain concentration for a certain minimum contact time. Other disinfectants include ozone, chlorine dioxide and other chlorine compounds such as calcium hypochlorite (HTH), sodium hypochlorite (bleach) and monochloramine.

Chlorine gas is the most commonly used disinfectant on large scale as it is a very effective disinfecting agent, it is more cost effective than other disinfectants and its application can be accurately controlled.

How can one tell if water is properly disinfected and safe to drink?

It is not possible to tell if water is microbiologically safe to drink by visual inspection. There are basically two ways in which the safety of water can be determined:

- The first method is to do a microbiological assessment of the water by determining the presence or absence of certain organisms in the particular water.
- The second method is to determine the amount of residual chlorine in the water. If there is residual chlorine present in water with a low turbidity, it can normally be accepted that the water is safe to drink.

Microbiological assessment of water is done by means of determining the presence or absence of certain indicator organisms. If these indicator organisms are absent in a water sample, it is assumed that the water is properly disinfected. A detailed discussion of the use of indicator organisms and the actual methods are described in the *Analysis Guide*. The conventional methods normally take about two days to produce an answer, while some of the new rapid methods can give an answer in a much shorter time.

Another method of assessing the microbiological quality of water is to determine the amount of **residual chlorine** in the treated water. This method normally gives an answer within minutes. The chlorine residual method is normally applied at a water treatment plant to determine if the disinfection process is functioning properly. It is also used to determine residual chlorine concentrations in distribution systems.

NOTE: Tests to determine the presence of indicator organisms are normally not part of the monitoring of the treatment process but rather as part of a surveillance program to assess the microbiological safety of water at the point of use.

How does disinfection by means of chlorine take place?

Chlorine is a strong oxidising agent and it reacts and oxidises some of the essential systems of micro-organisms thereby inactivating or destroying them. The different forms in which chlorine is used for disinfection, have different oxidising powers and this must be taken into account to ensure effective disinfection.

Chlorine can be added to water in different forms. On large-scale plants the most common form in which chlorine is used, is chlorine gas. Calcium hypochlorite and sodium hypochlorite are two other chlorine compounds that can be used for disinfection of water.

Chlorine gas, Cl_2 is delivered to the plant in gas cylinders and the chlorine is introduced into the water by means of special dosing devices (chlorinators).

Calcium hypochlorite, $Ca(OCl)_2$ (commonly known as HTH), is available in granular or solid (tablet) form and is therefore a very convenient form in which to apply chlorine, especially for smaller or rural plants. It contains between 65 and 70% of available chlorine, it is relatively stable and can be stored for long periods (months) in a cool dry environment.

Sodium hypochlorite, NaOCl (commonly known as household bleach under different brand names) is available as a solution. Water treatment sodium hypochlorite contains 12 to 13% of hypochlorite, which is equivalent to 10 to 12% available chlorine. Bleach contains about 6 to 8% available chlorine. Sodium hypochlorite is relatively unstable and deteriorates fairly rapidly, especially when exposed to sunlight. It also forms HOCl and OCl^- upon dissociation.

Monochloramine (so-called combined available chlorine) is also used for water disinfection. It is formed when HOCl is added to water that contains a small amount of ammonia. The ammonia reacts with HOCl to form monochloramine, NH_2Cl. It is much less effective as a disinfectant than HOCl (the same order of effectiveness as chlorite ion). However, it has the advantage of being much more stable in water than free available chlorine. For this reason it is often used to provide residual protection in larger distribution systems.

The actual reactions of the different chlorine compounds are discussed in Note Box 5.

Figure 15 shows large chlorine cylinders that are used to supply chlorine gas for disinfection of water.

Figure 15: Chlorine cylinders providing chlorine gas for disinfection of water

Note Box 5: Chlorine reactions

Chlorine gas, Cl_2 dissolves in water to form hypochlorous and hydrochloric acid.

$Cl_2 + H_2O = HOCl + HCl$

The actual disinfecting agent is hypochlorous acid which dissociates as follows:

$HOCl$ t $H^+ + OCl^-$

The chlorine species in the form of hypochlorous acid, HOCl plus the hypochlorite ion, OCl^- are termed **free available chlorine**. Chlorine in the form of monochloramine (together with other chloramine species) is termed **combined available chlorine**.

NOTE: *See Volume 3: Analysis Guide* for a detailed discussion about the different forms in which chlorine can be present in water.

HOCl is much more effective for disinfection than the hypochlorite ion - about 60 to 200 times more effective. The relative quantities of these two species are determined by the pH of the water. At pH below 7 HOCl is the predominant species while at pH above about 7,5 hypochlorite ion predominates. It is therefore important that the pH of the water be taken into account when determining the required chlorine dosage for disinfection.

Calcium hypochlorite (HTH) dissolves in water as follows:

$Ca(OCl)_2 = Ca^{2+} + 2\ OCl^-$

The hypochlorite ion hydrolyses to form HOCl:

$OCl^- + H_2O = HOCl + OH^-$

A similar reaction takes place when sodium hypochlorite is added to water.

How is disinfection by means of chlorine controlled?

The two most important factors that determine the effectiveness of disinfection by means of chlorine are the chlorine concentration and the chlorine contact time. The pH of the water also plays an important role as well as the turbidity of the water, exposure to sunlight and the water temperature.

Concentration. The chlorine concentration is the most important control factor to ensure effective disinfection. However, since chlorine can exist in different forms in water with different degrees of effectiveness as is described above, the concentration of the actual chlorine species used for disinfection must be taken into account. It is normally accepted that sufficient chlorine must be added to water to give a **free chlorine residual** of not less than 0,2 mg/ℓ after 20 minutes contact time. Tables are available (see below) that give combinations of dosage and contact time at different pH values.

It is important to note that free available chlorine species are formed only after the breakpoint in the chlorination process. This means that sufficient chlorine must be added to react with any ammonia that may be present in the water and to oxidise the chloramines that are formed. The breakpoint chlorination process is discussed in detail in the *Analysis Guide*.

Contact time. The second important control factor for disinfection is the contact time. This refers to the time of contact between the dissolved chlorine and each unit or "pocket" of water. To ensure effective contact between chlorine and water, a contact chamber or basin must be provided with a so-called plug-flow pattern. This is to ensure that no short-circuiting takes place, because this may result in some parts of the water not being in contact with chlorine for the prescribed contact time. (An example of a plug flow system is a hosepipe where no back mixing or short-circuiting is possible. This is in contrast to a completely mixed system such as rinsing in a washing machine).

The following table gives the recommended chlorine concentration after 10 minutes contact time at different pH levels for free available chlorine and after 60 minutes for combined available chlorine.

pH value	Minimum free available chlorine after 10 min. contact time (mg/ℓ)	Minimum combined available chlorine after 60 min. contact time (mg/ℓ)
6	0,2	1,0
7	0,2	1,5
8	0,4	1,8
9	0,8	>3
10	0,8	>3

Turbidity. A further important factor that affects disinfection, is the turbidity of the water to be disinfected. The reason is that when water contains colloidal particles, they may "shield" the micro-organisms from the action of the disinfectant, or alternatively react with the chlorine and in this way prevent effective disinfection. It is therefore important to optimise the clarification processes to produce water for disinfection with as low as possible turbidity levels (<1, but preferably <0,5 NTU).

Sunlight. Chlorine in water is rapidly broken down (reduced) by sunlight to the inactive chloride ion, Cl^- that has no disinfecting power. This means that chlorine contact tanks should always be covered. Furthermore, chlorine compounds such as bleach should always be stored in dark containers out of sunlight.

What does disinfection by means of ultra-violet (UV) irradiation involve?

UV radiation kills or inactivates micro-organisms provided each organisms receives a minimum amount of irradiation. UV irradiation functions on the principle that each unit of water must be exposed to the irradiation for a minimum amount of time at a minimum dosage intensity.

Commercial UV units are used to disinfect water in many small- and large-scale water treatment plants. UV disinfection units have been used for many years and the process is accepted as an effective disinfection method.

It is important that the water to be disinfected is properly pretreated to ensure a low turbidity, preferably lower than 0,5 NTU. If the water contains high turbidity levels the colloids either absorb some of the radiation or shield the micro-organisms against radiation which reduces the effectiveness of the process.

A further important aspect is that the UV tubes is prone to the formation of layers of scale or other fouling material. This also reduces the effectiveness of radiation. It is therefore important that the tubes are regularly inspected and cleaned to prevent formation of scale or accumulation of other material on them.

Section 2D: Stabilisation of water for domestic use

What does stabilisation of water for domestic use mean?

Stabilisation of water refers to the chemical stability of water, specifically with respect to the tendency of the water to be corrosive or to form chemical scale in pipes and fixtures. Stabilisation of water involves the addition of chemicals to the water to adjust its chemical properties in order to prevent corrosion or scale formation.

The chemical stability status of water is determined by means of a chemical analysis of water and calculating certain indices or properties of the water. The index that has been most commonly used in the past to assess the stability of water is the Langelier Saturation Index, LSI. This index gives a qualitative indication of the stability of water and its calculation is discussed in the *Analysis Guide*.

A more useful measure of chemical stability of water is to calculate the calcium carbonate precipitation potential, CCPP, which is also discussed in the *Analysis Guide*.

Why is it important that water must be chemically stable?

Water that is not chemically stable may be:

- *Corrosive towards metal pipes and fittings causing leaks in distribution systems with substantial cost implications.*
- *Scale-forming, causing a layer of chemical scale to form in pipes and on heating elements. This also has substantial cost implications because the capacity of pipes is reduced and the heat transfer in kettles and geysers is reduced. From a cost point of view, it is very important to ensure that water for domestic use is chemically stable.*

When water that is corrosive is distributed to users in a distribution system, corrosion of metal pipes takes place and leaks will eventually develop in the system. This will result in water losses (unaccounted-for-water), the cost of which the water supplier has to carry but for which it does not receive any income. Water loss figures can be as high as 20 to 30% or even higher, making a substantial contribution to the cost of water. When losses are very high, the water supplier will have to implement water loss control programmes, adding to the cost. In extreme cases it may be necessary to replace sections of the distribution system at very high cost.

On the other hand if water is scale-forming it has cost implications as a result of the fact that the inside diameter of pipes and therefore the water conveying capacity is reduced, resulting in higher pumping cost. Furthermore, the effect of a layer of scale on heating elements in geysers and kettles causes higher energy consumption at additional costs to the consumer. The actual life of the elements is also reduced, causing premature expenditure to the consumer.

What does stabilisation of water involve?

