CHAPTER ONE

1 INTRODUCTION

Water purification is the process of removing undesirable chemicals, biological contaminants, suspended solids and gases from contaminated water. The goal of this process is to produce water fit for a specific purpose. Most water is disinfected for human consumption (drinking water) but water purification may also be designed for a variety of other purposes, including meeting the requirements of medical, pharmacological, chemical and industrial applications. In general, the methods used include physical processes such as filtration, sedimentation, and distillation, biological processes such as slow sand filters or biologically active carbon, chemical processes such as flocculation and chlorination and the use of electromagnetic radiation such as ultraviolet light.

The purification process of water may reduce the concentration of particulate matter including suspended particles, parasites, bacteria, algae, viruses, fungi; and a range of dissolved and particulate material derived from the surfaces that water may have made contact with after falling as rain.

The standards for drinking water quality are typically set by governments or by international standards. These standards will typically set minimum and maximum concentrations of contaminants for the use that is to be made of the water.

It is not possible to tell whether water is of an appropriate quality by visual examination. Simple procedures such as boiling or the use of a household activated carbon filter are not sufficient for treating all the possible contaminants that may be present in water from an unknown source. Even natural spring water – considered safe for all practical purposes in the 19th century – must now be tested before determining

what kind of treatment, if any, is needed. Chemical and microbiological analysis, while expensive, are the only way to obtain the information necessary for deciding on the appropriate method of purification.

CHAPTER TWO

SOURCES OF WATER

1. Groundwater:

The water emerging from some deep ground water may have fallen as rain many tens, hundreds, or thousands of years ago. Soil and rock layers naturally filter the ground water to a high degree of clarity and often it does not require additional treatment other than adding chlorine or chloramines as secondary disinfectants. Such water may emerge as springs, artesian spring or may be extracted from boreholes or wells. Deep ground water is generally of very high bacteriological quality (i.e., pathogenic bacteria or the pathogenic protozoa are typically absent), but the water may be rich in dissolved solids, especially carbonates and sulfates of calcium and magnesium. Depending on the strata through which the water has flowed, other ions may also be present including chloride, and bicarbonate. There may be a requirement to reduce the iron or manganese content of this water to make it acceptable for drinking, cooking, and laundry use. Primary disinfection may also be required. Where groundwater recharge is practised (a process in which river water is injected into an aquifer to store the water in times of plenty so that it is available in times of drought), the groundwater may require additional treatment depending on applicable state and federal regulations.

2. Upland Lakes and Reserviors:

Typically located in the headwaters of river systems, upland reservoirs are usually sited above any human habitation and may be surrounded by a protective zone to restrict the opportunities for contamination. Bacteria and pathogen levels are usually low, but some bacteria, protozoa or algae will be present. Where uplands are forested or peaty, humic acids can colour the water. Many upland sources have low pH which require adjustment.

3. Rivers, Canals and Low Land Reservoirs:

Low land surface waters will have a significant bacterial load and may also contain algae, suspended solids and a variety of dissolved constituents.

4. Atmospheric water generation :

Atmospheric water generation is a new technology that can provide high quality drinking water by extracting water from the air by cooling the air and thus condensing water vapor.

5. Rainwater harvesting or fog collection :

Rainwater harvesting or fog collection which collect water from the atmosphere can be used especially in areas with significant dry seasons and in areas which experience fog even when there is little rain. Desalination of seawater by distillation or reverse osmosis

6. Surface water :

Freshwater bodies that are open to the atmosphere and are not designated as groundwater are termed surface waters.

CHAPTER THREE

TREATMENT PROCESSES AND OPERATIONS

The processes and/or operations below are the ones commonly used in water purification plants. Some or most may not be used depending on the scale of the plant and quality of the raw (source) water.

Pre-treatment :

1. Pumping and containment : The majority of water must be pumped from its source or directed into pipes or holding tanks. To avoid adding contaminants to the water, this physical infrastructure must be made from appropriate materials and constructed so that accidental contamination does not occur.
2. Screening : The first step in purifying surface water is to remove large debris such as sticks, leaves, rubbish and other large particles which may interfere with subsequent purification steps. Most deep groundwater does not need screening before other purification steps.
3. Storage :Water from rivers may also be stored in bankside reserviors for periods between a few days and many months to allow natural biological purification to take place. This is especially important if treatment is by slow sand filters. Storage reservoirs also provide a buffer against short periods of drought or to allow water supply to be maintained during transitory pollution incidents in the source river.
4. Pre-chlorination : In many plants the incoming water was chlorinated to minimize the growth of fouling organisms on the pipe-work and tanks. Because of the potential adverse quality effects (see chlorine below), this has largely been discontinued.

