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WATER PURIFICATION TECHNOLOGIES

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4.1 Need for Water Purification

Provision of safe drinking water is an elementary human necessity and an important human right, especially for maintaining good health. The earth planet contains about 70% of water reservoirs in form of oceans, sea, rivers, lakes, and underground streams even then, 1000 million people worldwide living without the availability of safe drinking water and it is also clear from the studies that about 50% of them are affected by health issues due to shortage of healthy drinking water. People living in underdeveloped areas and in countries with poor economies usually drink water directly from rivers and ponds that resulted in fatal diseases like typhoid, diarrhea, cholera, hepatitis, polio, dysentery, and tapeworms (Werber et al., 2016). Data from selected countries on improved water resources in relation to life expectancy are shown in Table 4.1. This data indicates the chief expansion markers connected to water, fitness, and hygienic condition of seven dominated countries in the world that shows the significant differences between developing and developed countries. The table also presents very clearly that the children's health can be enhanced by the provision of good sanitation and safe drinking water. Availability of safe drinking water is directly correlated with better health in developed countries, about 99% population have good access to safe drinking water in developed countries like Spain or Norway, whereas in countries like Mozambique or Niger, the availability of safe drinking water finds to be less than 45%, so the birth success is very less in these countries and it is a fact that each year due to insufficient hygienic water, hygienic conditions, and sanitation deaths of about 1.5 million children are recorded. Not only this, more than 30% of children deaths has its roots in avoidable diseases that related to water and vulnerable deaths of about 90% among

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Table 4.1 Water Sanitation and Health Development Indicators

Rank's Position	Country	Human Development Index (HDI)	Life Expectancy at Birth (Years)	Under-Five Mortality Rate (per 1000 Live Births)	Population With Access to an Improved Sanitation (%)	Population With Access to an Improved Water Source (%)
1	Norway	0.965	79.6	4	100	100
8	United States	0.948	77.5	8	100	100
19	Spain	0.938	79.7	5	100	100
83	Ecuador	0.765	74.5	26	89	94
126	India	0.611	63.6	85	33	86
168	Mozambique	0.390	41.6	152	32	43
177	Niger	0.311	44.6	259	13	46

Source: Data extracted from Human Development Report; UNDP, 2006. United Nations Human Development Report. UNDP Press, USA.

the children under 5 years are recorded due to diarrheal diseases in the developing countries (Bain et al., 2014; Mehmood et al., 2013). Increased awareness of this problematic issue in previous years the population has highlighted the status of the basic need to safe and hygienic drinking water and to organize global attention for possible resolutions, as specified in numerous global statements such as 21 Program, UN Millennium Declaration in 2000 (Bain et al., 2014). State of World's Children in 2005 and the Human Development Report in 2006 were published and State Global Policy identifies that additional investigation for this ignored topic is required, and recalls that if water sanitation goals of the Millennium Development Goals are to meet in several emerging countries, the quantity of humans not having safe, clean, and hygienic water to drink must be halved by 2015. Water emergency in the developing nations should enforce to alleviate major health concerns in these countries. For this purpose, low-cost, ground-breaking, sustainable, and more effective technologies are required to provide safe drinking water to the consumer's treatment. A high level of skills is required in this area that will help to recover hygienic life style and the environment in underdeveloped countries (Khalid et al., 2014; Michalak et al., 2013).

There is a dire need to focus on water sources that are contaminated with human and animal wastes. Efforts should be made to treat these resources to reduce the risk of waterborne diseases. Engineering designs should be tailored in such a way to ensure safe limits of various physicochemical and microbiological parameters for raw water in available water resources. Different water treatment methods can be used to purify the water in these resources; some of the methods for purification are coagulation, flocculation, sedimentation, and chemical disinfection of raw water. But in the developing countries, these methods are highly variable in its use because of the availability of chemicals and resources (Bain et al., 2014). But some people mostly prefer to drink untreated water from the real and natural sources with some household water treatment methods like chlorination, boiling, etc. that are effective and low in cost.

4.2 Strategies in Water Management

Worldwide population has been increasing at fast pace, it becomes difficult to meet the full demand of water for growing population with the conventional methods and by existing processing methods of water. That is why the more conscientious use of the natural water resources, new and advanced strategies are required (WHO, 2011). Some of the strategies are summarized in Fig. 4.1.

Fig. 4.1 Management to protect water shortages and resources.

4.2.1 Production

This method is based to produce the safe drinking water from the saline and contaminated water to increase the amount of good quality drinking water and it must be obtained from the natural water reservoirs (WHO, 2011). Important strategies used in production procedures are stated as follows:

- removal of salts from the seawater by method of reverse osmosis (RO);
- separation of sulfates or by reducing the hardness components from hard water by nanofiltration (NF);
- water that received from dams and river sources purified by the method of ultrafiltration (UF).

4.2.2 Reuse

This method is created with a view to enhanced sanitization of wastewater by reprocessing of disinfected water which raises the exploitation possibility or decreases the safe drinking water, (WHO, 2011). Few examples are included:

- Discharged irrigation water can be reused by disinfecting the effluent by farm manure treatment machinery, using UF process to produce a good quality of water or with the help of membrane bioreactors.
- Clarification of gray water of hotel industry can be used in toilets and irrigation by using the UF.

