# Lesson D2

# WASTEWATER REUSE TECHNOLOGIES

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# Overview and summary

Wastewater is becoming an increasingly important source of water for reuse especially for irrigation purpose. The demands of growing communities for both food and water require the agricultural sector not only to increase food production but also to reduce its use of natural water resources. At the same time the amount of sewage is increasing. The reuse of wastewater primarly for irrigation can be a solution.

This lesson deals with the wastewater treatment technologies which are able to comply with the standards for water reuse. Usually the hygienic standard cannot be met by conventional treatment (even if it is highly efficient in removal of organics and nutrients) like activated sludge and secondary clarifier. Organic compounds and nutrients can be, contrary to conventional treatment goals, useful for irrigation because they have an additional fertilising effect on the fields.

The authors recommend therefore membrane filtration, reverse osmosis and UV radiation to disinfect the treated wastewater and to achieve the highest standard which can be used for almost all purposes. In case of reuse in restricted agriculture, other options are suitable like slow sand filtration or ponds with long residence time.

# 1. Introduction

## 1.1 Why thinking of wastewater reuse?

Considering the reuse of wastewater seems to be a silly idea itself because the term "wastewater" already contains the word "waste" which refers to something useless. But some important facts show that the question deserves its standing.

### 1.1.1 Lack of proper water and wastewater management

- 5 million people die due to water pollution problems every year. Additionally, about 20% of the world population have less than 20 litres of water per day and the world water consumption quadrupled in the last 50 years. During the next years, water demand will continually increase due to population growth (WBGU, 1999).
- 2 billion people are currently lacking access to sanitation and water; (WHO, http://www.euro.who.int/eprise/main/WHO/Progs/WSN/Home).
  Wastewater reuse can be a good option to improve this world wide situation.

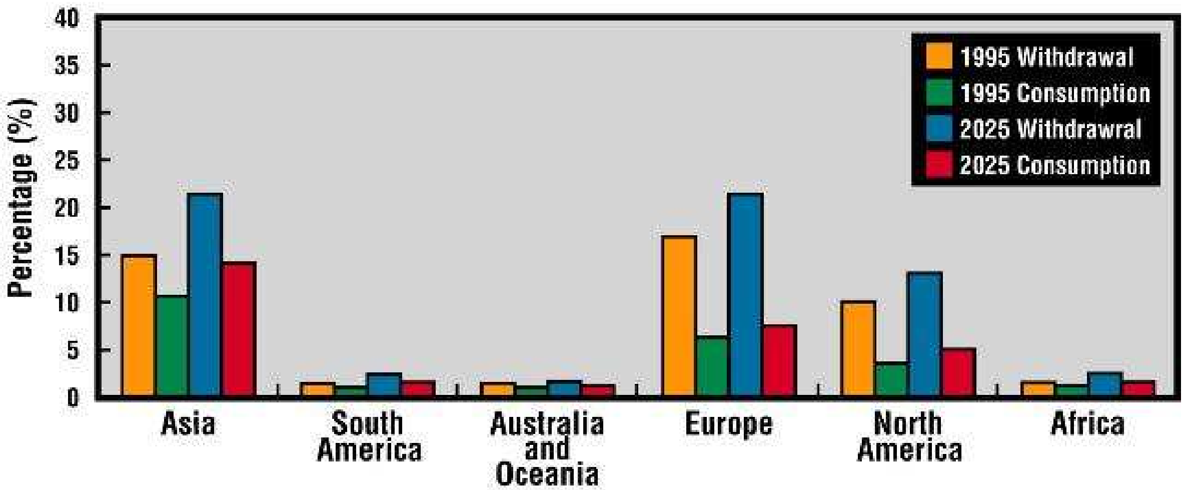


***Figure 1: Water use and withdrawals (source: www.unesco.org)***

### 1.1.2 Water imbalance management

The world is suffering the beginning of a "World water crisis". Many regions of the world are concerned and some are specifically endangered. The imbalance between water consumption through use and recharge of natural surface water (withdrawal) have sharply increased. The figure below shows clearly that Asia, Europe, and Northamerica already have this imbalance. It will increase in the coming decades, if nothing is done against it.

### 1.1.3 Presence of arid regions

Due to climate change or simply by men's activity like irrigation for agriculture, many regions have seen their availability of fresh water decreasing and even disappearing what led to new deserts, arid and semi-arid regions. The situation is particularly critical in the Middle East and North Africa where almost all conventional water resources have been exploited like in Saudi Arabia, the Arab Emirates, Oman, Qatar, Kuwait, Bahrain, Yemen, Jordan, Israel, Palestinian territories, and Libya *(Lazarova, 2001).*

### 1.1.4 Most of global water contains salt

The world only disposes 5% fresh water, 95% is sea water, rich of salt. Salt water cannot be used directly by plants and. They need fresh water for their survival. In regions where desalinated water is the main water source, activities like e.g. agriculture that utilises about 70% of global fresh water today, cannot be overcome with desalinated water. In such a case reuse of wastewater can be another option.

## 1.2 Planning issues

Wastewater reuse always comes along with public acceptance, environmental issues and investment costs. One should ensure that these basic requirements are fulfilled. Good understanding and clear definition of the whole procedure must be performed; it is necessary to do a preliminary study. This study must assess the effluent quality (water treatment and disposal needs), identify a potential reclaimed water market and set up an estimation of investment costs of the reclaiming procedure. The study must also provide insight into the viability of wastewater reuse and starting point for detailed planning. Table 1 summarises the major elements which need to be considered.

*Table 1: Summary of major elements of wastewater reuse planning (Asano, 1998)*

| Planning phase | Objective of planning |
|---|---|
| Assess wastewater treatment and disposal needs | Evaluate quantity of wastewater available for reuse and disposal options |
| Assess water supply and demand | Evaluate dominant water use patterns |
| Analyse market for reclaimed water | Identify potential users of reclaimed water and associated water quantity and quality requirements |
| Conduct engineering and economic analyses | Determine treatment and distribution system requirements for potential users of reclaimed water |
| Develop implementation plan with financial analysis | Develop strategies, schedules and financial options for implementation of project |

### 1.2.1 Market analysis

Once quality and quantity of reclaimed water are determined, a market analysis to identify its potential users has to be conducted. In particular water retailer records of the relevant zone are helpful. Potential users should be contacted and sites reusing effluent visited to detect eventual onsite problems or to define water systems modifications needed to accommodate the reuse. One should try to identify financial expectations of the users. These measures should be undertaken to gain the user confidence in the project and secure the market of reclaimed water.

### 1.2.2 Monetary analysis

When social, technical, and environmental concerns are considered in a reclaimed water project, the monetary aspect important for the realisation of the project has to be analysed. The economic analysis focuses on costs invested to construct and operate the reclaimed procedure, while the financial analysis is based on the market value of goods and services, including subsidies or monetary transfers (Asano, 1998).

Additionally, attention shall be given to maintenance aspects that will also create running costs.

For further information about financial aspects see lesson D3.

# 2. Overview of basic treatment technologies

The first step in wastewater treatment is usually a physical pretreatment.
The following biological treatment is the main efficient technology to degrade the majority of organic compounds, parts of the nutrients and to decrease the level of microbiological pollution. The most developed techniques at the level of urban treatment plants are intensive biological processes (removal of organics and nitrogen). Their principle is to enforce and concentrate the natural phenomena of organic and nutrient removal in a small space. They are especially appropriate and effective for high concentrated domestic wastewater and blackwater.