Stabilisation of water involves the addition of chemicals to the water to produce water with a calcium carbonate precipitation potential (CCPP) of about 4 mg/ℓ. This means that the water should be slightly supersaturated with calcium carbonate. The effect of this is that a very thin layer of calcium carbonate will form on surfaces protecting it against corrosion. At the low supersaturation value excessive scale formation is avoided.

NOTE: The calculation of the CCPP is quite complex and for this reason a computer program was developed that does the actual calculation of CCPP from input of the water analysis. The Stasoft program is a very user-friendly program and is available from the Water Research Commission at a nominal cost.

The Langelier Saturation Index can also be used to adjust the stability of water:

LSI = pH measured - pH_s

(pH_s is the pH at which the water is just saturated with respect to calcium carbonate).

LSI = 0: water is just saturated with calcium carbonate.

LSI < 0: water is undersaturated and will dissolve $CaCO_3$.

LSI > 0: water is supersaturated and will precipitate $CaCO_3$.

What chemicals are used in the stabilisation of water?

The two chemicals most commonly used are slaked lime, $Ca(OH)_2$ and carbon dioxide, CO_2.

- ***Lime** is used to stabilise soft water (low calcium content), and water with a low pH.*
- ***Carbon dioxide** is used to stabilise water with a high pH and to add alkalinity to water.*
- *Other chemicals that could also be used include **sodium carbonate**, Na_2CO_3 (also known as soda ash) and **sodium hydroxide**, NaOH (also known as caustic soda).*

The Stasoft program calculates the amount of chemicals to be used for stabilisation based on the analysis of the water.

PART 3

Point-of-use treatment processes

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Section 3A: General types of point-of-use treatment methods

What are point-of-use treatment processes?

Unlike treatment processes that are used as part of a water treatment plant, point-of-use processes are used for water treatment:

- *at home;*
- *in the field or;*
- *in emergency situations.*

The main objective of point-of-use treatment in emergency situations and most home treatment situations is to produce clear and microbiologically safe water. The processes used are normally relatively simple processes such as boiling, or adding chlorine in the form of bleach, or exposing the water to sunlight.

However, point-of-use treatment may also be used to improve the quality of treated water by removing specific substances such as tastes and odours and dissolved organic material from the treated water or to soften hard water. These units (called home treatment devices HTD) use specialised processes such as activated carbon adsorption and/or membrane processes and provide advanced treatment

NOTE: Point-of-use treatment processes are normally applied on small scale.

Which processes are applied in point-of-use applications?

Different processes can be applied in point-of-use applications. The following are examples of the types of processes that are used in home applications and in home treatment devices:

- *Disinfection processes: boiling of water; use of home bleach; exposure to sunlight, use of chlorine pill contacting devices, ultraviolet (UV) disinfection, and membrane processes;*
- *Clarification processes: use of natural coagulants, membrane filtration, ceramic- cartridge- and drum filtration;*
- *Softening processes: home ion-exchangers, membrane processes;*
- *Adsorption processes: activated carbon adsorption*

The list of point-of-use processes consists essentially of two categories, i.e. those used to produce clear and microbiologically safe water, and those aimed at advanced treatment for further improvement of the quality of treated water. The first group are those that would be used in emergency situations and in homes not provided with a treated water supply. The second group is used in home treatment devices for further improvement of treated water.

Section 3B: Emergency and home treatment processes

Which processes can be classified as emergency and home treatment processes?

The emergency and home treatment processes that can be used to produce safe and clear water for domestic use include:

- *boiling of water;*
- *use of home bleach and other chlorine compounds;*
- *exposure to sunlight;*
- *use of home filters, followed by disinfection;*
- *use of natural coagulants, followed by disinfection.*

These processes are considered to be "low technology" and can be applied in the home by people with limited training. Certain minimum requirements must however, be observed.

Certain other processes such as UV irradiation and membrane processes are also used in emergency situations on larger scale than home treatment. They are considered to be advanced processes and normally require some supervision and maintenance for sustainable operation.

Does boiling of water kill all micro-organisms?

When water is boiled most, but not all micro-organisms are killed. Normally, boiling kills most pathogens yielding water that is safe to drink. Heavily polluted water must be boiled for an extended period – at least 10 minutes, depending on the degree of contamination

NOTE: Care must be taken when boiling water to prevent injuries through burn wounds.

The boiling of drinking water is often advocated where the water supply is unsafe particularly where there are outbreaks of enteric diseases. In general, boiling of unsafe water improves the microbiological quality significantly. The general requirement is that water should be kept at a "rolling boil" for a minimum of 10 minutes to ensure destruction of pathogens. In order to ensure that all micro-organisms are killed, the water must be sterilised, which involves boiling the water under pressure for extended periods.

Most pathogens are killed at temperatures lower than the boiling point of water. It can therefore be accepted that taking clean water to the boiling point will reduce the probability of contracting microbiological diseases substantially. It has been shown that the organism causing cholera, Vibrio cholerae is killed at temperatures as low as 65°C.

NOTE: When boiled water is cooled, it may be re-contaminated if it is put in a dirty container when cooled or if it is not properly protected against pollution. It is therefore extremely important to prevent contamination of boiled water when it is transferred to other containers or when it is stored before use. Containers must be properly washed and the container covered to prevent contamination, e.g. by objects falling in the water.

How can water be disinfected by household bleach?

Bleach is a solution that contains dissolved chlorine in the form of sodium hypochlorite. When bleach is added to water in the correct amount and under the correct conditions it can disinfect the water as effectively as addition of chlorine gas at a water treatment works.

Bleach contains sodium hypochlorite at a concentration of about 4 to 5%. When it is added to water it forms the same chlorine species used for disinfection by means of chlorine gas. In order to achieve disinfection a certain minimum amount of chlorine must be in contact with the water for a certain minimum contact period. The dosage and contact period are determined by the water quality (chlorine demand of the water) and by the concentration of the bleach.

NOTE: The chlorine in bleach is unstable and the quality deteriorates with time, especially when exposed to sunlight. It is therefore important that **bleach be kept in a dark bottle out of sunlight** and furthermore, that it should not be kept for too long before being used (not longer than 1 month).

If it is assumed that bleach contains 4% chlorine, it means that each millilitre (mℓ) of bleach contains 40 mg of chlorine. Addition of 1 mℓ of bleach to 10 l of water therefore gives a concentration of 4 mg/ℓ chlorine.

It is rather difficult to measure a 1mℓ portion of bleach without a proper measuring device, therefore 1 teaspoonful which is equal to about 5 mℓ (5g or 5 000 mg) is a better volume to measure. One teaspoonful (5 mℓ at 40 mg chlorine/mℓ = 200 mg chlorine) added to 25 ℓ of water gives a concentration of 8 mg/ℓ chlorine and if this is allowed to stand preferably overnight or for at least 2 hours protected from sunlight, the water should be properly disinfected - provided the water is not heavily polluted.

5 mℓ (1 teaspoon) bleach per 25 litre water	= 8 mg/ℓ chlorine
5 mℓ (1 teaspoon) bleach per 20 litre water	= 10 mg/ℓ chlorine
10 mℓ (2 teaspoons) bleach per 40 litre water	= 10 mg/ℓ chlorine

The chlorine content of the water can be determined using a simple swimming pool test kit. It is recommended that the chlorine concentration should be at least 0,2 mg/ℓ after 2 hours contact time (2 hours after addition).

How can water be disinfected using HTH granules?

HTH is a dry granular chlorine product containing calcium hypochlorite. When the granules are added to water it forms chlorine that kills micro-organisms when left overnight or for a minimum period of two hours out of sunlight.

Calcium hypochlorite, $Ca(OCl)_2$ (commonly known as HTH) is available in granular or solid (tablet) form and is therefore a very convenient form in which to store and apply chlorine. It contains between 65 and 70% of available chlorine, it is relatively stable and can be stored for long periods (months) in a cool dry environment.

One teaspoon full of granules (about 3 000 mg) is sufficient to treat a 200 ℓ drum of relatively clean water:

(3000 mg x 0,65 = 1 950 mg of chlorine. When added to 200 litre of water a dosage of about 10 mg/ℓ of chlorine results).

NOTE: The HTH must be added to the water and stirred to dissolve the granules and then left overnight or for 2 hours out of sunlight before use.

How can water be disinfected using HTH pills?

HTH in pill form is also a very convenient way in which chlorine can be added to water. However it is not easy to control the dosage because dissolution of the pill depends on a number of factors that cannot be easily controlled. In the case of a treatment plant the chlorine can be dosed to the water by means of a commercial chlorine dispenser. Alternatively, the pill can be put into a drum full of water and removed after few minutes.

NOTE: *It is important that the chlorine concentration be determined after 30 minutes to ensure that there is at least 0,2 mg/ℓ residual chlorine in the water, but not more than about 4 mg/ℓ to ensure disinfection.*

A chlorine pill dispenser is commercially available and can be used in small-scale treatment plants in conventional or in emergency situations. It relies on the flow of water through the dispenser to dissolve sufficient chlorine from the pill to disinfect the water. The dispenser is not well suited for home treatment.

The chlorine pill can be used in home treatment situations by leaving it in a container for a period of time. However, control over the actual chlorine dosage is difficult in this case. It is recommended that a test kit be used to determine the actual chlorine concentration in the water. The concentration should be at least 0,2 mg/ℓ after 30 minutes to ensure disinfection. On the other hand, the chlorine concentration should not be more than about 4 mg/ℓ to prevent taste and other negative effects in the water.

How can water be disinfected by means of exposure to sunlight?

The ultra-violet radiation in sunlight has a disinfecting action on water by killing micro-organisms in the water. However, the disinfecting power of sunlight alone is rather limited. When combined with the action of oxygen, a more powerful disinfecting action is obtained, which is sufficient to disinfect small volumes of water.

UV irradiation has been used for many years to kill micro-organisms in water by means of long-term exposure to sunlight or more recently, by means of UV tubes specially designed for this purpose. Recent studies have shown that by combining the action of UV with that of oxygen in water an effective disinfecting action can be achieved.

The method is very useful for small-scale treatment of water. Practically the method can be applied by filling a small container (2, 5 or 20 litre) with water, leaving a small amount of air in the container. The container must be shaken after filling and thereafter about every hour and left in direct sunlight for about 6 hours.

NOTE: There are certain requirements that must be met for the method to be effective:

- the container must be shaken regularly to disperse the remaining micro-organisms and to mix and dissolve oxygen in the water
- the container must be from transparent or a light colour plastic material
- the water must be relatively clean, i.e. there must be no visual turbidity in the water
- the container must be left in direct sunlight for at least 6 hours.