- Backwash water can be used in swimming pools and for bathing purpose after sanitization by using the low-pressure RO.
- A huge amount of water can be collected during the process of backwashing of media filters at water plants and its reuse as potable water can be enhanced by using the UF.
- Clarification of gray type of water on ships can use practical graded water by UF technique and decontamination of pretreated industrial effluent in a semi-closed loop (UF, NF, low-pressure RO technique) for reprocessing.

4.2.3 Protections

This method is built on the inhibition of further adulteration in water reservoirs by enhanced decontamination of polluted and wastewater (WHO, 2011). Examples include landfill leachate sanitization and precise infiltration of the retentate to get landfill body which produces improved landfill gas which is quicker used in biodegradation process (NF and RO)

- acid mine drainage (AMD) handling by AMD NF;
- sanitization of waste products produced by animals, for example, pig slurry and dig estate through biogas plants using the techniques like UF, RO, nanofiltration;
- sanitization of the waste to decrease the adulteration of getting water contaminated by UF from sewage treatment plants; and
- sanitization of gray water present in different places like hotels or on ships can be done by techniques like membrane bioreactor based on UF process to protect the atmosphere.

Global concern is raised in recent times regarding ecological pollution, additional stringent lawful necessities regarding the quality related to regular use of water or drinking water, and stringent global waste release rules/guidelines. These are leading driving forces which increase the improved social acceptance and broader utilization/application of this knowledge in developing new techniques for water treatment (Vörösmarty et al., 2010). The alternative feature has been the cumulative understanding with regard to procedures connecting to the refusal linked features of the current technologies allowing for recovery of appreciated components, for example, the main goal of all water treatment strategies' is from wastewater discharge to clean water reuse. The idea behind water protection also applies to the clean water and it heightens the value of this precious commodity (water).

4.3 Technologies for Disinfection

A predominant goal for safe drinking water supply is the development of inexpensive and efficient technologies to provide wholesome water to the population. To achieve this goal, sterilization of water from traditional and developing pathogens is required without changing characteristics of water during the sanitization process. Most of the waterborne health problems are linked with the pathogens (Shannon et al., 2008). Mostly in the developing nations like sub-Saharan and southeast Asia, waterborne issues are responsible for the diseases like helminths, protozoa, fungi, viruses, and prions (Prüss et al., 2002). While some infectious agents eradicated or diminished, new ones continue to emerge and water is getting high importance in relation to the health of masses. Some filtration technologies are developing small units of filters along with ultraviolet (UV) radiation systems and ozonators to disinfect the water from microbes and are very important for water filtration plant developers.

4.3.1 UV Disinfection

Water purification is done using chemicals; UV lights are also effective for the inactivation of microorganisms. Germicidal wavelengths are used for the inactivation of protozoa, viruses, and bacteria (Song et al., 2016). The human naked eye cannot see this light. This light has shorter wavelengths as compared to visible light in the electromagnetic spectrum. Most of this light is absorbed by the earth ozone layer. A simple water treatment process using UV lights is shown in Fig. 4.2.

To be effective against microorganisms, the UV light should have a specific wavelength range, this limit is between the range of 200–300 nm are referred as germicidal which means that they have the ability to inactivating or distorting microorganisms, like bacteria, viruses, and protozoa (Lebik et al., 2014). This activity has permitted the use of UV light worldwide as an ecologically safe, chemicals free, and clean extremely real method of protection and sterilization of water against injurious microbes (Xu et al., 2013).

Although different chemical methods are available for the disinfection of water, UV radiation offers quick and most effective inactivation of microbial contamination through a physical procedure. When microorganisms are exposed to UV light it damages the DNA of the microorganism resulting in inactivation and growth retardation in the microbial population. UV irradiation has greater efficiency against all pathogenic microorganisms, including those organisms that are responsible for the spread of polio, cholera, hepatitis, typhoid, and other viral, bacterial, and parasitic diseases in drinking water. Along with this, UV irradiation has a weak activity for the transformation of chemical pollutants including pharmaceuticals, effluents from industry and pesticides by AOP (advance oxidation process) either alone or in addition with the use of H_2O_2 (hydrogen peroxide) (Song et al., 2016).