The following technologies are some examples of those used for an intensive treatment:

- Activated sludge plant / Sequencing batch reactor (SBR)
- Trickling filter
- Rotating biological contactors
- Anaerobic treatment systems

On the other hand there are extensive treatment techniques available which are less intensive processes close to nature, use very little energy and often much more space.

- Constructed wetlands (soil filter)
- Natural lagoon, stabilisation pond
- Slow sand filtration

## 2.1 Activated sludge plant / Sequencing batch reactor (SBR)

The activated sludge process is an aerobic (oxygen-rich), continuous-flow biological method for the treatment of domestic and biodegradable industrial wastewater, in which organic matter is utilized by microorganisms for life-sustaining processes, that is, for energy for reproduction, digestion, movement, etc. and as a food source to produce cell growth and more microorganisms. During these activities of utilization and degradation of organic materials, degradation products of carbon dioxide and water are also formed.

The activated sludge process is characterized by the suspension of microorganisms in the wastewater, a mixture referred to as the mixed liquor. Activated sludge is used as part of an overall treatment system, which includes primary treatment of the wastewater for the removal of particulate solids before the use of activated sludge as a secondary treatment process to remove suspended and dissolved organic solids.

The conventional activated sludge process consists of an aeration basin, with air as the oxygen source, where treatment is accomplished. Soluble (dissolved) organic materials are absorbed through the cell walls of the microorganisms and into the cells, where they are broken down and converted to more microorganisms, carbon dioxide, water, and energy. Insoluble (solid) particles are adsorbed on the cell walls, transformed to a soluble form by enzymes (biological catalysts) secreted by the microorganisms, and absorbed through the cell wall, where they are also digested and used by the microorganisms in their life-sustaining processes. The microorganisms that are responsible for the degradation of the organic materials are maintained in suspension by mixing induced by the aeration system.

The aeration basin is followed by a secondary clarifier (settling tank), where the flocs of microorganisms with their adsorbed organic materials settle out. A portion of the settled microorganisms, referred to as sludge, are recycled to the aeration basin to maintain an active population of microorganisms and an adequate supply of biological solids for the adsorption of organic materials. Excess sludge is wasted by being piped to separate sludge-handling processes. The liquids from the clarifier are transported to facilities for disinfection and final discharge to receiving waters, or to tertiary treatment units for further treatment.

Activated sludge processes are designed based on the mixed liquor suspended solids (MLSS) and the organic loading of the wastewater, as represented by the biochemical oxygen demand (BOD) or chemical oxygen demand (COD). The MLSS represents the quantity of microorganisms involved in the treatment of the organic materials in the aeration basin, while the organic loading determines the requirements for the design of the aeration system.

The sequencing batch reactor (SBR) is a fill-and draw activated sludge system for wastewater treatment. In this system, wastewater is added to a single “batch” reactor, treated to remove undesirable components, and then discharged. Equalization, aeration, and clarification can all be achieved using a single batch reactor, while the steps are performed after another. Aerobic decomposition, settling, and return occur in the same chamber. Air is bubbled through the liquid during the decomposition cycle. The bubbler shuts off, and the wastewater goes through a settling cycle (see figure 2). Once the bubbler turns back on, the tank re-enters the decomposition cycle, and settled bacteria mixes back into the aerobic environment. After settling of bacteria and solids, the treated effluent is discharged to the soil treatment system. Bacteria settle out more consistently in this kind of tank, but since it has more moving parts and requires a controller, it has more potential for mechanical and electrical failure.

To optimize the performance of the system, more batch reactors can be used in a predetermined sequence of operations. SBR systems have been successfully used to treat both municipal and industrial wastewater. They are uniquely suited for wastewater treatment applications characterized by low or intermittent flow conditions with low ground space demand, while conventional activated sludge technologies have a high demand on area.

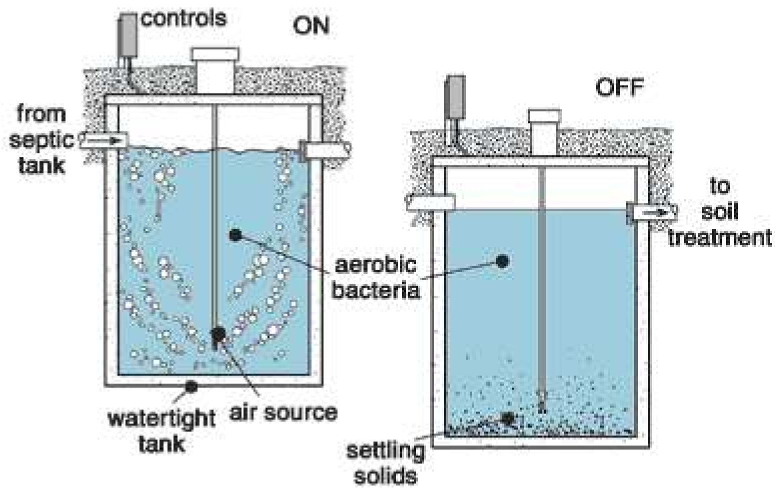


***Figure 2: Sequencing batch reactor during aeration (left) and settling (right)-*** *(Source University of Minnesota)*

## 2.2 Trickling filter (TF)

A trickling filter (TF) is a wastewater treatment system that biodegrades organic matter and can also be used to achieve nitrification. The wastewater trickles through a circular bed of coarse stones or plastic material. A rotating distributor (a rotating pipe with several holes across it) evenly distributes the wastewater from above the bed. The microorganisms in the wastewater attach themselves to the bed (also known as the filter media), which is covered with bacteria (see figure 3). The bacteria break down the organic waste and remove pollutants from the wastewater.

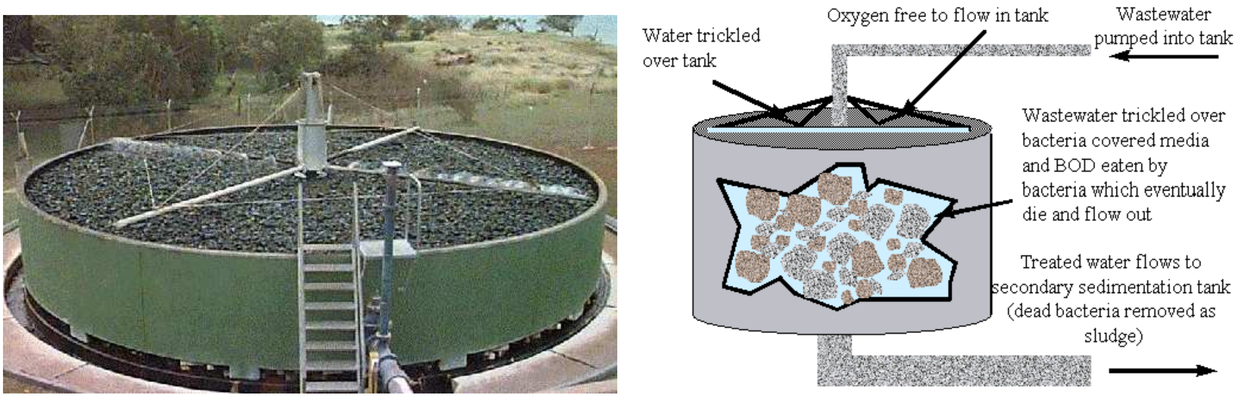


***Figure 3: Trickling filter***

When excess nutrients became a concern, it became necessary to adapt “conventional” sewage treatment systems to meet the increased oxygen demand placed on receiving waters by high ammonia nitrogen concentrations in wastewater effluents. TFs and other attached-growth processes proved to be well-suited for the removal of ammonia nitrogen by oxidizing it to nitrate nitrogen (nitrification).