What types of home filtration units are available?

There are different types of filtration units that can be used in the home. They range from expensive membrane filters that remove almost all contaminants from the water to less expensive cartridge filters and drum filters, to simple filters that can be constructed by the home dweller.

Commercially available filters are relatively expensive. They are often used in advanced home treatment devices to improve the quality of treated water. However, they are seldom used for home treatment to provide clean drinking water from polluted sources, mainly due to cost considerations.

Simple sand filters can be constructed by the home dweller according to plans that are available from development agencies. This type of filter improves the quality of water but does not ensure microbiologically safe water. The water must therefore be disinfected after filtration. These filters are used in many overseas countries, but not commonly used in South Africa.

NOTE: A simple filtration system that often provides good quality water is by means of riverbank filtration. The concept is not to abstract water from the water in a river or stream but to abstract the water after it has percolated and filtered through the natural sand in the riverbank. The easiest way of achieving this is to dig a hole a distance away from the stream and collect the water from the hole.

Does home filtration units produce safe water?

In general home filtration units produce clean water but not necessarily microbiologically safe water, depending on the nature of the filter medium. Reverse osmosis filtration produces water that is microbiologically safe because bacteria or viruses cannot pass the membrane. All other types of filters remove some bacteria, but viruses are not completely removed. Addition of a small amount of chlorine (safety chlorination) is required to ensure safety.

How can water be treated by means of natural coagulants?

Natural coagulants act in the same way as certain chemical coagulants by enmeshing the *colloidal particles in water in flocs. The flocs can settle and be removed from the water. Natural coagulant that are used include the seed of the Moringa oleifera tree, crushed peach pips and ash.*

The use of natural coagulants depends on the general availability of such coagulants. Unfortunately there is not much information available in South Africa on naturally occurring coagulants such as the seeds of the *M. oleifera* tree that is used more generally in other countries. Apart from the use of crushed peach pips and ash in some home treatment applications, this method is not generally used in this country.

Section 3C: Home treatment devices (Advanced point-of-use treatment processes)

Why is advanced home treatment devices used to treat water that has already been treated?

In South Africa the water from a well-controlled treatment plant is normally of very high quality and does not need any further treatment.

Some people however, have concerns about the quality of treated water for a variety of reasons. Some individuals have the perception that there are substances in our water sources that conventional processes are not capable of removing and therefore use home treatment units in the belief that these devices will be able to remove such substances.

There is world-wide concern about the quality of drinking water. The concerns stem from the fact that there are literally millions of chemical substances that could find their way into water sources from which drinking water is prepared. Conventional processes are normally designed to remove suspended and colloidal material from the water and to disinfect the water. They are not designed to remove organic compounds that may occur in water at very low concentrations.

Furthermore, analytical techniques have been developed to the extent that extremely low concentrations of these compounds can be detected in water. This has resulted in speculations about the safety of water. In turn these speculations cause uncertainty that is often exploited by some manufacturers and vendors of point-of-use equipment. They tend to scare consumers as a method to sell their equipment.

A further reason for point-of-use treatment is to soften hard water. In many areas the natural water contains high levels of hardness that causes formation of chemical scale in pipes and on elements of geysers and kettles. The water can be softened by means of ion exchange resins in a home water softener.

What advanced processes can be used for home treatment?

A variety of specialised home treatment devices are available for point-of-use treatment. They are based either on membrane filtration, activated carbon adsorption, UV irradiation, ion exchange, or combinations of these.

Membrane filtration processes include reverse osmosis and ultra filtration. These processes are discussed in detail in Part 5. Their main advantage as membrane HTD's is the fact that they are able to remove most contaminants from water. However, the cost for this type of unit is relatively high.

The main disadvantage of membrane processes is the fact that the product water constitutes only a small portion of the water that goes into the unit. The bulk of the water does not go through the membrane and is wasted if special measures are not taken to divert this water for another use such as watering of the garden. When using a reverse osmosis membrane unit, most of the salts are also removed from the water. This means that virtually all the calcium and magnesium is removed from the water. These elements must then be supplemented to prevent health problems if the water is consumed over a long period.

Activated carbon adsorption is also discussed in detail in Part 5. The main advantage of this process is that it removes tastes and odours from the water as well as a large variety of dissolved organic compounds.

There are two potential problems associated with the use of activated carbon in HTD's: The **first potential problem** is the fact that the adsorptive capacity of the carbon becomes exhausted after some time and the carbon must then be replaced. If it is not replaced no removal of organic substances takes place, and in some cases the more weakly adsorbed substances may be replaced from the carbon. This may result in the situation that the concentration of some substances may be higher in the product water than in the water being treated.

The **second potential problem** relates to the fact that activated carbon removes and concentrates organic substances in its porous structure. These compounds are used by micro-organisms as substrate (food). As a result micro-organisms will tend to multiply in the carbon bed, resulting in a deterioration in the bacteriological quality of the water. Special precautions such as regular back washing and rinsing of the unit must therefore be taken to prevent a proliferation of bacteria in the filter.

Ion exchange systems are used in HTD's to soften water in areas with hard natural water or in combination with other processes for general improvement of water quality. These systems are also discussed in Part 5. The resins become exhausted after a certain period of use and must be regenerated, normally using a salt solution. The units are often automated and regeneration takes place automatically on a time basis.

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Package water treatment plants

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Section 4A: General aspects of package water treatment plants

What is a package water treatment plant?

The term package water treatment plant is used to denote relatively small-scale treatment plants (usually less than 500 kℓ/d) that are not constructed as permanent structures, but rather as movable units. Typically a package plant is pre-assembled and transported to site or assembled on site in a structure such as a container. Package plants can be made up of conventional as well as advanced treatment processes.

The concept of a package plant is that it must be a self-contained unit that is capable of producing water of the required quality from the raw water source. Package treatment plants have been developed as a rapid way of meeting the demand for treated water in situations where treated water is not available or where there is a temporary need for water, e.g. construction sites.

Package plants are more and more used to meet the needs of rural or isolated communities for water supply where the construction of a conventional treatment plant would not be feasible. This type of plant is also used to provide an emergency water supply in crisis situations.

Which processes are used in a package treatment plant?

Most package plants consist of a series of conventional treatment processes similar to those used in a conventional water treatment plant. There are also different package plants that employ advanced/specialised processes such as membrane processes (described in Part 5). The actual processes that are used in a package plant depend on the raw water quality, the treatment objectives and the circumstances and conditions under which the plant has to be operated.

Most package plants for community water supply from surface water sources employ conventional treatment processes of coagulation-flocculation, sedimentation, sand filtration and disinfection. The processes are similar to those of conventional treatment plants but the equipment used in a package plant often is of a different design. For example, pressure sand filters are often used in package plants, compared to gravity sand filters that are mostly used in conventional plants.

NOTE: Package plants are often used where there are specific raw water quality problems. In such cases advanced/specialised processes are used in the package plant. Examples include package plants that employ a desalination process where the water source is brackish, or softening if the source water is very hard.

What are the advantages and limitations of package treatment plants?

The ***main advantages*** *of package treatment plants are:*

- *they can be erected within a short period of time;*
- *they are self-contained units capable of producing domestic water from a variety of raw water sources;*
- *the capital costs are generally lower than for a similar size permanent plant.*

The **main limitations or disadvantages** include:

- the unit cost of water from package plants is relatively high when compared to conventional treatment plants;
- the design life of a package plant is much shorter than that of a conventional plant (typically 5 years compared to 20 years for a conventional plant);
- close control (or automation) and fail-safe devices are required to ensure that product water of the required quality is produced.

NOTE: Package treatment plants have become a popular method in South Africa to meet the needs of smaller isolated communities for water supply. The reason is that treated water can be available very soon after a decision has been taken to install a package treatment plant. Packaged treatment plants are in general also relatively easy to operate.

The unit cost of water produced by package plants is relatively high for a number of reasons:

- package plants have relatively small capacities that result in higher unit costs;
- this type of plant is often erected in rural areas and special precautions are therefore included in the design to prevent equipment failures that can leave the community without water;
- some package plants use advanced technology such as membrane processes (see Part 5) or special filters resulting in high costs.

Figure 16 shows a general view of a package treatment plant.

Figure 16: General view of package treatment plant

When should erection of a package treatment plant be considered?

Package treatment plants can be considered for water supply when:

- *the water demand is relatively small (< 500 kℓ/day);*
- *construction of a conventional plant would be difficult, e.g. difficult terrain;*
- *construction of a conventional plant would be expensive, e.g. due to locality, availability of materials and skills, etc;*
- *there is an urgency to have treated water available;*
- *the need for water is temporary or could change drastically;*
- *there are specific problems with raw water quality.*

There are different situations in which the erection of a package plant would be more feasible than construction of a conventional plant. However, each situation must be considered individually in terms of the type of plant that would be best for the situation, taking the factors listed above into consideration.

Are there any specific aspects that must be considered with package plants?

Package plants based on conventional technology are very similar to conventional plants. The process control strategy on a package plant is important. Due to the small output it is desirable for a package plant to operate reliably with as little supervision as is possible. Other aspects that need specific consideration include chemical handling and dosing, technical support and maintenance.

The objective of the control system on a package plant, whether manual or automated is to provide adequate control of the quantity and quality of treated water produced by the plant. This requires the simplest and inexpensively maintained control system that can provide:

- adequate control over chemical dosages and dosing;
- effective alarms and cut-outs to prevent overloading of specific components;
- fail-safe design to prevent contamination of treated water in the case of power or component failures, or chemical depletion;
- manual override of automated procedures;
- sufficient ranges for control parameters.

Section 4B: Advanced processes applied in package treatment plants

When are advanced/specialised process used in package plants?

The main reason for using specialised processes in a package plant is for the removal of specific compounds that the raw water may contain.

Most package plants employ conventional treatment processes for the treatment of surface water sources. However, when the raw water source contains specific compounds that have to be removed such as excess dissolved solids, fluoride, nitrate, or hardness, advanced processes have to be used. In addition, the circumstances on the site may call for advanced or non-conventional process.

Which advanced/specialised processes are used in package plants?

A number of advanced/non-conventional processes are used in package plants for different purposes. The actual processes that would be used are determined by the raw water quality and by the specific circumstances under which the plant is to operate. The advanced/non-conventional processes typically include: membrane processes, ultra-violet disinfection, on-site chlorination systems, activated carbon adsorption, and ion exchange.

Which membrane processes are used in package plants?