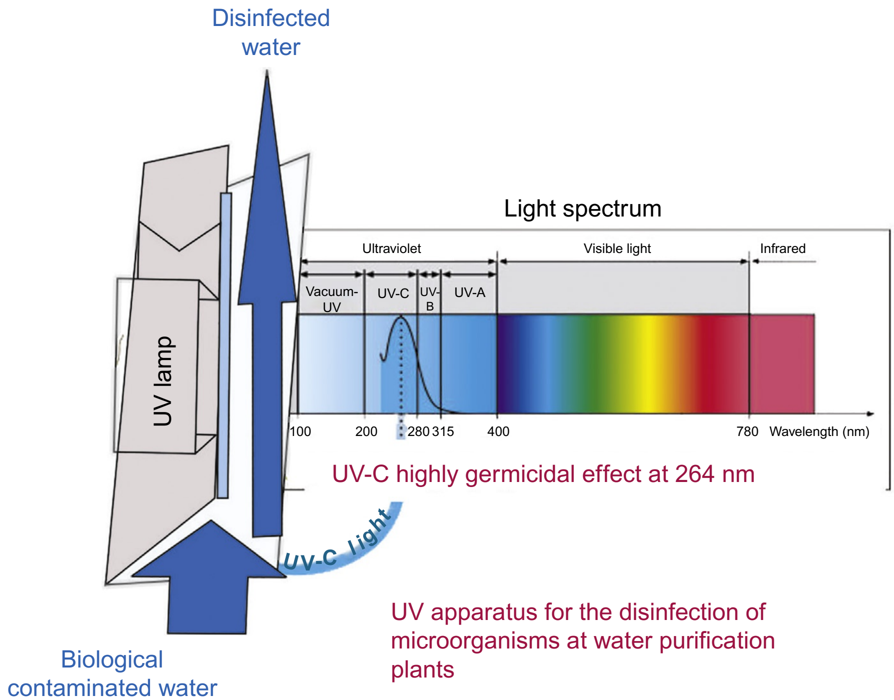

Fig. 4.2 An invisible ultraviolet light is a strong disinfectant for microorganisms.

Cellular RNA and DNA of the microorganisms absorb the high energy photons with the short wavelength at 254 nm (Santos et al., 2013). DNA dimers (linkages with the adjacent nucleotides forming double bonds) are produced by absorption of UV irradiation. Dimerization with adjacent molecules that is, nucleotide is the most prominent photochemical damage which may result in the formation of thymine dimmers as well. Formation of thymine dimmers in DNA is very important in the sense as these may inhibit replication of DNA of many pathogenic microorganisms (viruses or bacteria) and retards their growth so they may not be able to cause any infection (Strickler et al., 2015).

If the UV dose is low, some organisms may restore the photochemical mutation caused by UV irradiation via photo reactivation or dark repair. However, at amounts higher than 12 mJ/cm^2, experiments have illustrated that there is about the negligible potential for photoreactivation. It has also been noticed that few microbes like *Cryptosporidium* do not show any sign of nucleic acid that is, DNA repair under different conditions that is, light and the dark condition or pressure change like low-pressure or medium-pressure irradiation of

UV lamp at doses as low as 3 mJ/cm^2 (Santos et al., 2013). UV assembly should be designed keeping in view that it should deliver enough UV dose that should keep the cellular or photochemical damage and field testing should be performed to ensure the proper disinfection (Strickler et al., 2015).

There are various advantages of UV disinfection which are highlighted by Santos et al. (2013), Shannon et al. (2008), Song et al. (2016), and are listed as follows:

1. UV disinfection is a chemical-free method in which just light is pass out from the water.
2. UV light treatment does not require any storage, transportation, or exposure to dangerous/toxic chemicals.
3. UV lamp disinfection does not produce any lethal carcinogenic by-products which may affect the quality of the water adversely.
4. UV irradiation plays key role to inactivate the microorganisms including those pathogens which are resistant to chlorine like *Giardia* and *Cryptosporidium*.
5. UV light treatment may be utilized solely or in addition with H_2O_2 for decontamination of water for the removal of chemical pollutants and contaminants.

4.3.2 Ozonation

Ozone is a gas and it has specific properties like it is colorless and it has a distinctive odor, like the smell of the air after a thunderstorm (Xie et al., 2015). The use of ozone for water treatment in the United States and other countries was notable in 1800s. Ozone is a highly unstable and comprises three atoms of oxygen; due to instability the ozone molecule will quickly break down into oxygen and free radicals which have a very short life under normal conditions only survive for the milliseconds but these free radicals have a great reactivity potential (Ngwenya et al., 2013) (Fig. 4.3).

When compared with the chlorine, ozone has a much more tendency for the disinfection (Jiang et al., 2016). In addition, the oxidizing potential of ozone can also help to decrease the contamination of manganese, iron, and sulfur along with the elimination of taste and odor problems. The process of ozone reaction with sulfur contents and metals in the water may result in the production of elemental sulfur or insoluble metal oxides which can be eliminated by the employment of some measures at treatment facility after filtration (Richardson et al., 2000). During this process, other organic, inorganic contaminants and chemicals need to be clarified through either chemical oxidation or coagulation process. Ozone is an unbalanced element and its rate of dilapidation depends on the water chemistry, pH, and water temperature and ranges from few seconds to 30 min (Von Gunten, 2003).

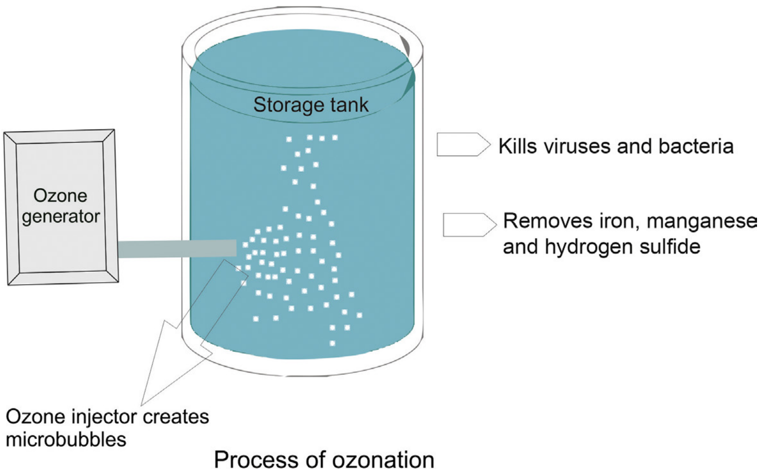

Fig. 4.3 Process of ozonation for water treatment.