## 2.3 Rotating biological contactors (RBC)

The Rotating Biological Contactor Process (RBC) consists of a series of discs attached to a common shaft. The discs are partially submerged in a trough of continuously flowing wastewater. As the discs rotate, a film of microorganisms growing on the discs consume oxygen from the air and substrate from the wastewater (see figure 4).

In this way, organic materials (substrate) are removed from the wastewater. The rotation of the RBC disks can be achieved by a motor and drive system on each shaft or by an air drive system with a coarse bubble diffuser at the bottom of the tank supplying air that is caught by the air cups attached to the disks. The rotation of the disks imparts a shear force to the biofilm, keeping its thickness relatively constant by removing the cells generated by consumption of the substrates. Rotation of the disks also serves to provide oxygen required for the growth of biomass and substrate degradation. A settling tank is normally required to remove the biomass from the effluent.

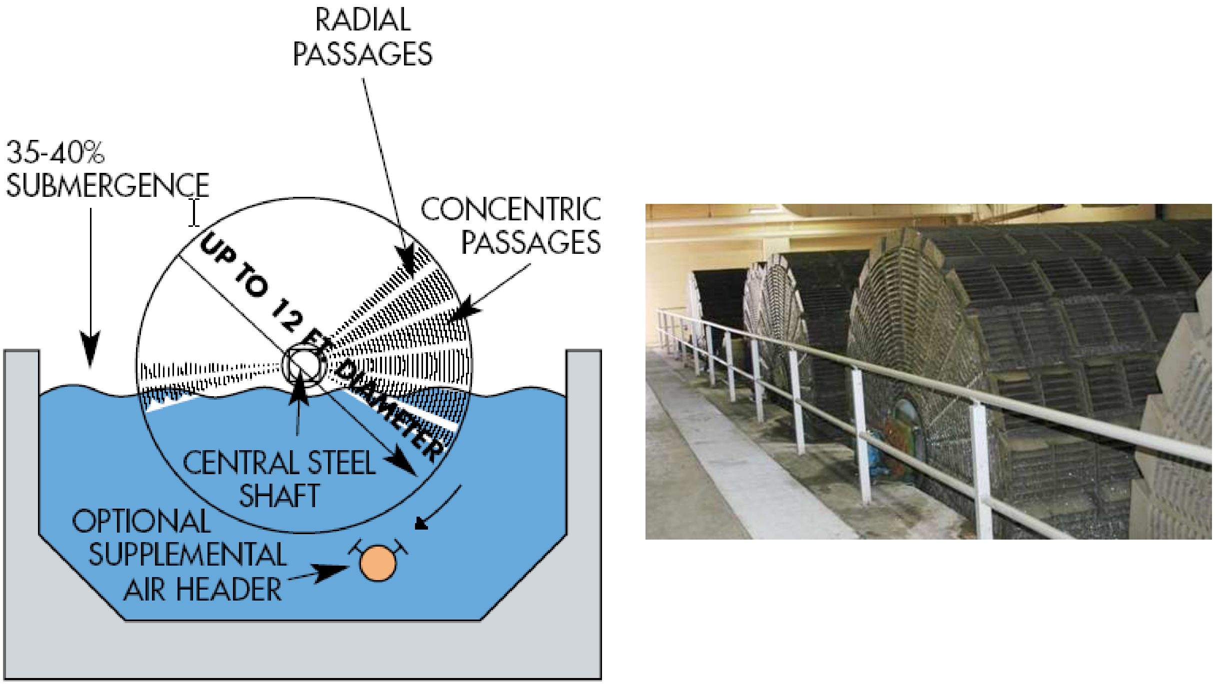


***Figure 4: Conventional Rotating biological contactors system*** *(Source USFilter and ChevronTexaco)*

### 2.4 Anaerobic treatment systems

Different types of anaerobic treatment systems can be used as pretreatment devices for high-strength wastewater and some onsite pretreatment applications. Two examples are in shown in figure 5. Anaerobic treatment systems are widely used in hot climates. These systems can reduce high BOD and TSS to levels that can be readily treated by typical aerobic processes such as suspended and fixed growth aerobic units or recirculating/intermittent media filters. International literature contains numerous references to anaerobic treatment systems.

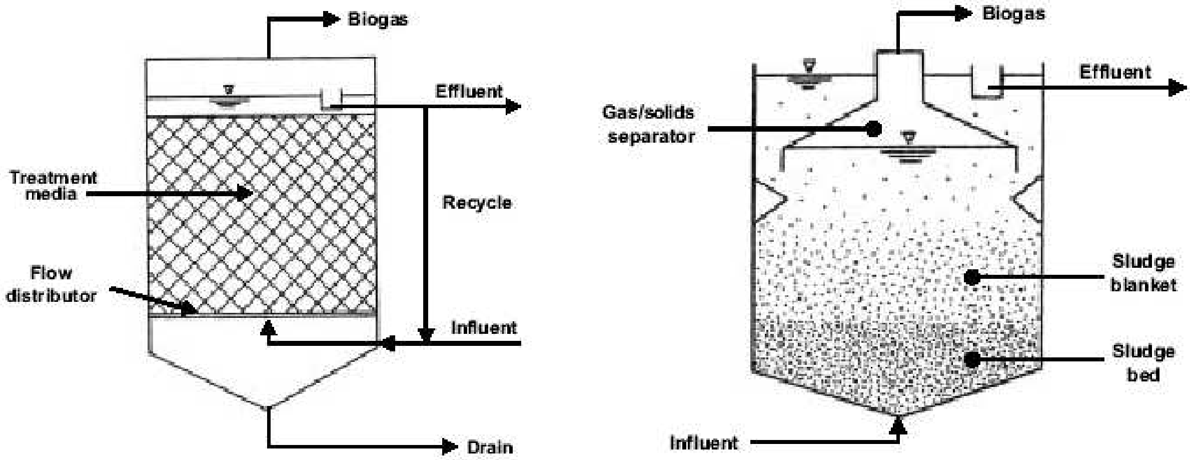


***Figure 5: Two different types of Anaerobic treatment systems: Schematic of the upflow anaerobic filter process (left) an upflow anaerobic sludge blanket process***

## 2.5 Constructed wetlands (soil filter)

Constructed wetlands are small artificial wastewater treatment systems consisting of one or more shallow treatment cells, with herbaceous vegetation that flourish in saturated or flooded cells. There are two basic types of constructed wetlands, Free Water Surface constructed wetlands (FWS) and Vegetated Submerged Bed constructed wetlands (VSB).

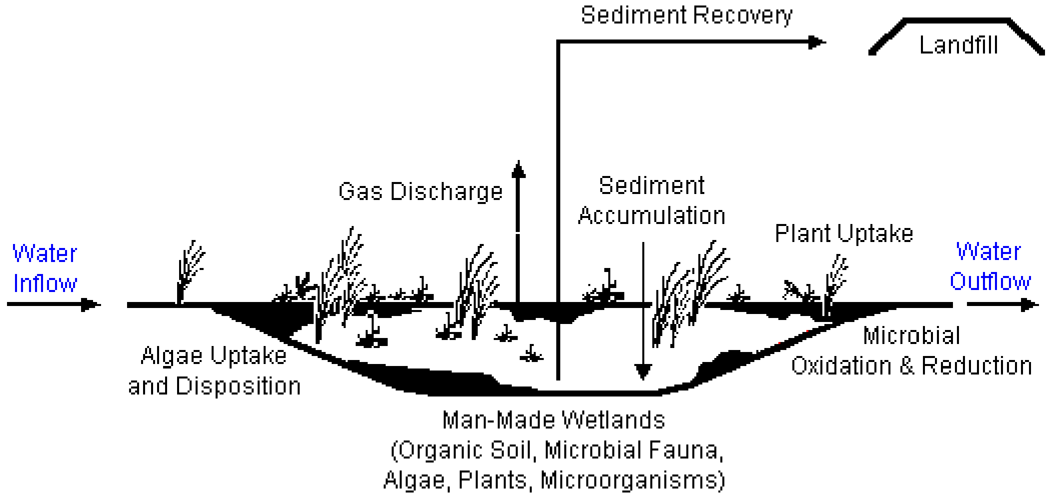


***Figure 6: Constructed Wetlands***

FWS wetlands have a combination of open water areas with some floating vegetation as well as emergent plants rooted in the soil bottom. They are usually more suitable to warmer climates, because biological decomposition rates are temperature dependent, decreasing with decreasing water temperature. In these systems wastewater is treated by the processes of sedimentation, filtration, digestion, oxidation, reduction, adsorption and precipitation.

