



برنامج المسار الوظيفي للعاملين بقطاع مياه الشرب والصرف الصحي

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Water treatment technology – الدرجة الثانية



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1. Water treatment.

1.1. Scientific background (Introduction)

Water resources, such as rivers, lakes and seas, receive large quantities of waste water from industrial, agricultural, and domestic sources, including municipal sewage treatment plants. These surface waters, which contain many unknown compounds, are used as a source of drinking water, as well as for agricultural, recreational and religious activities around the world. Consequently, water pollution can be a serious public health and aquatic ecosystem problem. Organic pollutants (include PAHs, phenols, Surfactants, pesticides, ...) are the widespread ubiquitous contaminants in the different compartments of the environments. These compounds are generally generated by natural and anthropogenic processes and can be introduced into the environments through various routes. Due to their toxic, mutagenic, and carcinogenic characteristics, organic pollutants are considered to be hazardous to the biota and environments and should be removed from water resources.

Water in general can be contaminated by the following agents:

- **Pathogens – disease-causing organisms** – that include bacteria, amoebas and viruses, as well as the eggs and larvae of parasitic worms.
- **Harmful chemicals** from human activities (industrial wastes, pesticides, fertilizers, organic constituent).
- **Chemicals and minerals** from the natural environment, such as arsenic, common salt and fluorides. Some non-harmful contaminants may influence the taste, smell, colour or temperature of water, and make it unacceptable to the community.

 National Primary Drinking Water Regulations					
Contaminant	MCL or TT ¹ (mg/L) ²	Potential health effects from long-term ³ exposure above the MCL	Common sources of contaminant in drinking water	Public Health Goal (mg/L) ⁴	
OC Acrylamide	TT ⁴	Nervous system or blood problems; increased risk of cancer	Added to water during sewage/ wastewater treatment	zero	
OC Alachlor	0.002	Eye, liver, kidney or spleen problems; anemia; increased risk of cancer	Runoff from herbicide used on row crops	zero	
R Alpha/photon emitters	15 picocuries per Liter (pCi/L)	Increased risk of cancer	Erosion of natural deposits of certain minerals that are radioactive and may emit a form of radiation known as alpha radiation	zero	
IOC Antimony	0.006	Increase in blood cholesterol; decrease in blood sugar	Discharge from petroleum refineries; fire retardants; ceramics; electronics; solder	0.006	
IOC Arsenic	0.010	Skin damage or problems with circulatory systems, and may have increased risk of getting cancer	Erosion of natural deposits; runoff from orchards; runoff from glass & electronics production wastes	0	
IOC Asbestos (fibers >10 micrometers)	7 million fibers per Liter (MFL)	Increased risk of developing benign intestinal polyps	Decay of asbestos cement in water mains; erosion of natural deposits	7 MFL	
OC Atrazine	0.003	Cardiovascular system or reproductive problems	Runoff from herbicide used on row crops	0.003	
IOC Barium	2	Increase in blood pressure	Discharge of drilling wastes; discharge from metal refineries; erosion of natural deposits	2	
OC Benzene	0.005	Anemia; decrease in blood platelets; increased risk of cancer	Discharge from factories; leaching from gas storage tanks and landfills	zero	
OC Benzo(a)pyrene (PAHs)	0.0002	Reproductive difficulties; increased risk of cancer	Leaching from linings of water storage tanks and distribution lines	zero	
IOC Beryllium	0.004	Intestinal lesions	Discharge from metal refineries and coal-burning factories; discharge from electrical, aerospace, and defense industries	0.004	
R Beta photon emitters	4 millirems per year	Increased risk of cancer	Decay of natural and man-made deposits of certain minerals that are radioactive and may emit forms of radiation known as photons and beta radiation	zero	
DBP Bromate	0.010	Increased risk of cancer	Byproduct of drinking water disinfection	zero	
IOC Cadmium	0.005	Kidney damage	Corrosion of galvanized pipes; erosion of natural deposits; discharge from metal refineries; runoff from waste batteries and paints	0.005	
OC Carbofuran	0.04	Problems with blood, nervous system, or reproductive system	Leaching of soil fumigant used on rice and alfalfa	0.04	
OC Carbon tetrachloride	0.005	Liver problems; increased risk of cancer	Discharge from chemical plants and other industrial activities	zero	
D Chloramines (as Cl ₂)	MRDL=4.0 ⁵	Eye/nose irritation; stomach discomfort; anemia	Water additive used to control microbes	MRDLG=4 ¹	
OC Chlordane	0.002	Liver or nervous system problems; increased risk of cancer	Residue of banned termiticide	zero	
D Chlorine (as Cl ₂)	MRDL=4.0 ⁵	Eye/nose irritation; stomach discomfort	Water additive used to control microbes	MRDLG=4 ¹	
D Chlorine dioxide (as ClO ₂)	MRDL=0.8 ⁵	Anemia; infants, young children, and fetuses of pregnant women: nervous system effects	Water additive used to control microbes	MRDLG=0.8 ¹	
DBP Chlorite	1.0	Anemia; infants, young children, and fetuses of pregnant women: nervous system effects	Byproduct of drinking water disinfection	0.8	
OC Chlorobenzene	0.1	Liver or kidney problems	Discharge from chemical and agricultural chemical factories	0.1	
IOC Chromium (total)	0.1	Allergic dermatitis	Discharge from steel and pulp mills; erosion of natural deposits	0.1	
IOC Copper	TT ⁵ ; Action Level = 1.3	Short-term exposure: Gastrointestinal distress. Long-term exposure: Liver or kidney damage. People with Wilson's Disease should consult their personal doctor if the amount of copper in their water exceeds the action level	Corrosion of household plumbing systems; erosion of natural deposits	1.3	
M <i>Cryptosporidium</i>	TT ⁷	Short-term exposure: Gastrointestinal illness (e.g., diarrhea, vomiting, cramps)	Human and animal fecal waste	zero	
LEGEND D Disinfectant IOC Inorganic Chemical OC Organic Chemical DBP Disinfection Byproduct M Microorganism R Radionuclides					

Contaminant	MCL or TT ¹ (mg/L) ²	Potential health effects from long-term ³ exposure above the MCL	Common sources of contaminant in drinking water	Public Health Goal (mg/L) ²
IOC Cyanide (as free cyanide)	0.2	Nerve damage or thyroid problems	Discharge from steel/metal factories; discharge from plastic and fertilizer factories	0.2
OC 2,4-D	0.07	Kidney, liver, or adrenal gland problems	Runoff from herbicide used on row crops	0.07
OC Dalapon	0.2	Minor kidney changes	Runoff from herbicide used on rights of way	0.2
OC 1,2-Dibromo-3-chloropropane (DBCP)	0.0002	Reproductive difficulties; increased risk of cancer	Runoff/leaching from soil fumigant used on soybeans, cotton, pineapples, and orchards	zero
OC o-Dichlorobenzene	0.6	Liver, kidney, or circulatory system problems	Discharge from industrial chemical factories	0.6
OC p-Dichlorobenzene	0.075	Anemia; liver, kidney or spleen damage; changes in blood	Discharge from industrial chemical factories	0.075
OC 1,2-Dichloroethane	0.005	Increased risk of cancer	Discharge from industrial chemical factories	zero
OC 1,1-Dichloroethylene	0.007	Liver problems	Discharge from industrial chemical factories	0.007
OC cis-1,2-Dichloroethylene	0.07	Liver problems	Discharge from industrial chemical factories	0.07
OC trans-1,2-Dichloroethylene	0.1	Liver problems	Discharge from industrial chemical factories	0.1
OC Dichloromethane	0.005	Liver problems; increased risk of cancer	Discharge from drug and chemical factories	zero
OC 1,2-Dichloropropane	0.005	Increased risk of cancer	Discharge from industrial chemical factories	zero
OC Di(2-ethylhexyl) adipate	0.4	Weight loss, liver problems, or possible reproductive difficulties	Discharge from chemical factories	0.4
OC Di(2-ethylhexyl) phthalate	0.006	Reproductive difficulties; liver problems; increased risk of cancer	Discharge from rubber and chemical factories	zero
OC Dinoseb	0.007	Reproductive difficulties	Runoff from herbicide used on soybeans and vegetables	0.007
OC Dioxin (2,3,7,8-TCDD)	0.0000003	Reproductive difficulties; increased risk of cancer	Emissions from waste incineration and other combustion; discharge from chemical factories	zero
OC Diquat	0.02	Cataracts	Runoff from herbicide use	0.02
OC Endothall	0.1	Stomach and intestinal problems	Runoff from herbicide use	0.1
OC Endrin	0.002	Liver problems	Residue of banned insecticide	0.002
OC Epichlorohydrin	TT ⁴	Increased cancer risk; stomach problems	Discharge from industrial chemical factories; an impurity of some water treatment chemicals	zero
OC Ethylbenzene	0.7	Liver or kidney problems	Discharge from petroleum refineries	0.7
OC Ethylene dibromide	0.00005	Problems with liver, stomach, reproductive system, or kidneys; increased risk of cancer	Discharge from petroleum refineries	zero
M Fecal coliform and <i>E. coli</i>	MCL ⁵	Fecal coliforms and <i>E. coli</i> are bacteria whose presence indicates that the water may be contaminated with human or animal wastes. Microbes in these wastes may cause short term effects, such as diarrhea, cramps, nausea, headaches, or other symptoms. They may pose a special health risk for infants, young children, and people with severely compromised immune systems.	Human and animal fecal waste	zero ⁶
IOC Fluoride	4.0	Bone disease (pain and tenderness of the bones); children may get mottled teeth	Water additive which promotes strong teeth; erosion of natural deposits; discharge from fertilizer and aluminum factories	4.0
M <i>Giardia lamblia</i>	TT ⁷	Short-term exposure: Gastrointestinal illness (e.g., diarrhea, vomiting, cramps)	Human and animal fecal waste	zero
OC Glyphosate	0.7	Kidney problems; reproductive difficulties	Runoff from herbicide use	0.7
DBP Haloacetic acids (HAA5)	0.060	Increased risk of cancer	Byproduct of drinking water disinfection	n/a ⁸
OC Heptachlor	0.0004	Liver damage; increased risk of cancer	Residue of banned termiticide	zero
OC Heptachlor epoxide	0.0002	Liver damage; increased risk of cancer	Breakdown of heptachlor	zero
M Heterotrophic plate count (HPC)	TT ⁷	HPC has no health effects; it is an analytic method used to measure the variety of bacteria that are common in water. The lower the concentration of bacteria in drinking water, the better maintained the water system is.	HPC measures a range of bacteria that are naturally present in the environment	n/a
LEGEND				
D Disinfectant	IOC Inorganic Chemical	OC Organic Chemical		
DBP Disinfection Byproduct	M Microorganism	R Radionuclides		

Contaminant	MCL or TT ^a (mg/L) ¹	Potential health effects from long-term ³ exposure above the MCL	Common sources of contaminant in drinking water	Public Health Goal (mg/L) ²
OC Hexachlorobenzene	0.001	Liver or kidney problems; reproductive difficulties; increased risk of cancer	Discharge from metal refineries and agricultural chemical factories	zero
OC Hexachlorocyclopentadiene	0.05	Kidney or stomach problems	Discharge from chemical factories	0.05
IOC Lead	TT5; Action Level=0.015	Infants and children: Delays in physical or mental development; children could show slight deficits in attention span and learning abilities; Adults: Kidney problems; high blood pressure	Corrosion of household plumbing systems; erosion of natural deposits	zero
M <i>Legionella</i>	TT7	Legionnaire's Disease, a type of pneumonia	Found naturally in water; multiplies in heating systems	zero
OC Lindane	0.0002	Liver or kidney problems	Runoff/leaching from insecticide used on cattle, lumber, gardens	0.0002
IOC Mercury (inorganic)	0.002	Kidney damage	Erosion of natural deposits; discharge from refineries and factories; runoff from landfills and croplands	0.002
OC Methoxychlor	0.04	Reproductive difficulties	Runoff/leaching from insecticide used on fruits, vegetables, alfalfa, livestock	0.04
IOC Nitrate (measured as Nitrogen)	10	Infants below the age of six months who drink water containing nitrate in excess of the MCL could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue-baby syndrome.	Runoff from fertilizer use; leaching from septic tanks, sewage; erosion of natural deposits	10
IOC Nitrite (measured as Nitrogen)	1	Infants below the age of six months who drink water containing nitrite in excess of the MCL could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue-baby syndrome.	Runoff from fertilizer use; leaching from septic tanks, sewage; erosion of natural deposits	1
OC Oxamyl (Vydate)	0.2	Slight nervous system effects	Runoff/leaching from insecticide used on apples, potatoes, and tomatoes	0.2
OC Pentachlorophenol	0.001	Liver or kidney problems; increased cancer risk	Discharge from wood-preserving factories	zero
OC Picloram	0.5	Liver problems	Herbicide runoff	0.5
OC Polychlorinated biphenyls (PCBs)	0.0005	Skin changes; thymus gland problems; immune deficiencies; reproductive or nervous system difficulties; increased risk of cancer	Runoff from landfills; discharge of waste chemicals	zero
R Radium 226 and Radium 228 (combined)	5 pCi/L	Increased risk of cancer	Erosion of natural deposits	zero
IOC Selenium	0.05	Hair or fingernail loss; numbness in fingers or toes; circulatory problems	Discharge from petroleum and metal refineries; erosion of natural deposits; discharge from mines	0.05
OC Simazine	0.004	Problems with blood	Herbicide runoff	0.004
OC Styrene	0.1	Liver, kidney, or circulatory system problems	Discharge from rubber and plastic factories; leaching from landfills	0.1
OC Tetrachloroethylene	0.005	Liver problems; increased risk of cancer	Discharge from factories and dry cleaners	zero
IOC Thallium	0.002	Hair loss; changes in blood; kidney, intestine, or liver problems	Leaching from ore-processing sites; discharge from electronics, glass, and drug factories	0.0005
OC Toluene	1	Nervous system, kidney, or liver problems	Discharge from petroleum factories	1
M Total Coliforms	5.0 percent ⁸	Coliforms are bacteria that indicate that other, potentially harmful bacteria may be present. See fecal coliforms and <i>E. coli</i>	Naturally present in the environment	zero
DBP Total Trihalomethanes (TTHMs)	0.080	Liver, kidney or central nervous system problems; increased risk of cancer	Byproduct of drinking water disinfection	n/a ⁹
OC Toxaphene	0.003	Kidney, liver, or thyroid problems; increased risk of cancer	Runoff/leaching from insecticide used on cotton and cattle	zero
OC 2,4,5-TP (Silvex)	0.05	Liver problems	Residue of banned herbicide	0.05
OC 1,2,4-Trichlorobenzene	0.07	Changes in adrenal glands	Discharge from textile finishing factories	0.07
OC 1,1,1-Trichloroethane	0.2	Liver, nervous system, or circulatory problems	Discharge from metal degreasing sites and other factories	0.2
OC 1,1,2-Trichloroethane	0.005	Liver, kidney, or immune system problems	Discharge from industrial chemical factories	0.003
OC Trichloroethylene	0.005	Liver problems; increased risk of cancer	Discharge from metal degreasing sites and other factories	zero

LEGEND
D Disinfectant IOC Inorganic Chemical OC Organic Chemical DBP Disinfection Byproduct M Microorganism R Radionuclides

Contaminant	MCL or TT ¹ (mg/L) ²	Potential health effects from long-term ³ exposure above the MCL	Common sources of contaminant in drinking water	Public Health Goal (mg/L) ²
M Turbidity	TT ¹	Turbidity is a measure of the cloudiness of water. It is used to indicate water quality and filtration effectiveness (e.g., whether disease-causing organisms are present). Higher turbidity levels are often associated with higher levels of disease-causing microorganisms such as viruses, parasites and some bacteria. These organisms can cause short term symptoms such as nausea, cramps, diarrhea, and associated headaches.	Soil runoff	n/a
R Uranium	30µg/L	Increased risk of cancer, kidney toxicity	Erosion of natural deposits	zero
OC Vinyl chloride	0.002	Increased risk of cancer	Leaching from PVC pipes; discharge from plastic factories	zero
M Viruses (enteric)	TT ²	Short-term exposure: Gastrointestinal illness (e.g., diarrhea, vomiting, cramps)	Human and animal fecal waste	zero
OC Xylenes (total)	10	Nervous system damage	Discharge from petroleum factories; discharge from chemical factories	10

NOTES

1 Definitions

- Maximum Contaminant Level Goal (MCLG)—The level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety and are non-enforceable public health goals.
- Maximum Contaminant Level (MCL)—The highest level of a contaminant that is allowed in drinking water. MCLs are set as close to MCLGs as feasible using the best available treatment technology and taking cost into consideration. MCLs are enforceable standards.
- Maximum Residual Disinfectant Level Goal (MRDLG)—The level of a drinking water disinfectant below which there is no known or expected risk to health. MRDLGs do not reflect the benefits of the use of disinfectants to control microbial contaminants.
- Maximum Residual Disinfectant Level (MRDL)—The highest level of a disinfectant allowed in drinking water. There is convincing evidence that addition of a disinfectant is necessary for control of microbial contaminants.
- Treatment Technique (TT)—A required process intended to reduce the level of a contaminant in drinking water.

2 Units are in milligrams per liter (mg/L) unless otherwise noted. Milligrams per liter are equivalent to parts per million (ppm).

3 Health effects are from long-term exposure unless specified as short-term exposure.

4 Each water system must certify annually, in writing, to the state (using third-party or manufacturers certification) that when it uses acrylamide and/or epichlorohydrin to treat water, the combination (or product) of dose and monomer level does not exceed the levels specified, as follows: Acrylamide = 0.05 percent dosed at 1 mg/L (or equivalent); Epichlorohydrin = 0.01 percent dosed at 20 mg/L (or equivalent).