4.3.2.1 Ozonation Process

Formation of ozone from oxygen is an energy consuming process. This process can be carried out in an instrument known as ozone generator and electric discharge is used to carry out this process for example, corona discharge (CD)-type ozone generators are available which produces ozone by utilizing a specific technique known as CD simulation of the lightning to produce ozone, and some ozone generators use UV radiations for the production of ozone as in UV-type ozone generators. Along with these profitable approaches process of ozone formation may also be completed through chemical reactions in conventional lab processes (Xie et al., 2015). The whole process involves a reaction in which clean and dry air are passed through a high-voltage electric discharge instrument commonly known as CD which breaks the molecules of oxygen and produces ozone molecules. Water treatment process leads approximately 1% or 10,000 mg/L absorption of ozone gas. UV ozonation is thought to be the best option for the small-scale systems while for the bulk production on a larger scale only the systems like CD and other massive generators for ozone production are considered as the favorable alternative (Richardson et al., 2000).

Raw water treatment is carried out by a process in which water is moved through a venturi throat that results in the creation of space/vacuum and ozone gas is drawn into the water or the air which contains ozone is then bubbled up through the water being treated in this process. Ozone has a property that it will react with different metals and such reaction will result in the production of insoluble metal oxides so postfiltration of water is mandatory (Von Gunten, 2003).

The studies of Richardson et al. (2000), Von Gunten (2003), and Xie et al. (2015) described the following advantages and disadvantages for using ozone gas.

1. Ozone is highly reactive and it can show reactions over an extensive pH range. Ozone has powerful germicidal and disinfecting effect than other processes like chlorination and it can be used for treatment against different microorganisms like bacteria, viruses, and protozoa. In a short reaction time, ozone gas can show very effective and strong oxidizing properties.
2. For the treatment of water, ozone gas does not require any kind of chemicals.
3. Ozone gas can be used for the treatment of a wide range of problems like it can be employed for the eradication of different kind of organic, inorganic, and microbiological impurities. Ozone can also be used for the treatment of water taste and odor problems. In addition, ozone can be used for disinfection and sterilization of water to get rid of microbes like viruses, bacteria, and protozoa (such as *Cryptosporidium* and *Giardia*).

4.3.2.2 Disadvantages of the Use of Ozone

1. Use of ozone for water treatment requires specific instruments, which leads to higher equipment and operational costs. Especially skilled professionals, proficient in ozone treatment and system maintenance are also required who are trained in the use of specific instruments and this may be a difficulty to find such trained professional in this process.
2. Ozonation process is a good way for sterilization, but it does not provide any germicidal or disinfection for residual contamination in the process for inhibition or prevention of regrowth.
3. Ozonation process produces by-products which are under evaluation process and it is a possibility that such by-products may possess mutagenic and carcinogenic properties. These by-products may include brominated aldehydes, ketones, and carboxylic acids by-products. This is a good reason to install a postfiltration system in water purification system that may comprise of an activated carbon filter system.
4. Use of ozone gas for water treatment is a system which needs additional reactions such as pretreatment for reduction of water hardness or for the prevention of the carbonate scale formation, the addition of chemicals like polyphosphate is required.
5. Ozonation process requires special mixing techniques because as compared to other gases such as chlorine, ozone is less soluble in water and therefore additional processing is required.

6. Ozone production is a process which requires specific reactions so there are some risks and issues associated with reactions of ozone generation such as fire hazard and toxicity.

4.4 Membrane Technologies

The membrane procedures are in use for the handling of water, these are utilizing separation processes which require pressure and in this method pressure is a force which is very powerful and variable across the membrane for water treatment. These membranes are used for the water treatment and in this process water to be treated is divided into a stream of filtrate and the remaining quantity is called as retentate or concentrate (Peters, 2010). The contaminants present in the feed water could be eliminated using membrane system and are accumulated in the retentate. During this procedure, membranes which are being utilized can be assessed on the basis of pore sizes and the variation in pore size can act as a well-defined barrier (Magara et al., 1998). These membranes allow a constant supply of quality filtered water. In addition to this semipermeability of the membrane, this process ensures a uniform supply of healthy water without microbial contamination (Madaeni, 1999). Purifying units may be comprised of different membranes such as RO, MF, NF, and UF membranes which have properties like high stability during operation, as this procedure is easy to handle if it is designed correctly. Different forms of operations are carried out by using a relevant switch or by executing a command that is already saved in the system. Such operations include start-up, intermittent operation, normal operation, cleaning, flushing, shutdown, or emergency shutdown. These instructions are corrected by the PLC (programmable logic controller) during the operation. The start-up and shutdown do not require any better care and system can itself understand such instructions within few minutes. The design of such systems is modular and it serves as a base for strong flexibility against sudden changes takes place such as a change in the volume of wastewater to be treated and its consequence would be an adjustment in the form of a small amount of carbon footprint for the treatment plant itself. Such treatment plants have many beneficial aspects, for example, cleanliness, density, ease of use, short structure time of these units as well as these units are cost effective and have long-term operational reliability. Some parameters such as membrane intrinsic properties and formation of their new combination with suitable elements and manufacturing design of unit should be followed strictly according to the each specific application's requirement (Alzahrani and Mohammad, 2014). For this purposes, a wide range of filtration membranes available in the market which are designed and used as per their capabilities and requirements and these are discussed further in detail.