VSB constructed wetlands, also known as subsurface flow wetlands, Consist of gravel soil beds planted with wetland vegetation. These systems have many of the same features of the FWS but are distinguished by their subsurface hydraulic grade. Unlike the FWS wetland, the wastewater stays beneath the surface, flows in contact with the roots and rhizomes of the plants and is invisible or unavailable to animals. VSB constructed wetlands are generally lower in cost and maintenance requirements than the FWS constructed wetlands.

## 2.6 Natural lagoon, stabilisation pond

Lagoon systems are shallow basins which hold the waste-water for several months to allow for the natural degradation of sewage. These systems take advantage of natural aeration and microorganisms in the wastewater to renovate sewage.

## 2.7 Membrane reactor

Membrane processes are primarily used for separations. As a unit operation they have several major attributes:

- They provide a well-defined, mass transfer surface area that is mostly independent of the operating conditions
- Their surface area provides selective transport of specific components between two phases
- Membrane process units are built of modules
- As devices, membrane modules typically provide high surface area per unit volume (the highest being for hollow fiber forms) and are relatively easy to operate
- The scale-up of membrane processes is usually linear with load

The selective separating layer in the module is what is typically called 'the membrane.' Currently membranes made from a broad spectrum of polymeric and inorganic compounds are commercially available.

There are many membrane processes or unit operations. They are differentiated primarily on the basis of the driving force for mass transfer through the membrane, the predominant transport mechanism, and the phases that are present. Each membrane unit operation has its own specific nomenclature, engineering characteristics, and concerns, but it is also possible that a given membrane module can be used for different membrane unit operations. Due to their very high capital, operation and maintenance costs, they are only suitable for special applications in wastewater treatment for developing countries. For application in wastewater treatment see Chapter 3.4.

## 2.8 Slow sand filtration

Slow sand filtration can be very effective to treat municipal treatment in a tertiary step. The application of slow sand filtration (SSF) is feasible on a biologically pre-treated wastewater. The mechanisms for water impurities removal are mechanical filtration, enhanced biological activity on surfaces and adsorption. These features make SSF very attractive for advanced treatment of effluents. The key parameters of the SSF are the depth of the sand filter and the effective size of the sand. The effective size of the sand is usually 0.15 – 0.4 mm and the depth between 0.6 to 1.0 m. The filter doesn't need to be backwashed regularly, it is easy to remove the first layer on the surface and to replace it with new material. The used material can be recycled or disposed. The SSF is able to remove significantly bacteria so that the effluent is almost hygienically safe.

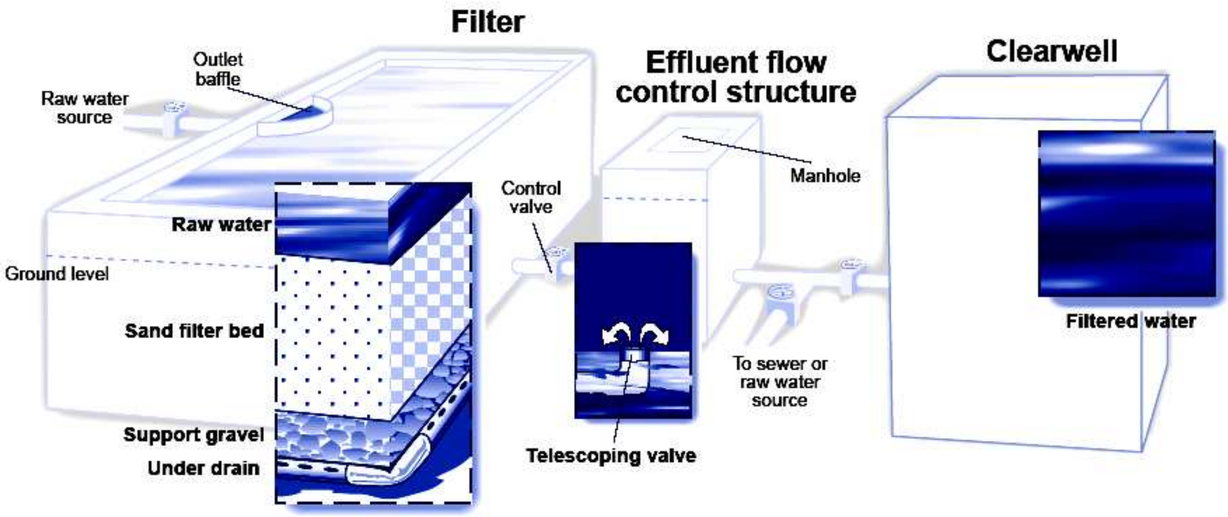


**Figure 7: Slow sand filtration system** (source: National Drinking Water Clearinghouse)
Table 2 gives an overview of the common technologies and their characteristics

***Table 2: Wastewater technologies and their characteristics (Wendland, 2003)***

| Technology | Climate | Ground space demand | Energy costs | Capital and operation costs | Technical knowledge for operation and maintenance | Hygienic Quality in the effluent |
|---|---|---|---|---|---|---|
| Activate sludge plant (SBR) | Good biological activity in warm climate, evaporation in warm and dry climate | low | high | High capital costs, lower operation and maintenance costs | high | Elimination by factor 10-100 |
| Trickling filter, rotation disc contactor | Independent, usually built in house | low | medium | High capital, operation and maintenance costs | medium | Elimination by factor 10-100 |
| Anaerobic reactor | No evaporation problems, the warmer, the better the biological activity | medium | Energy recovery | High capital costs but energy recovery of biogas | high | Elimination by factor 10-100 |
| Constructed Wetland | Transpiration depends on the type of plants | high | low | Low capital, operation and maintenance costs | medium | 1 log elimination |
| Lagoons (aerated or natural) | High evaporation rate in dry climate | high | Low for natural, medium for aeration | Low capital, operation and maintenance costs | low | > 3 log elimination for long residence time |
| Membrane reactor | Evaporation in warm and dry climate | very low | very high | High capital, operation and maintenance costs | high | Hygienically safe (UF) |
| Slow sand filtration | Evaporation in warm and dry climate | medium | medium | Low capital, operation and maintenance costs | medium | Hygienically almost safe |
| UV, Chlorine Ozone | Needs building | low | high | Low capital, high operation and maintenance costs | high | Hygienically safe |

The basic technologies applied in developed countries, primarily activated sludge process, are not able to meet common hygienic standard. The effluent of these plants contains still many pathogens which are usually highly diluted in the receiving waters so that they don´t harm. Only the filtration, physical and chemical technologies can meet the hygienic standards mostly required for water reuse.