5 Lead and copper are regulated by a Treatment Technique that requires systems to control the corrosiveness of their water. If more than 10 percent of tap water samples exceed the action level, water systems must take additional steps. For copper, the action level is 1.3 mg/L, and for lead is 0.015 mg/L.

6 A routine sample that is fecal coliform-positive or *E. coli*-positive triggers repeat samples—if any repeat sample is total coliform-positive, the system has an acute MCL violation. A routine sample that is total coliform-positive and fecal coliform-negative or *E. coli*-negative triggers repeat samples—if any repeat sample is fecal coliform-positive or *E. coli*-positive, the system has an acute MCL violation. See also Total Coliforms.

7 EPA's surface water treatment rules require systems using surface water or ground water under the direct influence of surface water to (1) disinfect their water, and (2) filter their water or meet criteria for avoiding filtration so that the following contaminants are controlled at the following levels:

- *Cryptosporidium*: 99 percent removal for systems that filter. Unfiltered systems are required to include *Cryptosporidium* in their existing watershed control provisions.
- *Giardia lamblia*: 99.9 percent removal/inactivation

- Viruses: 99.99 percent removal/inactivation

• *Legionella*: No limit, but EPA believes that if *Giardia* and viruses are removed/inactivated according to the treatment techniques in the surface water treatment rule, *Legionella* will also be controlled.

• Turbidity: For systems that use conventional or direct filtration, at no time can turbidity (cloudiness of water) go higher than 1 nephelometric turbidity unit (NTU), and samples for turbidity must be less than or equal to 0.3 NTU in at least 95 percent of the samples in any month. Systems that use filtration other than conventional or direct filtration must follow state limits, which must include turbidity at no time exceeding 5 NTU.

• HPC: No more than 500 bacterial colonies per milliliter

• Long Term 1 Enhanced Surface Water Treatment: Surface water systems or ground water systems under the direct influence of surface water serving fewer than 10,000 people must comply with the applicable Long Term 1 Enhanced Surface Water Treatment Rule provisions (e.g. turbidity standards, individual filter monitoring, *Cryptosporidium* removal requirements, updated watershed control requirements for unfiltered systems).

• Long Term 2 Enhanced Surface Water Treatment: This rule applies to all surface water systems or ground water systems under the direct influence of surface water. The rule targets additional *Cryptosporidium* treatment requirements for higher risk systems and includes provisions to reduce risks from uncovered finished water storage facilities and to ensure that the systems maintain microbial protection as they take steps to reduce the formation of disinfection byproducts. (Monitoring start dates are staggered by system size. The largest systems (serving at least 100,000 people) will begin monitoring in October 2006 and the smallest systems (serving fewer than 10,000 people) will not begin monitoring until October 2008. After completing monitoring and determining their treatment bin, systems generally have three years to comply with any additional treatment requirements.)

• Filter Backwash Recycling: The Filter Backwash Recycling Rule requires systems that recycle to return specific recycle flows through all processes of the system's existing conventional or direct filtration system or at an alternate location approved by the state.

8 No more than 5.0 percent samples total coliform-positive in a month. (For water systems that collect fewer than 40 routine samples per month, no more than one sample can be total coliform-positive per month.) Every sample that has total coliform must be analyzed for either fecal coliforms or *E. coli*. If two consecutive TC-positive samples, and one is also positive for *E. coli* or fecal coliforms, system has an acute MCL violation.

9 Although there is no collective MCLG for this contaminant group, there are individual MCLGs for some of the individual contaminants:

- Haloacetic acids: dichloroacetic acid (zero); trichloroacetic acid (0.3 mg/L)
- Trihalomethanes: bromodichloromethane (zero); bromoform (zero); dibromochloromethane (0.06 mg/L)

Water from surface sources is often contaminated by microbes; whereas groundwater is normally safer, but even groundwater can be contaminated by harmful chemicals from human activities or from the natural environment. Rainwater captured by a rooftop harvesting system or with small catchment dams is relatively safe, provided that the first water is allowed to flow to waste when the rainy season starts. The amount of water to be treated should also be assessed. This can be estimated by assuming that each person will need a minimum of 20–50 liters of water a day for drinking, cooking, laundry and personal hygiene.

In order to obtain a good water quality which don't affect the human health we must do water treatment.

2. Water supply approaches in Egypt

2.1. Water requirements in Egypt

2.1.1. Agriculture

Agriculture consumes about 80% of Egypt's share of Nile water annually. Although the country lost part of its fertile land to urbanization, this has been balanced by expansion of agricultural areas. Expansion in agriculture is carried out horizontally and vertically through crop intensification by cultivating the land more than once a year. In 1990 cultivated lands were 7.0 Million Feddans (MF) with cropped area of about 12.5 MF, while in 2009 cultivated areas and cropped lands were 9.5 MF and 17.50 MF, respectively.

2.1.2. Municipal water requirements

Include water supply for major urban and rural villages. Part of this water comes from the Nile system, either through canals or direct intakes on the river. The other part comes from groundwater resources. Municipal water demand was estimated to be 9.0 BCM In 2009, where approximately 95% of the Egyptian population relies on piped water supply. Sanitary facilities are less developed where approximately 50% of urban population and 20% of rural population are connected to a sewerage system. Municipal water production are diverted from two sources, surface water which supplies about 85% of total municipal water demand and groundwater, which supplies about 15% of total demands .

The improvement of the quality and productivity of the industrial sector are vital for economic and social progress and increasing rates of growth in Egypt.

The estimated value of the water requirement for the industrial sector during the year 2009 was 8.0 BCM/year. A small portion of that water is consumed through evaporation during industrial processes (only 1.0 BCM) while most of that water returns to the system in a polluted form. These numbers must be reconciled before conducting an accurate assessment of financial aspects of industrial water use and its effects on the economics of water.

In summary, the actual resources currently available for use in Egypt are 55.5 BCM/year, and 1.0 BCM/year effective rainfall on the northern strip of the Delta, non-renewable groundwater for western desert and Sinai, while water requirements for different sectors are in the order of 75 BCM/yr. The gap between the needs and availability of water is about 20 BCM/yr. This gap is overcome by recycling. The overall efficiency of the Nile system in Egypt is about 75%.

By the year 2020, water requirements will most likely increase by 20% (15 BCM/yr). Water quantity and water quality are inseparable. Since all water uses require that water quality falls within a range specific to that use. Thus the present rate of deterioration of quality will certainly increase the severity of the water scarcity problem or add to the cost (i.e., treatment requirements) of using water at the levels expected in 2020.

On the other hand Egypt imports cereals, oils and sugar; which make Egypt one of the largest food importers in the world. The agricultural imports bill in the country has rapidly increased putting a substantial burden on the country's foreign exchange resources. It was more than twofold that of imports in the early seventies, but the balance became negative and the gap continuously widened since the mid-seventies.

2.2. Water supply

The main source of water in Egypt is the Nile River. Egypt is unique among other countries in its dependence on water from one deterministic source. The 1959 Nile water agreement with Sudan, allocates 55.5 BCM/year to Egypt. This amount is supported by the multi-year regulatory capacity provided by the High Aswan Dam (HAD).

2.2.1. Rainfall

In Egypt occurs only in winter in the form of scattered showers. The average annual amount of effectively utilized rainfall water is estimated to be 1.0 BCM / year. This amount cannot be considered a reliable source of water due to high spatial and temporal variability.

2.2.2. Groundwater

Groundwater exists in Western Desert and Sinai in aquifers that are mostly deep and non-renewable. The total groundwater volume has been estimated at about 40,000 BCM. However, current abstraction is estimated to be 0.9 BCM/year. The main obstacles in utilizing this huge resource are the great depths (up to 1500 m in some areas) of these aquifers and deteriorating water quality at the increasing depths.

Groundwater in the Nile aquifer cannot be considered a separate source of water. The aquifer is recharged only by seepage losses from the Nile, the irrigation canals and drains and percolation losses from irrigated lands. Hence, its yield must not be added to Egypt's total water resources. Therefore, it is considered as a reservoir in the Nile river system with a large capacity but with only 7.5 BCM/year rechargeable lives storage. The current abstraction from this aquifer is estimated at 7.0 BCM in 2009.

2.2.3. Desalination

Desalination of seawater in Egypt has been given low priority as a water resource because the cost of desalination is high compared with other sources. Desalination is actually practiced in the Red Sea coastal area to supply tourism villages and resorts with adequate domestic water supply where the economic value of the water is high enough to cover the treatment cost. Other groundwater desalination units are constructed at several locations in Sinai as a water supply for Bedouins. It may be crucial to use such resource in the future if the growth of the demand for water exceeds all other available water resources. However, its use will depend on technological development in this field.

2.2.4. Treated domestic sewage

Treated domestic sewage is being reused for irrigation with or without blending with fresh water. The increasing demands for domestic water will increase the total amount of sewage available for reuse. It is estimated that the total quantity of reused treated wastewater in Egypt is about 2.5 BCM in 2009.

Reuse of non-conventional water sources such as agricultural drainage water and treated sewage water cannot be added to Egypt's fresh water resources. In fact, using these sources is a recycling process of the previously used Nile fresh water in such a way that improves the overall efficiency of the water distribution system. The amount of water that returns to drains from irrigated lands is relatively high (about 25 to 30%).

3. Water treatment process

Water treatment process selection is a complex task. Circumstances are likely to be different for each water utility and perhaps may be different for each source used by one utility. Selection of one or more water treatment processes to be used at a given location is influenced by the necessity to meet regulatory quality goals, the desire of the utility and its customers to meet other water quality goals (such as aesthetics), and the need to provide water service at the lowest reasonable cost.

Factors that should be included in decisions on water treatment processes include:

- Contaminant removal
- Source of water quality
- Reliability
- Existing conditions
- Process flexibility
- Utility capabilities
- Costs
- Environmental compatibility
- Distribution system water quality
- Issues of process scale

3.1. Factors influence process selection**3.1.1. Contaminant removal**

Contaminant removal is the principal purpose of treatment for many source waters, particularly surface waters. The quality of treated water must meet all current drinking water regulations. These regulations reviewed by ministry of health law 48 in 2007, water treatment processes should be selected to enable the water utility to be in compliance with these regulations, and those future regulations when they become effective.

When water utility customers and water utility management place a strong emphasis on excellent water quality, the maximum contaminant levels (MCLs) of drinking water regulations may be viewed as an upper level of water contaminants that should be seldom or never approached, rather than as a guideline for finished water quality. Many water utilities choose to produce water that is much better in quality than water that would simply comply with the regulations. Such utilities may employ the same treatment processes that would be needed to provide the quality that complies with regulations, but operate those processes more effectively. Other utilities may employ additional treatment processes to attain the high finished water quality they seek.

3.1.2. Source of water quality

A comparison of source of water quality and the desired finished water quality is essential for treatment process selection. With the knowledge of the changes in water quality that must be attained, the engineer can identify one or more treatment processes that would be capable of attaining the quality improvement. Depending on water utilities past experience with a water source, the amount of data available on source water quality may range from almost nonexistent to fairly extensive. Learning about the source or origin of the raw water can be helpful for estimating the nature of possible quality problems and developing a monitoring program to define water quality.

3.1.3. Reliability

Process reliability is an important consideration and in some cases could be a key aspect in deciding which process to select. Disinfection of surface water is mandatory, so this is an example of a treatment process that should be essentially fail-safe. The only acceptable action to take for a failure of disinfection in a plant treating surface water is to stop distributing water from the treatment works until the problem is corrected and proper disinfection is provided or until a "boil water" order can be put in place so the public will not drink nondisinfected surface water. To avoid disinfection failures and to minimize downtime in the event of an equipment failure, backup disinfection systems or spare parts must be kept on hand for dealing with emergencies. Process reliability would be a very important factor in evaluating alternative disinfection systems, as well as other processes whose failure could have immediate public health consequences.

3.1.4. Existing conditions

The choice of processes to incorporate into a treatment train may be influenced strongly by the existing processes when a treatment plant is evaluated for upgrading or expanding. Site constraints may be crucial in process selection, especially in pre-treatment when alternative clarification processes are available, some of which require only a small fraction of the space needed for a conventional settling basin. Hydraulic constraints can be important when retrofitting plants with ozone or granular activated carbon

(GAC) adsorption. The extra head needed for some treatment processes could result in the necessity for booster pumping on-site to accommodate the hydraulic requirements of the process. This adds to the overall cost of the plant improvements and, in some cases, might result in a different process being selected. The availability of high head can influence process selection in some instances. Pressure filtration might be selected for treatment of groundwater after oxidation, for iron or manganese removal. In this situation, use of gravity filtration would involve breaking head and pumping after filtration, whereas with pressure filters it might be possible to pump directly from the well through the filters to storage.

3.1.5. Process flexibility

The ability of a water treatment plant to accommodate changes in future regulations or changes in source water quality is quite important. In the present regulatory environment, water utilities must realize that more regulations are likely in the future. For some utilities, these future regulations may require additional treatment or more effective treatment, such as when a previously unregulated contaminant is present in the source water or a maximum contaminant level is lowered for a contaminant in the utility's source water.

3.1.6. Utility capabilities

After treatment processes are selected, designed, and on-line, the water utility must be able to operate them successfully to attain the desired water quality. The issue of system size versus treatment complexity becomes important with smaller systems. If successful treatment plant operation requires more labor than a small system can afford, or if the level of technical skills exceeds that readily attainable in a community, treatment failure may occur. Availability and access to service and repair of equipment involves considerations of time and distance from service representatives, and this may be problematic for some small, very remote water utilities. Selected treatment processes need to be operable in the context for which they will be employed. System size is not the only determining factor in successful operation. Sometimes, management is not sufficiently progressive or does not realize the

necessity of providing well-trained staff with modern tools and techniques to facilitate successful treatment plant operation. In this situation, utility management needs to be informed of the complexities and requirements for treatment processes before plans for treatment are adopted.

Quality goals: Introduction of relatively complex treatment processes at a water utility whose management is not supportive of actions that will be needed for successful operation is a recipe for trouble.

The adaptability of treatment to automation or enhanced supervisory control and data acquisition (SCADA) can be important for systems of all sizes. For large systems, automation or enhanced SCADA may be a way to keep operating costs in line by having a smaller but highly trained and talented operating staff. For small utilities, using automation or enhanced SCADA in conjunction with remote monitoring of processes may enable a small system to use a form of contract operation or circuit rider operation in which the highly trained specialist is not on-site all of the time but maintains close watch over the treatment processes through instrumentation and communications facilities.

3.1.7. Costs

Cost considerations usually are a key factor in process selection. Evaluation of costs for alternative process trains using principles of engineering economics might at first seem to be straightforward, but this may not be the case. When different treatment trains are evaluated, their capabilities are not likely to be identical, so the resulting treated-water quality from different trains likewise may not be identical. The basis for process comparison has to be decided upon in such situations. If a certain aspect of water quality improvement is beneficial but not really necessary, perhaps it is not sufficiently valuable to enter into cost considerations. For example, both diatomaceous earth filters and granular media filters with coagulation pretreatment can remove particulate matter, but the process train employing coagulation, flocculation, and sedimentation can remove more colour and total organic carbon (TOC) from source water. For treatment of water with low colour and low (TOC) concentrations, the treatment for particulate

contaminant removal may be sufficient, and the use of a lower-cost filtration process, such as diatomaceous earth filtration, might be favored. On the other hand, if additional water quality improvement is needed, then any process train under consideration must be able to attain that improvement. Cost estimates should be made taking into consideration the entire life cycle cost of a process train. Both capital and operating and maintenance (O&M) costs must be included in the estimate.

3.1.8. Environmental compatibility

Environmental compatibility issues cover a broad spectrum of concerns including residual waste management, the fraction of source water wasted in treatment processes, and energy requirements for treatment. The effect of water treatment extends beyond the treatment plant. The benefits of providing safe drinking water are very great, but caution must be taken that the treatment processes selected to provide that safe water do not create serious environmental problems.

Residuals, or sludge and other by-products of water treatment, are commonly thought of when environmental compatibility is considered. Disposal of large volumes of water works sludge to surface waters is no longer permitted in most locations. Therefore, the residuals produced by coagulation, enhanced coagulation, and lime softening need to be dealt with in an environmentally acceptable manner.

3.1.9. Distribution system water quality

The influence of treatment processes on desired water quality in the distribution system is a factor to be considered in process evaluation, and includes:

- Chemical and microbiological stability of water leaving the treatment plant.
- Microbiological control in the distribution system.
- Compatibility of the quality with water from other sources.
- Minimization of formation of disinfection by-products in the distribution system.
- Prevention of internal corrosion and deposition.

3.1.10. Issues of process scale

Feasibility to scale processes up to very large sizes or to scale them down to very small sizes can be important in some cases. Complex treatment processes, such as coagulation and filtration of surface water or precipitation lime softening, can be scaled down physically, but the costs of equipment and the need for a highly trained operator may make the scaled-down process impractical. Processes that are practical and manageable at 10 mg d (38,000 m³/day) or even 1 mg d (3,800 m³/day) may be too complex at 0.01 mg d (38 m³/day). On the other hand, processes that work very well for small water systems may not be practical for large systems.

Membrane filtration has worked very well for small systems, but microfiltration plants in the size range of 100 to 500 mg d (3.8×10^5 to 1.9×10^6 m³/day) would at this time entail a very large amount of piping and valving to interconnect large numbers of small modules.

Processes that employ treatment modules (e.g. microfiltration) are expanded to larger sizes by joining together more modules. This can become problematic for a 100-fold size expansion.

On the other hand, granular media filters can be expanded by designing the filter to have a large or small surface area. One single granular media filter bed could be as small as 4 ft² (0.37 m²), or as large as over 1000 ft² (93 m²), and filtration plants with capacities ranging from 27,000 gal / day (package plant) to 1 billion gal / day (100 m³/day to 3.8×10^6 m³ / day) have been built.