4.4.1 Microfiltration

Microfiltration is a process which involves the method of membrane filtration having the same selective types of membrane type. The purpose of microfiltration is sterilization from microorganisms for example, viruses, bacteria, clearance of pigment, and elimination of other impurities in size range of submicron of the particle. The most commonly used commercial membranes that are made up of porous material and have a pore size in the scale of 0.1–1.0 Lm (1 mm = 1000 Lm), with an average pore size of 0.2 Lm. Microfiltration membranes usually require 500 kPa (5 bar) of pressure for its operation (Ang et al., 2015).

4.4.2 Ultrafiltration

Many manufacturing units are taking advantage of UF technology since last two decades (Yamamura et al., 2007). In UF, screening of impurities is carried out on the basis of pore size that lies between 1 and 100 nm depending on the size of impurities. Many suspended, colloidal matter, macromolecules, protozoa, bacteria, and most viruses are separated out using the UF (Nakatsuka et al., 1996). UF membranes can accomplish multiple removal microorganisms, it has a capacity to reduce 7 logs of total coliform bacteria, 4.4–7 log reduction for *Cryptosporidium*, 4.7–7 log reduction for *Giardia lamblia*, and 6 logs or higher for some viruses as MS_2 bacteriophages (Zularisam et al., 2006). This property of UF makes it suitable for the production safe drinking water, without adding the hazardous chemicals or any other thermal treatment (Ang et al., 2015). During the process of UF, two streams are generated one filtrate that is free from contaminants and another retentate that contains all the impurities in the form of physiochemical or microbiological entity. The principal benefit of UF is that it does not require any aided treatment for production of drinking water irrespective of the contaminants present in the feeding water (Yamamura et al., 2007).

4.4.3 Nanofiltration

In the membrane technologies NF is one of the most common technologies that are used for the purification of drinking water. NF works with least consumption of energy per unit filtration of water, a higher rate of reflux and use of exchanged RO membrane system make it possible to achieve a high level of efficiency in this process (Mohammad et al., 2015). The structure of NF membrane lies between the nonporous RO membrane and a porous membrane of UF technology. NF membranes available in the market contain a fixed charge that is used for the separation of surface groups like carboxyl or sulfonic acids.

Hence this technology allows the separation of impurities based on size, electrostatic effect, and ion exchange method. The pore size of NF membrane is about 1 nm so that it can screen out even the small-sized impurities; the electrostatic property of the membrane surface allows only the monovalent ions to pass through it while retaining the most of the multivalent ions. All these advantages of NF make this technology a very helping hand in the selective removal of solute particles (Marchetti et al., 2014). Apart from water purification, many industrial application involves the use of NF technology for the purpose of treatment of pulp during bleaching process, treatment of wastewater from the textile industry, separation of pharmaceuticals from fermentation broths, separation of minerals in the dairy industry, and recovery of metals from wastewater and elimination of viruses (Mohammad et al., 2015). NF is one of the proficient techniques for the remediation of natural organic and inorganic impurities in the surface water. This technique also inhibits the formation of organic materials that are generated as by-products during water treatment by other technologies. In the NF technique, inorganic salts are also efficiently removed due to electrostatic charge of the membrane while macromolecules are separated out on the basis of pore size (Al-Amoudi, 2016).

4.4.3.1 Separation Mechanisms in NF

NF has benefits of lower operational pressure in comparison with RO, and the deposition of organic matter is comparatively low in comparison with UF (Xiong et al., 2014). Separation of molecules which are larger and colloidal in nature can be carried out using sieving mechanism which would be the major filtration method. For the separation of ions and lower molecular weight substances, NF procedure is used as major separation process. Researchers identified the NF rejection mechanisms has following steps (Shirazi et al., 2015):

1. The procedure of wetted surface—Water is polar in nature and it forms a hydrogen bond with the membrane itself and as a result, all molecules which can make linkages as hydrogen bond with the membrane can be sieved and separated.
2. Preferential sorption/capillary rejection—Different kind of membranes can be used these may include membranes which have micropores. In such cases, due to different electrostatic constants of solution and membrane, electrostatic repulsion may occur.
3. Solution-diffusion method—Here in this procedure, the membrane which is used for separation is nonporous and even solute and solvent can be found suspended in the membrane in its active layer and because of the process of diffusion through the active layer of membrane, the solvent transfer may occur.
4. Charged capillary method—In this process, a membrane is used with an electric double layer in the pores, such membrane may

establish rejection. Due to the streaming potential, ions which have the same charge as that of the membrane are attracted by the membrane and counter-ions are repelled by a membrane.

4.4.4 Reverse Osmosis

RO distillation system is recognized as the principal significant and extensively used technology for the formulation of pure water from mineral-rich water. It is estimated that almost half of the installed water purification systems prefer RO technology all over the world, due to its easy adaptability and comparatively low energy expenses and higher efficiencies than concentrations required for other thermal procedures used for water purification (Fritzmann et al., 2007). Furthermore, with the recent advancements in RO-based technologies regarding membrane material and energy expenses, there is a significant decrease in water purification cost thus the market potential for this technology is expanding over the time (Xie et al., 2015).

