Consortium for Educational Communication

Module
on
Treatment Of Water

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TEXT

1. INTRODUCTION

Water has always played a prominent role in human civilization. It was invariably near water sources like rivers, lakes, or groundwater springs, where people first began to settle and grow crops for sustenance. Water is needed for basic necessities such as drinking, preparing food, bathing, cleaning, irrigating crops, and a variety of other tasks. This basic necessity is colorless, tasteless, and odorless in nature. It is also, an excellent solvent that can dissolve most of the minerals coming in contact with it. The property of being a universal solvent makes it susceptible to contain chemical and biological impurities (i.e. suspended or dissolved inorganic/organic compounds and micro organisms). These compounds may leach in from various natural sources or waste deposits. Inorganic compounds, in general, originate from weathering and leaching of rocks, soils, and sediments, which principally are calcium, magnesium, sodium and potassium salts of bicarbonate, chloride, sulphate, nitrate, and phosphate. Besides, lead, copper, arsenic, iron and manganese may also be present in trace amounts. Organic compounds originate from decaying plants and animal matters and from agricultural runoffs, which constitute natural humic material to synthetic organics used as detergents, pesticides, herbicides, and solvents. However, municipal and industrial wastes also contribute to a wide spectrum of both organic and inorganic impurities. These constituents and their concentrations influence the quality of water resource.

Being a potential carrier of impurities, water requires various treatments before its end-use. The treatments involve removal of contaminants through various processes. Water treatment is installed either for removal of disease causing entities or removal of those entities that cause nuisances. It is important to have ready access to clean and safe water so as to prevent various fatal outbreaks. The goal of water treatment is to protect public health. However, the broader goal is to provide safe potable drinking water or in some cases treat waste water for safe discharge into water bodies/ seepage through soil.

Various water treatments involved in the purification and disinfection of water include, coagulation, flocculation, sedimentation, filtration, reverse osmosis, ozonation, and chlorination.

2. HAZARDS TO THE WATER SUPPLY

In general, water can be contaminated by either chemical impurities or biological impurities. Water being a universal solvent, easily dissolves many chemicals and other materials. Water supplies become contaminated through many different channels. Chemicals can migrate from various disposal sites into the stream of drinking water. Discharges from various industries also pose a threat to safety of water. Water is also prone to contamination by micro-organisms.

1) Chemical impurities

Chemicals migrate easily from disposal sites and animal wastes; pesticides may be carried to lakes and streams by rainfall runoff; human wastes may be discharged to receiving water that ultimately flows to water used for drinking. Other sources of contamination include discharge from industry, erosion of natural deposits, corrosion of household plumbing systems, and leaching from septic tanks. Nitrates, inorganic compounds that can enter water supplies from fertilizer runoff and sanitary wastewater discharges, are harmful to young children. Excessive levels of such chemicals can result in fatal conditions. Naturally occurring contaminants also are found in drinking water. For example, the radioactive gas radon-222 occurs in certain types of rock and can seep into groundwater. People can be exposed to radon in water by drinking it while showering or when washing dishes. As is the case with food, it would be impossible to remove all contaminants from our water supply. It has been proved that at very low levels, many contaminants are generally not harmful.

Water from surface sources is often contaminated by microbes, whereas groundwater is normally safer. But groundwater gets contaminated by leaching of harmful chemicals from human activities or 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. Therefore, the water sources used for supplying water are not always clean, and treatments are required to produce clean drinking water. Treatments to remove disease-causing pathogens have occurred in one form or another throughout recorded history to improve smell, taste, or clarity.

2) Biological impurities

Most outbreaks of water-borne diseases are due to contamination by bacteria and viruses, probably from human or animal waste. Runoff from farms is another source of hazards that affects safety drinking water. Two pathogens commonly associated with drinking water are *Cryptosporidium parvum* and *Giardia lamblia*. Both of these are protozoa whose cysts are difficult to destroy. Contamination with such protozoa causes serious gastrointestinal illness. *Cryptosporidium* in particular may pass through water treatment filtration and disinfection processes in sufficient numbers to cause health problems.

3. MULTIPLE BARRIERS

For long, the process of providing safe drinking water has relied on the application of the 'multiple barrier concept'. It is important to consider the source of water, whether marshy and soft, or hard and running from elevated and rocky situations, or if saltish and unfit for cooking, for water contributes much to health.