4. Examples of treatment process

4.1. Surface water treatment.

Surface water treatment can be accomplished by a variety of process trains, depending on source water quality. Some examples are given below, beginning with conventional treatment. All surface waters require disinfection, so regardless of the treatment train chosen to treat surface water, that process train must include disinfection. Examples of surface water treatment plant are expressed below.

4.1.1. Dissolved air flotation

For reservoirs and other surface waters with significant algal blooms, filtration processes lacking clarification can be quickly overwhelmed by filter-clogging algae. The processes suitable for low-turbidity source waters (Conventional treatment) are not very successful when treatment of algal-laden water is necessary. The sedimentation basins employed in conventional treatment are not very successful for algae removal, though, because algae tend to float rather than to sink. The density of algae is close to that of water and when they produce oxygen, algae can create their own flotation devices. Therefore, a process that is better suited for algae removal is dissolved air flotation (DAF), in which the coagulated particulate matter, including algae if they are present, is floated to the top of a clarification tank. In DAF, the clarification process and the algae are working in the same direction. Like conventional treatment, DAF employs chemical feed, rapid mix, and flocculation, but then the DAF clarifier is substituted for the sedimentation basin. A DAF process scheme is shown in Figure (1). Waters having high concentrations of algae may also have high concentrations of disinfection by-products (DBP) precursors, so pre-disinfection with free chlorine could lead to DBP compliance problems. Chlorination just before or after filtration and use of alternative disinfectants, such as chloramines, may need to be considered.

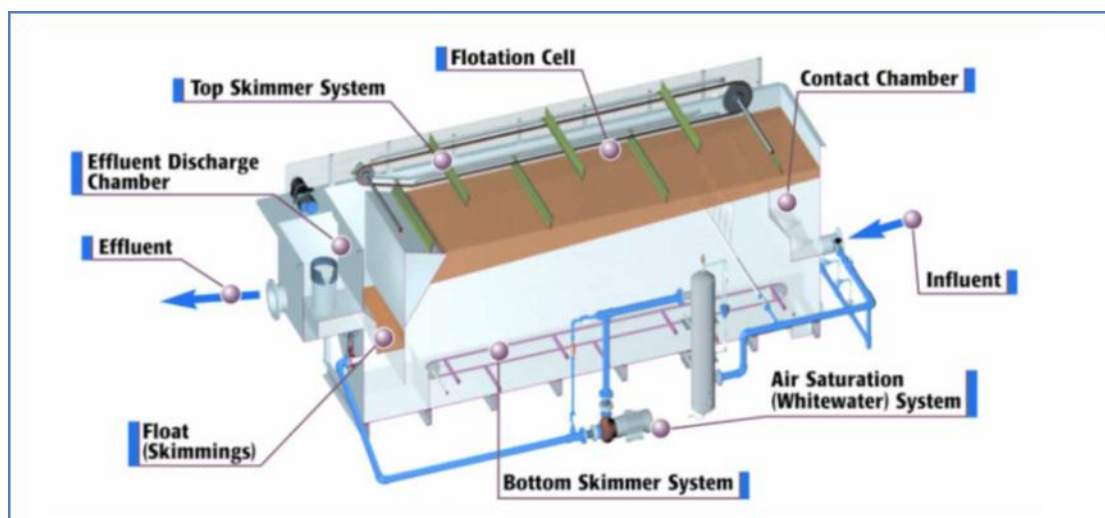


Figure (1) DAF process scheme.

4.1.2. Membrane filtration.

Membrane filtration covers a wide range of processes and can be used for various source water qualities, depending on the membrane process being used. Microfiltration, used for treatment of surface waters, can remove a wide range of particulate matter, including bacteria and particles that cause turbidity. Viruses, however, are so small that some tend to pass through the microfiltration membranes. Microfiltration is practical for application to a wider range of source water turbidities than slow sand filtration or diatomaceous earth (DE) filtration, but microfiltration cannot handle the high turbidities that are encountered in many conventional treatment plants. Microfiltration does not remove dissolved substances, so the disinfection process appropriate for water treated by this process will depend on the dissolved organic carbon (DOC) and precursor content of the source water. Advantages for membrane filtration include very high removal of Giardia cysts and Cryptosporidium oocysts, ease of automation, small footprint for a membrane plant, and the feasibility of installing capacity in small increments in a modular fashion rather than all at once in a major expansion, so that capital expenditures can be spread out over time. A microfiltration process train is shown in Figure (2).

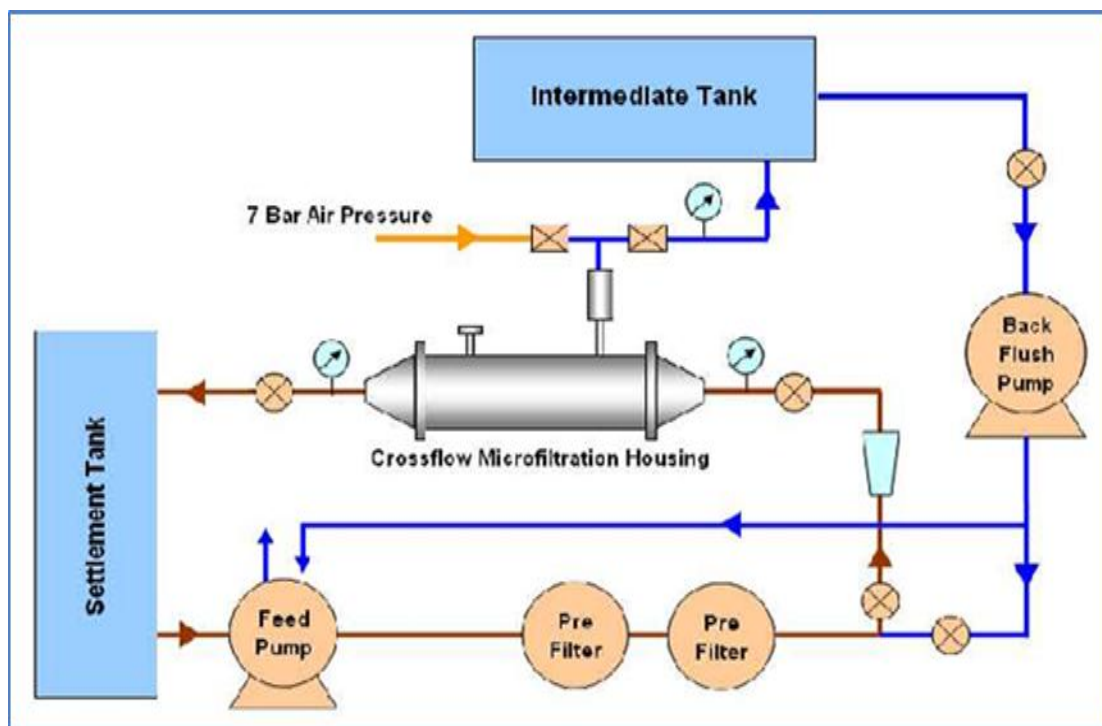


Figure (2) Microfiltration process train.

4.1.3. Conventional treatment.

Many water treatment plants used a combination of coagulation, sedimentation, filtration and disinfection to provide clean and safe drinking water to the public Figure (3). Worldwide, a combination of coagulation, sedimentation and filtration is the most widely applied water treatment technology, and has been used since the early 20th century.

Figure (4) is a process diagram for a conventional water treatment plant. The combination of the first 3 steps primarily removes colloids (including some microorganisms) and natural organic matter (NOM). Step 4 (rapid sand filtration) is a polishing step that removes much of the Colloidal material remaining after step 3 (sedimentation).

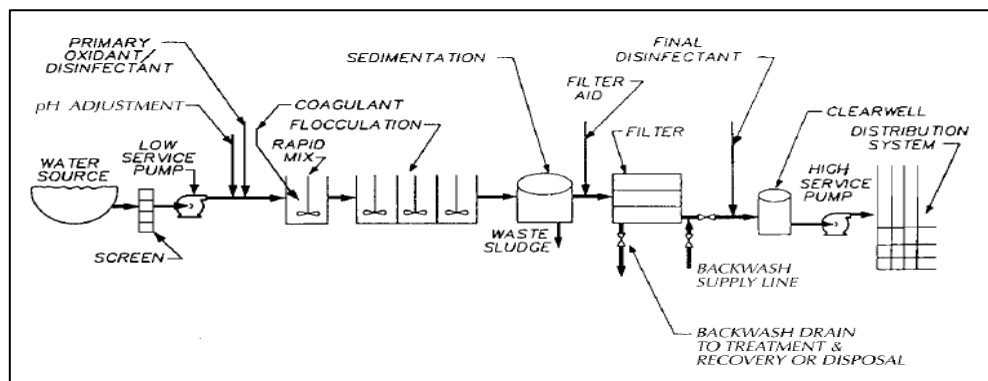


Figure (3) Water treatment plant.

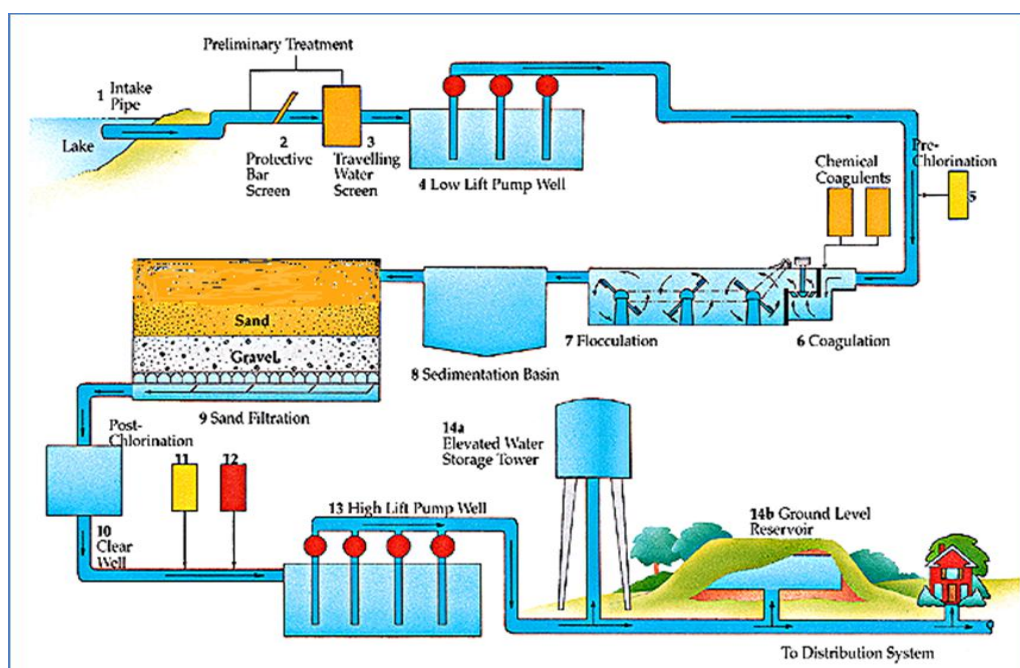


Figure (4) Conventional water treatment plant.

The conventional treatment process is the most used in Egypt. The process of conventional treatment includes five main steps:

- Disinfection
- Coagulation
- Flocculation
- Sedimentation
- Filtration

Coagulation and flocculation occur in successive steps intended to overcome the forces stabilizing the suspended particles, allowing particle collision and growth of floc. If step one is incomplete, the following steps will be unsuccessful.

4.1.3.1. Disinfection

There many disinfectants materials used in water treatment as:

- Chlorine
- Chlorine dioxide
- Ozone
- Ultraviolet radiation
- Chloramines
- Other agents

The most used disinfectant in Egypt water treatment plant is chlorine because of the following advantages:

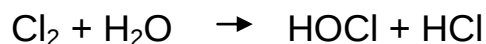
1. Chlorination is a well-established technology.
2. Presently, chlorine is more cost-effective than either UV or ozone disinfection (except when dechlorination is required and fire code requirements must be met).
3. The chlorine residual that remains in the wastewater effluent can prolong disinfection even after initial treatment and can be measured to evaluate the effectiveness.
4. Chlorine disinfection is reliable and effective against a wide spectrum of pathogenic organisms.
5. Chlorine is effective in oxidizing certain organic and inorganic compounds.
6. Chlorination has flexible dosing control.
7. Chlorine can eliminate certain noxious odour during disinfection.

Also chlorine has the following disadvantages:

1. All forms of chlorine are highly corrosive and toxic. Thus, storage, shipping, and handling pose a risk requiring increased safety regulations.
2. Chlorine oxidizes certain types of organic matter, and creating more hazardous compounds (e.g., tri halo methane's [THMs]).
3. The level of total dissolved solids is increased in the treated effluent.
4. The chloride content of the wastewater is increased.
5. Chlorine residual is unstable in the presence of high concentrations of chlorine-demanding materials, thus requiring higher doses to effect adequate disinfection.
6. Some parasitic species have shown resistance to low doses of chlorine, including oocysts of *Cryptosporidium parvum*, cysts, of *Endameba*, histolytic and *Giardia lamblia*, and eggs of parasitic worms.

4.1.3.1.1. Chlorine**Mode of action**

Chlorine gas and water react to form HOCl and hydrochloric acid (HCl). In turn, the HOCl dissociates into the hypochlorite ion (OCl^-) and the hydrogen ion (H^+), according to the following reactions:

**The reactions are reversible and pH dependent:**

- Between pH 3.5 and 5.5, HOCl is the predominant species.
- Between about pH 5.5 and 9.5, both HOCl and OCl^- species exist in various proportions.
- Above pH 8, OCl^- species are predominates.

The OCl^- and HOCl species are commonly referred to as free chlorine, which is extremely reactive with numerous components of the bacterial cell. HOCl can produce oxidation, hydrolysis and deamination reactions with a variety of chemical substrates, and produces physiological lesions that may affect several cellular processes. Baker (1926) theorized that chlorine destroys microorganisms by combining with proteins to form N-chloro compounds.

Chlorine was later found to have powerful effects on sulfhydryl groups of proteins (Green & Stumpf, 1946, Knox et al., 1948; Venkobachar, Iyengar & Rao, 1977) and to convert several amino acids by oxidation into a mixture of corresponding nitriles and aldehydes (Patton et al., 1972).

The exact product of the reaction depends on chlorine concentration and pH (Dakin 1916, 1917; Wright 1936). Cytochromes, iron-sulfur proteins and nucleotides are highly vulnerable to oxidative degradation by HOCl , suggesting that chlorine causes physiological damage primarily to the bacterial cell membranes (Venkobachar, Iyengar & Rao, 1977; Camper & McFeters, 1979; Haas & Engelbrecht, 1980; Albrich, McCarthy & Hurst, 1981). Respiration, glucose transport and adenosine triphosphate levels all decrease in chlorine-treated bacteria (Venkobachar, Iyengar & Rao, 1977; Camper & McFeters, 1979; Haas & Engelbrecht, 1980). Electron microscopy of chlorinated bacteria has demonstrated morphological changes in the cell membrane (Zaske, Dockins & McFeters, 1980). In addition, chlorination can kill microbes by disrupting metabolism (Wyss, 1961) and protein synthesis (Pereira et al., 1973), or by modifying purine and pyrimidine bases and thus causing genetic defects (Patton et al., 1972; Hoyano et al., 1973; Haas & Engelbrecht, 1980). Nearly 100 years of chlorination for disinfection of drinking-water has demonstrated the effectiveness of this process for inactivation of microbial pathogens, with the notable exception of *Cryptosporidium*.

Effectiveness of chlorine against bacteria and viruses

Table (1) shows CT values for 99% (2-log) inactivation of bacteria for various chlorine - based disinfectants. In general, the heterotrophic bacteria grown in drinking-water were more resistant to disinfection than the laboratory-grown *Escherichia coli*.

Table (1) Comparative efficiency of disinfectants for the production of 99% bacterial inactivation in oxidant demand-free systems.

Disinfectant	<i>Escherichia coli</i>			Heterotrophic bacteria		
	pH	Temp (°C)	CT mg/min l ⁻¹	pH	Temp (°C)	CT mg/min l ⁻¹
Hypochlorous acid	6.0	5	0.04	7.0	1-2	0.08 ± 0.02
Hypochlorite ion	10.0	5	0.92	8.5	1-2	3.3 ± 1.0
Chlorine dioxide	6.5	20	0.18	7.0	1-2	0.13 ± 0.02
	6.5	15	0.38	8.5	1-2	0.19 ± 0.06
	7.0	25	0.28			
Monochloramine	9.0	15	64	7.0	1-2	94.0 ± 7.0
				8.5	1-2	278 ± 46.0

Source: Adapted from LeChevallier, Cawthon & Lee (1988)

Certain bacteria show a high level of resistance to free chlorine. Spore forming bacteria such as *Bacillus* or *Clostridium* are highly resistant when disseminated as spores. Acid-fast and partially acid-fast bacteria such as *Mycobacterium* and *Nocardia* can also be highly resistant to chlorine disinfection. One study showed that nearly all of the bacteria surviving chlorine disinfection were Gram positive or acid fast (Norton & LeChevallier, 2000), possibly because Gram-positive bacteria have thicker walls than Gram-negative ones.

Enteric viruses are generally more resistant to free chlorine than enteric bacteria, with CT values for 99% inactivation ranging from about 2 to more than 30 mg/min l⁻¹ (Figure 5). Viruses associated with cellular debris or organic particles may require high levels of disinfection due to the protective nature of the particle surface (Akin & Hoff, 1986; Hoff, 1992). Chlorination effectively inactivates viruses if the turbidity of the water is less than or equal to 1.0 nephelometric turbidity unit (NTU). It requires free chlorine residual of 1.0 or greater for 30 minutes, and a pH of less than 8.0. For ground water where turbidities are generally low, or for filtered surface water, White (1999) suggests the CT guidelines for the 99% virus inactivation shown in Table (2). These data are based

on conservative interpretation of inactivation data for Coxsackie A2.