# 3. Disinfection technologies

The regulation in many countries requires the disinfection of the treated water in order to protect farmers and consumers. The goal of disinfection is the removal, killing or inactivation of pathogens so that there is no danger for health any more. This means at least a reduction of 4-5 logs in municipal wastewater.

The conventional wastewater treatment with physical and biological technologies is not able to disinfect the wastewater efficiently. Since organic load and suspended solids have an negative impact on the disinfection rate, it is recommended to treat the wastewater biologically before disinfection.

Disinfection methods can generally be grouped in two types: physical and chemical methods. An overview is given in table 3.

***Table 3: Disinfection efficiency of several technologies (Jacangelo & Trussell, 2001)***

| Disinfection Technology | Bacteria | Viruses | Protozoa | Total |
|---|---|---|---|---|
| Chlorine gas | +++ | +++ | +/- | ++ |
| Chloramine | + | - | -- | - |
| Chlorine dioxide | ++/+++ | ++/+++ | + | ++ |
| Ozone | +++ | +++ | ++/+++ | ++/+++ |
| UV | ++/+++ | + | ++ | ++ |
| Ultrafiltration (<0.01 µm) | +++ | +++ | +++ | +++ |

+++ very good, ++ good, -bad, --very bad

If all methods with chlorine are considered as one there are three common methods of disinfection in general: Chlorination, ozonation, and ultraviolet (UV) disinfection. Disinfection is considered to be the primary mechanism for the inactivation/destruction of pathogenic organisms to prevent the spread of waterborne diseases to downstream users and the environment. It is important that wastewater be adequately treated prior to disinfection in order for any disinfectant to be effective. All three disinfection methods can effectively meet the discharge permit requirements for treated wastewater. However, the advantages and disadvantages of each must be weighed when selecting a method of disinfection.

## 3.1 Chlorine disinfection

Chlorine, the most widely used disinfectant for municipal wastewater, destroys target organisms by oxidation of cellular material. It may be applied as chlorine gas, hypochlorite solutions, and other chlorine compounds in solid or liquid form.

Chlorination is a well-established technology. Presently, chlorine is more cost-effective than either UV or ozone disinfection (except when dechlorination is required and fire code requirements must be met). The chlorine residual that remains in the wastewater effluent can prolong disinfection even after initial treatment and can be measured to evaluate the effectiveness. Chlorine disinfection is also reliable and effective against a wide spectrum of pathogenic organisms and is effective in oxidizing certain organic and inorganic compounds including certain noxious odors.

But is has to be considered that the chlorine residual, even at low concentrations, is toxic to aquatic life and may require dechlorination. All forms of chlorine are highly corrosive and toxic. Thus, storage, shipping, and handling pose a risk, requiring increased safety regulations. In some cases Chlorine oxidizes organic matter in wastewater, creating more hazardous compounds. In all cases the level of total dissolved solids is increased in the treated effluent. Another problem in developing counries can be that some parasitic species have shown resistance to low doses of chlorine ans the long-term effects of discharging dechlorinated compounds into the environment are unknown.

***Table 4: Chlorine dosage ranges according to wastewater* type (Rowe & Abdel-Magib, 1995)**

| Type of wastewater | Dosage ranges (mg/l) |
|---|---|
| Raw | 6 – 40 |
| Primary effluent | 5 – 24 |
| Secondary effluent | 2 – 9 |
| Filtered effluent | 1 – 6 |

## 3.2 Ultraviolet disinfection system

An Ultraviolet (UV) disinfection system transfers energy from a mercury arc lamp to an organism's genetic material. When UV radiation penetrates the cell wall of an organism, it destroys the cell's ability to reproduce. UV radiation, generated by an electrical discharge through mercury vapor, penetrates the genetic material of microorganisms and retards their ability to reproduce. The effectiveness of a UV disinfection system depends on the characteristics of the wastewater, the intensity of UV radiation, the amount of time the microorganisms are exposed to the radiation, and the reactor configuration. For any one treatment plant, disinfection success is directly related to the concentration of colloidal and particulate constituents in the wastewater.

The main components of a UV disinfection system are mercury arc lamps, a reactor, and ballasts. The source of UV radiation is either the low-pressure or medium-pressure mercury arc lamp with low or high intensities.

Physical methods include *ultraviolet rays* (UV), a more than 100 years old technique. The wastewater must flow through a chamber where it is exposed to UV light at a wavelength of 200 to 310 nm. The inactivation of the pathogens takes place due to the absorption of UV via proteins and the cells are damaged irreversibly.

The advantages (Cornel & Weber, 2004), no unwanted by-products, good efficiency, the technology is easy to combine with other treatment options.

As disadvantages are known: Lack of depository effect, possible regrowth of pathogens, the wastewater must be free of suspended solids, the fouling on protection pipes an lack of practicable dosage measurement.

A very important issue with UV treatment is the fact that the wastewater must be very well treated and nearly free of turbidity and suspended solids which can be realised by high efficient biological treatment, best followed by a sand filtration step.

## 3.3 Ozonation

Like chlorine, ozone is a strong oxidizing agent. The ozonation (or ozonization) of compounds in water is a complex process. The mechanisms are very complicated, the parameters are many, but the possibilities of developing cost-effective treatment schemes for drinking water and waste water are large.

The ozonation can be applied as an alternative way of water purification capable of being used instead of conventional chlorination, in combination with chlorine, hydrogen peroxide and other oxidizing agents, as well as together with ultra-violet irradiation, ultrasound, sand, adsorption and on-exchange filtration. It is becoming traditional to use ozone at the end of process. For effective disinfection to be possible ozone concentration should be brought to 0.4-1mg/l and sustained like this within 4 minutes (Chichirova 1999). Thanks to its floculating effect ozone can be used for water pretreatment for converting permeates into colloidal form with subsequent precipitation on filters.

The advantage of ozonization is in the fact that ozone, besides being disinfectant, is able to discolor, eliminate the smells and flavors of water and, in general, make it more tasty. Ozone does not change natural properties of water. Ozone came into use as a disinfectant of potable water earlier, than chlorine. But it has not found the same wide application for water treatment techniques in developing countries because of shortage of electric power, as well as because chemical and physical properties of ozone aqueous solution are not sufficiently known yet.

## 3.4 Filtration

Disinfection due to filtration is already applied in the field of drinking water and landfill leachate treatment. The different types of membrane filtration are listed in table 5.

*Table 5 Membrane technologies in wastewater treatment (MUNLV, 2003)*

| **Membrane process** | **Phase separation** | **Driving power (Pressure difference)** | **Application (Separation performance)** |
|---|---|---|---|
| Microfiltration | liquid / solid | 0.1 – 3 bar | Suspended solids |
| Ultrafiltration | liquid / liquid | 0.5 – 10 bar | Macro molecules, Bacteria, Viruses |
| Nanofiltration | liquid / liquid | 2 – 40 bar | Organic molecules |
| Revers osmosis | liquid / liquid | 5 – 70 (120) bar | All ions and molecules |

In wastewater treatment micro and ultrafiltration is mainly applied for separation of suspended solids, respective disinfection. A porosity of less than 0.2 µm (ultrafiltration) is required to remove pathogens totally (ATV 1998). Although viruses may be even smaller, they are also removed because they are located on particles.

Membranes can be used as a separate final step after biological treatment or as integrated unit in an intensive technology like activated sludge reactor. The possible applications within the activated sludge process are shown in figure 8.