There are a number of different membrane processes that can be used in package treatment plants to achieve different objectives,:

- *reverse osmosis is used to desalinate brackish or saline water;*
- *nanofiltration is used to soften hard water;*
- *ultrafiltration and microfiltration are used for the clarification of feed water containing colloidal material.*

These specialised membrane processes are relatively expensive and sophisticated and are only used under circumstances where the high costs are justified. There are certain circumstances under which microfiltration (MF) could play a role for water supply in rural communities, in view of the simplicity of its operation. However, the use of MF for this purpose has not yet been demonstrated in practical situations and further development appears to be necessary.

Membrane systems are discussed in more detail in Part 5.

When is ultra-violet disinfection used in package plants?

Ultra-violet (UV) disinfection is used in package plants when the handling and dosing of hazardous chlorine compounds is to be avoided. UV is as effective as chlorine in destroying micro-organisms and disinfecting the water.

What are the advantages and disadvantages of UV for disinfection compared to chlorine?

*The **main advantage** of UV disinfection compared to chlorine for small-scale and rural applications is that the handling and dosing of hazardous chlorine compounds is eliminated.*

*The **main disadvantage** of UV disinfection is the fact that there is no residual protection against re-contamination.*

On large-scale applications chlorine handling does not present problems and the main advantage of UV disinfection is the fact that no chlorine disinfection by products are formed.

What does on-site chlorine generation and disinfection involve?

On-site generation of chlorine or chlorine compounds is achieved through electrolysis of a salt solution. The process involves the application of an electrical current to a salt solution in a specially designed electrolysis cell. In the electrolysis process part of the salt is converted to chlorine gas or sodium hypochlorite that is used to disinfect water.

What are the advantages and limitations of on-site chlorine generation?

*The **main advantage** of on-site generation is the fact that transport and handling of chlorine gas or compounds is eliminated. **Another advantage** is the fact that solar cells can be used to provide the electricity for the process since only a small direct electrical current is required for the process. **The main limitation** is the fact that the equipment is relatively sensitive and must be well operated and maintained to prevent process failure.*

These advantages make the process very suitable for small rural communities. However, the equipment is relatively sensitive and must be well cared for. Especially the electrodes are fragile and expensive to replace. Solar panels are also easily damaged or removed in isolated areas. Some systems use membranes as part of the cell, and these are susceptible to fouling and damage. Skilled operators who are able to run and maintain the electrolysis cell must be used to operate the plant and this adds to the cost of the final water. If a failure of the process occurs disinfection ceases and alternative disinfectants have to be used.

When is activated carbon adsorption used in package plants?

Activated carbon is used to remove substances that cause unacceptable taste and odour in the water that cannot be removed by conventional treatment processes. The use of activated carbon in a package plant adds to the complexity of the plant and adds to the cost of the treated water.

When is ion exchange used in package plants?

Ion exchange is used in package plants when the raw water contains unacceptable levels of hardness. The hardness-causing ions are exchanged in the process for sodium ions that do not cause hardness. Ion exchange adds to the complexity of the process and the cost of the final water.

PART 5

Advanced/Specialised treatment processes

PART 1

General aspects of water treatment

PART 2

Conventional water treatment processes

PART 3

Point-of-use treatment processes

PART 4

Package water treatment plants

PART 5

Advanced/specialised treatment processes

YOU ARE HERE

PART 6

Specific issues in water treatment: Management, treatment problems, safety, fluoridation, and waste disposal

Section 5A: Different types and general nature of advanced/specialised treatment processes

What is meant by the term advanced treatment processes?

The term advanced treatment processes is used to denote non-conventional water treatment processes that are used for specific purposes such as for the desalination of water or the removal of specific substances from water. These processes are generally more sophisticated and therefore more costly than most conventional processes.

Conventional treatment processes (Part 2) are normally considered to include coagulation-flocculation, sedimentation (or flotation), sand filtration, chlorination and stabilisation processes applied with the objective to produce clarified (low turbidity), disinfected and stabilised water for domestic use. These processes are normally used in municipal water treatment plants designed to produce water for domestic use.

Advanced processes (Part 5) are processes that are applied to achieve specific objectives other than, or in addition to clarification, disinfection and stabilisation of water. This category includes processes such as desalination processes, activated carbon adsorption, softening and iron and manganese removal.

A number of advanced and specialised processes are used in water treatment. These processes can be used as individual processes to achieve a specific objective or they can be included in a train of treatment processes together with conventional processes or other specialised processes.

An example of an advanced process as part of a conventional process train is the use of activated carbon adsorption to remove tastes and odours from water. Another example of an advanced process is the application of reverse osmosis to desalinate brackish water.

The advanced processes discussed in this Guide are applied in a number of cases in South Africa. However, they are not generally used and their application is limited to situations where specific problems exist.

NOTE: There are different specialised processes that are still in various stages of development that have not been proven in practical applications. These processes are often promoted by people in order to demonstrate the process, but also to identify problems and to use the opportunity to do further development on the process. Water suppliers and local communities should be careful when considering installation of such processes.

When is advanced/specialised processes used in water treatment?

Advanced processes are normally used when conventional treatment processes are not capable of producing water that is fit for domestic use from a specific water source.

There are many water sources that contain substances that cannot readily be removed by conventional processes. Examples of such water sources or substances of concern are:

- brackish water with excessive levels of total dissolved solids;
- surface water containing high concentrations of dissolved organic substances that may have health implications or that give unacceptable tastes and odours to the water;
- water that contains specific substances such as nitrates, fluorides, arsenic or other toxic substance at unacceptable levels (see *Assessment Guide*).

In cases such as these the use of advanced/specialised processes must be considered.

NOTE: Advanced processes are normally more sophisticated than conventional processes, they require higher levels of expertise to operate and generally results in higher treatment costs

Which processes are generally considered to be advanced processes?

The following are the main categories of processes regarded as advanced processes:

- *desalination processes: reverse osmosis, electrodialysis, distillation processes, ion exchange;*
- *activated carbon treatment for removal of tastes and odours and other dissolved organic compounds;*
- *processes for removal of specific substances from water, including hardness, iron, manganese, nitrate, and fluoride;*
- *specialised membrane processes for softening and clarification of water.*

Section 5B: Advanced processes for the desalination of water

When is desalination processes applied in water treatment?

Desalination processes are used to treat brackish water (or seawater), i.e. water containing excessive amounts of dissolved inorganic salts in order to produce water that is fit for domestic use.

Brackish water. Water is considered to be;

- slightly brackish when the total dissolved solids concentration is higher than about 750 mg/ℓ to about 1 500 mg/ℓ;
- moderately brackish when the TDS is in the range 1 500 to 4 000 mg/ℓ;
- highly brackish when TDS values are higher than 4 000 mg/ℓ;

Seawater contains about 33 000 mg/ℓ of total dissolved solids.

Fresh water, i.e. water that is fit for domestic use is classified as water containing less than 500 mg/ℓ of total dissolved solids (TDS). This is the ideal value (*Assessment Guide*) but humans can drink water with higher concentrations of total dissolved solids without any negative effects. At higher levels the water may have a brackish or salty taste depending on the nature of the dissolved compounds. Some waters containing specific dissolved substances such as magnesium sulphate may have a laxative effect on people not used to drinking the water.

Many ground water sources in South Africa are brackish, especially in the more arid parts of the country. These sources are often the only source of water and, although unfit for domestic use, people are forced to use the water in order to survive. These water sources can be made fit for domestic use by means of desalination processes. Even seawater can be desalinated and made fit for domestic use. However, these processes are relatively sophisticated, are costly and require close supervision and control.

What is the principle of operation of desalination processes?

There are a number of different desalination processes, each based on a different principle of operation

- *Reverse osmosis is a membrane process in which high pressure is used to produce fresh water from brackish- or sea water by forcing fresh water through a specially fabricated membrane assembly.*
- *Electrodialysis is also a membrane process, but in this case an electric current is used to extract the dissolved salts through a different type of membrane from the water.*
- *Distillation processes are based on a different principle. In this case the water is heated and the water vapour that forms (and is free of salt) is condensed to produce pure water.*
- *Ion exchange processes utilise tiny resins that have the ability to exchange dissolved ions in the water with hydrogen and hydroxyl ions (the component ions of water) or they can also be used to soften water by exchanging hardness causing ions for non-hardness-causing sodium ions.*

What are the main characteristics of the reverse osmosis process?

The principle of reverse osmosis (RO) is that feed water with a high TDS concentration under high pressure is applied to the membranes and pure water is forced through the membrane while the dissolved salts are rejected by the membrane.

The membrane modules are the 'heart' of the reverse osmosis system. Membranes are relatively sensitive to mechanical, chemical and temperature effects and must be protected against damage, for example by chlorine and against fouling or blocking. Membranes have a limited life span (typically 3 years) which means that they have to be replaced periodically. Other elements of a reverse osmosis plant include:

- pre-treatment processes
- high pressure pumps
- post treatment processes
- membrane cleaning facilities.

The nature of the membranes is such that pure water permeates the membrane while most of the dissolved salts (such as sodium chloride) as well as all colloidal substances and most organic substances cannot permeate the membrane. This means that all bacteria and even viruses are separated from the product water (permeate), thus producing water of very high quality for domestic use.

The membranes are manufactured from synthetic polymers in the form of thin plastic sheets or tubes that are fabricated into units called modules. The nature of the modules determines the pretreatment requirements and also plant performance.

RO membranes are characterised in terms of the percentage rejection of dissolved salts. For example, 95% rejection means that the concentration of dissolved solids in the product water will only be 5% of that of the feed water, while for a 99% rejection membrane the concentration in the product will only be 1% of that of the feed water.

The second important characteristic of an RO plant is the water recovery. This refers to the amount of product water as a percentage of the feed water. For example a plant with a water recovery of 80% will have a product stream equal to 80% of the feed water and a brine- or concentrate stream equal to 20% of the feed water stream. The disposal of the brine (that contains the salts that have been removed in a smaller but more concentrated form) represents a cost factor that has to be taken into account when calculating the water cost.

Figure 17 shows a schematic layout of a reverse osmosis plant, while **Figure 18** shows a photograph of a small-scale RO plant.