The concept of multiple barriers for water treatment is the cornerstone of safe drinking-water production. The barriers are selected so that the removal capabilities of different steps in the treatment process are enhanced. This approach provides sufficient backup to allow continuous operation in the face of normal fluctuations in performance, which will typically include periods of ineffectiveness. Having multiple barriers means that a failure of one barrier can be compensated for by effective operation of the remaining barriers, minimizing the likelihood that contaminants will pass through the treatment system and harm consumers. Traditionally, the barriers have included:

a) Protection of source water (water used for drinking-water should originate from the highest quality source possible)

b) Coagulation, flocculation and sedimentation

c) Filtration

d) Disinfection

e) Protection of the distribution system.

If these conventional barriers are thought to be inadequate, it may be advisable to consider adding multiple stages of filtration or disinfection. The combination of filtration and chlorination appears to provide sufficient duplication in removal of contaminants.

4. PROCESS CONTROL MEASURES

There are many hazards that may be of concern in source waters or within the distribution system. Developing a monitoring scheme for each is an impossible task; therefore, another approach is needed. The food and beverage industry uses the “hazard analysis critical control point” (HACCP) approach to determine the key points within the manufacturing chain where contamination can be measured and prevented. A similar concept can be used by water utilities, to prioritize the key contamination points within the treatment and distribution system. This approach allows utilities to focus their resources on monitoring these points and correcting any deviations from acceptable limits. The latest edition of the World Health Organization (WHO) *Guidelines for Drinking-Water Quality* (WHO, 2004) incorporates such an approach, providing guidance on the development of a water safety plan. The plan is developed using a water safety framework, which combines HACCP principles with water quality management and the multiple barrier concept.

Most microbiological monitoring programs for drinking-water have not been designed using such a framework. However, many of the relevant concepts are found in the overall process control of water treatment plants and distribution systems. The water safety framework is not only applicable to microbial monitoring of drinking-water treatment; it can also be applied to aspects such as turbidity, disinfectant residuals, and pressure and particle counts.

5. WATER TREAMENT

Water treatment process involves removal of contaminants and can be divided into following stages:

a) Pretreatment

b) Primary treatment

c) Pressurized filtration

d) Chemical treatment

e) Disinfection

5.1 PRETREATMENT

Pretreatments usually involve grit removal by passing water through various mesh screens. Screeners and grit chamber are usually employed in preliminary treatment.

a) Screeners:

A screener is a device with openings (usually uniform in size) to remove the floating materials and suspended particles. The process of screening can be carried out by passing sewage through different types of screeners (with different pore sizes). The screeners are classified as coarse, medium or fine, depending on the size of the openings. The coarse screen has larger openings (75-150 mm). The openings for medium and fine screens respectively are 20-50 mm and less than 20 mm.

Different types of screens-fixed bar screen (coarse or medium) disc type fine screen, drum type fine screen are in use.