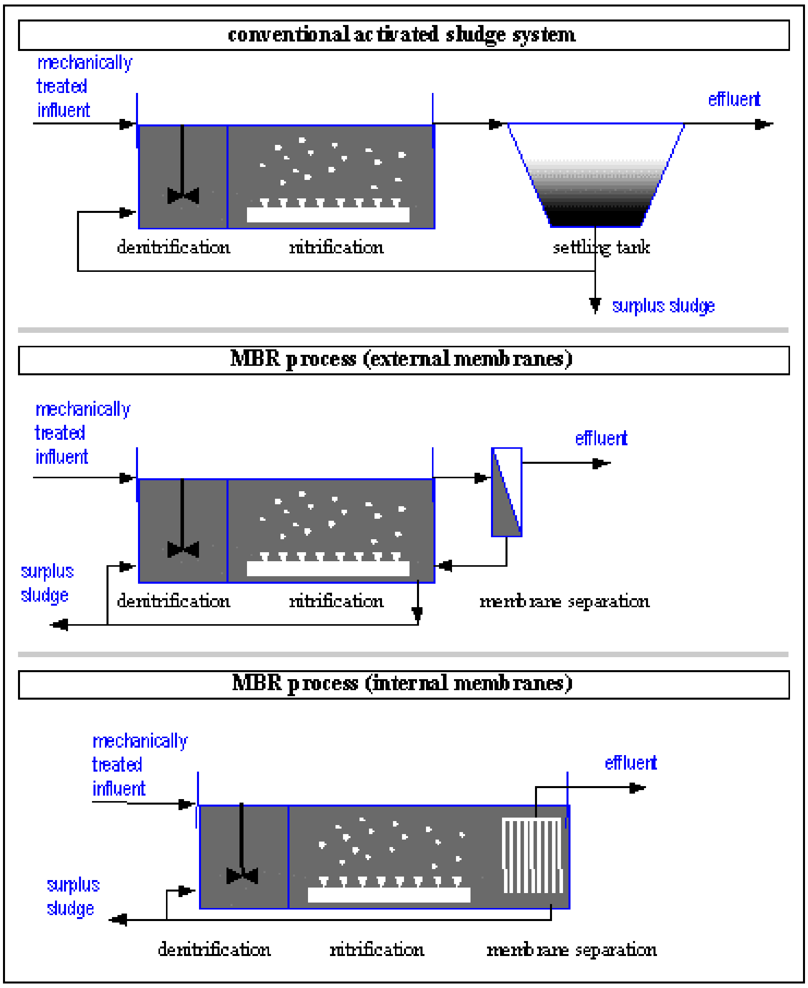


***Figure 8: Implementation of membrane technologies in activated sludge systems***

Firstly the filtration can be applied as last unit for tertiary treatment. Secondly the membrane bioreactor has been developed in the last years that is characterised by a combination of activated sludge process and membrane filtration. In this case, the filtration unit replaces the sedimentation unit. The activated sludge process can be operated with higher biomass concentrations than the conventional activated sludge process. Therefore the space needed for this technique is much smaller.

Advantages of filtration are the following:

- Pure physical treatment
- No chemical agents necessary
- No unwanted by-products
- Good efficiency
- Can be combined with activated sludge process (membrane bioreactor)

As disadvantages are known:

- High investment and running costs, especially energy demand
- Clogging due to fouling and biofouling on the membranes which requires the use of chemicals
- Membranes must be replaced from time to time

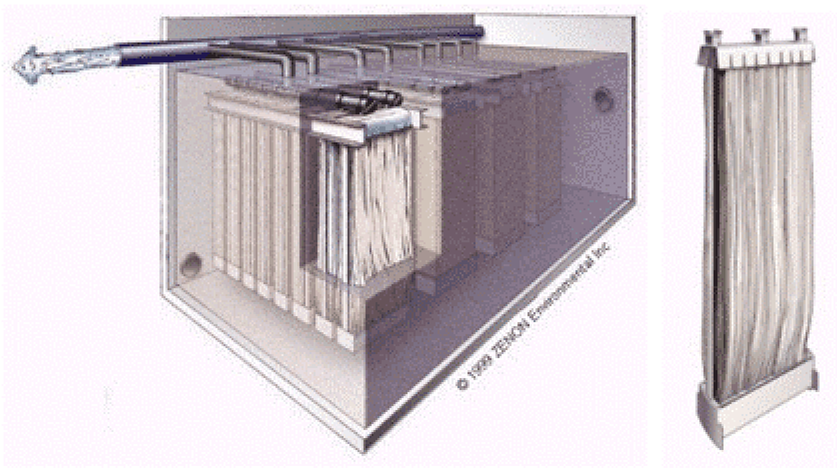

***Figure 9:  Membrane modules by Zeenon, Germany***

Membranes represent a very promising technology that still needs development to cope with biofouling effects.