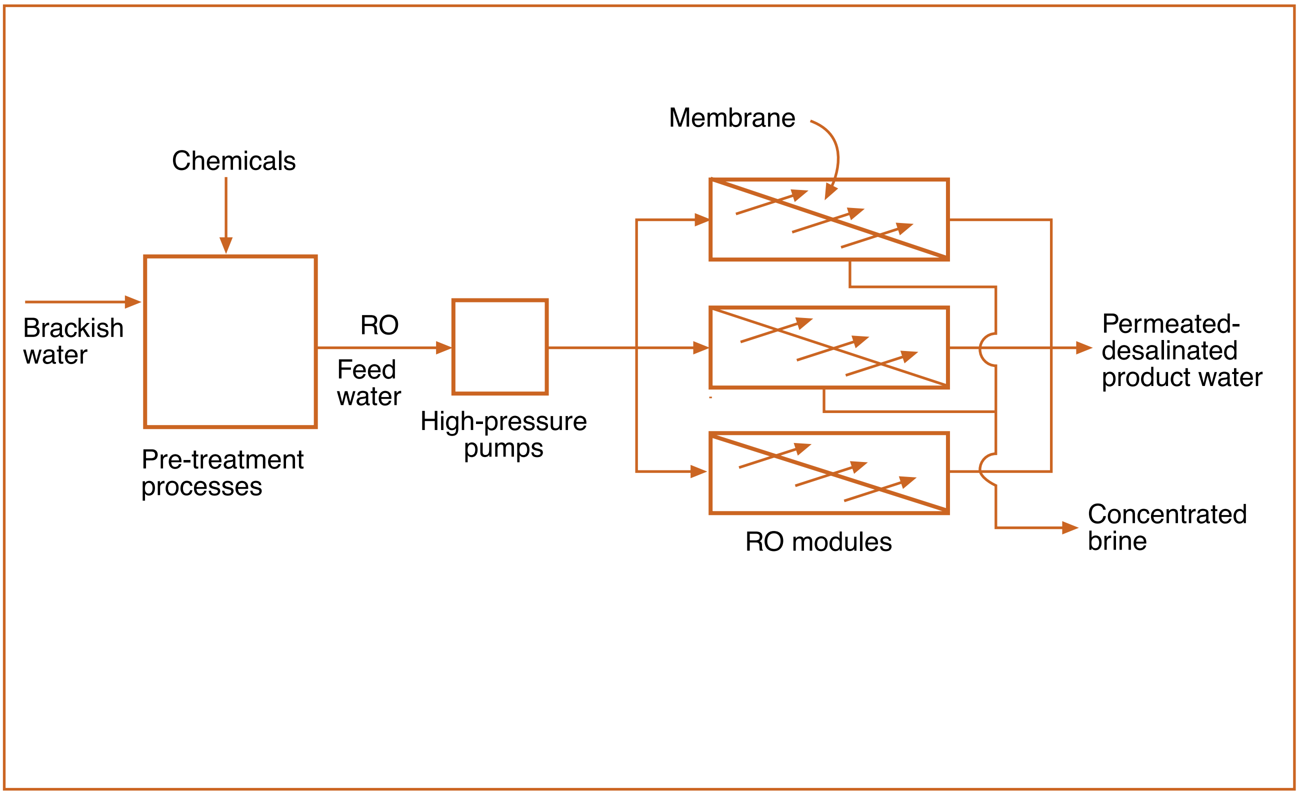


Figure 17: Layout of reverse osmosis plant

Figure 18: Small-scale RO plant

What are the most important factors to consider in the application of reverse osmosis for the desalination of water?

Reverse osmosis is applied successfully on both small and large to produce fresh water from brackish water and from seawater. There are however, also many examples where serious problems and even plant failure have been experienced. From these applications the following factors have been identified as crucial to successful application:

- *Protection of the membranes against degradation and fouling*
- *Pretreatment*
- *Water recovery*
- *Brine disposal*
- *Close supervision and control of operation*
- *Close control of maintenance.*

Membranes represent a large part of the capital cost of a reverse osmosis plant. They furthermore also make a significant contribution to the running costs of an RO plant since they have a limited life and have to be replaced on a regular (planned) basis. However, if the membranes are damaged or fouled and have to be replaced before their scheduled or planned time of replacement, it could have a very negative impact on the sustainability of the scheme.

For this reason it is extremely important to treat the feed water to the required quality as prescribed by the membrane manufacturer. Pretreatment processes therefore have to be carefully designed and be closely controlled during operation.

Under which conditions could reverse osmosis be considered for the treatment of water for domestic use?

Reverse osmosis is a high cost sophisticated process that requires close supervision and control. For this reason it should only be considered as treatment process under special circumstances. These circumstances include the following:

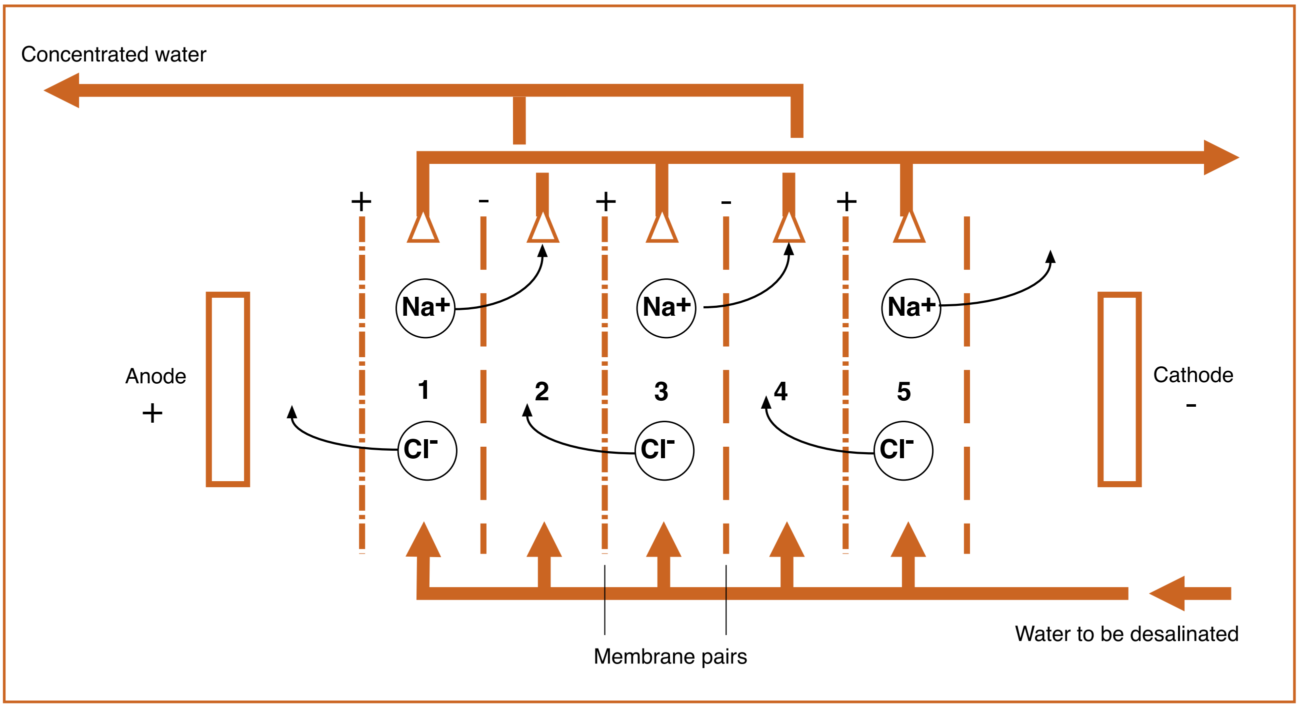
- *When there is no alternative water supply available other than brackish water or seawater*
- *When the community can afford to pay a relatively high price for their water supply (or when funds are available over the long term to subsidise costs)*
- *When the cost of desalination is lower than to convey water from distant sources (pipeline for large volumes or tanker for small volumes)*
- *Where a reliable electrical power supply is available (other sources of energy such as sunlight or wind power can also be used but add to the complexity and cost of the process)*
- *When the required level of expertise is locally available for operation, control and maintenance of the desalination plant (or when a high level of plant automation and fail-safe procedures is provided and expertise is available on call and to give scheduled support).*

A reverse osmosis plant (especially the membrane assembly) is a sensitive piece of equipment that can easily be damaged if proper operating and control procedures are not closely followed. These operational and control measures are normally relatively easily complied with on large-scale plants where the required levels of expertise are available. It is more difficult on small-scale plants in isolated areas to comply with these requirements and for this reason high levels of automation are built into the plant design for such conditions. Backup services must then be available for this type of plant.

What is the principle of operation of the electrodialysis process?

Electrodialysis (ED or EDR) is also a membrane process used for the desalination of brackish water (normally not seawater). However, unlike RO that uses pressure as driving force, ED uses electrical potential as the driving force. ED membranes differ from RO membranes since they are electrically charged and two types of membranes are used in pairs in an ED plant.

The heart of an electrodialysis plant is the membrane pairs (consisting of two membranes and a spacer) which are stacked one on top of the other to form a membrane stack (Note Box 5 gives a schematic representation). A positive and negative electrode at the top and bottom of the stack creates an electrical potential across the stack. The water to be desalinated is circulated in a thin layer across the surface of the membranes and the electrode attracts ions of opposite charge in the water to the particular electrode. The charged membranes allow ions of opposite charge to pass through each membrane but reject ions with the same charge. In this way alternative cells of desalinated water and concentrated brine are created.



The principle of electrodialysis

In addition to the membrane stack, an ED plant also consists of pretreatment processes, an electrical system to convert electrical power to direct current, a system for the cleaning of membranes and a post treatment section.

A particular design of the electrodialysis process is the so-called EDR (electrodialysis reversal) process. EDR differs from conventional ED in that the polarity of the electrodes is reversed at a certain time interval (typically every 20 minutes). The polarity reversal has the effect that ions flow in the opposite direction through the membrane after each reversal. This has the advantage that any fouling that may have formed during one cycle of operation is removed from the membrane after polarity reversal, because those cells that have been concentrate cells before reversal become product cells after reversal and are flushed clean before the new cycle starts.

What are the most important factors to consider in the application of electrodialysis for the desalination of water?

The factors to consider in the application of ED are very similar to those mentioned for reverse osmosis. EDR is applied successfully on both small and large scale to produce fresh water from brackish water (it is not applied for desalination of seawater). There are, however, also many examples where serious problems have been experienced. The following factors have been identified as crucial to successful application:

- *protection of the membranes against degradation and fouling - this factor is less critical than in the case of RO*
- *pretreatment - less critical than RO*
- *close supervision and control of operating conditions*
- *close control of maintenance*
- *quality of the product water.*

ED has certain **advantages** over RO. ED membranes are more robust and have a longer life expectancy than RO membranes. They can be cleaned using stronger solutions and can even be cleaned individually by disassembling of the membrane stack. In spite of being more robust, the membranes can be damaged and fouled and for this reason it is important to treat the feed water to the required quality as prescribed by the membrane manufacturer. Pretreatment processes therefore have to be carefully designed and be closely controlled during operation.