Global Water Aptitude and International Desalination Association designate the worldwide production of pure water from osmotic water plants are approximately 19.8 billion gallons per day (Malaeb and Ayoub, 2011). Among various other industries, the membrane industry is regarded as a major region in relevance to its worth, which often results in billions. The foremost membrane engineering corporations include Hydranautics (Nitto-Denko), DOW-Filmtec, Toray, CSM, Koch Membrane Systems, and GE Osmonics. Lot of investment incurred by these industries to fulfill customer requirements in relevance to water purification (Shenvi et al., 2015). Furthermore, among various factors, three Ps which are pollution, population, and progress are recognized as major aspects regarding the influence of water purification market. Recently, great attention is given toward advancement and supplication of pure water system due to various complications associated with water pollution, rising human population, and industrial advancement (Werber et al., 2016).

The RO membranes (semipermeable) are recognized as crucial part of ROs, which predominantly permit only specific water molecules passage by inhibiting salt contents under high pressure (Fig. 4.4). The salts and water saturated by using RO membrane can happen only by diffusion mechanism (Shenvi et al., 2015). This is possible when the external pressure is greater than the osmotic pressure ($\Delta p > \Delta\pi$), RO membrane permeability allows the flow of water from concentrated to dilute solutions.

$$J = A(\Delta p - \Delta\pi)$$

where $\Delta\pi$ is the osmotic pressure variation between feed and permeate, Δp is the membrane pressure change, and A is constant that states

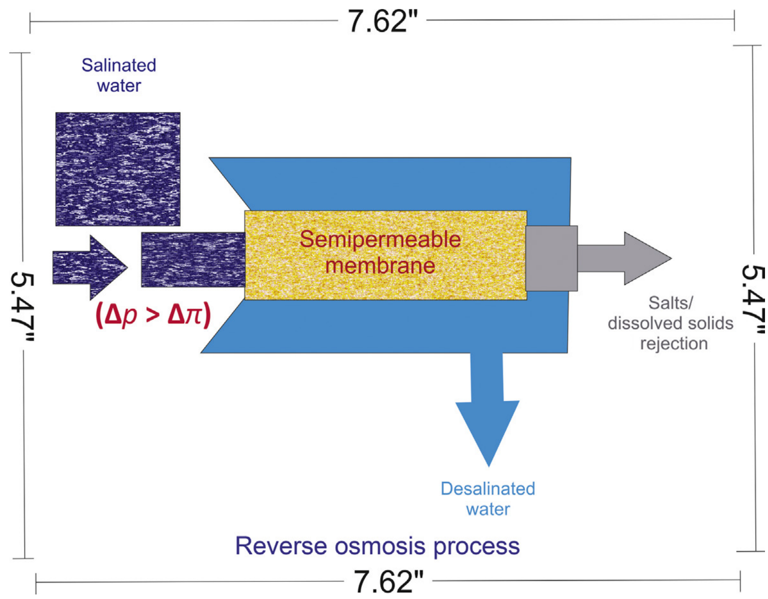

Fig. 4.4 Schematic representation of the process of reverse osmosis.

the physical appearances of various membranes (Post et al., 2007). RO films possess an average pore size of 1 nm and require very higher pressures of almost 80 bars. Also, these high pressures have potential applications in overcoming the osmotic sea water pressure, that is, around 25 bar (Kim et al., 2014). Furthermore, the RO membranes efficiency greatly depends on its water fluxing and salt elimination property. The perfect RO membrane considered to possess salt elimination of almost greater to 99%. Likewise, the NF membranes are employed for water purification applications, although their salt removing efficiency is not considerably higher compared to RO membrane. Most commonly, usage of either NF and RO membrane significantly rely on pure water formulation requirements and applications (Werber et al., 2016).

A classic RO-based system comprises four main procedures: pretreatment, high-pressure forces, salt parting, and posttreatment (Shenvi et al., 2015) and is described in details as follows:

1. *Pretreatment*: Treatment of sea water before its arrival to RO element is recognized to have major importance because polluted sea water is documented to possess a greater quantity of pollutants like colloidal suspension, substantial biological constituents, mud, sand, and numerous embedded solids. Mostly, the osmotic membrane remains more vulnerable for the attack of these polluted constituents, so it is designed in such a way to avoid solid polluted suspensions with effective handling (Pontie and Charcosset, 2015). Moreover membrane blockage by various reasons including fine

particles incorporation, significantly results in irreversible fouling membrane that greatly influences the membranes life, its performance, and formulation cost (Khawaji et al., 2008). Preferably, the various factors tangled in RO pretreatment comprises screening, chlorination, acid treatment, multimedia filtration, microfiltration, and dichlorination (Pontie and Charcosset, 2015). Profound media filters encompass anthracite, sand, and packing layers components ranging from 5 to 10 μm. Microfiltration generally employed for particles retention up to 0.2 μm (Alzahrani and Mohammad, 2014). For pretreatment process of water, various different chemicals are required which includes sodium hypochlorite, ferric chloride as a flocculant, sodium bisulfite to dechlorinate, and sulfuric acid (Malaeb and Ayoub, 2011).