Widely varied techniques are available to remove the fine solids, micro-organisms and some dissolved inorganic and organic materials. The

choice of method will depend on the quality of the water being treated, the cost of the treatment process and the quality standards expected of the processed water.

PH Adjustment :

Pure water has a pH close to 7 (neither alkaline nor acidic). Sea water can have pH values that range from 7.5 to 8.4 (moderately alkaline). Fresh water can have widely ranging pH values depending on the geology of the drainage basin or aquifer and the influence of contaminant inputs (acid rain). If the water is acidic (lower than 7), lime, soda ash, or sodium hydroxide can be added to raise the pH during water purification processes. Lime addition increases the calcium ion concentration, thus raising the water hardness. For highly acidic waters, forced draft degasifiers can be an effective way to raise the pH, by stripping dissolved carbon dioxide from the water. Making the water alkaline helps coagulation and flocculation processes work effectively and also helps to minimize the risk of lead being dissolved from lead pipes and from lead solder in pipe fittings. Sufficient alkalinity also reduces the corrosiveness of water to iron pipes. Acid (carbonic acid, hydrochloric acid or sulfuric acid) may be added to alkaline waters in some circumstances to lower the pH. Alkaline water (above pH 7.0) does not necessarily mean that lead or copper from the plumbing system will not be dissolved into the water. The ability of water to precipitate calcium carbonate to protect metal surfaces and reduce the likelihood of toxic metals being dissolved in water is a function of pH, mineral content, temperature, alkalinity and calcium concentration.

Coagulation and Flocculation :

One of the first steps in a conventional water purification process is the addition of chemicals to assist in the removal of particles suspended in water. Particles can be inorganic such as clay and silt or organic such as algae, bacteria, viruses, protozoa and natural organic matter. Inorganic and organic particles contribute to the turbidity and color of water.

The addition of inorganic coagulants such as aluminum sulfate (or alum) or iron (III) salts such as iron(III) chloride cause several simultaneous chemical and physical interactions on and among the particles. Within seconds, negative charges on the particles are neutralized by inorganic coagulants. Also within seconds, metal hydroxide precipitates of the aluminum and iron (III) ions begin to form. These precipitates combine into larger particles under natural processes such as Brownian motion and through induced mixing which is sometimes referred to as flocculation. The term most often used for the amorphous metal hydroxides is "floc." Large, amorphous aluminum and iron (III) hydroxides adsorb and enmesh particles in suspension and facilitate the removal of particles by subsequent processes of sedimentation and filtration.

Aluminum hydroxides are formed within a fairly narrow pH range, typically: 5.5 to about 7.7. Iron (III) hydroxides can form over a larger pH range including pH levels lower than are effective for alum, typically: 5.0 to 8.5.

In the literature, there is much debate and confusion over the usage of the terms coagulation and flocculation—where does coagulation end and flocculation begin? In water purification plants, there is usually a high energy, rapid mix unit process (detention time in seconds) where the coagulant chemicals are added followed by flocculation basins (detention times range from 15 to 45 minutes) where low energy inputs turn large paddles or other gentle mixing devices to enhance the

formation of floc. In fact, coagulation and flocculation processes are ongoing once the metal salt coagulants are added.

Organic polymers were developed in the 1960s as aids to coagulants and, in some cases, as replacements for the inorganic metal salt coagulants. Synthetic organic polymers are high molecular weight compounds that carry negative, positive or neutral charges. When organic polymers are added to water with particulates, the high molecular weight compounds adsorb onto particle surfaces and through interparticle bridging coalesce with other particles to form floc. Polydadmac is a popular cationic (positively charged) organic polymer used in water purification plants.

Sedimentation:

Waters exiting the flocculation basin may enter the sedimentation basin, also called a clarifier or settling basin. It is a large tank with low water velocities, allowing floc to settle to the bottom. The sedimentation basin is best located close to the flocculation basin so the transit between the two processes does not permit settlement or floc break up. Sedimentation basins may be rectangular, where water flows from end to end, or circular where flow is from the centre outward. Sedimentation basin outflow is typically over a weir so only a thin top layer of water that furthest from the sludge exits.