The biggest disadvantage of EDR compared to RO is the fact that the product water is of poorer quality when considered for domestic use. The reason is that in the case of RO pure water is forced through the membrane while almost all contaminants are prevented from permeating the membrane. In the case of ED and EDR the dissolved ions are removed from the feed water but all contaminants such as micro-organisms remain in the product water. This means that the product water has to undergo further treatment to make it fit for domestic use.

Under which conditions could electrodialysis be considered for the treatment of water for domestic use?

Electrodialysis, like reverse osmosis, is a high cost sophisticated process that requires close supervision and control. For this reason it should only be considered as treatment process under special circumstances. These circumstances are similar to those for the application of RO:

- *When there is no alternative water supply available other than brackish water*
- *When the community can afford to pay a relatively high price for their water supply (or when funds are available over the long term to subsidise costs)*
- *When the cost of desalination is lower than to convey water from distant sources (pipeline for large volumes or tanker for small volumes)*

- *Where a reliable electrical power supply is available (other sources of energy such as sunlight photovoltaic cells can also be used but add to the complexity and cost of the process)*
- *When the required level of expertise is locally available for operation, control and maintenance of the desalination plant (or when a high level of plant automation and failsafe procedures is provided and expertise is available on call and for scheduled support).*

An electrodialysis plant and especially the membrane system is a sensitive piece of equipment that can be relatively easily damaged if proper operating and control procedures are not closely followed. These operational and control measures are normally relatively easily complied with on large-scale plants where the required levels of expertise are available. It is more difficult on small-scale plants in isolated areas to comply with these requirements and for this reason high levels of automation are built into the plant design for such conditions. Back-up services are then required for this type of plant.

What is the principle of operation of distillation processes?

There are different types of distillation processes that are used for the desalination of brackish water and seawater. All distillation processes utilise the principle that energy is applied to the salt feed water in order to produce water vapour (which does not contain any dissolved salts). The vapour is separated from the feed water and then condensed to form pure desalinated water. Most large-scale commercial distillation plants are used for the desalination of seawater. However, small-scale desalination of brackish water using solar energy is also possible.

Very large seawater distillation plants have been in operation for many years in some Middle East countries and other arid regions to produce water for domestic (and industrial) use. The cost of distilled seawater is relatively high because of the large energy consumption of distillation processes.

What does solar distillation of sea or brackish water involve?

Solar distillation (also called a solar still) involves the use of solar energy to produce water vapour from sea or brackish water and the subsequent condensation of the vapour to produce fresh water. This is normally achieved using shallow basins covered by transparent glass panels arranged in such a manner that vapour condenses on the underside of the glass panels and flow down into collection troughs.

Solar distillation appears to be a very attractive process for desalination of water in arid areas with many sunshine hours because it is a relatively simple process and the energy is available at no cost. However, the reality is that there are very few solar distillation plants operating on a sustainable basis anywhere in the world. The main reasons are firstly the fact that the capital costs for the erection of the glass or plastic cover and maintenance costs are very high per unit of desalinated water produced. The second reason is that leakage of the vapour must be minimised. This is quite difficult to achieve. As a result of these reasons the process that seems so attractive, is mostly economically non-viable.

Section 5C: Advanced processes for softening and clarification of water

Why is it necessary to soften water?

Hard water contains excessive amounts of calcium and magnesium ions (see Analysis Guide) and cause problems with formation of chemical scale in hot water systems and in distribution systems. Hard water also results in excessive soap and detergent usage because it does not foam or lather readily.

Many groundwater sources in South Africa, especially in dolomitic areas contain high concentrations of hardness-causing substances (mainly calcium and magnesium ions). Hard water does not have health implications but cause problems in distribution systems and fixtures (see *Assessment Guide*). The elements of geysers and kettles become covered by chemical scale and this increases electricity consumption and reduces the life of these elements.

Hard water therefore has mainly economic effects and these are the main reasons for softening of water.

What does chemical softening of water involve?

Chemical softening involves the addition of chemicals to hard water to remove calcium and magnesium ions from the water by means of precipitating them in the form of calcium carbonate, $CaCO_3$ and magnesium hydroxide, $Mg(OH)_2$.

The lime-soda ash process is widely used for softening and involves the addition of lime to the water for the precipitation of calcium carbonate hardness. This is followed by addition of soda ash, Na_2CO_3 for the precipitation of calcium non-carbonate hardness.

The calcium carbonate and magnesium hydroxide that form during softening are removed in a sedimentation step. Softening takes place at elevated pH levels (11,2 for magnesium removal) and the water must therefore be stabilised before use. This is normally done by the addition of CO_2 to reduce the ph to about 7,5 to 8,5.

What does softening by means of ion exchange involve?

In the application of ion exchange for softening, hard water flows through a column of ion exchange resin (similarly to water flowing through a sand filter). During passage of the water through the bed, calcium and magnesium ions in the water is exchanged for sodium ions in the resin. The removal of calcium and magnesium ions results in softened water.

Ion exchange (IX) comprises the reversible inter-change of cations and anions between the ion exchange resin and water. In softening applications, calcium and magnesium and other divalent cations are exchanged for sodium ions in a cationic exchanger. This application does not result in any desalination as it simply comprises an exchange of hardness-causing cations for sodium ions.

The ion exchange resins have a certain exchange capacity and when this is exhausted, the resin must be regenerated. Regeneration involves the passing of a brine solution through the resin bed to replace the calcium and magnesium ions with sodium ions. The waste stream resulting from regeneration contains the ions removed from the resin together with excess regeneration chemicals. This means that the waste contains very high concentrations of these ions and special care must be taken during handling and disposal of the waste to prevent contamination of water supplies.

What does nanofiltration (NF) softening of hard water involve?

NF is a pressure-driven membrane processes similar to RO. The main difference between the processes is that NF only removes larger ions such as hardness-causing ions while RO removes all ions. NF is therefore more and more used in the USA and Europe to soften hard.

What advanced processes are used for the clarification of water?

Nanofiltration, ultrafiltration (UF) and microfiltration (MF) are membrane processes similar to RO that are used for different purposes in water treatment. Whereas RO is used to desalinate water, the other processes are used to achieve different quality objectives.

Nanofiltration cannot be used for general desalination because monovalent ions such as sodium chloride readily permeate the membrane. However, divalent hardness-causing ions (calcium and magnesium) are rejected by the charged NF membranes and these membranes are therefore used to soften water.

Ultrafiltration membranes have larger pore sizes than RO and NF (1 to 50 nm) with operating pressures of 100 to 500 kPa. UF remove all colloidal material including all bacteria and most viruses from water.

Microfiltration uses membranes with pores within the size range of 50 to 150 nm) and with operating pressures of about 50 to 100 kPa. MF membranes therefore remove many (but not all) bacteria and colloidal matter.

Because of the much smaller pore sizes of UF compared to MF, the product water from a UF plant is of a much better quality than that of MF. All viruses and bacteria are normally removed by UF (because pore sizes are smaller that that of the micro-organisms) but in practice some organisms may still permeate the membrane at imperfections in the membrane. MF normally removes all bacteria but for the same reason as mentioned above some bacteria and many viruses may end up in the product water. However, because the general quality of the water produced is of such high quality only a small amount of disinfectant is required to ensure disinfection.

What are the advantages and limitations of UF and MF?

*The main **advantages** of UF and MF are:*

- *the good quality of the product water;*
- *the fact that they are relatively simple to operate; and*
- *the fact that they can be used in very small unit sizes.*

*The main **limitations** of UF are related to the fact that*

- *the membranes can be damaged or clogged if pretreatment, membrane operation and membrane cleaning are not properly controlled*
- *furthermore, UF treatment costs are relatively high compared to conventional treatment.*

MF is a simpler process to operate than UF, the membranes are cheaper and the operating costs are lower. The main limitation in the case of MF relates to proper operation and cleaning of the membrane to prevent fouling of the membranes.

Section 5D: Activated carbon adsorption processes for removal of dissolved organic substances from water

What is the role of activated carbon adsorption in water treatment?

Activated carbon adsorption is used mainly for the removal of dissolved organic substances from water. The substances that are removed include those that cause taste and odour problems in water, disinfection by-products, and specific substances such as organic pesticides.

All natural waters contain small amounts of dissolved organic material. Most of the organic material is harmless and does not cause any problems in water for domestic use. There are, however, a number of organic compounds that could be harmful or have other negative effects such as causing a bad taste in water. Dissolved organic substances are in general only partially removed by conventional treatment processes. Advanced processes such as activated carbon and some membrane processes have to be used to remove these substances.

How does adsorption by activated carbon take place?

Activated carbon is specially prepared to create a very well developed internal porous structure inside the carbon particles. The organic molecules move from the water into the very small pores where they are attracted to the surface and held onto the surface by physical and chemical forces. In this way the organic molecules are removed from the water.

Activation of carbon is done by means of high temperature treatment of certain types of coal or other material such as peach pips. The activation process involves heating and steam treatment of the coal to develop the porous structure required of activated carbon.

During water treatment the water comes into close contact with the carbon when it flows through a bed of carbon granules or is mixed with powdered carbon. As a result of the close contact the organic molecules diffuse into and inside the pores of the carbon where they are exposed to physical and chemical forces that keep the molecule weakly attached to the carbon surface. When the surface of the pore is completely covered by molecules, the carbon is said to be exhausted. This means that very little further adsorption can take place and the carbon has to be regenerated to restore its adsorption ability.

What does treatment of water by activated carbon adsorption involve?

There are two basic activated carbon systems that are used in water treatment:

- *The first is granular activated carbon (GAC) that is used as a bed of carbon granules through which the water filters.*
- *The second system is powdered activated carbon (PAC) in which the carbon is used in powder form. The powdered carbon is mixed with water and after a certain period separated from the water.*

Granular activated carbon is normally regenerated and reused, while powdered carbon is normally discarded after use.

Granular activated carbon adsorption takes place in filter beds of activated carbon. The carbon is placed in columns through which the water flows at a slow rate. The amount of carbon and the depth of the carbon layer in a filter and the flow rate determine the carbon contact time.