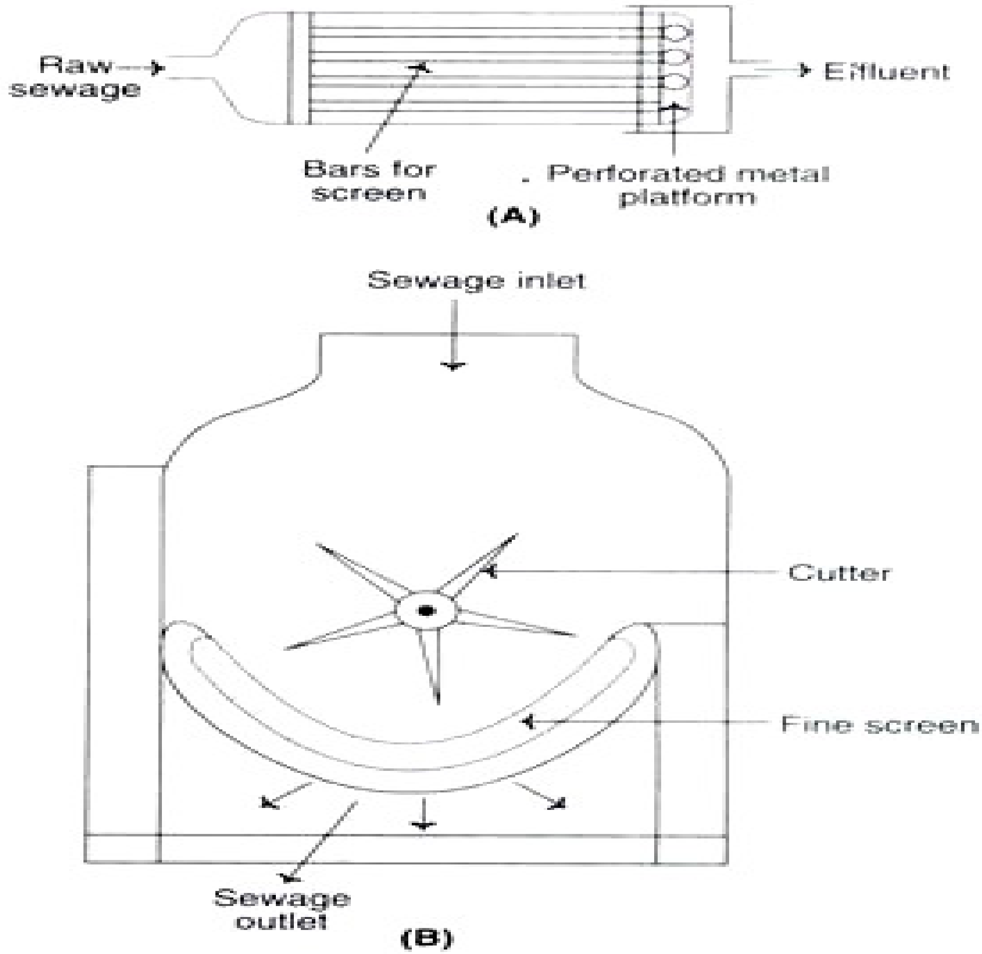


Fig. 57.1 : Diagrammatic representation of screeners
(A) Fixed bar screen (coarse or medium)
(B) Shredder.

Fig 1: Illustration of screeners used in pretreatment

Grit Chambers

The heavy inorganic materials (specific gravity 2.4-2.7) like sand, ash and others can be removed by using grit chambers. This technique is based on the process of sedimentation due to gravitational forces. Grit chambers may be kept either before or after the screens. A diagrammatic representation of a typical grit chamber is depicted in Fig. 2.

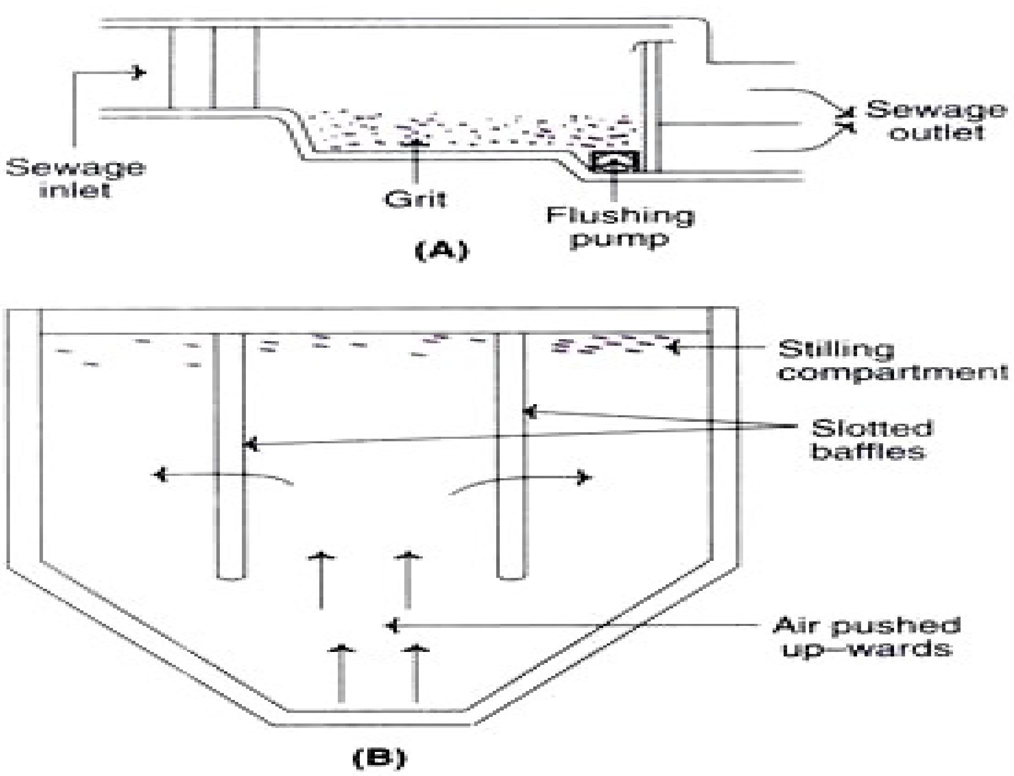


Fig. 57.2 : (A) Grit chamber (B) Skimming tank (cross section).