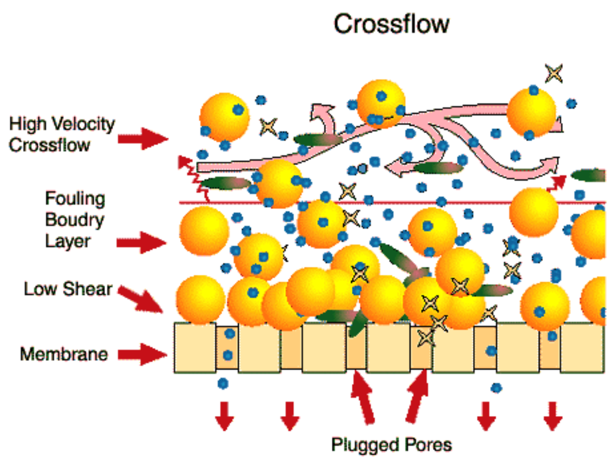


***Figure 10: Cross flow filtration***

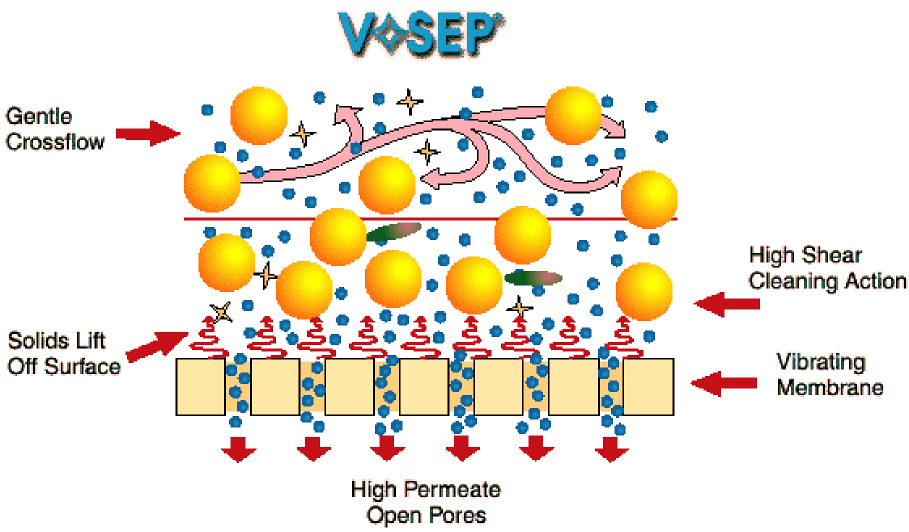


***Figure 11: Vibrating membranes with cross flow filtration***

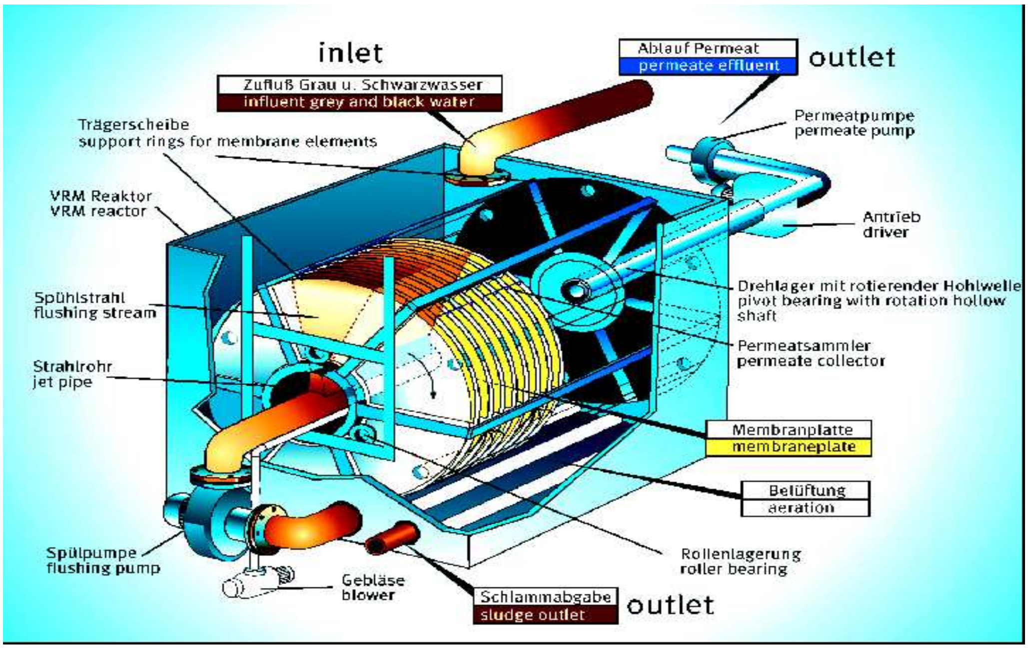


***Figure 12: Vacuum rotation membrane by Huber, Germany***

New technologies work with vibrating or rotating membranes to avoid fouling like shown in Figure 13 and 14.

Reverse osmosis is the best technology to produce clean water from wastewater since it removes even salts, heavy metals and pharmaceutical residues.

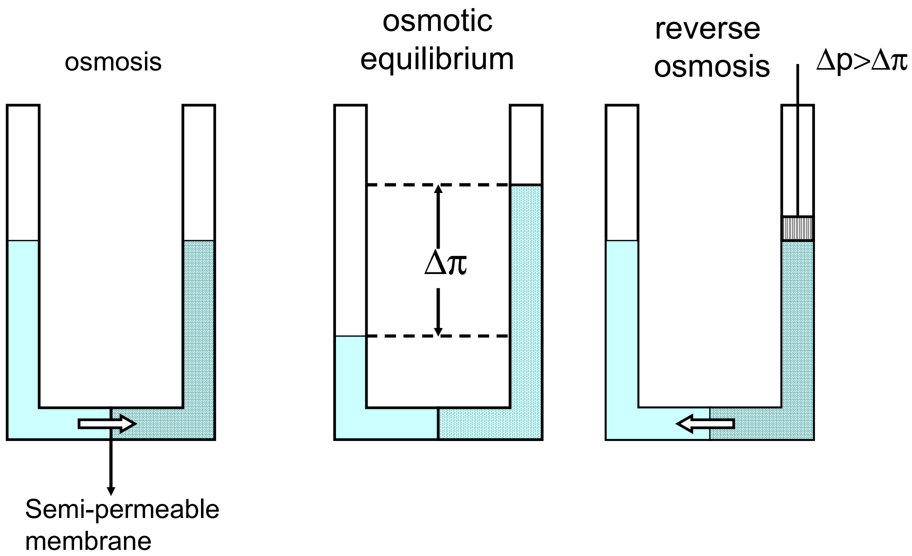


***Figure 13: Principle of reverse osmosis***

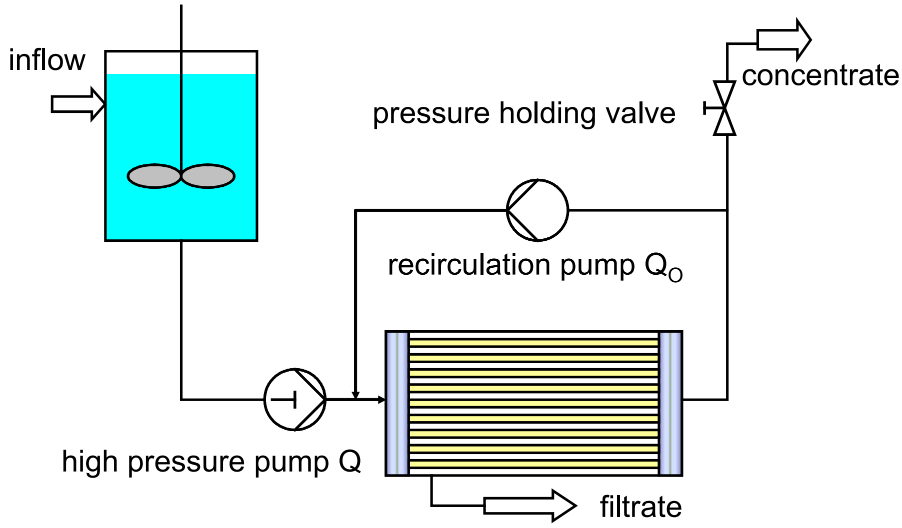


***Figure 14: Treatment scheme of reverse osmosis***

Like shown in Figure 14 a high driving power is needed for reverse osmosis, see also table 5. That is why it requires high energy costs. A practical example is presented in the next chapter.

# 4. Case studies

Many concepts for wastewater reuse are applied worldwide with different technologies and for different purposes. A good overview is given in van der Graaf et al (2005).
In this lesson two high tech water reuse plants are presented to illustrate the efficiency of water reuse.

## 4.1 Torreele Wastewater Treatment Plant, Belgium

In Torreele, a wastewater treatment plant with ultrafiltration as pre-treatment and reverse osmosis was realised in 2002 for aquifer recharge.

*Problem*
Seawater infiltration makes drinking water production difficult in the coastal area of Belgium. To combat this problem, The Belgian Intermunicipal Water Company of the Veurne Region (IWVA) wanted to design a plant that could produce water suitable for aquifer recharge.

Surface water is typically used to recharge the aquifers, but since these water sources tend to experience reduced flows during the summer months, an alternate supply of continuous high quality water was required to protect the aquifers from seawater infiltration and to reduce demand on potable surface water.

*Solution*
After extensive piloting, IWVA selected a system which included ZENON’s ultrafiltration (UF) membranes in December 2000. This system's multi-barrier approach consisted of a ZeeWeed® system, followed by reverse osmosis (RO) and ultraviolet (UV) disinfection.

UF is the method of choice for RO pretreatment. When compared to conventional pretreatment, ZeeWeed® membranes remove suspended solids and colloidal material more reliably and with the use of fewer chemicals. The membrane is capable of handling solids spikes, and consistently produces an ideal RO feed typically yielding an SDI < 3. ZeeWeed® enables the RO system to operate with a higher sustainable flux, smaller system size, and lower cleaning frequency, thereby signifi cantly reducing operating and capital costs.

The new IWVA Station Torreele tertiary plant produces treated water equivalent to nearly 40 percent of the annual drinking water requirements for this area. The system also constantly meets the drinking water regulatory limits for parasites and salt.