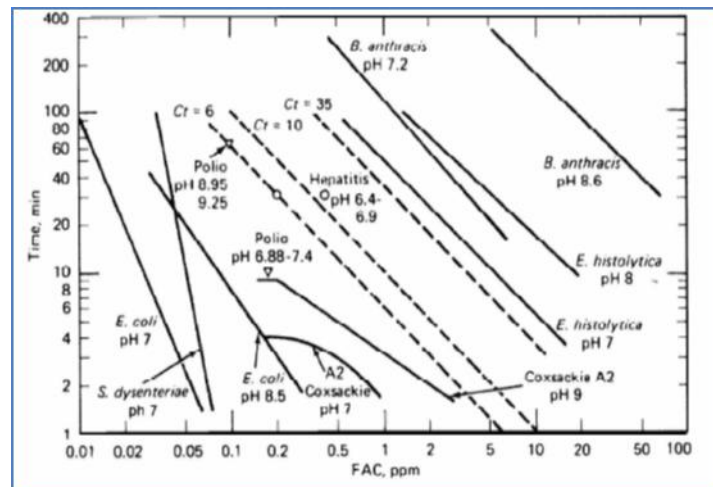


Figure (5). Disinfection (2-log) of microorganisms by free available chlorine (White, 1999).

Table (2). Disinfection time–chlorine concentration envelopes for 99% virus inactivation at 0–5°C and 10°C

pH range	CT in mg/min l ⁻¹	
	0–5°C	10°C
7.0–7.5	12	8
7.5–8.0	20	15
8.0–8.5	30	20
8.5–9.0	35	22

Adapted from White (1999)

Effectiveness of chlorine against protozoa

Protozoan cysts such as *Entamoeba histolytica* and *Giardia lamblia* are highly resistant to chlorine disinfection and may require prolonged contact times at high chlorine residuals (2–3 mg/l) to achieve 99.9% (3-log) inactivation. Clark, Read & Hoff (1989) have described a mathematical model for *Giardia* inactivation that is based on the infectivity data:

$$CT = 0.9847 C^{0.1758} pH^{2.7519} temp^{-0.1467}$$

where:

C = the disinfectant residual concentration

temp = the reaction temperature in degrees Celcius

The United States Environmental Protection Agency (USEPA) has published extensive CT tables for *Giardia* inactivation, for different temperature, pH, chlorine residual and other factors (USEPA, 1989b). For example, at a temperature of 25°C and pH 8.0, with a chlorine residual in the range of 1 to 2.6 mg/l, a contact time of 54–65 minutes is needed to achieve a 3-log reduction in *Giardia* (Table 3). If the temperature is reduced to 10°C, the contact time increases to 162–194 minutes (Table 3 and 4), and at 0.5°C it increases further, to 304–368 minutes (Table 5).

Table (3). Estimated CT values for inactivation of *Giardia* cysts with free chlorine at 25°C

Chlorine (mg/l)	pH 7 Log inactivation			pH 8 Log inactivation		
	1	2	3	1	2	3
1	12	25	37	18	36	54
1.6	13	27	40	19	39	58
2	14	27	41	20	41	61
2.6	15	29	44	22	43	65

Source: Adapted from EPA, 1990.

Table 3.4. Estimated CT values for inactivation of *Giardia* cysts with free chlorine at 10°C

Chlorine mg/l	pH 7 Log inactivation			pH 8 Log inactivation		
	1	2	3	1	2	3
1	37	75	112	54	108	162
1.6	40	79	119	58	116	174
2	41	83	124	61	121	182
2.6	44	87	131	65	129	194

Source: Adapted from EPA, 1990.

Table (5). Estimated CT values for inactivation of *Giardia* cysts with free chlorine at 0.5°C.

Chlorine mg/l	pH 7 Log inactivation			pH 8 Log inactivation		
	1	2	3	1	2	3
1	70	140	210	101	203	304
1.6	75	151	226	110	219	329
2	79	157	236	115	231	346
2.6	84	168	252	123	245	368

Source: Adapted from EPA, 1990.

E. histolytica cysts were inactivated at pH 7.0 in 10 minutes at 25°C with a residual of 3.5 mg/l (Chang, 1982). At pH 4, 30°C and 10 minutes of exposure, 2 mg/l of free chlorine produced a 99.9% reduction of cysts; however, if the pH was increased to 10, a chlorine concentration of 12 mg/l was needed to achieve the same (3-log) reduction. Data on other emerging protozoan pathogens are lacking, although a recent report indicated that the microsporidian *Encephalitozoon* syn. *Septata intestinalis* was

inactivated by more than (3 log) when exposed to 2 mg/l chlorine for 16 min at pH 7 and 25°C (Wolk et al. 2000).

Chlorine-based disinfectants are generally not effective at inactivation of *Cryptosporidium* (Table 6) and early studies found that *Cryptosporidium* oocysts were resistant to a variety of hospital disinfectants, including bleach (Campbell et al., 1982). Chlorine disinfection has not been effective in preventing outbreaks of cryptosporidiosis caused by *Cryptosporidium* in drinking-water and recreational water. Korich et al. (1990) reported that 80 mg/l of free chlorine or monochloramine required 90 minutes to achieve 90% inactivation of oocysts, and suggested that conventional disinfection practices would do little to inactivate waterborne *Cryptosporidium*. However, Rasmussen et al. (1994) examined the disinfection effectiveness of several biocides and found that inactivation of oocysts required an oxidation/reduction potential of about 800 mV, maintained for 30 minutes (Table 6). These authors suggest that oxidation/reduction potential is more important than CT for oocyst inactivation.

Table (6). Summary of free chlorine and monochloramine disinfection results for *Cryptosporidium*

Chlorine residual (mg/l)	Contact time (min)	CT product (mg/min.l ⁻¹)	Temp (°C)	pH	Per cent inactivation	Analytical method
Free chlorine						
80 ^a	90	7200	25	7	> 99	Mouse infectivity
15 ^b	240	3600	22	8	47	Mouse infectivity
968 ^c	1440	1,393,920	10	7	85	Excystation
17 ^{d,e}	30	510	NR	NR	99	Excystation
Monochloramine						
80 ^a	90	7200	25	7	99	Mouse infectivity
15 ^b	240	3600	22	8	99.6	Mouse infectivity
3.75 ^c	1440	5400	10	7	80.5	Excystation
NR = not reported						
^a Korich et al. (1990)						
^b Finch, Kathleen & Gyurek (1994)						
^c Ransome, Whitmore & Carrington (1993)						
^d Rasmussen et al. (1994)						
^e Estimated chlorine residual to achieve an oxidation-reduction potential of 800 mV						

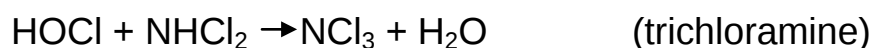
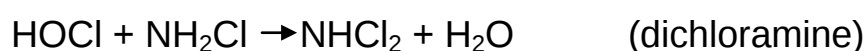
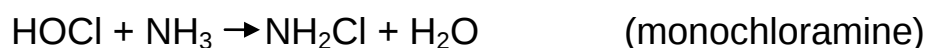
By - products of disinfection with chlorine

THMs and other halogenated compounds are the main by-products of disinfection with chlorine.

4.1.3.1.2. Chloramination

Mode of action

In dilute aqueous solutions (1–50 mg/l), chlorine reacts with ammonia in a series of bimolecular reactions:



These competing reactions are dependent upon pH and the relative chlorine to nitrogen concentration (expressed as $\text{Cl}_2:\text{N}$). To a lesser degree they are also dependent upon temperature and contact time. The reaction of HOCl and ammonia will convert all the free chlorine to monochloramine at pH 7–8 when the $\text{Cl}_2:\text{N}$ ratio is equimolar (5:1 by weight) or less. Ingols (1958) examined the reaction of monochloramine with several amino acids and tripeptides. Exposure of alanine, tyrosine and glycylglycylglycine to the disinfectant for several hours at 25°C and pH 8.0 converted these compounds to organic chloramines. The sulfhydryl groups of cystine were oxidized to disulfides (by comparison, exposure of the same compounds to HOCl produced a variety of oxidized, hydrolysed or deaminated reactants).

Reaction of monochloramine with hemin (an important component of enzymes such as cytochromes, catalases and peroxidases) resulted in products that could not be reactivated by reducing compounds. The author concluded that monochloramine may kill bacterial cells by reacting primarily with membranebound enzymes.

Jacangelo & Olivieri (1985) examined the reaction of monochloramine with amino acids, nucleic acids, nucleotides, nucleosides, purine and pyrimidine bases, and ribose sugars. Monochloramine was most reactive with sulfur-containing amino acids and tryptophan. When the sulfhydryl groups of cysteine were

in excess, 1 mol of monochloramine reacted with 2 mol of cysteine to form 1 mol of the cystine disulfide. When monochloramine was in excess, the reaction proceeded beyond the disulfide state.

Watters et al. (1989) extended the observations of Jacangelo & Olivieri (1985) by examining whole cells. They found that *Enterobacter cloacae* could be reactivated after exposure to chloramine by addition of sodium sulfite, and hypothesized that sodium sulfite could reduce oxidized disulfides, or result in other types of oxidative injury. Interestingly, sodium sulfite had no effect on organisms exposed to free chlorine. The results suggest that free chlorine and chloramine react with different functional groups in the cell membrane.

Jacangelo & Olivieri (1985) found that monochloramine reacted more slowly with nucleic acids and free purine and pyrimidine bases than with amino acids. These results support the observation that many viruses are inactivated more slowly than bacterial cells. Berman & Hoff (1984) showed that simian rotavirus SA11 required more than 6 hours contact with 10 mg/l preformed monochloramine at pH 8.0 to achieve 99% inactivation. Shih & Lederberg (1976) found that exposure of *Bacillus subtilis* deoxyribonucleic acid (DNA) to monochloramine induced single and double stranded breaks, reduced the transforming activity of DNA and enhanced the sensitivity of DNA to endonuclease cleavage.

Effectiveness of monochloramine

Monochloramine is not recommended as a primary disinfectant because of its weak disinfecting power (Table 1). This disinfectant is not effective for inactivation of *Cryptosporidium* (Table 6). In systems using monochloramine, free chlorine is usually applied for a short time before addition of ammonia, or an alternative primary disinfectant is used (e.g. ozone, chlorine dioxide).

By-products of disinfection with monochloramine

Treatment to produce a monochloramine residual poses the risk of nitrite formation in the distribution system, especially in low-flow stagnant areas, because bacteria on surfaces and in deposits may nitrify any slight excess of ammonia.

4.1.3.1.3. Chlorine dioxide

Chlorine dioxide is a strong oxidant that can be used to control iron, manganese and taste and odour causing compounds. It has also been used as a secondary disinfectant in many European countries.

Mode of action

Chlorine dioxide is highly soluble in water (particularly at low temperatures), and is effective over a range of pH values (pH 5 – 10). Theoretically, chlorine dioxide undergoes five valence changes in oxidation to chloride ion:



However, in practice, chlorine dioxide is rarely reduced completely to chloride ion (White 1999). Chlorine dioxide is thought to inactivate microorganisms through direct oxidation of tyrosine, methionyl, or cysteinecontaining proteins, which interferes with important structural regions of metabolic enzymes or membrane proteins (Gates 1998). In water treatment, chlorine dioxide has the advantage of being a strong disinfectant, but not forming THMs or oxidizing bromide to bromate.

Effectiveness of chlorine dioxide against bacteria and viruses

Chlorine dioxide is roughly comparable to free chlorine for inactivation of bacteria and viruses at neutral pH (White, 1999), but is more effective than free chlorine at pH 8.5 (Hoff & Geldreich, 1981).

Effectiveness of chlorine dioxide against protozoa

Chlorine dioxide is an effective disinfectant for control of *Giardia lamblia*; the required CT values for 1-log inactivation (pH 6–9) range from 5 mg min/l at 20 °C to 21 mg/min l⁻¹ at 0.5 °C (USEPA, 1989b; White, 1999). The 3-log inactivation CT values (pH 6–9) range from 19 mg/min l⁻¹ at 15 °C to 63 mg/min l⁻¹ at 0.5 °C. These values are 3–14 times less than those required for free chlorine, but approximately 20 times more than those required for ozone. Figure 5 summarizes results from various studies of

Cryptosporidium inactivation by chlorine dioxide. Peeters et al. (1989) reported 1.5 and 1.2-log inactivation of Cryptosporidium, using an animal infectivity method, for CT values of 3 and 9.8 mg/min l⁻¹, respectively (average of initial and final concentrations). Korich et al. (1990) reported a CT value of 78 mg/min l⁻¹, with an initial concentration of 1.3 mg/l and a contact time of 60 minutes, for a 90% (1-log) inactivation of Cryptosporidium, based on mouse infectivity. The CT for 1-log inactivation was calculated to be 51 mg/min l⁻¹ (average of initial and final concentrations). Finch, Liyanage & Belosevic (1995) recalculated the Korich data using a dose-response model developed for CD-1 mice, and estimated a 99% (or 2-log) inactivation. Ransome, Whitmore & Carrington (1993), employing the excystation viability method, reported Cryptosporidium inactivation ranging from 0.14 to 1.4-log for average CT values ranging from 6.5 to 67.5 mg/min l⁻¹, respectively. Based on results from 12 animal infectivity experiments, Finch et al. (1997) reported Cryptosporidium inactivation ranging from 0 to greater than 3.2-log for average CT values ranging from 12.5 to 212 mg/min l⁻¹. Chlorine dioxide concentration decreased markedly at contact times of more than 30 minutes, a factor that could result in low CT values.

LeChevallier et al. (1996) found that oocysts were more rapidly inactivated by chlorine dioxide at pH 8.0 than at pH 6.0, and that effectiveness was reduced by 40% when temperature was reduced from 20 °C to 10 °C. This finding is supported by other studies (Bernard et al., 1965; Owens et al., 1999; Ruffle, Rennecker & Marinas, 1998). Chlorine dioxide inactivation rates using a cell culture technique to determine infective oocysts were similar to rates generated using animal infectivity tests.

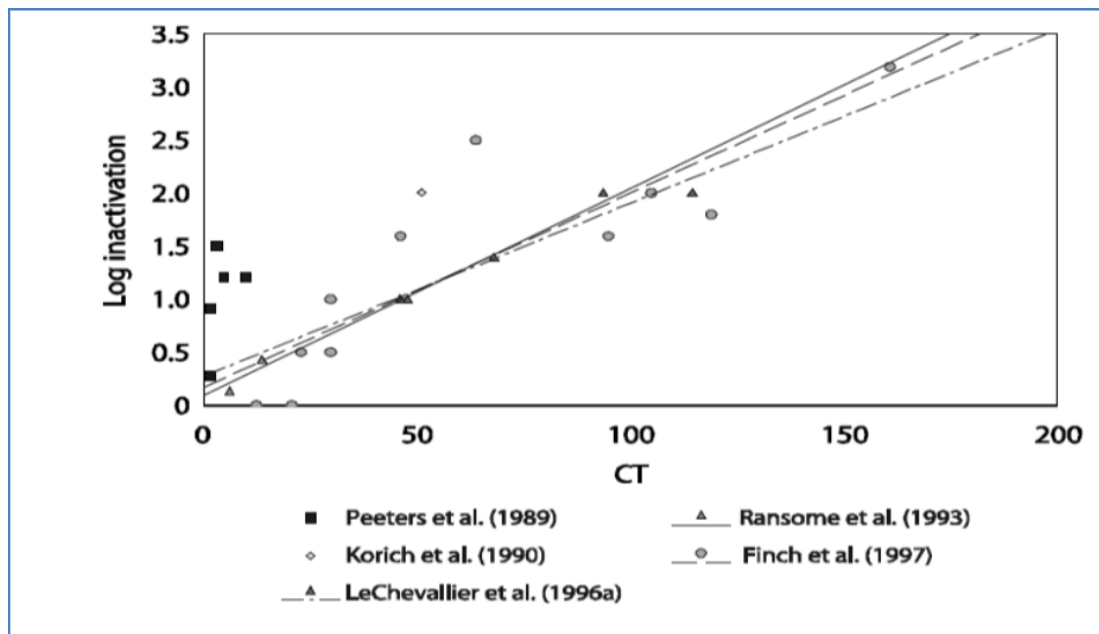


Figure (6). Summary of *Cryptosporidium* inactivation by chlorine dioxide

By-products of disinfection with chlorine dioxide

The chlorine in chlorine dioxide exists in a +4 oxidation state, compared to an oxidation state of +1 for chlorine in free chlorine (in hypochlorous and hypochlorite ions). This means that chlorine and chlorine dioxide have different pathways for disinfection and formation of by-products when used in drinkingwater treatment. For example, chlorine dioxide does not produce significant levels of halogenated organic by-products.

Chlorine dioxide forms undesirable inorganic by-products (chlorite and chlorate ions) upon its reaction with constituents of water such as dissolved organic carbon, microbes and inorganic ions. Therefore, a water utility may need to provide additional treatment depending on the level of these inorganic by-products and their specific regulatory requirements (Gordon & Bubnis, 1995; WHO, 2000).

4.1.3.1.4. Ozone

Ozone has been used for more than a century for water treatment, mostly in Europe, although its use is now spreading to other countries.

Mode of action

The mechanism by which ozone inactivates microbes is not well understood. Ozone in aqueous solution may react with microbes either by direct reaction with molecular ozone or by indirect reaction with the radical species formed when ozone decomposes. Ozone is known to attack unsaturated bonds, forming aldehydes, ketones or carbonyl compounds (Langlais, Reckhow & Brink, 1991).