Fig 2: Illustration of grit chambers used in pretreatment

5.2 PRIMARY TREATMENT

It involves various traditional water treatment processes that are designed to remove various particulates from water. Applications of primary treatment include removal of high levels of turbidity that may be due to algal cells, or viruses and protozoan cysts. Each of the process used in preliminary treatment has a particular function that determines the water quality. Various advanced processes that are used in primary treatment to remove particulates involve coagulation, flocculation, and filtration

5.2.1 COAGULATION & FLOCCULATION

Coagulation: It is the process of using chemical and/or physical techniques to promote particulate settling by reducing net electrical repulsion forces between particles.

Flocculation: It is the process of agglomerating particles in water or wastewater to promote settling by using high-molecular-weight materials such as polymers, starches, and multiple charged ions.

Coagulation and flocculation are used in conjunction with subsequent filtration. Coagulation promotes the interaction of small particles to form larger particles. Addition of a substance leads to the formation of hydrolysis products that cause coagulation, particle destabilization, and interparticle collisions. And flocculation produces interparticle contacts that lead to the formation of large particles.

Various methods of coagulation and flocculation involve

a) Conventional clarification

Conventional clarification typically refers to chemical addition, rapid mixing, flocculation and sedimentation (usually in a rectangular basin). Removal of particles depends mainly on the terminal settling velocity of the particles and the rate of basin surface loading or overflow. The efficiency of the sedimentation process may be improved by using inclined plates or tubes. For conventional treatment processes, chemical coagulation is critical for effective removal of microbial pathogens. In the absence of a chemical coagulant, removal of microbes is low because sedimentation velocities are low. A chemical coagulant destabilizes microbial particles (e.g. by neutralizing or reducing their surface electrical charge, enmeshing them in a floc particle or creating bridges between them) and allows particles to come into contact with one another. Flocculation of microbial particles creates aggregates with sufficient settling velocities to be removed in the sedimentation basin. When properly performed, coagulation, flocculation and sedimentation can result in 1–2 log removals of bacteria, viruses and protozoa. However, performance of full-scale, conventional clarification processes may be highly 14 Water treatments and pathogen control variable, depending on the degree of optimization.

b) High-rate clarification

High-rate clarification involves using smaller basins and higher surface loading rates than conventional clarifiers, and is therefore referred to as high rate clarification. Processes include floc-blanket sedimentation (also known as ‘solids-contact clarification’), ballasted-floc sedimentation, and adsorption or contact clarification. In floc-blanket sedimentation, a fluidized blanket increases the particle concentration, thus increasing the rate of flocculation and sedimentation. Ballasted-floc systems combine coagulation with sand, clay, magnetite or carbon to increase the particle sedimentation rate. Adsorption or contact clarification involves passing coagulated water through a bed where particles attach to previously adsorbed material. High-rate clarifiers can be as effective as or even more effective than conventional basins for removal of microbes. The choice of an appropriate blanket polymer is important for optimal operation.