*Process Overview*
The secondary effluent first passes through the headworks, consisting of a 1mm (0.04") mechanical screen. Once dosed with chlorine, the water is held in a reservoir, and then flows by gravity into the ZeeWeed® UF tanks. Filtration is achieved by drawing water to the inside of the membrane fiber using suction created by permeate pumps.

Permeate is then sent to an RO system, passes through a UV disinfection unit, and is pumped into the dune area. From there, the water seeps into the groundwater table over an open pond of approximately 2 hectares (20,000 m2).

The infiltration water is composed of 90 percent RO filtrate and 10 percent ZeeWeed® filtrate. This mixing is done to remineralize the RO filtration, so the salt content matches that of the natural dune water.

More information on http://www.iwva.be/docs/torreele_en.pdf.

## 4.2 NEWater, Singapore

In Singapore, 3 water reclamation plants were installed between 2002 and 2004 and they produce today a capacity of 92,000 m3/day for industrial use and groundwater recharge.

*Problem*
The primary objective of the initiative for the project NEWater was to determine the suitability of using treated wastewater as a source of raw water to supplement Singapore's water supply because of the increasing water demand and decreasing water resources in Singapore.

*Solution and process overview*
NEWater is the product from a multiple barrier water reclamation process. The first barrier is the conventional wastewater treatment process whereby the used water is treated to globally recognised standards in the Water Reclamation Plants.

The second barrier is the first stage of the NEWater production process known as Microfiltration (MF). In this process, the treated used water is passed through membranes to filter out and retained on the membrane surface suspended solids, colloidal particles, disease-causing bacteria, some viruses and protozoan cysts. The filtered water that goes through the membrane contains only dissolved salts and organic molecules.

The third barrier or the second stage of the NEWater production process is known as Reverse Osmosis (RO). In RO, a semi-permeable membrane is used. The semi-permeable membrane has very small pores which only allow very small molecules like water molecules to pass through. Consequently, undesirable contaminants such as bacteria, viruses, heavy metals, nitrate, chloride, sulphate, disinfection by-products, aromatic hydrocarbons, pesticides etc, cannot pass through the membrane. Hence, NEWater is RO water and is free from viruses and bacteria and contains very low levels of salts and organic matter.

At this stage, the water is already of a high grade water quality. The fourth barrier or third stage of the NEWater production process really acts as a further safety back-up to the RO. In this stage, ultraviolet or UV disinfection is used to ensure that all organisms are inactivated and the purity of the product water guaranteed.

With the addition of some alkaline chemicals to restore the acid-alkali or pH balance, the NEWater is now ready to be piped off to its wide range of applications.

***Table 6: Water quality of NEWater in Singapore (http://www.pub.gov.sg/NEWater_files/newater_quality/index.html)***

| Water Quality Parameters | NEWater | USEPA /WHO Standards |
|---|---|---|
| A) Physical | | |
| Turbidity (NTU) | <5 | 5 / 5 |
| Colour (Hazen units) | <5 | 15 / 15 |
| Conductivity (µS/cm) | <200 | Not Specified(- / -) |
| pH Value | 7.0 - 8.5 | 6.5-8.5 / - |
| Total Dissolved Solids (mg/L) | <100 | 500 / 1000 |
| Total Organic Carbon (mg/L) | <0.5 | - / - |
| Total Alkalinity (CaCO3) (mg/L) | <20 | - / - |
| Total Hardness (CaCO3) (mg/L) | <20 | Not available |
| B) Chemical (mg/l) | | |
| Ammoniacal nitrogen (as N) | <1.0 | - / 1.5 |
| Chloride (Cl) | <20 | 250 / 250 |
| Fluoride (F) | <0.5 | 4 / 1.5 |
| Nitrate (NO3) | <15 | - / - |
| Silica (SiO2) | <3 | - / - |
| Sulphate (SO4) | <5 | 250 / 250 |
| Residual Chlorine (Cl, Total) | <2 | - / 5 |
| Total Trihalomethanes (as mg/l) | <0.08 | 0.08 / - |
| C) Metals (mg/l) | | |
| Aluminium | <0.1 | 0.05-0.2 / 0.2 |
| Barium (Ba) | <0.1 | 2 / 0.7 |
| Boron (B) | <0.5 | - / 0.9 |
| Calcium (Ca) | <20 | - / - |
| Copper (Cu) | <0.05 | 1.3 / 2 |
| Iron (Fe) | <0.04 | 0.3 / 0.3 |
| Manganese (Mn) | <0.05 | 0.05 / 0.5 |
| Sodium (Na) | <20 | - / 200 |
| Strontium (Sr) | <0.1 | - / - |
| Zinc (Zn) | <0.1 | 5 / 3 |
| D) Bacteriological | | |
| Total Coliform Bacteria (Counts/100 ml) | Not detectable | Not detectable |
| Enterovirus | Not detectable | Not detectable |

Please look for more information in

http://www.pub.gov.sg/NEWater_files/overview/index.html

# 5. References

Asano, T (1998): *Wastewater reclamation and reuse,* volume 10, Lancaster – Basel

ATV (1998): *Disinfection of biologically treated wastewater*, in German. ISBN 3-927719-75-2

Chichirova, Natalia D. and Igor V. Evgeniev: *Technology of Ozonization of Water and filtering media in heat-and-power engineering*, Chemistry and Computational Simulation. Butlerov Communications. 1999. No. 2

Cornel, P., Weber, B. (2004): *Production of water for irrigation with chemico physical wastewater treatment,* in German. 73. Darmstädter Seminar, Schriftenreihe WAR 159

Metcalf and Eddy, Inc, (2003): *Wastewater Engineering: treatment and reuse*, fourth Ed. Mc Graw Hill

Henze et al., (1997): Henze, M. Harremoës, P. Jansen, J. La C. Arvin, E.: *Wastewater treatment: biological and chemical processes*; Second Ed. Springer

Icekson-Tal, O. Avraham, J. Sack and H. Cikurel (2003): *Water reuse in Israel - the Dan Region Project: evaluation of water quality and reliability of plant's operation,* Water Supply Vol 3 No 4 pp 231–237 © IWA Publishing 2003

Jacangelo, J.G., Trussell, R.R. (2001) International Report Water and Wastewater Disinfection: Trends, Issues and Practices, Preprints 2nd World water congress in Berlin, October 2001

Judd, S & Jefferson, B (2003): *Membrane for industrial Recovery and Reuse, Ed. Elsevier*

Lazarova, V et al., (2001): *Role of water reuse for enhancing integrated water management in Europe and Mediterranean countries* (Water Science and technology) Vol. 43 N° 10, pp 25-33

Mujeriego, R & Asano, T. (1999): *The role of advanced treatment in wastewater reclamation and reuse* (Water Science and technology) Vol. 40 N° 4-5, pp 1-9

Nuortila-Jokinen, (1997): *Choice of optimal membrane processes for economical treatment of paper machine clear filtrate* Lappeenranta University of Technology; Research Paper 58.

Scott, K. & Hughes, R. (1996): *Industrial membrane separation technology*. First Ed. By the Authors

Rowe, R. D. & Abdel-Magib, I. M. (1995): Handbook of Wastewater Reclamation and Reuse Library of Congress Cataloging-in-Publication Data

van der Graaf, J.H.J.M, de Koning, J., Ravazzini, A. and Miska, V, (2005) *Treatment matrix for reuse of upgraded wastewater*, Water Supply Vol 5 No 1 pp 87–94

Wendland, C. (2003): *Sanitation concepts for small communities. Contribution to the decision making process for the pilot plants within the EMWater project,* presented on the 1st Regional Meeting in Amman, Jordan, EMWater project