In 1904,Allen Hazen showed that the efficiency of a sedimentation process was a function of the particle settling velocity, the flow through the tank and the surface area of tank. Sedimentation tanks are typically designed within a range of overflow rates of 0.5 to 1.0 gallons per minute per square foot (or 1.25 to 2.5 meters per hour). In general, sedimentation basin efficiency is not a function of detention time or depth of the basin. Although, basin depth must be sufficient so that water currents do not disturb the sludge and settled particle interactions are promoted. As particle concentrations in the settled water increase

near the sludge surface on the bottom of the tank, settling velocities can increase due to collisions and agglomeration of particles. Typical detention times for sedimentation vary from 1.5 to 4 hours and basin depths vary from 10 to 15 feet (3 to 4.5 meters).

Inclined flat plates or tubes can be added to traditional sedimentation basins to improve particle removal performance. Inclined plates and tubes drastically increase the surface area available for particles to be removed in concert with Hazen's original theory. The amount of ground surface area occupied by a sedimentation basin with inclined plates or tubes can be far smaller than a conventional sedimentation basin.

Sludge storage and removal : As particles settle to the bottom of a sedimentation basin, a layer of sludge is formed on the floor of the tank. This layer of sludge must be removed and treated. The amount of sludge that is generated is significant, often 3 to 5 percent of the total volume of water that is treated. The cost of treating and disposing of the sludge can be a significant part of the operating cost of a water treatment plant. The sedimentation tank may be equipped with mechanical cleaning devices that continually clean the bottom of the tank or the tank can be periodically taken out of service and cleaned manually.

Floc blanket clarifiers : A subcategory of sedimentation is the removal of particulates by entrapment in a layer of suspended floc as the water is forced upward. The major advantage of floc blanket clarifiers is that they occupy a smaller footprint than conventional sedimentation. Disadvantages are that particle removal efficiency can be highly variable depending on changes in influent water quality and influent water flow rate.

Dissolved Air Flotation:

When particles to be removed do not settle out of solution easily, dissolved air flotation (DAF) is often used. Water supplies that are

particularly vulnerable to unicellular algae blooms and supplies with low turbidity and high colour often employ DAF. After coagulation and flocculation processes, water flows to DAF tanks where air diffusers on the tank bottom create fine bubbles that attach to floc resulting in a floating mass of concentrated floc. The floating floc blanket is removed from the surface and clarified water is withdrawn from the bottom of the DAF tank.

Filtration:

After separating most floc, the water is filtered as the final step to remove remaining suspended particles and unsettled floc.

Rapid sand filters : The most common type of filter is a rapid sand filter. Water moves vertically through sand which often has a layer of activated carbon or anthracite coal above the sand. The top layer removes organic compounds, which contribute to taste and odour. The space between sand particles is larger than the smallest suspended particles, so simple filtration is not enough. Most particles pass through surface layers but are trapped in pore spaces or adhere to sand particles. Effective filtration extends into the depth of the filter. This property of the filter is key to its operation: if the top layer of sand were to block all the particles, the filter would quickly clog.

To clean the filter, water is passed quickly upward through the filter, opposite the normal direction (called *backflushing* or *backwashing*) to remove embedded particles. Prior to this step, compressed air may be blown up through the bottom of the filter to break up the compacted filter media to aid the backwashing process; this is known as *air scouring*. This contaminated water can be disposed of, along with the sludge from the sedimentation basin, or it can be recycled by mixing with the raw water entering the plant although this is often considered

poor practice since it re-introduces an elevated concentration of bacteria into the raw water.

Some water treatment plants employ pressure filters. These work on the same principle as rapid gravity filters, differing in that the filter medium is enclosed in a steel vessel and the water is forced through it under pressure.

Advantages:

- Filters out much smaller particles than paper and sand filters can.
- Filters out virtually all particles larger than their specified pore sizes.
- They are quite thin and so liquids flow through them fairly rapidly.
- They are reasonably strong and so can withstand pressure differences across them of typically 2–5 atmospheres.
- They can be cleaned (back flushed) and reused.

Slow sand filter : Slow sand filters may be used where there is sufficient land and space, as the water must be passed very slowly through the filters. These filters rely on biological treatment processes for their action rather than physical filtration. The filters are carefully constructed using graded layers of sand, with the coarsest sand, along with some gravel, at the bottom and finest sand at the top. Drains at the base convey treated water away for disinfection. Filtration depends on the development of a thin biological layer, called the zoogleal layer or Schmutzdecke, on the surface of the filter. An effective slow sand filter may remain in service for many weeks or even months if the pre-treatment is well designed and produces water with a very low available nutrient level which physical methods of treatment rarely achieve. Very low nutrient levels allow water to be safely sent through distribution systems with very low disinfectant levels, thereby reducing consumer irritation over offensive levels of chlorine and chlorine by-products. Slow sand filters are not backwashed; they are maintained by

having the top layer of sand scraped off when flow is eventually obstructed by biological growth.