c) Dissolved air flotation

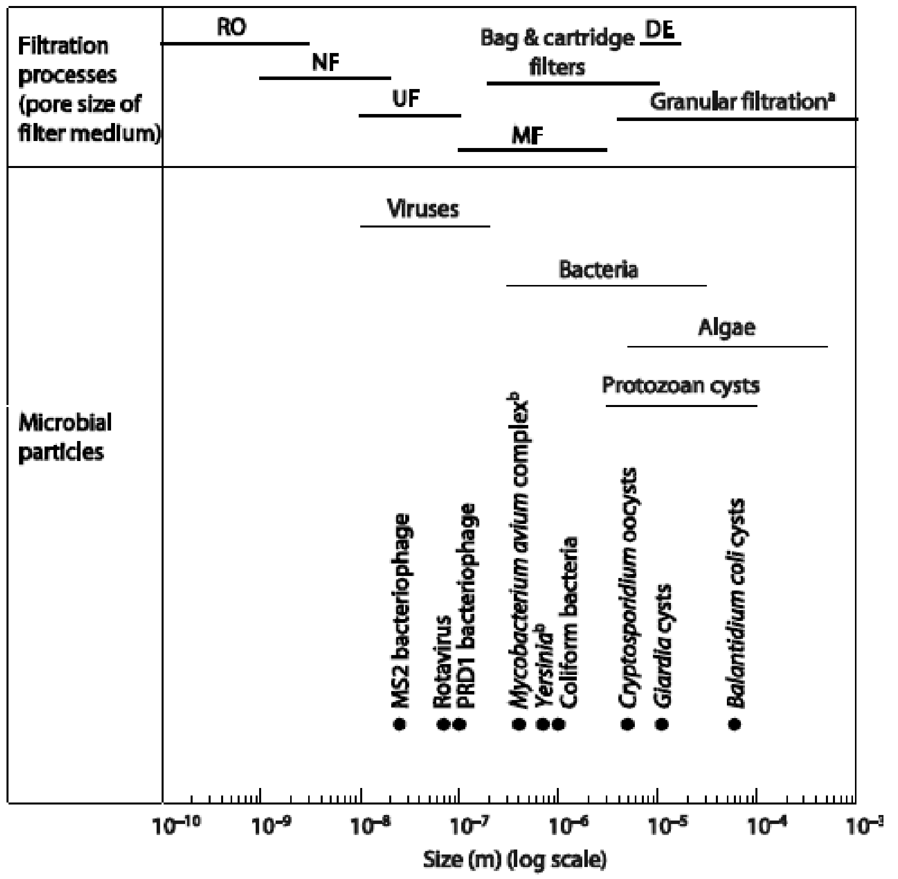
In dissolved air flotation (DAF), bubbles are produced by reducing pressure in a water stream saturated with air. The rising bubbles attach to floc particles, causing the agglomerate to float to the surface, where the material is skimmed off. It can be particularly effective for removal of algal cells and *Cryptosporidium* oocysts. It is most applicable to waters with heavy algal blooms or those with low turbidity, low alkalinity and high color, which are difficult to treat by sedimentation because the floc produced has a low settling velocity.

d) In-line coagulation

In-line coagulation can be used with high-quality source waters (e.g. those where turbidity and other contaminant levels are low). The coagulants are added directly to the raw water pipeline before direct filtration. Typically, the coagulants are added before an in-line static mixer, and it is not necessary to use a basin for sedimentation. In-line coagulation permits the particle destabilization necessary for effective particle removal by filtration, but does not remove microbes by sedimentation.

5.2.2 FILTRATION

Various filtration processes are used in drinking-water treatment. Filtration can act as a consistent and effective barrier for microbial pathogens. Figure 3 shows the most commonly used filtration processes in potable water treatment, the pore size of the filter media and the sizes of different microbial particles. These size spectra are useful for understanding removal mechanisms and efficiencies, and for developing strategies to remove microbes by different filtration processes.



DE = diatomaceous earth; MF = microfiltration; NF = nanofiltration; RO = reverse osmosis; UF = ultrafiltration.

Figure 2.5 Pore size of filter medium and size of microbial particles

Fig 3: Commonly used filtration processes

a) GRANULAR HIGH-RATE FILTRATION

Granular media filtration is the most widely used filtration process in drinking water treatment. Under optimal conditions, a combination of coagulation, flocculation, sedimentation and granular media filtration can result in better removal of protozoan pathogens with chlorine-resistant cysts.

Granular filters can be constructed as monomedium (e.g. silica sand), dual media (e.g. anthracite coal and sand) and trimedia (e.g. coal, sand and garnet). Granular activated carbon is used when both filtration of particles and adsorption of organic compounds are desired. Depending on raw water quality, granular filtration can be operated in three different modes:

- *Conventional*, which includes addition of coagulants (rapid mixing), flocculation (slow mixing), sedimentation and filtration;
- *Direct filtration*, in which the sedimentation step is omitted;
- *In-line filtration,* in which both flocculation and sedimentation steps are omitted.

b) SLOW SAND FILTRATION

Slow sand filtration involves passing water through a sand filter by gravity at a very low filtration rate, without the use of coagulation. The filter typically consists of a layer of sand supported on a layer of graded gravel. As water passes through the filter, microbes and other substances are removed. The removal mechanisms are believed to be a combination of biological, physical and chemical mechanisms. Specific mechanisms may include biological action (e.g. ciliate protozoa acting as bacterial predators), attachment of microbes to sand media (e.g. by electrochemical forces and through bridging by microbial extracellular polymers) and physical straining.