Additionally, ozone can participate in electrophilic reactions, particularly with aromatic compounds, and in nucleophilic reactions with many of the components of the microbial cell. Carbohydrates and fatty acids react only slightly with ozone, but amino acids, proteins, protein functional groups (e.g. disulfide bonds) and nucleic acids all react very quickly with it (Langlais, Reckhow & Brink, 1991). It is likely, therefore, that microbes become inactivated through ozone acting on the cytoplasmic membrane (due to the large number of functional proteins), the protein structure of a virus capsid, or nucleic acids of microorganisms.

Free radicals formed by the decomposition of ozone are generally less effective for microbial inactivation than molecular ozone, because microbial cells contain a high concentration of bicarbonate ions that quench the free radical reaction, and many microbial cells also contain catalase, peroxidase, or superoxide dismutase to control the free radicals produced by aerobic respiration. In addition, some bacteria contain carotenoid and flavonoid pigments that protect them from ozone. These factors can account for reports that heterotrophic bacteria may be less susceptible to ozone inactivation than *Giardia* (Wolfe et al., 1989). Studies of peroxone (a mixture of ozone and hydrogen peroxide that promotes the generation of hydroxyl free radicals) showed that peroxone was comparable to ozone, or slightly more potent, when CTs were based on ozone residuals (Wolfe et al., 1989). These results suggest that free radicals provide little benefit in terms of microbial destruction.

Effectiveness of ozone against bacteria and viruses

Of the vegetative bacteria, *Escherichia coli* is one of the most sensitive (Table 7), while Gram-positive cocci (*Staphylococcus* and *Streptococcus*), Gram-positive bacilli (*Bacillus*) and mycobacteria are the most resistant (Langlais, Reckhow & Brink, 1991). *Mycobacterium avium* can be effectively controlled by low doses of ozone (CT_{99.9} of 0.1–0.2 mg/min l⁻¹), whereas the organism is highly resistant to free chlorine (CT_{99.9} of 551–1552 mg/min l⁻¹ for water-grown isolates) (Taylor et al., 2000).

Table (7). CT values (mg/min l⁻¹) for 99% inactivation at 5°C

Microorganism	Free chlorine (pH 6–7)	Preformed chloramines (pH 8– 9)	Chlorine dioxide (pH 6–7)	Ozone (pH 6–7)
<i>E. coli</i>	0.034–0.05	95–180	0.4–0.75	0.02
Poliovirus 1	1.1–2.5	770–3740	0.2–6.7	0.1–0.2
Rotavirus	0.01–0.05	3810–6480	0.2–2.1	0.006–0.06
Phage f2	0.08–0.18	–	–	–
<i>G. lamblia</i> cysts	47–>150	–	–	0.5–0.6
<i>G. muris</i> cysts	30–630	1400	7.2–18.5	1.8–2.0

Adapted from Hoff (1986)

Viruses are generally more resistant to ozone than vegetative bacteria, although phage appear to be more sensitive than human viruses (Langlais, Reckhow & Brink, 1991).

Effectiveness of ozone against protozoa

For the protozoa *Giardia lamblia* and *Naegleria gruberi*, ozone inactivation (Table 7) did not follow linear kinetics, due to an initial latent phase. However, CT products could be reasonably estimated with a CT₉₉ (a CT for 99% inactivation) of 0.53 and 4.23 mg/min l⁻¹, respectively, at 5°C (Wickramamayake, Rubin & Sproul, 1984).

Ozone is effective for removal of *Cryptosporidium* (Table 3.8). Noticeable for *Cryptosporidium* is the impact of the analytical method on the CT values.

Generally, excystation and vital staining are more conservative measures of oocyst inactivation than animal infectivity. Reliance on excystation and vital staining alone could greatly overestimate disinfection requirements for *Cryptosporidium*. On average, 4.5

mg/min l⁻¹ CT was required for 99% oocyst inactivation (measured by mouse infectivity) by ozone at 20–25 °C (Table 8).

However, Finch et al. (1993) indicated that the conventional method of determining CT by using the final concentration of reactants at the end of the contact time overestimates the CT needed for disinfection and unduly increases treatment costs. The authors recommended the Holm disinfection model, which integrates the disinfectant concentration and time throughout the reactor. Using this alternative calculation, CT for *Cryptosporidium* inactivation were 6.9 mg/min l⁻¹ at 7°C and 2.4 mg/min l⁻¹ at 22 °C.

Table (8) Summary of ozone disinfection results for *Cryptosporidium*

Ozone residual (mg/l)	Contact time (min)	CT product (mg/min l ⁻¹)	Temp °C	Per cent inactivation	Analytical method
1 ^a	5	5	25	90–99	Mouse infectivity
1 ^a	10	10	25	>99	Mouse infectivity
0.77 ^b	6	4.6	'Room'	>99	Mouse infectivity
0.51 ^b	8	4.1	'Room'	>99	Mouse infectivity
0.16–1.3 ^c	5–15	7	7	99	Mouse infectivity
0.17–1.9 ^c	5–15	3.5	22	99	Mouse infectivity
2.4 (avg) ^d	2.3	5.5	22–25	99	Mouse infectivity
1.25 ^e	15	18.75	10	98.6	Excystation
4 (approx) ^f	2	8	'Room'	>90	Excystation
1–5 ^g	10	10–50	5	18–39	Stain
1–5 ^g	10	10–50	20	70–>99	Stain
0.7–1.5 ^h	14–25	9.8–27	8–10	42–84	Stain

^a Korich et al. (1990)
^b Peeters et al. (1989)
^c Finch et al. (1993)
^d Owens et al. (1994)
^e Ransome, Whitmore & Carrington (1993)
^f Armstrong et al. (1994)
^g Parker, Greaves & Smith (1993)
^h Hall, Pressdee & Carrington (1994)

To date, there are no accepted CT values for ozone for inactivation of *Cryptosporidium*, either for regulatory or operational application. Results of disinfection studies vary widely between studies and even between replicate trials. The USEPA is evaluating options for *Cryptosporidium* disinfection by ozone and, for developmental and cost-estimating purposes, is using values that encompass the range of experimental variability (Table 9). These values will probably be replaced with consensus values eventually, but are presented here to demonstrate the range of ozone CT values for different water temperatures and levels of inactivation.

Table 9. CT (mg/min l⁻¹) for Cryptosporidium inactivation by ozone

Log inactivation	Temperature		
	1°C	13°C	22°C
0.5	6	2	0.6
1.0	12	4	1.5
1.5	24	8	3.0
2.0	40	11	4.4
2.5	45	15	6.0
3.0	62	22	8.0

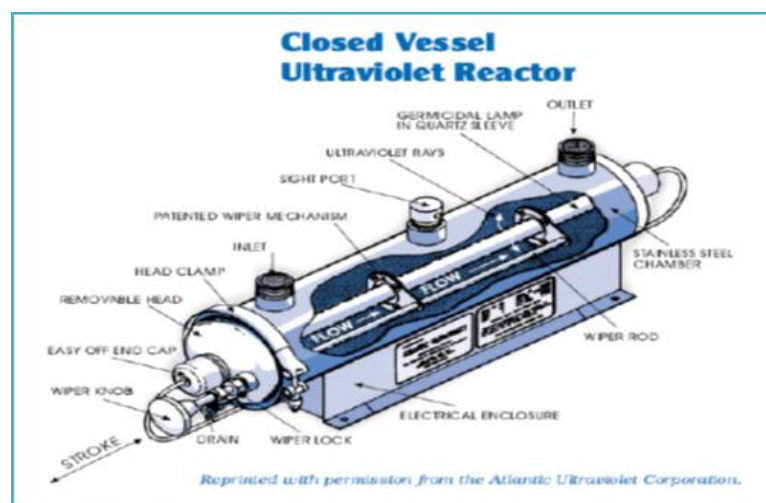
Source: Estimated based on preliminary data from G Finch (personal communication). For illustrative purposes only.

Effectiveness of ozone against algal toxins

Ozonation is an effective process for destruction of both intracellular and extracellular algal toxins. Essentially complete destruction of microcystins, nodularin and anatoxin-a can be achieved if the ozone demand of the water is satisfied (Yoo et al., 1995b; Chorus & Bartram 1999).

4.1.3.1.5. Ultraviolet light Mode of action

UV light can be categorized as UV-A, UV-B, UV-C or vacuum-UV, with wavelengths ranging from about 40 to 400 nm. The UV light effective for inactivating microorganisms is in the UV-B and UV-C ranges of the spectrum (200–310 nm), with maximum effectiveness around 265 nm. Thymine bases on DNA and ribonucleic acid (RNA) are particularly reactive to UV light and form dimers (thymine–thymine double bonds) that inhibit transcription and replication of nucleic acids, thus rendering the organism sterile.



Thymine dimers can be repaired in a process termed 'photoreactivation' in the presence of light, or 'dark repair' in the absence of light (Jagger, 1967). As a result, the strategy in UV disinfection has been to provide a sufficiently high dosage to ensure that nucleic acid is damaged beyond repair.

Effectiveness of UV against bacteria and viruses

Table (10) shows that UV is an effective disinfectant for bacteria and viruses (USEPA, 1986; Wolfe, 1990; Battigelli, Sobsey & Lobe, 1993). *Bacillus subtilis* spores are commonly used as a bioassay organism because of their resistance to inactivation, requiring about 31 mW-sec/cm² for a 4-log inactivation of spores (Qualls & Johnson, 1983). MS-2 is an F-specific single-stranded RNA virus about 20 nm in diameter that can be used as a viral surrogate (Braunstein et al., 1996). Adenoviruses are double-stranded DNA viruses and are very resistant to UV inactivation. Typical doses used for drinking-water disinfection would not be effective for treatment of adenoviruses.

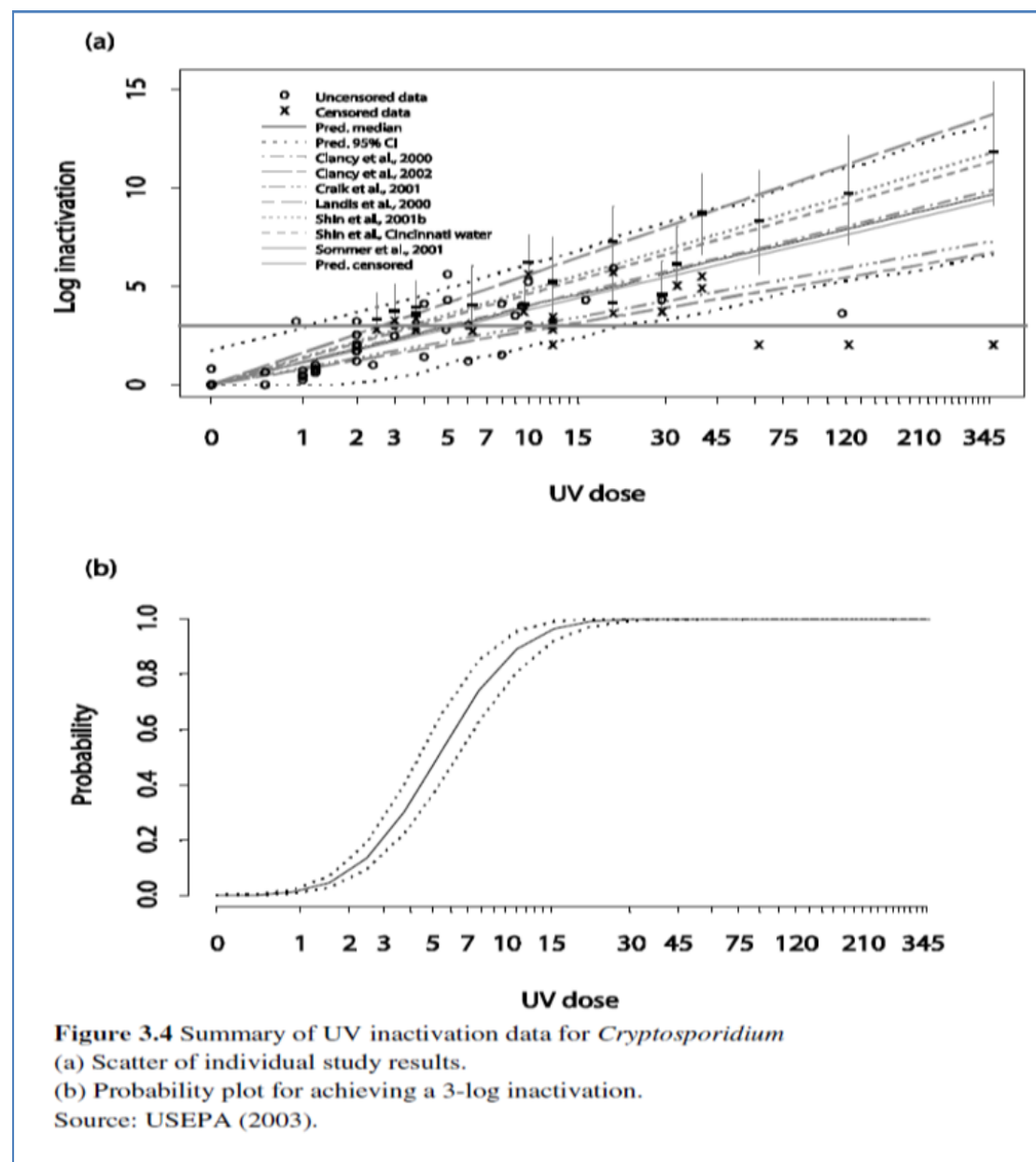
Table (10). Typical UV dosages required for 4-log inactivation of selected microbes.

Organism	4-log inactivation dose range (mW-sec/cm ²)	Water source
Bacteria:		
<i>Bacillus subtilis</i> spores	31	Laboratory water
<i>Escherichia coli</i>	20	Laboratory water
<i>S. faecalis</i>		Laboratory water
<i>Salmonella typhi</i>	30	Laboratory water
<i>Vibrio cholera</i>	0.65	Laboratory water
Viruses:		
MS-2	50	Groundwater (1 source)
	64–93	Groundwater (11 sources)
	100	Laboratory water
Coxsackie AZ	30	Laboratory water
Hepatitis A	6–15	Groundwater (3 sources)
	16	Laboratory water
Poliovirus	23–29	Groundwater (8 sources)
	30	Laboratory water
Rotavirus — Wa	50	Laboratory water
Rotavirus SA11	40	Tap water
Adenovirus	186	Laboratory water (4 studies)

Adapted from Malley (2000) and USEPA (2003)

Effectiveness of UV against protozoa

Most of the early work on UV disinfection of *Giardia* (Rice & Hoff, 1981; Karanis et al., 1992) and *Cryptosporidium* (Lorenzo-Lorenzo et al., 1993; Ransome, Whitmore & Carrington, 1993; Campbell et al. 1995) relied upon excystation or vital staining to determine viability and found that UV inactivation was not effective for *Giardia* cysts or *Cryptosporidium* oocysts. However, more recent work (Clancy et al., 1998ab; Bukhari et al., 1999; USEPA, 2003) using mouse infectivity or cell culture showed that low or medium-pressure mercury vapour UV lamps, or pulsed UV technology can achieve 3-log inactivation of *Cryptosporidium* oocysts at UV doses less than 10 mW-sec/cm² (Figure 7). Similar sensitivities to UV inactivation have recently been shown for *Giardia* (Craig et al., 2000).



Guidelines and standards relating to the use of UV

Recently, guidelines have been developed to evaluate the effects of reactor design, selection of UV lamps, performance standards for lamp ageing and fouling, and the accuracy of UV sensors (DVGW, 1997; ONORM, 2001; USEPA, 2003). Standards for the installation and operation of UV systems are important because the effectiveness of UV disinfection can be impaired by the transmittance of the water, colour and the presence of particulate material.

4.1.3.1.6. SECONDARY DISINFECTION

This section looks at the use of secondary disinfection to maintain water quality in distribution systems. The publication Safe piped water: Managing microbial water quality in piped distribution systems (Ainsworth, 2004) provides more detail on this topic.

4.1.3.2. Maintenance of water quality in the distribution system

The purpose of a secondary disinfectant is to maintain the water quality achieved at the treatment plant throughout the distribution system up to the tap.

Secondary disinfection provides a final partial barrier against microbial contamination and serves to control bacterial growth. The practice of residual disinfection has become controversial, with some opponents arguing that if biological stability is achieved and the system is well maintained, the disinfectant is unnecessary. These positions are presented in a series of papers published in Water Supply (Vol. 16(3/4), 1998).

4.1.3.3. Factors affecting microbial occurrence Disinfectant residual and disinfectant level

The growth of bacteria and occurrence of coliforms depend on a complex interaction of many factors including water temperature, disinfectant type and residual, pipe material, corrosion and other engineering and operational parameters (Berger, LeChevallier & Reasoner, 1992; LeChevallier et al., 1991, 1993; LeChevallier, Welch & Smith, 1996). Recent research has indicated that various disinfectants differ in their ability to interact with biofilm bacteria

(LeChevallier, 1991; De Beer, Srinivasan & Stewart, 1994). Monochloramine, although a much less reactive disinfectant than free chlorine, is more specific in the type of compounds that it will react with. Therefore, monochloramine can be more effective than free chlorine at penetrating and inactivating certain types of biofilm, particularly those containing corrosion products (LeChevallier, Lowry & Lee, 1990; LeChevallier et al., 1993; Norton & LeChevallier, 1997). A study of 30 distribution systems showed a difference in the density and occurrence of coliform bacteria between systems using free chlorine and those using chloramines (LeChevallier et al., 1996). Modelling indicates that the penetration of free chlorine into a biofilm is limited by its fast reaction rate (De Beer, Srinivasan & Stewart, 1994). Free chlorine is essentially consumed before it can react with the bacterial components of the film (Chen & Stewart, 1996).