A specific "large-scale" form of slow sand filter is the process of bank filtration, in which natural sediments in a riverbank are used to provide a first stage of contaminant filtration. While typically not clean enough to be used directly for drinking water, the water gained from the associated extraction wells is much less problematic than river water taken directly from the major streams where bank filtration is often used.

Membrane filtration : Membrane filters are widely used for filtering both drinking water and sewage. For drinking water, membrane filters can remove virtually all particles larger than 0.2 um—including *giardia* and *cryptosporidium.* Membrane filters are an effective form of tertiary treatment when it is desired to reuse the water for industry, for limited domestic purposes, or before discharging the water into a river that is used by towns further downstream. They are widely used in industry, particularly for beverage preparation (including bottled water). However no filtration can remove substances that are actually dissolved in the water such as phosphorus, nitrates and heavy metal ions.

Removal of ions and other dissolved substances :
Ultrafiltration membranes use polymer membranes with chemically formed microscopic pores that can be used to filter out dissolved substances avoiding the use of coagulants. The type of membrane media determines how much pressure is needed to drive the water through and what sizes of micro-organisms can be filtered out.

Ion exchange: Ion exchange systems use ion exchange resin- or zeolite-packed columns to replace unwanted ions. The most common case is water softening consisting of removal of Ca^{2+} and Mg^{2+} ions replacing them with benign (soap friendly) Na^{+} or K^{+} ions. Ion exchange resins are also used to remove toxic ions such as nitrite, lead, mercury, arsenic and many others.

Precipitative softening: Water rich in hardness (calcium and magnesium ions) is treated with lime (calcium oxide) and/or soda-ash (sodium carbonate) to precipitate calcium carbonate out of solution utilizing the common-ion effect.

Electrodeionization: Water is passed between a positive electrode and a negative electrode. Ion exchange membranes allow only positive ions to migrate from the treated water toward the negative electrode and only negative ions toward the positive electrode. High purity deionized water is produced with a little worse degree of purification in comparison with ion exchange treatment. Complete removal of ions from water is regarded as electrodialysis. The water is often pre-treated with a reverse osmosis unit to remove non-ionic organic contaminants.

Disinfection :

Pumps used to add required amount of chemicals to the clear water at the water purification plant before the distribution. From left to right: sodium hypochlorite for disinfection, zinc orthophosphate as a corrosion inhibitor, sodium hydroxide for pH adjustment, and fluoride for tooth decay prevention.

Disinfection is accomplished both by filtering out harmful micro-organisms and also by adding disinfectant chemicals. Water is disinfected to kill any pathogens which pass through the filters and to provide a residual dose of disinfectant to kill or inactivate potentially harmful micro-organisms in the storage and distribution systems. Possible pathogens include viruses, bacteria, including *Salmonella*, *Cholera*, *Campylobacter* and *Shigella*, and protozoa, including Giardia *lamblia* and other *cryptosporidia*. Following the introduction of any chemical disinfecting agent, the water is usually held in temporary

storage – often called a contact tank or clear well to allow the disinfecting action to complete.

Chlorine disinfection

The most common disinfection method involves some form of chlorine or its compounds such as chloramine or chlorine dioxide. Chlorine is a strong oxidant that rapidly kills many harmful micro-organisms. Because chlorine is a toxic gas, there is a danger of a release associated with its use. This problem is avoided by the use of sodium hypochlorite, which is a relatively inexpensive solution that releases free chlorine when dissolved in water. Chlorine solutions can be generated on site by electrolyzing common salt solutions. A solid form, calcium hypochlorite, releases chlorine on contact with water. Handling the solid, however, requires greater routine human contact through opening bags and pouring than the use of gas cylinders or bleach which are more easily automated. The generation of liquid sodium hypochlorite is both inexpensive and safer than the use of gas or solid chlorine.

All forms of chlorine are widely used, despite their respective drawbacks. One drawback is that chlorine from any source reacts with natural organic compounds in the water to form potentially harmful chemical by-products. These by-products, trihalomethanes (THMs) and haloacetic acids (HAAs), are both carcinogenic in large quantities and are regulated by the United State Environmental Protection Agency (EPA) and the Drinking Water Inspectorate in the UK. The formation of THMs and haloacetic acids may be minimized by effective removal of as many organics from the water as possible prior to chlorine addition. Although chlorine is effective in killing bacteria, it has limited effectiveness against protozoa that form cysts in water (Giardia *lamblia* and *Cryptosporidium*, both of which are pathogenic).