c) Pre-coat filtration

Pre-coat filtration was developed by the US Army during World War II as a portable unit for the removal of *Entamoeba histolytica* (a protozoan parasite prevalent in the Pacific war zone) from drinking-water. The process involves forcing water under pressure or by vacuum through a uniformly thin layer of filtering material pre-coated onto a permeable, rigid, supporting structure (referred to as a septum). Pre-coat materials include diatomaceous earth and perlite, with diatomaceous earth more commonly used in drinking-water treatment. As water passes through the filter media and septum, the pre-coat materials (filter cake) capture microbes and other particles, mainly by physical straining. Often, a "body feed" solution containing the filter media slurry is added continuously to the system, to maintain the permeability of the filter cake. As the cake becomes thicker due to the captured particles, head loss increases until further filtration is impractical. The filter cake is removed from the support septum and disposed of. The filter is then cleaned and pre-coated with a new layer of coating materials, and a new filter cycle starts. Because the major removal mechanism is physical straining, efficiency of pre-coat filtration depends to a large extent on the grade (size) of the coating materials and on the size of the microbes. Other factors influencing the removal efficiency are chemical pretreatment of the filter media, filtration rate and body feed rate. Chemical pretreatment of the raw water is usually not necessary; however, the raw water must be of high quality (low turbidity) to maintain a reasonable filter run time.

d) Roughing filters

A roughing filter is a coarse media (typically rock or gravel) filter used to reduce turbidity levels before processes such as slow sand filtration, diatomaceous earth (DE) or membrane filtration. Roughing filters typically have a filter box divided into multiple sections containing gravel beds of decreasing particle size, inlet and outlet structures, and flow-control devices. Examples of common configurations are shown in Figure 4. Roughing filters have achieved peak turbidity removals ranging from 60 to 90%. Generally the more turbid the water is initially, the greater is the reduction that can be achieved. These filters can achieve similar reductions of *coliform*s. Pilot studies of various roughing filter configurations (horizontal-flow, up-flow and down-flow) have shown to reduce faecal coliform bacteria by 93–99.5%. These filters in combination with a dynamic roughing filter (which contains a thin layer of fine gravel on top of a shallow bed of coarse gravel, with a system of underdrains) are used to pretreat high turbidity events, and can achieve a faecal coliform removal of 86.3%. When followed by slow sand filtration, the removal can reach upto 99.8%, with an overall combined treatment efficiency of 4.9–5.5 log units. Roughing filters remove clay particles more effectively than algal cells. Addition of alum coagulant before treatment with a horizontal roughing filter improves the filter's performance for turbidity, color, organic carbon, head loss and filter

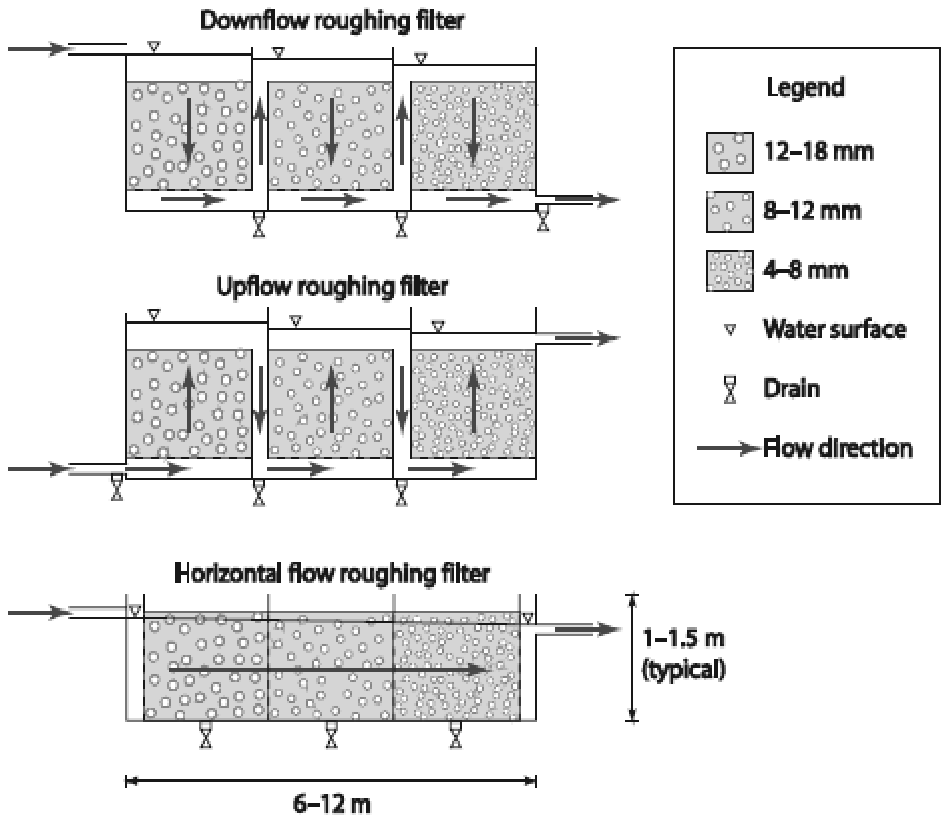


Figure 2.1 Typical roughing filter configurations (Collins et al., 1994)

run length.