Chloramines, on the other hand, are slower reacting; they can diffuse into the biofilm and eventually inactivate attached bacteria, a mechanism that has been demonstrated using an alginate bead model (Chen and Stewart, 1996). Stewart, McFeters & Huang (2000) showed that free chlorine did not effectively penetrate alginate beads containing bacterial cells, but chloramines did penetrate into the alginate material and reduced bacterial levels nearly one million-fold over a 60 minute interval (2.5 mg/l chloramines, pH 8.9). Kool, Carpenter & Fields (1999) reported that hospitals supplied with water containing a chloramine residual were 10 times less likely to have water-associated legionella infections. Similarly, Heffelfinger et al. (2003), in a study of 166 hospitals, found that nosocomial legionellosis was five times less likely in the hospitals served with chloraminated water. The authors attributed the effectiveness of chloramines for legionella control to the ability of the disinfectant to penetrate biofilms. In addition to the type of disinfectant used, the residual maintained at the end of the distribution system was also related to coliform occurrences (LeChevallier, Welch & Smith, 1996). Systems that maintained dead-end free chlorine levels of less than 0.2 mg/l or monochloramine levels of less than 0.5 mg/l had substantially more coliform occurrences than systems maintaining higher disinfectant residuals. Systems with high assimilable organic carbon (AOC) levels needed to maintain high disinfectant residuals to control coliform occurrences. Therefore, maintenance of a

disinfectant residual alone does not ensure that treated waters will be free of coliform bacteria.

Biostability

The presence of biodegradable organic matter in water will promote bacterial growth, and may be related to the occurrence of coliform bacteria in distribution systems (Bourbigot, Dodin & Lheritier, 1984; Camper et al., 1991; Geldreich & Stevens, 1987; LeChevallier, Babcock & Lee, 1987; LeChevallier et al., 1991).

Biodegradable organic matter is commonly measured as AOC or biodegradable dissolved organic carbon (BDOC). Van der Kooij (1987) showed that AOC concentrations increased in water samples treated with increasing chlorine doses. Similarly, Hambsch & Werner (1993) reported higher biodegradability of humic substances after chlorination. LeChevallier et al. (1992) found that chlorination may increase AOC levels, depending on the point of chlorine application.

Corrosion control and pipe materials

Corrosion of iron pipes can influence the effectiveness of chlorine - based disinfectants for inactivation of biofilm bacteria (LeChevallier, Lowry & Lee, 1990; LeChevallier et al., 1993; Ainsworth, 2004). Free chlorine is affected to a greater extent than monochloramine, although the effectiveness of both disinfectants is impaired if corrosion rates are not controlled (LeChevallier, Lowry & Lee, 1990; LeChevallier et al., 1993). Improving corrosion control can improve the ability of residual disinfectants to control bacterial growth (Norton & LeChevallier, 1997).

The pipe surface itself can influence the composition and activity of biofilm populations. Biofilms develop more quickly and support a more diverse microbial population on iron pipe surfaces than on plastic polyvinylchloride (PVC) pipes, even with adequate corrosion control, biological treatment of water to reduce AOC levels and consistently maintained chlorine residuals (LeChevallier et al., 1993; Camper, 1996).

Pressure, cross-connection control and maintenance

Microbial quality of drinking-water cannot depend only on maintenance of a residual disinfectant. The extensive nature of the distribution system, with many kilometres of pipe, storage tanks, interconnections with industrial users and the potential for tampering and vandalism, provides opportunities for contamination. Cross-connections are a major risk to water quality. Although the risk can be reduced by vigilant control programs, complete control is difficult to achieve and water utilities worldwide face challenges in maintaining an effective cross-connection control program.

Despite the best efforts to repair main breaks using good sanitary procedures, main breaks provide an opportunity for contamination to enter the distribution system. Utilities typically isolate the affected section and repair, superchlorinate and flush the repaired pipe. However, it may be difficult to achieve flushing velocities sufficient to remove all contaminated debris; also, microbiological tests to check the final water quality may not detect contaminating organisms. McFeters, Kippin & LeChevallier (1986) reported high levels of damaged coliform bacteria, not detectable by standard coliform techniques, following the repair of a main break. Resampling of the site one week later showed persistence of high levels of the coliform bacteria, detectable only using m-T7 agar, a medium specially designed to recover chlorine-damaged coliforms. Backflow devices to prevent the entry of contaminated water are important as a distribution system barrier. Because of high costs, backflow devices are installed mainly on service lines for facilities that use potentially hazardous substances (e.g. hospitals, mortuaries, dry cleaners and industrial users). It is not common for all service connections to have backflow devices, so the possibility of back-siphonage exists at certain points. Also, installation of backflow devices for all service connections would make routine checking of the devices nearly impossible and, without routine inspection, the proper functioning of the units cannot be assured. Even when backflow devices have been installed, contamination events have occurred. For example, the failure of a backflow check valve allowed water stored for fire protection to enter the distribution system in Cabool, Missouri (USA) (Geldreich, 1996). A broken vent in the storage tank allowed birds to enter and

contaminate the water with Salmonella. Three people died from Salmonella infection.

Residual chlorine requirements at consumers points

	WHO	USEPA
Residual concentration, mg/L	0.2	0.25

Effectiveness of disinfectants

Disinfectant	unit	1-log	2-log	3-log	4-log
bacteria					
Chlorine	mg.min/l	0.1_0.2	0.4-0.8	1.5_3	10_12
Chloroamine	mg.min/l	4_6	12_20	30_75	200_250
Chlorine dioxide	mg.min/l	2_4	8_10	20_30	50_70
Ozone	mg.min/l		3_4		
virus					
Chlorine	mg.min/l		2.5_3.5	4_5	6_7
Chloroamine	mg.min/l		300_400	500_800	1000_1200
Chlorine dioxide	mg.min/l		2_4	6_12	12_20
Ozone	mg.min/l		0.3_0.5	0.5_0.9	0.6_1
protozoan cysts					
Chlorine	mg.min/l	20_30	35_45	70_80	
Chloroamine	mg.min/l	400_650	700_1000	1100_2000	
Chlorine dioxide	mg.min/l	7_9	14_16	20_25	
Ozone	mg.min/l	0.2_0.4	0.5_0.9	0.7_1.4	

4.1.3.2. Coagulation

The first step destabilizes the particle's charges. Coagulants with charges opposite those of the suspended solids are added to the water to neutralize the negative charges on dispersed non-settleable solids such as clay and colour-producing organic substances.

Once the charge is neutralized, the small suspended particles are capable of sticking together. The slightly larger particles formed through this process and called microflocs, are not visible to the naked eye. The water surrounding the newly formed microflocs should be clear. If it is not, all the particles' charges have not been neutralized, and coagulation has not been carried to completion. More coagulant may need to be added.

A high-energy, rapid-mix to properly disperse the coagulant and promote particle collisions is needed to achieve good coagulation. Over-mixing does not affect coagulation, but insufficient mixing will leave this step incomplete. Coagulants should be added where sufficient mixing will occur. Proper contact time in the rapid-mix chamber is typically 1 to 3 minutes.

4.1.3.3. Flocculation

Following the first step of coagulation, a second process called flocculation occurs. Flocculation, a gentle mixing stage, increases the particle size from submicroscopic microfloc to visible suspended particles.

The microflocs are brought into contact with each other through the process of slow mixing. Collisions of the microfloc particles cause them to bond to produce larger, visible flocs called pinflocs. The floc size continues to build through additional collisions and interaction with inorganic polymers formed by the coagulant or with organic polymers added. Macroflocs are formed. High molecular weight polymers, called coagulant aids, may be added during this step to help bridge, bind, and strengthen the floc, add weight, and increase settling rate. Once the floc has reached its optimum size and strength, the water is ready for the sedimentation process. Design contact times for flocculation range from 15 or 20 minutes to an hour or more.

4.1.3.4. Sedimentation

Sedimentation basins are used in conventional plants. Direct-filtration plants skip the sedimentation stage and go directly to filtration. Detention times for sedimentation are in the range of 1 to 4 hours. Inlets are designed to distribute water evenly and at uniform velocities. Overflow rates should not exceed 20,000 gallons per day per foot of weir length. Velocity should not exceed 0.5 feet per minute.

Sedimentation basins are used to settle out the floc before going to the filters. Some type of sludge collection device should be used to remove sludge from the bottom of the basin.

4.1.3.5. Filtration

The purpose of filtration is to remove suspended particles from water by passing the water through a medium such as sand. As the water passes through the filter, floc and impurities get stuck in the sand and the clean water goes through. The filtered water collects in the clear well, where it is disinfected and then sent to the customers.

Filtration is usually the final step in the solids removal process which began with coagulation and advanced through flocculation and sedimentation. In the filter, up to 99.5% of the suspended solids in the water can be removed, including minerals, floc, and microorganisms.

Filtration is now required for most water treatment systems. Filters must reduce turbidity to less than 0.5 NTU in 95% of each month's measurements and the finished water turbidity must never exceed 1 NTU in any sample.

4.2 Membrane Processes

4.2.1 Reverse Osmosis

In RO, water is extracted by pressurizing saline water through semi-permeable membranes that allow passage of water but not salt (Fig. 8). This ability to inhibit the flow of salt is termed salt rejection, defined as the ratio of salt concentration in the filtrate (permeate) to the salt concentration in the feed. A minimum pressure the osmotic pressure has to be exceeded to operate the process. The osmotic pressure increases with water salinity. Pressures appreciably exceeding the osmotic pressure are used to ensure an acceptable rate of water production. Production rates are reported in gallons of filtrate per square foot of membrane surface area per day (gfd) or in other units such as liters of filtrate per square meter of membrane surface area per hour (LMH).

In the early years of RO, asymmetric cellulose membranes were used as the semi-permeable barriers (Saltonstall 1977). In these membranes, the separation layer and the underlying support were made of the same material. The development of thin film composite (TFC) membranes in the 1980s was a major development in improving the performance characteristics of RO membranes (Cadotte et al. 1980).

Composite membranes consist of a semi-permeable barrier laminated to an underlying support. This allowed the optimization of the membrane layer and the support structure individually resulting in major improvements in membrane permeability and salt rejection characteristics. The TFC's used are generally comprised of aromatic polyamide or polyetherurea films deposited onto a porous support by chemical reaction.

The membranes are manufactured as flat sheets and subsequently rolled into spirals (Fig. 9). This configuration, the spiral wound membrane, provides a high ratio of membrane surface area to packing volume. The diameters of spiral wound membranes have steadily increased over the years and today, module diameters as large as 16 in. can be manufactured, each with a membrane area of 160 m² (Anonymous 2008). Up to eight modules are packed into a fiberglass-reinforced housing and constitute a unit of separation. Several such units are typically linked together in parallel to form a stack. Stacks can then be linked together in series to form a complete system.

4.2.2 Electrodialysis

Though electrodialysis was the first commercialized membrane - based desalination technology, it currently serves a relatively small market. The technology removes cations and anions from the salt water through application of an electric field. A stack (Fig. 10) is comprised of alternating cation and anion selective membranes placed under an electric field gradient. The end compartments contain the anode and cathode along with their respective electrolyte solutions. Feed water flows in the space between the membranes and is subjected to a potential gradient. Under the influence of the electric field, the cations permeate through the cation selective membrane towards the cathode while the anions migrate towards the anode. As the ion selective membranes are in an alternating arrangement, cations migrating into an adjacent compartment are restricted from further movement towards the cathode by the intervening anion selective membrane and vice versa. The migrating cations and anions are trapped in the intervening channels forming the concentrate compartment. The feed solution in the meantime is depleted of both cations and anions. The energy for separation is proportional to the current flow and increases with salinity.

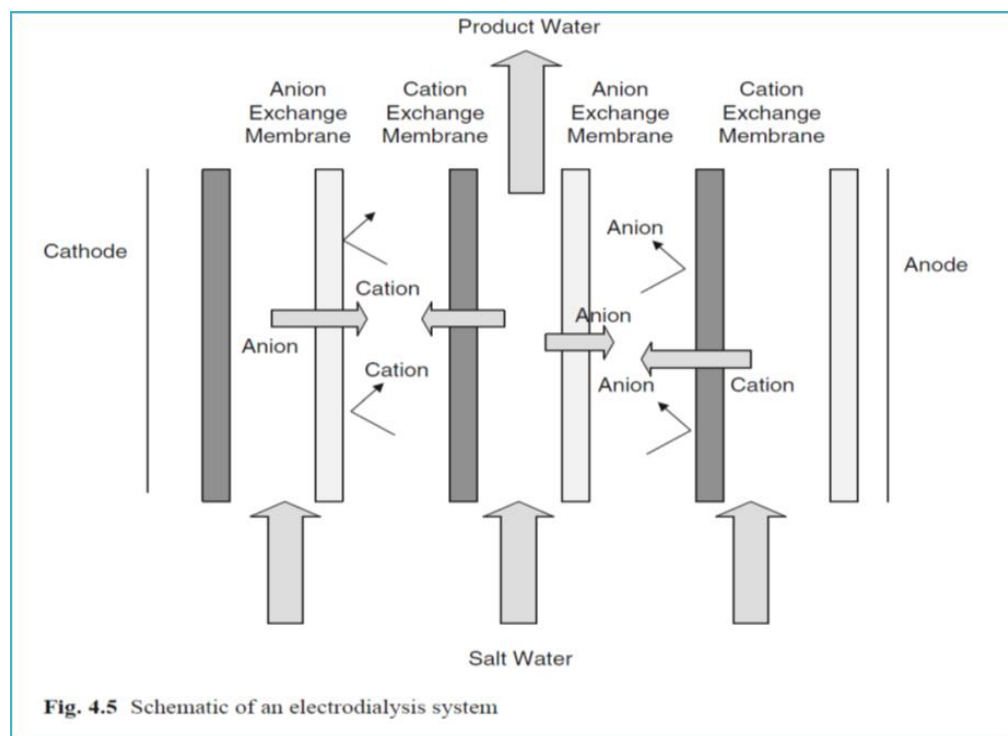


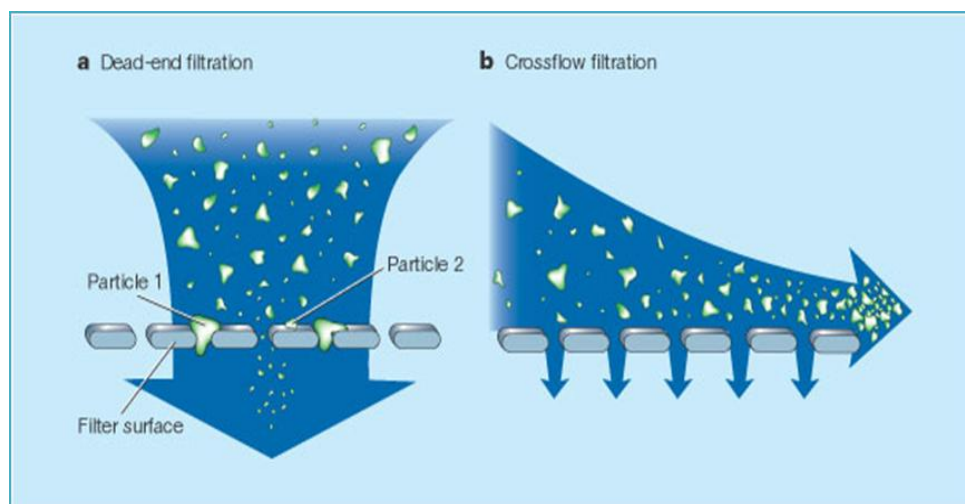
Figure (10). Schematic of an electrodialysis system

4.2.3. Microfiltration (MF) and Ultrafiltration (UF)

Microfiltration (MF) and Ultrafiltration (UF) are filtration processes that operation on a physical sieving separation process. They are best used for the removal of suspended solids, Giardia, Cryptosporidium and the reduction of turbidity. They are also used as a pretreatment to desalination technologies such as nanofiltration and reverse osmosis.

MF has the largest pore size (0.1 – 3 microns) of the wide variety of membrane filtration systems. UF pore sizes range from 0.01 to 0.1 micron. In terms of pore size, MF fills in the gap between ultrafiltration and granular media filtration. In terms of characteristic particle size, this MF range covers the lower portion of the conventional clays and the upper half of the range for humic acids. This is smaller than the size range for bacteria, algae and cysts, and larger than that of viruses. MF is also typically used for turbidity reduction, removal of suspended solids, Giardia and cryptosporidium. UF membranes are used to remove some viruses, color, odor, and some colloidal natural organic matter. Both processes require low transmembrane pressure (1–30 psi) to operate, and both are now used as a pretreatment to desalination technologies such as reverse osmosis, nanofiltration, and electrodialysis.

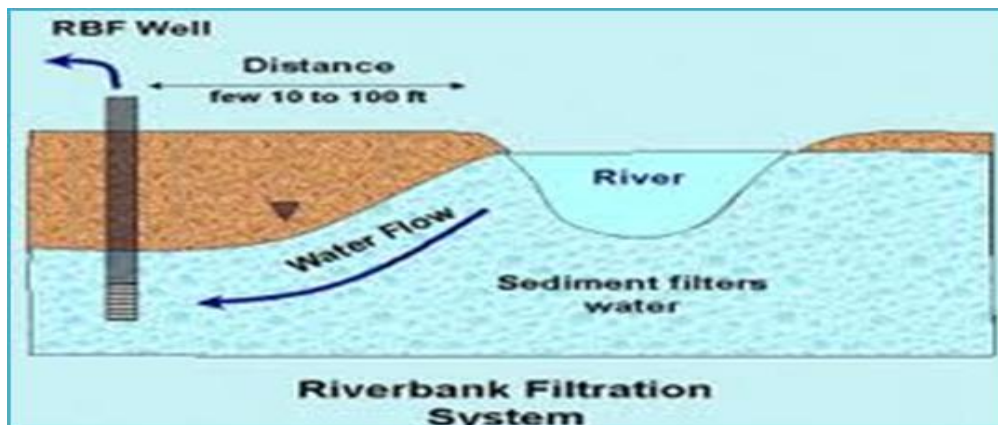
MF membranes can operate in either cross flow separation or dead-end filtration. Cross flow separation is where only part of the feed stream is treated and the remainder of the water is passed through the membrane untreated. In dead-end separation, all of the feed water is treated.