2. *Pressurization*: In this process, untreated water is pumped and for this purpose, high-pressure steel pumps are required. The essential requirements for using pressure depend on the exact type of used water which could be either seawater or brackish water. In this module, the membrane which is incorporated might have the property of tolerating high pressure with sufficient mechanical capability. This kind of operational pumps with high pressure makes the RO system more load (Rezzadori et al., 2017).
3. *Separation*: Membrane is considered as a crucial element of the osmotic system. As the RO membrane performs as a semipermeable barrier that is selectively permeable to water over it and it retains salts. By applying high pressure, most of the salts can enter the permeate side of the membrane (Malaeb and Ayoub, 2011). Moreover, it is possible that a certain volume of dissolved gases is present in the water and at later treatment stages it will be removed. RO membranes which are used commonly utilizes cellulose acetate and diacetates as a basic component but recently, polyamide membranes which are ultrathin in nature are used in the most of the markets (Pontie and Charcosset, 2015). These are available normally in different forms such as hollow fiber or spiral wound design.
4. *The process of posttreatment*: In this phase, infiltrate (permeate) received is exposed to pH alterations ranges from acidic to neutral. Later stages comprise different processes, for example, recarbonation, elimination of carbon dioxide, elimination of H_2S via aeration, and decontamination or disinfection by utilizing calcium hypochlorite or chlorine gas (Li et al., 2013). Demineralization can be done by employing methods like filtration or chemical injection (Lin et al., 2014). These sections are generally essential to get better water taste and also fulfill the last essentialities of the treated water. Management of brine and various other chemical compounds produced during pure water formulation is crucial before its expulsion in seawater (Li et al., 2013).

4.4.4.1 Difficulties Associated With Process of RO

Scaling

Membrane filtration of seawater has enhanced the absorption of numerous soluble salts but when solubility such salts extends to supersaturation point, they decline for further precipitation and form outer membrane scales which in turn results in lowering RO system efficiency (Shmulevsky et al., 2017). The use of antiscaling agents is the extensively implemented method to avoid scaling of different salts such as silica, iron, barium sulfate, calcium carbonate, gypsum, etc. The incidence of such salts in various amounts highly depends on feeding water (Pramanik et al., 2017). In the start of this process, on the outer surface of membrane antiscaling compounds are accumulated to avoid the initiation of scale development. Most frequently used such antiscaling compounds include surface active reagents, organic phosphates and phosphonates, and organic natural polymers that significantly obstruct, formulation, development, and kinetics of crystal nucleation (Dahdal et al., 2014). Likewise, various scales formation by silica enhances major complication during water purification process as it requires great expenses to overcome these situations. Also, the incorporation of antiscaling substances may not significantly reduce silica because of various factors impact on silica precipitation. Carbonated scales could avoid by regulating the pH of water ranges at 4 and 6. Various studies documented the enhancing levels of bicarbonate for significant reduction of gypsum scales in internal water feeds (Kempter et al., 2013). The bicarbonate adsorption of crystal surface results in reduction of gypsum scales on surface membranes. Superficial coating of polyacrylamide material results in accumulation of scales on the membrane surface, where gypsum is used for reduction of the scaling inclination (Radu et al., 2015). Feed can be pretreated by different methods like pH modification, NF/UF, and ion exchange may also assist in the reduction of scaling (Zhao et al., 2014). Another method which is known as flow-reversal mechanism can also be used to prevent the process of scaling has also been reported. It is possible that flow can be reversed before the start time of the process with the help of replacing the supersaturated brine solution with the unsaturated raw water and this makes the nucleation time as zero thus determining the beginning time (Kazner et al., 2014).

Boron Removal Process

The removal of boron can be done by various membranes; this is considered as modern topic of interest that remains a task today. Regarding, the various WHO regulations, the permitted quantity of boron in pure water should not be more than 0.5 mg/L (Park et al., 2016). The efficacy of RO progression for boron exclusion has not more enough, preferably due to the presence of various elements in water. For instance, boron is present in the form of uncharged boric acid in the seawater at normal pH and this can pass through semipermeable membrane easily like water with a rejection value of <80% (Cengeloglu et al., 2008). Borate ions come into being at high pH, which displays almost 99% rejecting level (Dydo et al., 2014). Therefore, such properties like pH of the respective solutions and ionic strength can display crucial role in leading the boron rejection during desalination. Moreover, for effective boron exclusion, RO plant possesses two or more phases. At the first phase, irrespective of pH modification, contaminated water is fed to the RO membrane at a very high pressure and at this level; most of the dissolved contaminants are eliminated. At later phase, the water containing remaining impurities is incorporated with high pH at low-pressure RO membrane for removal of boron (Park et al., 2016). Alternative method employed for boron eradication involves, first pass the boron-contaminated water through RO membrane having high pressure and then this water is passed through the selective medium containing ion-exchange resin for removal of boron that is, boron selective resin (BSR). BSR method have appreciable results for the elimination of boron but this great technology requires high initial and operating cost that is considered to be the major disadvantage in the removal of boron from contaminated water, so further research and studies are suggested for the identification of cheap and economical alternatives for the removal of boron (Shenvi et al., 2015).