Fig 4: Roughing filters

e) Micro strainers

Micro strainers are fabric meshes woven of stainless steel or polyester wires, with apertures ranging from 15 to 45 μm (usually 30–35 μm). Such meshes are useful for removing algal cells and large protozoa (e.g. *Balantidium coli*), but have no significant impact on bacteria or viruses. Micro strainers generally remove about 40–70% of algae and, at the same time, about 5–20% of turbidity.

f) Off-stream storage

Off-stream storage refers to a storage reservoir that directly or indirectly feeds a potable water intake. The effects of off-stream storage are difficult to generalize because important physical, biological and chemical processes are influenced by hydrological and limnological characteristics of the reservoir. Similarly, round reservoirs and lowland impoundments are influenced by strong winds. On the other hand, long reservoirs whose depth increases with length are best represented as a series of interconnected individual basins. The characteristics of reservoirs created by construction of a dam differ from those of a natural or artificial lake. The major factors that influence the treatment process are the degree of compartmentalization, the hydraulic residence time, the shape and flow through the reservoir, and the quality of the source water. The poorer quality of the impounded water can result from failure to:

• Manage algal growth;

• Control influx of nitrogen, phosphorus or other contaminants;

• Limit faecal contamination from run-off of surrounding areas or roosting birds.

g) Bank infiltration

Bank infiltration refers to the process of surface water seeping from the bank or bed of a river or lake to the production wells of a water treatment plant. During the water's passage through the ground, its quality changes due to microbial, chemical and physical processes, and due to mixing with groundwater. The process can also be described as 'induced infiltration,' because the well-field pumping lowers the water table, causing surface water to flow into the aquifer under a hydraulic gradient. Bank infiltration can be accomplished through natural seepage into receiving ponds, shallow vertical or horizontal wells placed in alluvial sand and gravel deposits adjacent to surface waters, and infiltration galleries. Bank infiltration has been widely used in European countries and is of increased interest in many other countries. Variations on the underground passage concept include soil aquifer treatment, injection of surface water for underground passage and aquifer recharge. The efficiency of the process depends on a number of factors: the quality of the surface water (turbidity, dissolved organic matter, oxygen, ammonia and nutrients), the composition and porosity of the soil, the residence time of the water in the soil and the temperature. This efficiency can vary over time, depending on the difference in level between the source water (e.g. river stage) and groundwater. This difference can influence the degree of groundwater mixing and the residence time of the infiltrated surface water.

5.3 PRESSURIZED/ MEMBRANE FILTRATION

In membrane filtration, a thin semi permeable film (membrane) is used as a selective barrier to remove contaminants from water. There are very few contaminants that cannot be removed by membrane processes. For the past two decades, the use of membrane filtration in drinking-water treatment (including pathogen removal) has been growing, due to increasingly stringent drinking-water regulations and decreasing costs of purchasing and operating membrane filters. The membrane processes most commonly used to remove microbes from drinking-water are microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO). Not all of these processes are used primarily for removal of pathogens. For example, RO is used mainly for desalination and NF for softening and for removal of precursors of disinfectant by-products. Nevertheless, the ability to remove pathogens broadens the application of these types of filter when used for these other treatment objectives.

5.3.1 Microfiltration

Microfiltration membranes have pores of 0.1 μm or more. Theoretically, microfiltration can remove protozoa, algae and most bacteria very effectively. However, factors such as bacteria growing in the membrane systems can lead to poor removal of bacteria. Viruses, which are 0.01–0.1 μm in size, can generally pass through microfiltration membranes, but may be removed by the membrane if they are associated with large particles. Numerous pilot studies have directly evaluated the removal of *Giardia*, *Cryptosporidium* and other specific microbial pathogens by microfiltration.