4.3. Ground water

4.3.1. Bank Filtration as Natural Filtration

When wells are placed close to a surface water source (such as a lake or a river) and pumped, a portion of the surface water is induced to flow to the well. As the water travels from the river to the well through the riverbed sediments and underlying aquifer material, suspended and dissolved contaminants of surface water are “naturally” filtered out using a combination of physical, chemical, and biological processes. If the surface water is a river, the system is called riverbank filtration (RBF). If a lake serves as source water, the system is a lake bank filtration. These natural filtration systems have been operating for more than 100 years in Europe and for over half a century in the United States, providing safe drinking water to communities. For the RBF systems to work effectively there must be a hydraulic connection between the river and the alluvial aquifer where the wells are located. Unclogged river bottoms are ideal for RBF operations. RBF systems are known to remove turbidity, microbes, and chemicals present in surface water and the removal efficiency is a function of well location, pumping rate, source water quality, etc. A fraction of dissolved organic carbon (DOC) is also removed which helps in reducing the formation potential of disinfection byproducts during chlorination of the filtrate from RBF systems. RBF systems can be adapted to a given site using engineering judgment. Use of inflatable dams to raise water levels in rivers in low-flow periods can augment well yields. Similarly, diverting a part of the water from the river to an infiltration basin and strategically placing wells between the river and the infiltration basin can enhance yield. Over the years, several improvements to the design and construction of the RBF systems have taken place. Use of these methods at future sites can improve the efficiency of RBF. Besides siting issues, periodic maintenance and early-warning systems to monitor river water quality are needed for sustainable operation of RBF systems. RBF has one of the best potentials to be used as a natural filtration system in populated riparian communities in developing countries.



4.3.2. Removal of iron and manganese

The treatment of iron and manganese is possible by two different ways.

- Ex-situ removal of iron and manganese
- In-situ removal of iron and manganese

The processes that are used for the removal of Fe and Mn invariably comprise two stages.

- a. An oxidation process in which the soluble forms of Fe and Mn are oxidized to form insoluble precipitates.
- b. A solid-separation process in which the precipitated material is removed from the water stream.

4.3.2.1. Ex-situ removal of iron and manganese

In this method groundwater is purified on the surface (after abstraction) by different processes like chemical oxidation followed by filtration, aeration followed by filtration, iron exchange method in treatment systems and raising the pH with neutralizing filter (Wilson et al., 1999). Conventional iron and manganese treatment plants depend on the different physical and chemical reactions by using manganese greensand, aeration and chemical oxidation accomplished by ozone, chlorine, Potassium permanganate or chlorine oxide.

Manganese greensand is considered as the most common medium used for the removal and manganese through the pressure filtration. This filtration medium is a processed material that consists of nodular grains of the clay mineral glauconite. The material is coated with manganese oxide. The glauconite will facilitate the bonding of coating because it is having ion exchange

properties. This treatment will provide a catalytic effect in the chemical oxidation reactions that is necessary for iron and manganese removal.

Alternatively, the precipitation reaction may be carried out in a biological process in which bacteria exert a rateenhancing biocatalytic effect on the oxidation reaction rate in the presence of dissolved oxygen. The associated bacteria include Gallionella, Leptothrix and Sphaerotilus, among others. Biologically mediated removal of iron and manganese has been shown to be an effective, economic and environmentally attractive method for the removal of iron and manganese, with many installations in operation worldwide

4.3.2.1.1. Oxidation followed by filtration

Before the process of filtration of iron and manganese, it is required to oxidize them to a state in which they turn into insoluble products. The process of oxidation involves the transfer of electrons from iron and manganese to oxidizing agent that we are using. By the process of oxidation the ferrous ion (Fe^{+2}) will change into ferric ion (Fe^{+3}), which readily forms insoluble hydroxide $\text{Fe}(\text{OH})_3$. Same case will be with manganese, like Mn^{+2} will oxidize into Mn^{+4} which will form insoluble products MnO_2 . In the process of oxidation we use different type of oxidants which include chlorine, chlorine dioxide and potassium permanganate. Small groundwater systems often use chlorine or potassium permanganate in the process of oxidation because dosing is very easy, demands simple equipment and also fairly inexpensive (Tech Brief, 1998).

The process of chlorination is used at large scale for the oxidation of iron and manganese. Oxidation of divalent iron and manganese by chlorine can cause a problem that is formation of trihalomethanes (THMs) in highly colored waters. As compared to others, potassium permanganate (KMnO_4), as an oxidant is expensive than others. The dosing of potassium permanganate should be controlled carefully. If we use too little permanganate, it will not be enough to oxidize all the iron and manganese and if we use too much, then it will enter in distribution systems and will cause a pink color. There is another problem that is associated with the use of permanganate is that it can form precipitates that

can form mud balls on the filters (Tech Brief, 1998). The process of chlorination is used at large scale for the oxidation of iron and manganese.

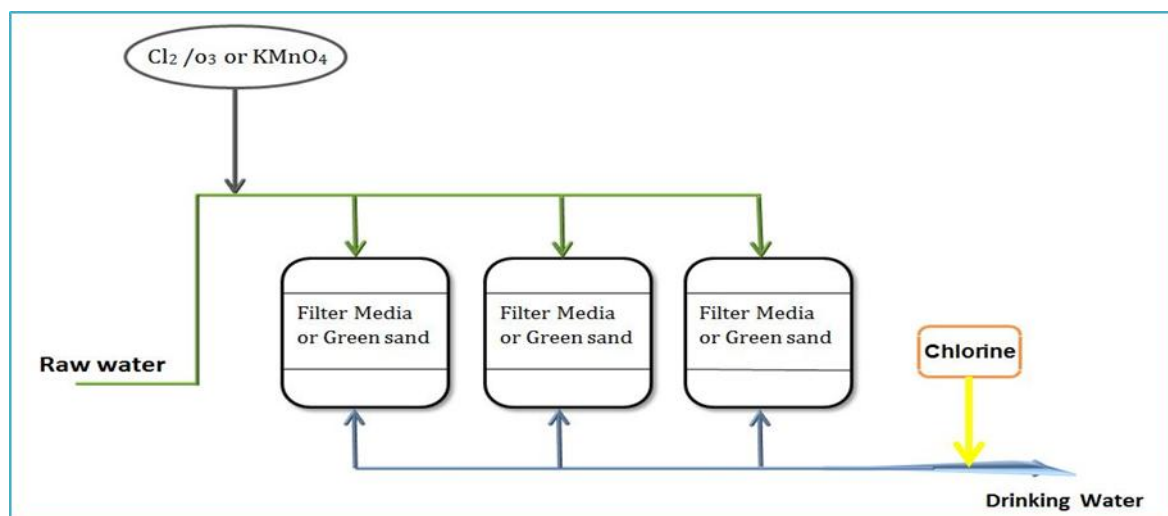


Figure (11): Conventional treatment plant.

4.3.2.1.2. Aeration followed by filtration

The water can be aerated with or without adjustment of pH values. The increase in pH will help in the oxidation of iron and if it is raised high enough it will favor the oxidation of manganese. Very high pH is required for the oxidation of soluble manganese (without adding any strong oxidant). For the complete oxidation of manganese the pH value needed to be increased to 9.5 or more but for oxidation of iron 7.0 to 8.0 pH range are enough in the process of aeration.

After aeration a strong oxidizing agent like ozone, chlorine, potassium permanganate, chlorine dioxide can added to oxidize the remaining iron and manganese.

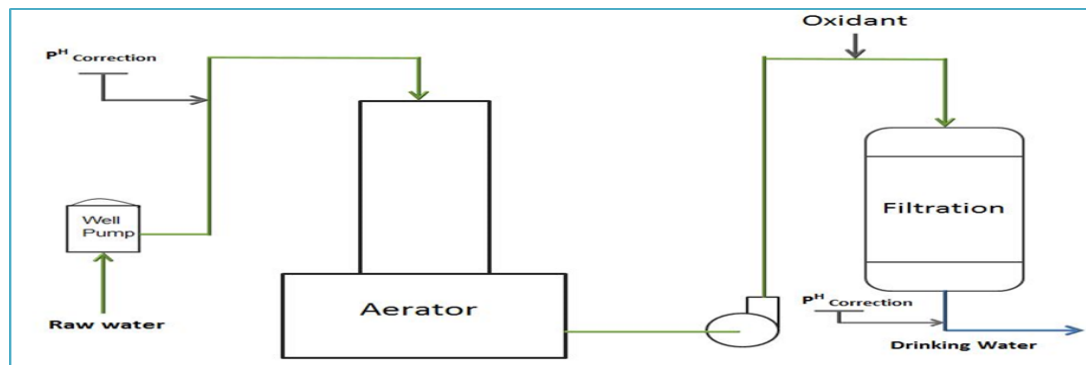


Figure (12) Aeration, additional oxidation followed by Filtration (McPeak and Aronovitch, 1983).

4.3.2.1.3. Ion Exchange

We can use the ion exchange method if we want to remove small quantities of iron and manganese, because it will be having risk of rapid clogging. The process of removing iron and manganese by ion exchange is accomplished by using of sodium from strong acid cation.

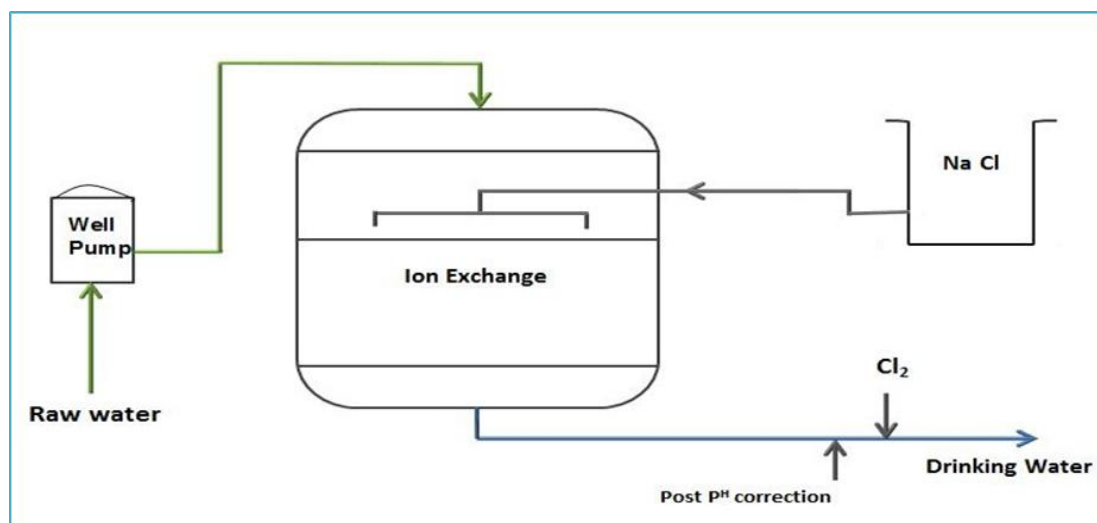


Figure (13) Ion exchange method for removal of iron and manganese.

4.3.2.1.4. Biological removal of iron and manganese

The process infrastructure used for biological removal of iron is virtually the same as used in rapid gravity filtration. During filtration dissolved iron and Manganese are converted to the insoluble ferric hydroxide species ($\text{Fe}(\text{OH})_3$) and manganese dioxide (MnO_2) that

is retained within the filter voids and is intermittently removed by backwashing.

Oxidation by biological means is one of the most recent technologies used by water treatment engineers. It has been successfully applied as a method of Fe, Mn removal, since the microorganisms play a key role not only in oxidizing the elements but also in assisting the precipitation of Fe, Mn. The biological oxidation method has been identified as catalytic in nature for the precipitation, cheaper than chemical oxidation, having a high removal capacity, and causing a rapid oxidation, which are found to be more compact or otherwise superior in nature to the precipitates formed by other treatment processes. Oxidizing bacteria are generally robust and, because of the variety of species involved, one type or another develop satisfactorily and grow under a wider range of conditions in the filter materials than would be expected were only a single species involved. What is more, the Fe bacteria are known to be non-pathogenic and cause no harm or disease when ingested via water. Due to the numerous advantages that biological iron removal offers over the purely physicochemical method it has the potential to become the most favored method (Ankrah and Sogaard, 2009 ; Dimitrakos Michalakos, 1997).

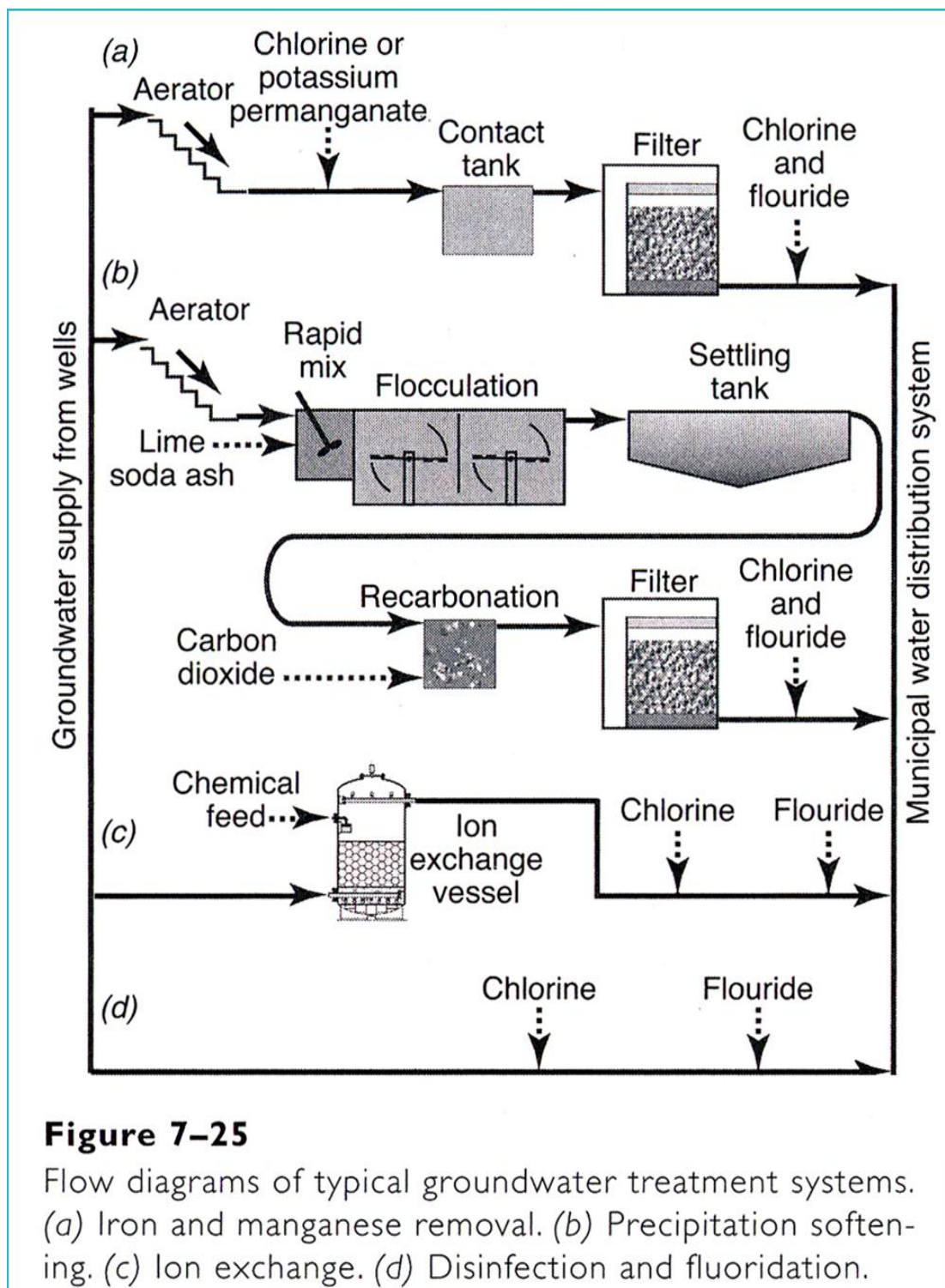


Figure (14) Flow diagrams of typical groundwater treatment system

3.6.2. In-situ removal of iron and manganese

In-situ removal is a useful technique, which consists of elimination of dissolved iron and manganese in groundwater before pumping. This technique includes the use of Vyredox method in which highly oxidized zone is created around the well to be treated by the periodic injections of oxygen rich water (aerated water) through the injection wells situated around the supply well in a ring. The number of injection wells may depend on geochemical and hydrogeological conditions. The water that is used to inject through injection wells must be degassed and oxygen enriched. (Hallberg and Martinell 1976). This can be performed in special aerator, which is called an oxygenator (Hallberg and Martinell 1976).

In 1969 first operational Vyredox plant was built and more than 100 treatment plants had been constructed in more than 10 countries until 1988 (Braester and Martinell, 1988) cited in (Tredoux et al., 2004). The principle and scope of this method is explained in detail in next chapter.