Chlorine dioxide disinfection

Chlorine dioxide is a faster-acting disinfectant than elemental chlorine. It is relatively rarely used, because in some circumstances it may create excessive amounts of chlorite, which is a by-product regulated to low allowable levels in the United States. Chlorine dioxide is supplied as an aqueous solution and added to water to avoid gas handling problems; chlorine dioxide gas accumulations may spontaneously detonate.

Chloramine disinfection

The use of chloramine is becoming more common as a disinfectant. Although chloramine is not as strong an oxidant, it does provide a longer-lasting residual than free chlorine and it will not form THMs or haloacetic acids. It is possible to convert chlorine to chloramine by adding ammonia to the water after addition of chlorine. The chlorine and ammonia react to form chloramine. Water distribution systems disinfected with chloramines may experience nitrification, as ammonia is a nutrient for bacterial growth, with nitrates being generated as a by-product.

Ozone disinfection

Ozone is an unstable molecule which readily gives up one atom of oxygen providing a powerful oxidizing agent which is toxic to most waterborne organisms. Because of its excellent disinfection and oxidation qualities, ozone is widely used for drinking water treatment. Ozone can be added at several points throughout the treatment

system, such as during pre-oxidation, intermediate oxidation or final disinfection. Usually, it is recommended to use ozone for pre-oxidation, before a sand filter or an active carbon filter (GAC). After ozonization these filters can remove the remaining organic matter (important for final disinfection).

This combination has several benefits:

- Removal of organic and inorganic matter
- Removal of micro-pollutants, such as pesticides
- Enhancement of the flocculation/coagulation-decantation process
- Enhanced disinfection and reduction of disinfection byproducts
- Odor and taste elimination

Removal of organic matter and inorganic matter : All water sources contain natural organic matter (NOM). Concentrations (usually measured as dissolved organic carbon, DOC) differ from 0,2 to more than 10 mg L-1. NOM creates direct problems, such as odor and taste in water, but also indirect problems such as organic disinfection byproduct formation, support of bacterial regrowth in the distribution system, etc. To produce pure drinking water, the removal of NOM is a prior task in modern water treatment.
Ozone, like any other oxidant, seldom achieves a complete mineralisation of NOM. Organic matter is partly oxidized and becoming more easily biodegradable. This results in a higher amount of BDOC (Biodegradable DOC). As a result, ozone improves the removal process of NOM by a subsequent filter, when it is used as a pre-oxidant. In a research paper of Siddiqiui et al. the effect of ozone in combination with a biological filter is described. The combined treatment resulted in a reduction of DOC of 40-60%. The removal is even greater when ozone is used in combination with a coagulant. This is because ozone can enhance the coagulation process. The combination coagulation–ozone–bio filtration results in a DOC reduction of 64%. When only bio filtration was apllied, the reduction rate was only 13%. The optimal

concentration to remove organic matter by ozone was at an ozone dose of: O_3/DOC = 1 mg/mg.
Most inorganic matter can be eliminated by ozone quite fast. After ozonation, bio filtration is also required for inorganic matter. Namely, oxidation forms unsoluble compounds that need to be removed during the next water purification step.

Pesticides : Micro- pollutants such as pesticides may occur in surface water, but also increasingly in groundwater. Drinking-water standards for pesticides in the European Union are strict: 0,1 μg l-1 for each compound .
Several surveys show that ozone can be very effective for the oxidation of several pesticides. At a water treatment plant in Zevenbergen (Holland) it was proved that three barriers (storage–ozonation–granular active carbon filter (GAC filter)) are effective and safe enough for the removal of pesticides. From 23 tested pesticides, 50 % was degraded sufficiently (80 % degradation). Table 1 shows an overview of pesticides that are easily degraded by ozone. For highly resistant pesticides, a higher dosage of ozone is advised, or ozone combined with hydrogen peroxide .

Table 1: degradation of pesticides that are easily degradable by ozonation (%)

Pesticide	**pH 7,2; 5 °C; O_3/DOC = 1,0**	**pH 7,2; 20 °C; O_3/DOC = 1,0**	**PH 8,3; 20 °C; O_3/DOC = 1,0**
diazinon	86	92	92
dimethoate	97	97	97
parathion-methyl	85	91	91
diuron	91	95	98
linuron	67	81	89
methabenzthiazuron	78	90	94
metobromuron	83	91	94
MCPA	83	87	90
MCPP	91	93	93
chlortoluron; isoproturon; metoxuron; vinclozolin	> 99	> 99	> 99