5.3.2 Ultrafiltration

Ultrafiltration membranes have pores of 0.01 μm or more, small enough to remove some viruses in addition to bacteria and protozoa. Ultrafiltration acts as an absolute barrier to protozoan cysts as long as membranes remain intact. It acts as a barrier for *Giardia* and *Cryptosporidium.* Removal of viruses by Ultrafiltration is significantly better than removal by microfiltration, and depends essentially on the pore size of the membranes. The membranes with the lowest molecular weight cutoffs achieve the highest removal efficiency.

5.3.3 Nanofiltration and reverse osmosis

The pore sizes of nanofiltration and reverse osmosis membranes are smaller than those of ultrafiltration membranes. However, nanofiltration and reverse osmosis alone are seldom used to remove microbial pathogens because microfiltration or ultrafiltration are more cost-effective and can achieve a similar degree of microbial removal.

5.4 CHEMICAL TREATMENT

5.4.1 Hardness Removal

a) Lime softening

Precipitate lime softening is a process in which the pH of the water is increased (usually through the addition of lime or soda ash) to precipitate high concentrations of calcium and magnesium. Typically, calcium can be reduced at pH 9.5–10.5, although magnesium requires pH 10.5–11.5. This distinction is important because the pH of lime softening can inactivate many microbes at the higher end (e.g. pH 10–11), but may have less impact at more moderate levels (e.g. pH 9.5). In precipitate lime softening, the calcium carbonate and magnesium hydroxide precipitates are removed in a clarifier before the water is filtered. The microbial impact of lime softening can, therefore, be a combination of inactivation by elevated pH and removal by settling

b) Ion Exchange

Ion exchange is a treatment process in which a solid phase presaturant ion is exchanged for an unwanted ion in the untreated water. The process is used for water softening (removal of calcium and magnesium), removal of some radio nuclides (e.g. radium and barium) and removal of various other contaminants (e.g. nitrate, arsenate, chromate, selenate, and dissolved organic carbon). The effectiveness of the process depends on the background water quality, and the levels of other competing ions and total dissolved solids. Although some ion exchange systems can be effective for adsorbing viruses and bacteria, such systems are not generally considered a microbial treatment barrier, because the organisms can be released from the resin by competing ions. Also, ion exchange resins may become colonized by bacteria, which can then contaminate treated effluents. Back flushing and other rinsing procedures, even regeneration, will not remove all of the attached microbes. Impregnation of the resin with silver suppresses bacterial growth initially, but eventually a silver-tolerant population develops. Disinfection of ion exchange resins using 0.01% per acetic acid (1 hour contact time) has been found to be effective.

5.5 INACTIVATION (DISINFECTION) PROCESSES

Disinfection involves three processes

• *Pretreatment oxidation* — in which oxidants are added to water early in the treatment process.

• *Primary disinfection* — a common component of primary treatment of drinking-water, and important because granular filter media does not remove all microbial pathogens from water.

• *Secondary disinfection* — used to maintain the water quality achieved at the treatment plant throughout the distribution system up to the tap.

5.5.1 PRETREATMENT OXIDATION

Water utilities often add oxidants early in the treatment process to:

- Maximize the contact time with the oxidant;
- Oxidize compounds for subsequent removal by the treatment process (e.g. iron or manganese);
- Provide initial treatment in sufficient time for water to be further treated if necessary (e.g. oxidation of taste and odor compounds);
- Control growth of microorganisms and higher organisms (e.g. zebra mussels) on intake structures and in treatment basins;
- Enhance particle removal in subsequent clarification and filtration processes.

5.5.2 PRIMARY DISINFECTION

A disinfection barrier is a common component of primary treatment of water. Primary disinfection is typically a chemical oxidation process, although ultraviolet (UV) irradiation and membrane treatment are gaining increased attention. Different types of disinfectant are chlorine, monochlorine, chlorine dioxide, ozone, UV light, and mixed oxidants. These disinfectants are judged in terms of their effectiveness against various pathogenic microorganisms.

1. Chlorination – A water treatment method that destroys harmful bacteria, parasites, and other organisms. Chlorination also removes soluble iron, manganese, and hydrogen sulfide ions from the water.

2. Ozonation – A water treatment process that destroys harmful bacteria and other microorganisms through an infusion of ozone. Ozone (O_3) is a gas created when oxygen molecules are subjected to high electrical voltage.

3. Ultraviolet radiation – A disinfection process for water treatment that involves passing ultraviolet (UV) light through water to kill microorganisms.

5.5.3 SECONDARY DISINFECTION

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. Monochloramine is a commonly used secondary disinfectant.