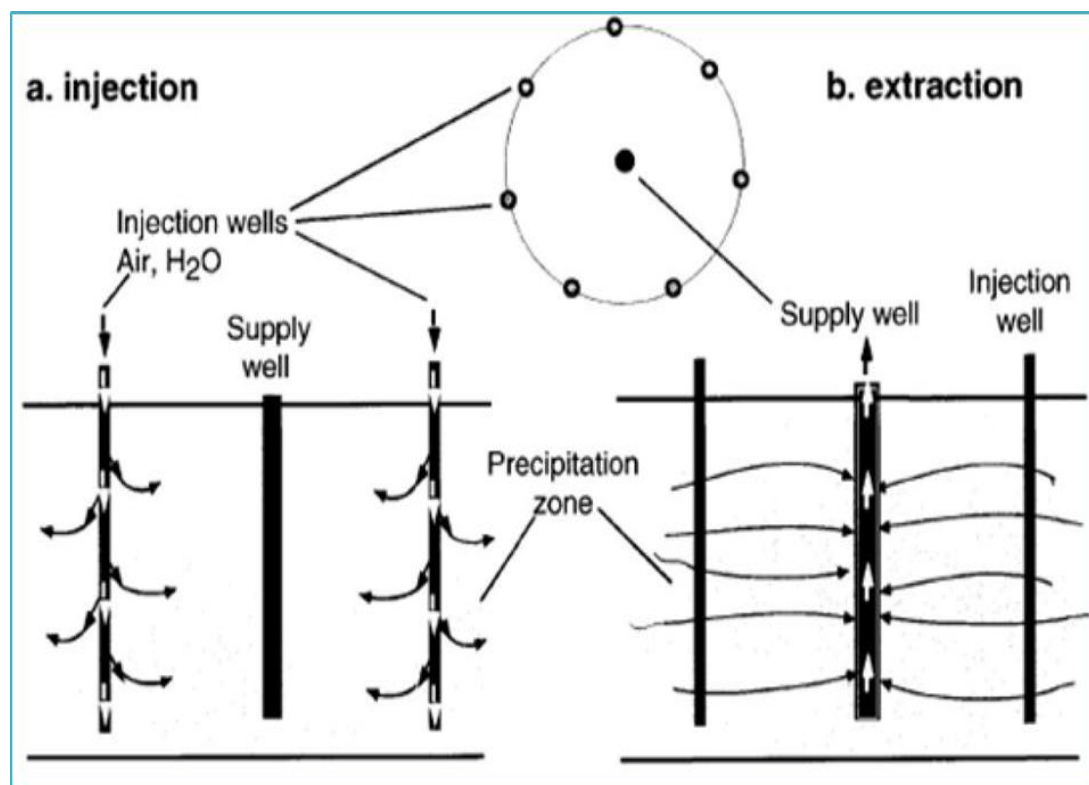


Figure (15) Location of one supply and several injection wells (Mettler, 2002).

4.4. Activated carbon

Activated carbon (AC) is solid, porous, black carbonaceous material and tasteless. Marsh (1989) defined AC as a porous carbon material, usually chars, which has been subjected to reaction with gases during or after carbonization in order to increase porosity. AC is distinguished from elemental carbon by the removal of all non-carbon impurities and oxidation of the carbon surface. While according to Norlia Baharun (1999), AC is an organic material that has an essentially graphitic structure. The main features common to all AC are: graphite like planes which show varying degrees of disorientation and the resulting spaces between these planes which constitute porosity, and the unit built of condensed aromatic rings is referred to as basic structure unit (BSU). Benaddi (2000) also stated that AC is predominantly an amorphous solid with a large internal surface area and pore Volume. Cokes, Chars and activated carbon are frequently termed amorphous carbon.

From all the definition, it can be summarized that AC is black, amorphous solid containing major portion of fixed carbon content and other materials such as ash, water vapor and volatile matters in smaller percentage. Besides that, AC also contain physical characteristic such as internal surface area and pore volume. The large surface area results in a high capacity for absorbing chemicals from gases or liquids. The adsorptive property stems from the extensive internal pore structure that develops during the activation process.

Activated carbon is a processed carbon material with a highly developed porous structure and a large specific surface area. It consists of course, principally of carbon (87% to 97%) but also contains such elements as hydrogen, oxygen, sulphur and nitrogen, as well as various compounds either originating from the raw material used in this in its production or generated during its manufacture. Active carbon may also contain various useless mineral substances in quantities of (1 % to 20%) these substances are often removed, when the content of the so called ash decreases to (0.1 % to 0.2%).

Active carbon has ability to adsorb various substances both from the gas and liquid phases. It is this ability to arrest different molecules at the inner surface of active carbon that justifies calling

it an adsorbent, and a very powerful adsorbent indeed it is. The pore volume of usually exceed $0.2 \text{ cm}^3/\text{g}$ but in many instances it is greater than $400 \text{ m}^2/\text{g}$ but often exceeds this value, reaching $1000 \text{ m}^2/\text{g}$, the linear dimension of the pores (i.e. their radii range from 0.3 to several thousand nanometers).

Porous carbons, also called activated carbons, have been used for thousands of years. Their application in water purification can be dated back to 2000 BC when the ancient Egyptians used charcoal to purify water for medical purposes. The major development of activated carbon began during World War (I), when granular activated GAC was manufactured for use gas masks for protection against poisonous gases. In the last sixty years the technology involved in activated carbons manufacture has advanced. Powdered activated carbon PAC is extensively used in water purification together with GAC in water purification.

Activated carbons are used for gas and liquid phase adsorption. Nearly 80% of about 350000 tons per year is used for liquid phase applications and approximately 8000 tons per year for gas phase applications, these figures are based on the world wide usage.

Activated carbons are excellent adsorbents and thus are used to purify, decolorize, deodorize, dechlorinate, detoxicate, filter, or remove or modify the salts, separate and concentrate in order to permit recovery; they also used as catalysts and catalyst supports. These applications of activated carbons are of interest to most economic sectors and concern areas as diverse as the food, pharmaceutical, chemical, petroleum, mining, nuclear, automobile and vacuum industries as well as treatment of drinking water, industrial and urban wastewater, and air and gas purification.

4.4.1. ADSORPTION

Adsorption is a natural process by which molecules of a dissolved compound collect on and adhere to the surface of an adsorbent solid. Adsorption occurs when the attractive forces at the carbon surface overcome the attractive forces of the liquid.

Granular activated carbon is a particularly good adsorbent medium due to its high surface area to volume ratio. One gram of a typical commercial activated carbon will have a surface area equivalent to

1,000 square meters. This high surface area permits the accumulation of a large number of contaminant molecules.

4.4.2. ADSORPTION CAPACITY

The specific capacity of a granular activated carbon to adsorb organic compounds is related to the molecular surface attraction, the total surface area available per unit weight of carbon and the concentration of contaminants in the wastewater stream. The basic instrument for evaluating activated carbon use is the adsorption isotherm. The isotherm represents an empirical relationship between the amount of contaminant adsorbed per unit weight of carbon and its equilibrium water concentration.

This relationship can be expressed in the form:

$$X/M = KC (1/n)$$

Where:

- X/M = Amount of contaminant adsorbed per unit weight of carbon
- C = Concentration of contaminant in the water stream
- K, n = Empirical constants particular to the contaminant

The constants (K) and (n) are determined by plotting experimental results on log-log paper with the concentration of contaminant on the X-axis and the amount of contaminant adsorbed on the y-axis.

The slope of the line developed is equal to $(1/n)$ and the intercept equal to (K) . These dimensionless, empirical constants are useful for comparing the adsorption capacities for different compounds or for assessing the adsorption capacities of various activated carbons.

Liquid phase adsorption isotherms have been developed for most commercial activated carbons for a variety of specific compounds.

Figure (16) presents a typical adsorption isotherm used to predict activated carbon adsorption capacity. An isotherm is specific to a particular contaminant and the type of activated carbon used.

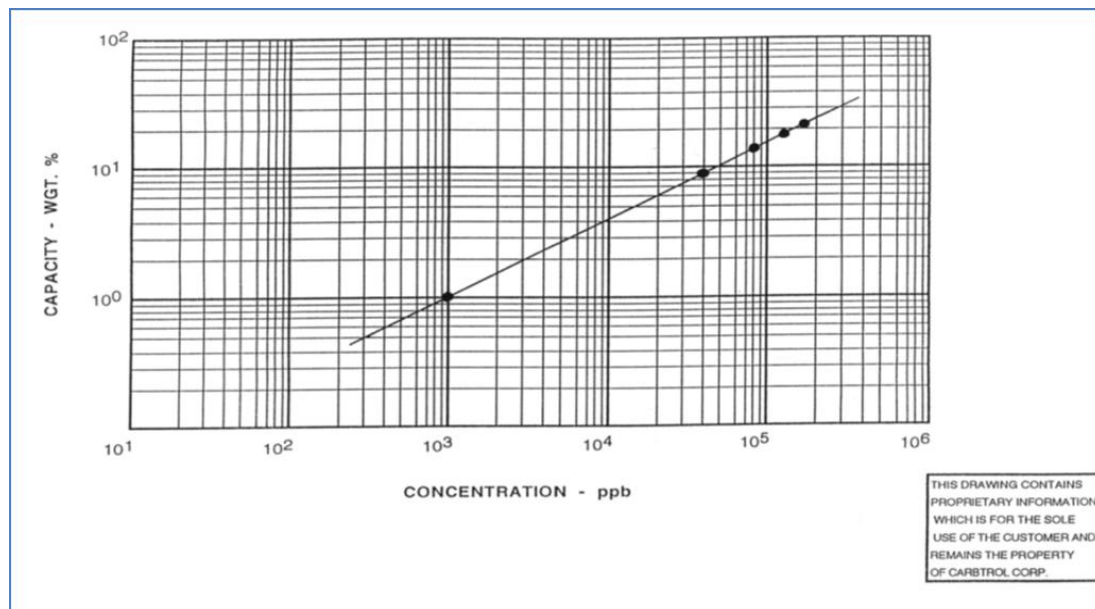
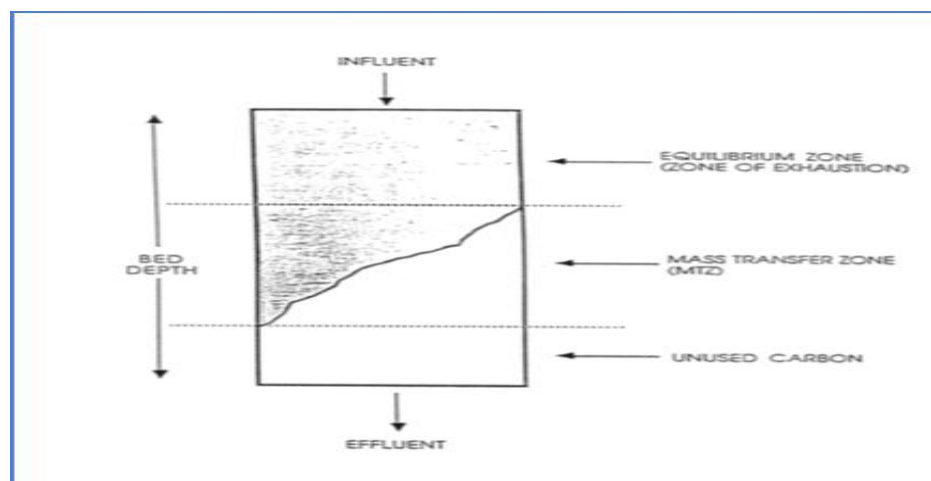


Figure (16) A typical adsorption isotherm.

4.4.3. DESIGN CONSIDERATIONS

As a contaminated water stream passes through a confined bed of activated carbon, a dynamic condition develops which establishes a mass transfer zone. This “mass transfer zone” is defined as the carbon bed depth required to reduce the contaminant concentration from the initial to the final level, at a given flow rate.



As the mass transfer zone moves through a carbon bed and reaches its exit boundary, contamination begins to show in the effluent. This condition is classified as “breakthrough” and the amount of material adsorbed is considered the breakthrough capacity. If the bed continues to be exposed to the water stream, the mass transfer zone will pass completely through the bed and

the effluent contaminant level will equal the influent. At that point, saturation capacity is reached. The saturated capacity is that which is represented by the isotherm.

To take full advantage of the adsorption capacity difference between breakthrough and saturation, several carbon beds are often operated in series. This allows the mass transfer zone to pass completely through the first bed prior to its removal from service. Effluent quality is maintained by the subsequent beds in the series.

When sizing an activated carbon system, it is necessary to choose an appropriate contact time for the water and the carbon. EBCT (empty bed contact time) is the terminology used to describe this parameter.

EBCT is defined as the total volume of the activated carbon bed divided by the liquid flow rate and is usually expressed in minutes.

The appropriate EBCT for a particular application is related to the rate of adsorption for the organic compound to be removed. While this rate will vary for individual applications, experience has shown that for most low concentration dissolved organics an EBCT contact time of 10 to 15 minutes is normally adequate.

4.4.4. CHOICE OF TECHNOLOGIES

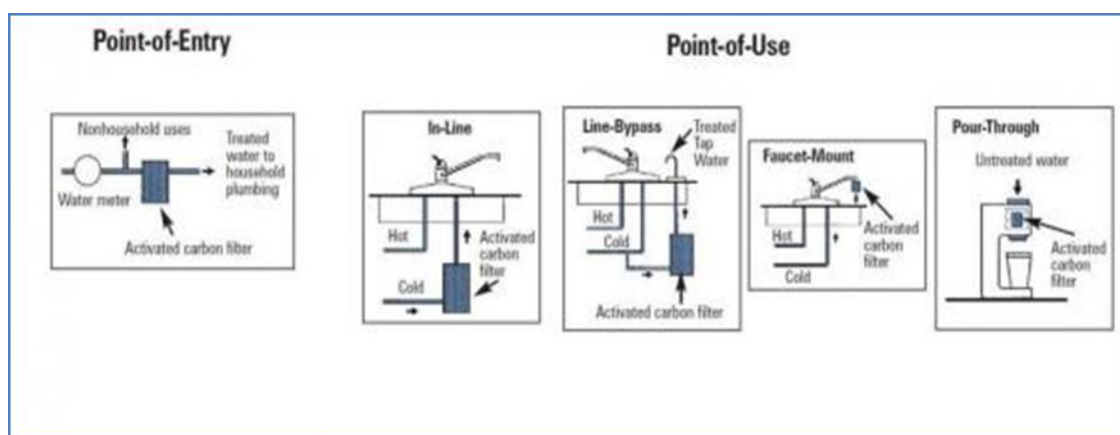
Carbon adsorption is an extremely versatile technology. For many water treatment applications it has proved to be the least expensive treatment option. Adsorption is particularly effective in treating low concentration waste streams and in meeting stringent treatment levels.

One of the major attributes of activated carbon treatment is its ability to remove a wide variety of toxic organic compounds to non-detectable levels (99.99%). Its suitability on a specific application will normally depend on costs as they relate to the amount of carbon consumed.

Activated carbon units are commonly used to remove organics (odours, micropollutants) from drinking water at centralised and decentralised level. At centralised level, they are generally part of one of the last steps, before the water is fed into the water distribution network. At decentralised level, activated carbon filtration units can either be point-of-use (POU) or point-of-entry

(POE) treatment. A POE device is recommended for the treatment of radon and volatile organic compounds because these contaminants can easily vaporise from water in showers or washing machines and expose users to health hazards. POU devices are useful for the removal of lead and chlorine. The structure of POU devices can either be in-line, line-bypass faucet mounted (see also advanced filters) or pour-through (similar to the design of ceramic candles, colloidal silver or biosand filters).

Activated carbon filters can also be used as a tertiary treatment in wastewater treatment plants to remove micropollutants from municipal effluents or recalcitrant contaminants from industrial effluents.



4.4.5. SOURCE OF ACTIVATED CARBON

Activated carbon, also called activated charcoal, is a form of carbon that has been processed with oxygen to create millions of tiny pores between the carbon atoms. This increases the surface area of the substance from 500 to 1500 m²/g, or 300-2,00 m²/g. One pound of activated carbon has the surface area equivalent of six footballfields. The increased surface area of activated carbon makes the material suitable for adsorption, a process by which impurities in substances such as fluids, vapors or gas are removed. Impure molecules are held within the carbon's internal pore structure by electrostatic attraction or chemisorption. The adsorption process helps carbon reduce dangerous matter, activate chemical reactions, and act as a carrier of biomass and chemicals.

Activated carbon is usually made from charcoal, but can be produced from wood, peat or even coconut shells. There are over

150 grades of activated carbon, each with their own uses and applications. Commercially, there are three major product groups:

- Powdered activated carbon; particle size 1-150 μm
- Granular activated carbon, particle size 0.5-4 mm
- Extruded activated carbon, particle size 0.8-4 mm

The pore size distribution is highly important for the practical application. Ideally, the carbon material used should have a pore structure that is larger in size than the material it is trying to adsorb. The best fit depends on the compounds of interest, the matrix (gas, liquid) and treatment conditions. According to the International Union of Pure and Applied Chemistry, there are three distinct groups of pores:

- Macropores (> 50 nm diameter)
- Mesopores (2-50 nm diameter)
- Micropores (< 2 nm diameter)



Micropores generally contribute to the major part of the internal surface area. Macro and mesopores can generally be regarded as the highways into the carbon particle, and are crucial for kinetics. Macropores can be visualized using scanning electron microscopy.

المراجع

• تم الإعداد بمشاركة المشروع الألماني GIZ

• و مشاركة السادة :-

- د/ سناء أحمد الإله شركة مياه الشرب والصرف الصحى بالفيوم
- د/ شعبان محمد على شركة مياه الشرب والصرف الصحى بالفيوم
- د/ حمدى عطيه مشالى شركة مياه الشرب والصرف الصحى بالغربية
- د/ سعيد أحمد عباس شركة مياه الشرب والصرف الصحى بالغربية
- د/ عبدالحفيظ السحيمي شركة مياه الشرب بالقاهرة الكبرى
- د/ مى صادق شركة مياه الشرب بالقاهرة الكبرى