Reduction of disinfection byproducts and improved disinfection :
Disinfection byproducts (DBP) are mainly formed during the reaction between organic material and a disinfectant. The reaction of chlorine with organic matter can lead to the formation of chlorinated organic DBP's, such as trihalomethanes (THM). Ozone can also react with organic matter and form DBP's. These are mainly organic disinfection byproducts, such as aldehydes and ketones, which can be easily degradaded in a bio filter (90-100%). Generally, these organic ozone DBP's do not form any risk of violation of drinking water standards, when ozone is used a pre-oxidant.
To reduce the amount of DBP's at a conventional disinfection system (disinfection by chlorine products) it is important that the potential to

form DBP's remains low. This is often expressed as DBP formation potential (DBPFP). The potential to form DBP's can be reduced by the removal of (most of the) NOM, for example by pre-oxidation with ozone (ozone-filtration). This combination can lower the DBPFP by 70-80%, when chlorine is used as a final disinfectant. This concerns the DBPFP for THM's, HAA (haloacetic acids) and chloral hydrate.

Ozone is a more effective disinfectant than chlorine, chloramines, and even chlorine dioxide. An ozone dose of 0,4 mg L-1 for 4 minutes is usually effective for pre-treated water (low NOM concentration). Several studies proved that ozone, unlike chlorine products, can deactivate resistant micro-organisms. However, as ozone rapidly decomposes in water, its life-span in aqueous solutions is very short (less than one hour). Therefore ozone is less suitable for residual disinfection and can be used only in particular cases (mainly in short distribution systems). Chlorine and chlorine dioxide often replace ozone as a final disinfectant. For primary disinfection (prior to the bio filtration), ozone is very suitable. This will lead to a more complete disinfection and a lower disinfectant concentration.

Odour and taste elimination : Odour and taste production in drinking water can have several causes. Odour and taste forming compounds can be present in raw water, but they can also be formed during water treatment. These compounds may derive from the decomposition of plant matter, but normally they are a result of the activity of living organisms present in the water. Inorganic compounds such as iron, copper and zinc can also generate some taste. Another possibility is that the chemical oxidation (chlorine treatment) leads to an unpleasant tastes and odors.

Odour and taste forming compounds are often very resistant. This causes elimination to be a very intensive process. For the elimination of taste and odor, several processes can be appropriate, such as oxidation, aeration, granular active carbon (GAC) filtration or sand filtration. Usually, a combination of these techniques is applied.
Ozone can oxidize compounds in a range of 20–90% (dependent on the

type of compound). Ozone is more effective for the oxidation of unsaturated compounds. As was the case for the oxidation of pesticides, ozone combined with hydrogen peroxide (AOP process) is more effective than ozone alone. Geosmin and 2-methylisoborneol (MIB) are examples of resistant odorous compounds, which are often present in the water. These are produced by algae and have a low odor and taste threshold. Nevertheless, ozone is still very affectively removes these compounds, see figure 1.

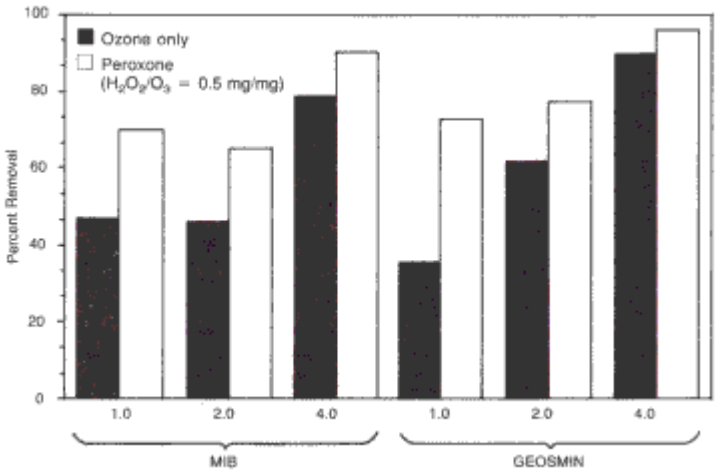

Figure 1: Removal of MIB and Geosmin (Colorado river water, US)

Generally, the most effective way to remove taste and odor components appears to be a combination of pre-oxidation and filtration. Table 2 shows several combinations of techniques to improve taste. Ozone with sand filtration and GAC filtration is the most efficient combination (82% removal).