The contact time is an important parameter that determines the effectiveness of adsorption. Activated carbon does not have the same adsorptive capacity and rate of adsorption for all organic molecules. The longer the contact-time, the better the adsorption of even those compounds that are poorly adsorbed.

After a certain period of time the adsorption capacity of the carbon becomes exhausted. Exhaustion occurs when breakthrough occurs of the compound that is being removed. This means that the concentration of the particular compound starts to increase in the product water and breakthrough occurs when a pre-determined concentration is reached. The column must then be taken out of use and the carbon removed for regeneration.

Granular activated carbon columns are normally placed last in the treatment train where as much as possible of all contaminants have been removed. The reason is that carbon treatment is a costly process and other substances can reduce the adsorption capacity of the carbon if they are not removed.

Powdered activated carbon adsorption functions on the same principle as the granular process. The main difference is that the carbon in this case is added to the water in a fine powder form. Adsorption takes place in the same way as with granular carbon. However, in this case the carbon is added early in the treatment process because it has to be removed by sedimentation and sand filtration from the water. In this case the contact time is determined by the hydraulic retention time of the carbon before it is removed.

The most important parameters in this case are the **carbon dosage** and the **contact time.** The carbon dosage is determined in adsorption isotherm tests in which the optimum dosage is determined for removal of the substance of concern.

The main advantage of powdered carbon is that it need not be used on a continuous basis, but can be used as and when the need arises. This means the overall cost is less than in the case of granular carbon where the carbon inventory in the columns represents a large capital outlay.

Section 5E: Processes for the removal of iron and manganese from water

When is it necessary to remove iron and manganese from water?

Iron and manganese sometimes occur in groundwater and some polluted surface water sources in relatively high concentrations. These substances are soluble and invisible and are not removed by conventional treatment processes. However, during treatment and distribution iron and manganese may be oxidised and cause problems in the distribution systems and in the home. The iron and manganese products precipitate and settle in the systems and may cause discolouration of water and staining of clothes. It is therefore necessary to remove iron and manganese when they occur in higher concentrations than recommended for domestic use.

What does removal of iron and manganese involve?

Dissolved iron and manganese occur in reduced form in some waters (i.e. they can be oxidised). It is therefore necessary to oxidise the iron and manganese to forms that can subsequently be precipitated and removed during filtration. Oxidation can be achieved by means of oxidants such as chlorine, ozone, potassium permanganate or air. The iron is normally precipitated as ferric hydroxide, while manganese is precipitated as the oxide.

Dissolved iron occurs as Fe^{2+} and is readily oxidised to Fe^{3+} which can be precipitated as $Fe(OH)_3$ and be removed during sedimentation and sand filtration. Iron can be oxidised by aeration of the water, but sometimes a stronger oxidant such as chlorine may be necessary when the iron occurs in complexed form.

Manganese is not readily oxidised by air and stronger oxidants are required. Potassium permanganate is an effective oxidant for the oxidation of Mn^{2+} to Mn^{4+} that precipitates as MnO_2. The sand in a sand filter that is used for the removal of iron and manganese gets coated with a layer of manganese dioxide and this coated sand (green sand) assists in the removal of iron and manganese.

Section 5F: Processes for the removal of fluoride and nitrate from water

What does fluoride removal from water involve?

Fluoride removal from water is necessary when the fluoride concentration of the water exceeds the recommended values in the Assessment Guide. Defluoridation of water involves the removal of fluoride to acceptable levels for domestic use by means of adsorption onto activated alumina. The process takes place in an adsorption bed through which the water flows. The activated alumina becomes saturated with fluoride after some time and must therefore be reactivated periodically.

Activated alumina is a porous inorganic adsorbent that readily adsorbs fluoride. It performs much better than synthetic resins that have a much lower affinity than activated alumina. A typical fluoride removal plant consists of two or more adsorption beds packed with activated alumina. The pH of the water to be treated is adjusted to about 5,5 and passed down flow through a 1,5 m bed of activated alumina that removes the fluoride from the water.

The product water from the adsorption beds initially has a very low fluoride concentration. However, after some time the fluoride concentration starts to increase due to gradual fluoride breakthrough. The normal practice is to collect the product water in a storage tank to equalise the fluoride concentration. A breakthrough value for the fluoride concentration in the product water is determined at which the bed is taken out of use and regenerated. Normally, the water to be treated is then directed to a second (stand-by) unit while the saturated unit is regenerated.

The exhausted activate alumina is backwashed and then subjected to a two-step regeneration process, first with base followed by acid.

Fluoride removal is a specialised process and qualified operators are required to operate the process under closely controlled conditions. The expertise is normally not available in rural areas and fluoride removal would therefore only be possible with technical support. A system that has been proposed is that the activated alumina is supplied in a column to the plant, and when exhausted the column is replaced with a stand-by column. The exhausted column is then removed for regeneration by the supplier or contractor.

What does nitrate removal from drinking water involve?

The removal of nitrate from drinking water can be achieved by means of advanced processes, i.e. reverse osmosis, ion exchange and electrodialysis. It is also possible to remove nitrate from water by means of biological denitrification.

Many groundwater sources in South Africa contain elevated levels of nitrate due to pollution from pit latrines, pollution from animal wastes around boreholes and the excessive use of nitrogen fertilisers. Drinking water with a high nitrate concentration is harmful to humans, especially babies and infants (see *Assessment Guide*).

The advanced processes that can be used for nitrate removal are sophisticated, costly and require trained staff for operation. It will therefore, be feasible to use these processes for nitrate removal only under special circumstances. An example of such special circumstances may be when there is no alternative water source available and the cost to pipe in water or transport water to the area will be excessive.

Since high nitrate concentrations in water mainly affect small babies, it is often feasible to provide low-nitrate water from tanks to families with babies at clinics or other suitable locations rather than to treat the whole water supply to remove nitrate.

PART 6A

Specific issues in water treatment: Management, treatment problems, safety, fluoridation and waste disposal

PART 1

General aspects of water treatment

PART 2

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PART 6

Specific issues in water treatment: Management, treatment problems, safety, fluoridation, and waste disposal

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Section 6A: General management aspects of water treatment

What are the most important areas of management responsibility in water treatment?

The following are areas that demand management attention:

- *planning to ensure production output;*
- *leading and motivation of staff;*
- *quality control to ensure final water quality;*
- *responsibility to optimise treatment and to solve treatment problems.*

The objective of the operation of a water treatment plant is to produce water of a safe and acceptable quality on a sustainable basis. This requires management as well as operational input. Management input involves actions of planning, organising, leading and controlling of all facets of operation, maintenance, record keeping, training, communication, and ensuring that safety requirements are observed.

What does planning of water treatment activities entail?

Planning is one of the most important management functions to ensure the production of water of the required quality on a sustainable basis. Planning with respect to the following is essential: production schedules, maintenance schedules, plant upgrading or extensions, budgets, training programmes, quality surveillance.

Proper planning must be done of all the activities required to produce treated water of the required quality on a sustainable basis. Planning is often regarded as involving only long-term plans for plant extensions or upgrading. However, equally important is short-term planning for the day-to-day activities on a plant, medium-term planning to ensure that sufficient funds are available (budgets), and planning for specific items and programmes.

What does leading and motivation of staff entail?

Leading and motivation of staff entails actions and activities of a manager aimed at getting people to enthusiastically perform their tasks effectively. Key aspects of motivating staff include training, fair and equitable treatment of individuals, clear performance expectations, recognition of efforts, etc.

In order to ensure that no uncertainty exists about what is required from every member of the treatment plant team, an accurate and up to date **operating manual** must be available. Normally, in the case of a new scheme, the design engineer would be required to compile such a manual that contains a complete description and layout of the water scheme. It should contain the assumed design parameters with operating instructions and details of all mechanical and electrical plant and equipment. The manual should be updated as plant layout changes or new equipment is installed.

Management should ensure that the operating manual is available to operators and that instructions are followed to ensure that the processes are properly operated and controlled. Management must ensure that operating instructions are available to operators in the form and language that they can understand.

What does control of water treatment plant operation involve?

Control is an essential management function to ensure that plans are carried out and that objectives are met. The control of a water scheme includes control of all activities on a plant and supporting services to ensure that water of the required quality is produced on a sustainable basis.

There are many items and aspects that have to be controlled in a water treatment plant. The manner in which a manager can perform his/her control functions, is by means of:

- measuring operating conditions, activities and programmes, and the quality of treated water;
- compilation of reports that give a record of the measured items, whether it is the quality of treated water or the maintenance programmes carried out;
- measuring or evaluation of the records against standards for that particular item;
- identification of reasons for discrepancies; and
- taking of corrective action.

Log sheets play an important role in monitoring and controlling the performance of a treatment plant. The log sheets should make provision for the important operating parameters, including flow into and out of the works, turbidity and pH of the raw and final purified water. The residual chlorine in the final water is a very important parameter to ensure safety of the water. It should also make provision for the washing programme of filters, desludging of settling tanks and a water balance of the works, giving water production losses. Records should also be kept of electricity consumption (ammeter kWh and hour meter readings).

Laboratory analysis of water samples is essential to monitor and control plant operation. To do this a sampling and analysis schedule must be drawn up and implemented. The results from these programmes must be evaluated by the responsible manager to ensure compliance with requirements and to take corrective action if necessary.

Who should assume responsibility for management functions?

On a large treatment plant there is normally a plant manager on site who assumes overall management responsibility. There may also be lower level managers who are responsible for specific sections of the plant or for specific functions. However, on small, and rural treatment plants there may only be operators on the plant with people in management positions located somewhere else. In these cases the plant operators have to assume some management responsibilities.

Even on small or rural treatment plants management functions have to be performed. This means that the operator on such a plant must assume responsibility for some management functions such as planning. However, the overall control function cannot be delegated by the manager who has responsibility for the treatment scheme.

What level of training is required from treatment plant operators?

The level of training required differs for different types of treatment plants. In the case of advanced processes a relatively high level of training is required. The required level may be that *of a Technikon certificate or diploma. In the case of simple and smaller plants a lower level of training may be sufficient. The Department of Water Affairs and Forestry is in the process of reviewing the regulations that stipulate the number of people and qualifications required for different types and sizes of water treatment plants*

Section 6B: Treatment problems related to the operation of treatment plants

What are the main problems that could be encountered at a treatment plant?

The two main problems that could be encountered are:

- *the product water does not comply with quality requirements;*
- *the required volume of treated water cannot be produced.*

These problems may be caused by a variety of reasons, including:

- poor design of treatment plant or individual processes;
- processes not operated according to design criteria;
- break down of equipment;
- inadequate technical back-up;
- change in raw water quality;
- poor planning of operations;
- insufficient resources;

What should be done when problems occur on a treatment plant?