Table 2: effect of ozone and subsequent treatment on odor threshold and odor reduction at Saint-Maur pilot treatment (France)

Treatment	Average Taste Threshold	Flavor Reduction (%)
Raw water	10	–
Settled water	7	30
Filtered water	5.3	47
Filtered water with ozone	3.3	67
Sand without ozone	3	70
Sand with ozone	3	70
Sand and activated carbon without ozone	2.8	72
Sand and activated carbon with ozone	1.8	82
Activated carbon without ozone	2.3	77
Activated carbon with ozone	2.8	72

Ultraviolet disinfection

Ultraviolet light (UV) is very effective at inactivating cysts, in low turbidity water. UV light's disinfection effectiveness decreases as turbidity increases, a result of the absorption, scattering, and shadowing caused by the suspended solids. The main disadvantage to the use of UV radiation is that, like ozone treatment. For the past 100 years science has recognized the bactericide effects of the ultraviolet area of the electromagnetic spectrum.

The specific wavelengths responsible for this reaction are situated between 240 - 280 nanometers (referred to as nm) with a peak wavelength at 265 nm. They are known as UV-C.

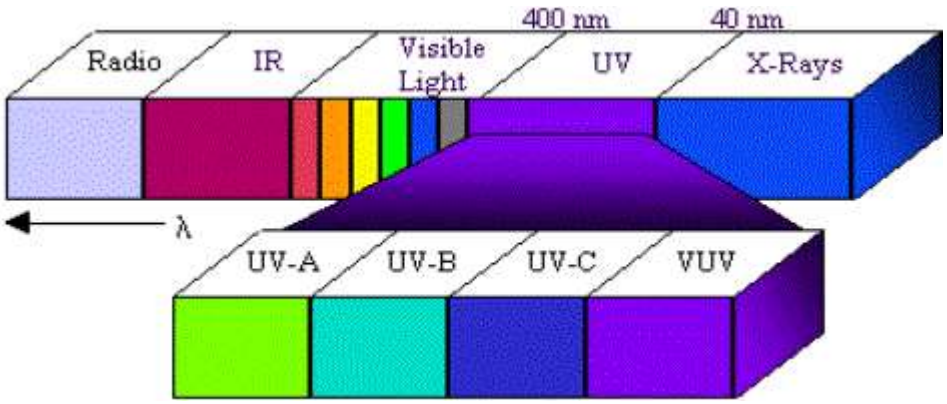

Fig. 2- UV-C in the spectrum of electromagnetic radiation pressure UV lamps.

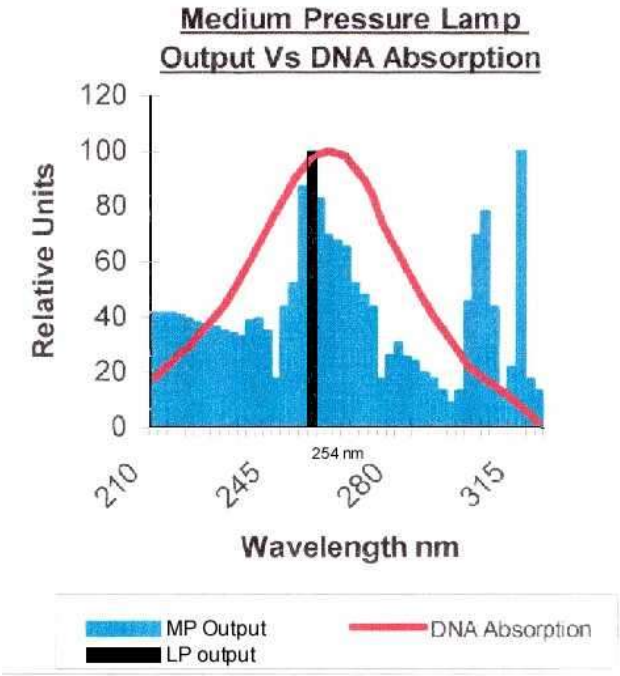

Fig. 3 - spectral energy distribution curve for germicidal action and spectral power distribution for low and medium pressure UV lamps

Effect of ultraviolet : When a micro-organism is exposed to UV-C, the nuclei of the cells are modified, due to photolytic processes. In result, cell division and, by extension, reproduction is prevented.

UV-C production : The Ultra Violet source is basically a fused silica quartz tube, typically l5mm to 25mm diameter ranging from 100mm-1200mm long. The inert gas with which the tube is filled, provides the primary discharge and the necessary action to excite and vaporize the miniscule deposits of mercury within.

The low pressure UV lamp is only capable of producing lines at 185nm and 254 nm. An increase in the current supplied would cause the UV lamp to rapidly heat up thus increasing the mercury pressure to produce the typical medium pressure spectral output shown in Diagram 2.

Ultraviolet dose :The UV dose is the product of UV intensity (expressed as energy per unit surface area) and residence time.

Therefore: DOSE = I x T

This is commonly expressed as 1mJ/cm2=1000 micro Watt second/cm2

The minimum dose expressed by Willand gives the user the guaranteed assurance of success. Average and cumulative doses offered by others depend on turbulent flow characteristics which can disappear when flow is variable.

Willand recommend the appropriate UV dose for each application taking into account water quality, arc tube ageing, industry specifications, as well as microbiological standards.

Dose/Destruction relationship : The relationship between the dose and the destruction achieved of a target micro-organism can be summarized as follows:

$N/N_o = e^{-KD}$

Where:
N = Initial Number of target organisms
No = Number of target organisms after treatment
K = Constant associated with target organisms
D = Dose

From the above relationship doubling of the dose applied will increase the destruction by a factor of 10. Therefore doubling the dose required for 90% destruction will produce 99% destruction of the target organism. tripling the dose will produce a 99.9% destruction of the target organism and so on.

Some 90% destruction values are shown in Fig. 3 and the relationship between UV dose and destruction are shown in Fig. 4

Table 3 - DOSE REQUIREMENTS - COMMON MICRO-ORGANISMS

Species	Dose (mJ/cm^2)
Bacillus subtilis (spore)	12.0
Clostridium tetani	4.9
Legionella Pneumophilla	2.04
Pseudonomas aeruginosa	5.5
Streptococcus feacalis	4.5
Hepatitis A virus	11.0
Hepatitis Poliovirus	12.0
Saccharomyces cervisiae	6.0
Infectious pancreatic necrosis	60.0

Table 4 - E.coli (Waterborne indicator Pathogen) DOSE = 5.4 mJ/cm2

Dose mJ/cm^2	Reduction in number of live microorganisms
5.4	90.0%
10.8	99.0%
16.2	99.9%
21.6	99.99%
27.0	99.999%

Disadvantage:

It leaves no residual disinfectant in the water; therefore, it is sometimes necessary to add a residual disinfectant after the primary disinfection process. This is often done through the addition of chloramines, discussed above as a primary disinfectant. When used in this manner, chloramines provide an effective residual disinfectant with very few of the negative effects of chlorination.

Various portable methods of disinfection

Available for disinfection in emergencies or in remote locations. Disinfection is the primary goal, since aesthetic considerations such as taste, odor, appearance, and trace chemical contamination do not affect the short-term safety of drinking water.

Solar water disinfection

One low-cost method of disinfecting water that can often be implemented with locally available materials is solar disinfection (SODIS). Unlike methods that rely on firewood, it has low impact on the environment.

One recent study has found that the wild Salmonella which would reproduce quickly during subsequent dark storage of solar-disinfected water could be controlled by the addition of just 10 parts per million of hydrogen peroxide.

CHAPTER FOUR

ADDITIONAL TREATMENTS

1. Water fluoridation:

In many areas fluoride is added to water with the goal of preventing tooth decay. Fluoride is usually added after the disinfection process. In the U.S., fluoridation is usually accomplished by the addition of hexafluorosilicic acid, which decomposes in water, yielding fluoride ions.

2. Water conditioning:

This is a method of reducing the effects of hard water. In water systems subject to heating hardness salts can be deposited as the decomposition of bicarbonate ions creates carbonate ions that precipitate out of solution. Water with high concentrations of hardness salts can be treated with soda ash (sodium carbonate) which precipitates out the excess salts, through the common-ion effect, producing calcium carbonate of very high purity. The precipitated calcium carbonate is traditionally sold to the manufacturers of toothpaste. Several other methods of industrial and residential water treatment are claimed (without general scientific acceptance) to include the use of magnetic and/or electrical fields reducing the effects of hard water.

3. Plumbosolvency reduction:

In areas with naturally acidic waters of low conductivity (i.e. surface rainfall in upland mountains of igneous rocks), the water

may be capable of dissolving lead from any lead pipes that it is carried in. The addition of small quantities of phosphate ion and increasing the pH slightly both assist in greatly reducing plumbo-solvency by creating insoluble lead salts on the inner surfaces of the pipes.

4. Radium Removal:

Some groundwater sources contain radium, a radioactive chemical element. Typical sources include many groundwater sources north of the Illinois River in Illinois. Radium can be removed by ion exchange, or by water conditioning. The back flush or sludge that is produced is, however, a low-level radioactive waste.

5. Fluoride Removal:

Although fluoride is added to water in many areas, some areas of the world have excessive levels of natural fluoride in the source water. Excessive levels can be toxic or cause undesirable cosmetic effects such as staining of teeth. Methods of reducing fluoride level is through treatment with activated alumina and bone char filter media.