*If technical know-how is available, the **first step** is to identify and quantify the problem as accurately as possible. The **next step** is to determine possible causes of the problem and **the third step** is to take corrective action to remove or correct the cause of the problem.*

Depending on the nature of the problem and possible causes, these steps could involve relatively simple actions that can be carried out by operating staff, or on the other hand they could involve major investigations by specialists to solve the problem.

The nature of the problem determines the possible solutions and actions that could be taken. For example, if the problem is product water that does not comply with quality requirements and the cause is identified as changes in raw water quality, the solution is to do laboratory tests to determine the required dosages.

If the problem is caused by broken down equipment, it must be determined whether proper maintenance of the equipment was done, whether the equipment was operated as specified, or whether the breakdown was caused by poor specification of the equipment. The corrective steps must then be taken according to the cause of the problem.

In the case of a major problem that could not be solved by in-house expertise, the assistance of professional people must be obtained. Normally, the consultant who designed the plant is a good starting point. Other possible sources of assistance to solve problems are institutions such as the CSIR or universities.

Section 6C: Safety issues on a treatment plant

What safety requirements must be observed on a treatment plant?

The Occupational Health and Safety Act (Act 85 of 1993) stipulates safety regulations on treatment plants. It is the responsibility of management to ensure that everyone on a treatment plant is fully aware of all safety requirements and that training is provided if necessary.

The Act stipulates that the responsibility for unsafe conditions or procedures devolves to the Chief Executive or highest level of an operating authority. It is not unusual for the manager to be prosecuted for an accident that takes place on his works. It is therefore important that all operations comply with the requirements and spirit of the regulations.

The National Occupation and Safety Association (NOSA) strives to cultivate an awareness of safety and safe working procedures. Their aim is to promote safety in the workplace and they advocate certain measures such as that certain areas are to be demarcated where protective equipment must be worn. This applies especially where hazardous chemicals are handled at a water treatment works.

Registers must be kept of inspections on safety equipment.

What are the important safety aspects that must be observed in handling and storage of hazardous chemicals?

Water treatment plant personnel use different types of chemicals during their normal operational activities. Some of these chemicals may be hazardous if they are not handled properly. For this reason a face mask and protective clothing must be worn during handling of hazardous chemicals. In the case of a spillage or leakage, proper procedures must be followed. All staff on a treatment plant who might be exposed to chemicals must be given specific safety training.

Chemicals such as chlorine (gas and pellet form), ferric chloride, lime, acid and polyelectrolytes should be handled with care and in accordance with safety prescriptions, as they could be harmful.

If chlorine gas is used for disinfection, operators and other staff must be given specific training in the handling of containers and the operation of chlorinators. Showers and eye wash points must be placed at strategic points where people could be exposed to chemicals.

Section 6D: Fluoridation of water

Why is it necessary to fluoridate water?

A small amount of fluoride in the diet is essential for the development of strong and healthy teeth. Since the amount of fluoride taken in with food is limited, the fluoride intake has to be supplemented. It has been shown in many studies that the fluoridation of drinking water is the most feasible way of supplementing the fluoride intake of communities.

Is fluoride not a poisonous substance?

Fluoride is beneficial if taken in small quantities. However, if the daily intake of fluoride exceeds a certain level over a long period, it normally has harmful effects.

There is a long and ongoing debate over the benefits of fluoridation of drinking water versus the dangers and negative effects of fluoridation. Although the benefits of fluoridation are not disputed, many groups are strongly opposed to fluoridation of drinking water.

One of the main arguments against fluoridation is that people do not have a choice to take or not to take fluoride when drinking water is fluoridated. Another argument against fluoridation is that the practice would create the possibility of accidents if excessive amounts are added to water due to poor control of operating plants. The counter argument is that high concentrations of fluoride have to be taken in the drinking water over a long period before harmful effects would develop.

In spite of the opposition against fluoridation, the South African government has decided in principle that community water supplies will be fluoridated. There are certain situations that will be exempted from fluoridation (small operations), but all the regulatory aspects have not been finalised.

Why must certain waters be defluoridated?

In some areas in South Africa the fluoride concentration in natural ground water is excessively high. In these areas many people experience the effects of dental fluorosis (discolouration and mottling of teeth). Where the high fluoride water is the only water source, it is necessary to use a specialised process to reduce the fluoride in the water to acceptable levels.

What does fluoridation of water involve?

Fluoridation of water involves the addition of predetermined amounts of a fluoride-containing chemical to the water during the water treatment process in order to increase the fluoride concentration in the water to a specific level.

The amount of fluoride to be added to water during treatment is determined by the concentration of fluoride that the treated water should have. This concentration is a function of the average maximum daily temperature of the area, because the temperature determines largely how much water people drink. This determines the amount of fluoride taken in daily. Tables of fluoride concentration in treated water at different temperatures will form part of the guidelines on fluoridation that will be made available before fluoridation is implemented.

The two chemicals that are mostly used for fluoridation in other countries are sodium fluoride (NaF) and sodium silicofluoride (Na_2SiF_6). Sodium fluoride is a white, odourless material available either as a powder or in the form of crystals. It dissolves in water to give a solution of about 4% at ambient temperatures typically encountered in SA. Approximately 1,58 kg of sodium fluoride added to 1 Mℓ of water gives a concentration of 0,7 mg/ℓ fluoride, the concentration accepted for South African conditions.

Sodium silicofluoride is a white odourless crystalline material. It has a much lower solubility in water than sodium fluoride (about 0,44%). Approximately 1,16 kg of sodium silicofluoride added to 1 Mℓ of water will give a concentration of 0,7 mg/ℓ fluoride.

Three methods of feeding fluoride compounds to water is in general use:

- dry chemical feeder for dry compounds;
- solution feeder for dissolved fluoride compounds;
- saturator feeder for smaller systems.

The first two methods are normally used at large treatment plants, while the saturator is restricted to smaller systems. The saturator feeding system is based on the principle that a saturated fluoride solution will result if water is allowed to trickle through a bed of sodium fluoride crystals. The saturated solution is then fed by a small pump into the main water stream being treated.

Section 6E: Handling and disposal of wastes at a water treatment plant

What waste products are generated during water treatment?

The substances removed during water treatment constitute the waste products that are formed. These substances include debris removed from the raw water by screens as well as the suspended and colloidal material removed during sedimentation and filtration. In the case of specialised process, different waste streams are formed such as the brine from desalination plants.

How can the waste products be handled and disposed of?

There are different methods of handling and disposal of the waste products. Organic wastes must be stabilised before disposal, while inorganic wastes are normally concentrated or dewatered before disposal.

The **sludge** produced at a water treatment plant is constituted of the colloidal and suspended material that settles in the sedimentation tank. The quantity and quality of the sludge is a function of the raw water quality and the type of coagulant and flocculant used. For turbid waters (suspended solids 1 000 mg/ℓ or more), about 1 – 3% of the volume of water treated can be generated as sludge.

The aim in sludge handling is to discharge the sludge as concentrated as possible as the water discharged with the sludge is very seldom reclaimed on a small works, and is therefore lost.

In a small water treatment works holding ponds or dams are provided of sufficient size to hold all the sludge produced at the water treatment works. The normal practice is to have two dams side by side. This would allow the waterworks operator to take one dam out of operation, allow the clear water on top of the sludge layer to drain out, or evaporate. The sludge dries out with time and can then be removed and used as landfill on a suitable site.

The solids remaining in the water after sedimentation are removed in the sand filters. The suspended solids remain in the upper layer of the sand in the filter bed and are removed during back washing of the filter bed. The **filter wash water** normally contains 100 - 1 000 mg/ℓ of solids.

The current practice for handling the wash water in small plants is to gravitate the water to a holding tank or sludge lagoon where most of the suspended matter settles and the overflow runs into the nearest stream. At larger works the supernatant from the wash water is returned to the head of the works, after settling of the suspended solids.

If the water treatment works is run efficiently the filter wash water is normally between 2% to 5% of the volume of water treated.

In most water treatment works **chemical wastes** are also produced. The chemicals used at the plant, i.e. the main coagulant normally either a metal hydroxide, or polyelectrolyte, a stabilising agent such as lime or sodium carbonate and chlorine, either in liquid/gas or dry granular- form are fed into day tanks where they are diluted to be fed with dosing pumps or gravity feeders to the incoming raw water.

When these tanks are cleaned, chemical wastes are produced. It is good practice to clean these day holding tanks on a regular basis and drain the residues into the filter wash water/sludge system where it will find its way in the sludge lagoons. The residues should not be discharged in a natural water course as it could lead to fish kills, as slugs of the residues could dramatically change the pH conditions is small pools.

Screenings are substances removed by screens placed at the entrance of a water treatment works. The purpose is to keep out weeds, algae and floating debris. Screen openings are designed to remove specific matter. These screenings consist of grass, weeds, wood, etc. and could be disposed of in fills or could be burned.

Algae can be removed by mechanical screens or strainers, or by a flotation plant where the water treatment plant has to deal with eutrophic waters. The primary aim is to reduce the volume of scum, i.e. to drain the water from it. These organic residues can be disposed of in sludge lagoons, to an existing sewage works, or dumped on waste heaps. The dried algae can also be composted and then disposed of in landfills.

The processes used for the removal of dissolved inorganic substances always produce **rejects and concentrates** which must be disposed of and which require special methods to ensure that the environment is not polluted. The usual method of disposal is in a lined dam with sufficient area to allow for full evaporation and ensuring that overflow or leakage does not take place.

REFERENCE BOOKS

The following list contains some general water treatment handbooks. Some focus more on design aspects while others are more descriptive and process oriented.

1. American Water Works Association (2000). *Water quality and treatment: a handbook of community water supplies*. McGraw-Hill Inc.
2. American Water Works Association, American Society of Civil Engineers (1998). *Water treatment plant design*. McGraw-Hill Inc.
3. C Binnie, M Kimber and G Smethurst (2002). *Basic water treatment*. IWA Publishing.
4. JA Cotruvo, GF Craun and N Hearne (1999). *Providing safe drinking water in small systems.* Lewis Publishers.
5. Degremont (1991). *Water treatment handbook*. Lavoisier Publishing.
6. MJ Hammer (1986). *Water and wastewater technology*. Prentice-Hall.
7. C Kerr (1990). *Community health and sanitation.* Intermediate Technology Publications.
8. FA Van Duuren (1997). *Water purification works design.* Water Research Commission.