Brine Disposal

The rejected water containing high amounts of salts and minerals that are removed during the purification of contaminated water by RO membranes is known as brine. Along with dissolved minerals and salts brine water also contains many organic compounds, particulates of antiflocculants, antiscalants, acids, metals, and metalloids (Chaea et al., 2017). The most in use brine elimination practices include direct release into sea, release on substantial surface, and flushing into the open drains or sanitary channels. Such disposal of highly salinized water at sea or inland surface channels brings lot of environmental and ecological threats. Nonstop flow in sea has a significant effect on the algal compounds and plant life and outcomes in mud development. Exclusion of brine into the pond is mostly approved for local RO desalination plants that serve in the arid and semiarid regions where the sea is not available for direct discharge, in the pond disposal the brine water is evaporated by the abundance of sunshine and minerals are collected at the base of the pond (Ng et al., 2008). Though, vanishing ponds devour too much space, high salinity discharge may disturb the soil and plants efficiency.

Disbanding the brine along with seawaters, assisted in plummeting the ecological influence by dilution. The diffusion of brine into the sea is affected by the depth and velocity of discharge (Chaea et al., 2017). SAL-PROC technology is used that is demonstrated as a combined protocol for removal of soluble constituents from inorganic saline water in a sequence, by various evaporation and cooling technique along with mineral separation (Shenvi et al., 2015).

The components extracted by various procedures include sodium chloride, gypsum, calcium carbonate, calcium chloride, and magnesium hydroxide are of great quality and adopted by numerous water companies. Elimination of scale components of feed water resulted in a smaller amount of brine and advanced recovery rates (Chaea et al., 2017). It is claimed that a two-stage brine alteration seawater RO purification system (brine alteration system, BAS) is in the capacity to produce the potable water having total dissolved solids less than 200 ppm (Mohamed et al., 2005). This technology reduces the manufacturing cost by 20%–25%. Further, the studies also state that the brine produced in RO plant is processed by the electrodialysis (ED) which reduces the absorption of salts in the feed and it increases the value of RO permeate (Ng et al., 2008).

4.4.5 Future Development of Membrane Technology

Currently, significant expansions occurred in manufacturing membrane by focusing attention on the combination of different membrane procedures in thermal parting techniques and chemical or biological alterations (Cohen-Tanugi and Grossman, 2012). By keeping these, products worth, highly compacted creation units and methods with better efficiency, sustainable, low energy consuming, and the ecologically responsive process can be attained (Zhao et al., 2012). The future expansion of membrane skill will be inclined to various aspects such as:

- The extent of sanitization of the fluid to be preserved as expected from the customer or enforced by laws, driven by various forces for solutions development. For this reason, these would be primary environmental features such as enhancing pollution, stricter discharge regulations, and escaping of chemicals (Kang and Cao, 2014).
- A decrease in treatment costs for increasing operational experience and longer life of the membrane system (Ghaffour et al., 2013).
- The numerous membranes formulation altered to definite applications (Cath et al., 2006).
- Improved struggles for reducing membrane fouling (Mansouri et al., 2010).

- Reliable procedure monitoring (Cath et al., 2006).
- Consistent expulsion control (Cath et al., 2006).
- Standard plant perceptions with a feasible version of each individual situation in place (Ghaffour et al., 2013).
- Recognition of plug and play concepts (Cath et al., 2006).
- Extensive use of different methods which include agreements on Make and Self-Operate or Make Operate-Transfer, and based on quality necessities, membrane technology combination of water management system.

4.4.5.1 Electrodialysis

This technology signifies a modern liberal electromembrane partitioning method. Particularly, for the brackish water purification demonstrating the foremost demand for skill, ED is currently recognized to be in great competition with the normal RO (Tsiakis and Papageorgiou, 2005). There is a growing trend to use ED for the wastewater reclamation and purification of water effluents in the pharmaceutics and food industries. The main advantage for using this technology is the electromembrane departure process that does not compromise on health and nourishing attributes of the ending products for example, by addition of coagulants or restoring constituents (Bernardes, 2016). ED process (Fig. 4.5) includes water passage amid two electrodes with opposite electrical charges. The negative electrode attracts the various metal ions that present in contaminated water while the positive electrode attracts nonmetal ions. Both metal and nonmetal ions can be removed from the electrodes (Chen et al., 2016).

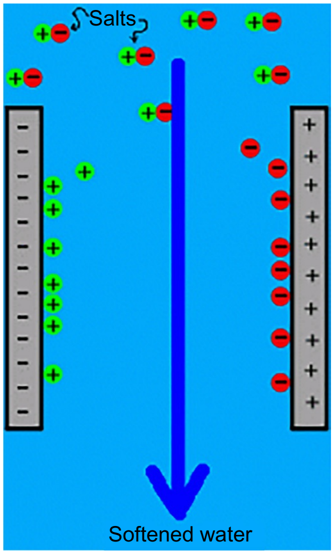

Fig. 4.5 Process of electrodialysis.

ED water treatment is generally used for hard water, which possesses 500 mg/L calcium carbonate. Recently, some latest components were added in ED process that results in improved proficiency of ED with great control of polarity. This technique is regarded electrodialysis reversal (EDR) and it has the capacity to reduce the scaling and fouling problems which are very common in ED process (Lee et al., 2013).

4.5 Advanced Oxidation Process

Some researchers describe the advanced oxidation process (AOPs) to define a procedure of hydroxyl radicals (OH) for organic and inorganic oxidation of water layers (Ganiyu et al., 2015). There are many AOPs process used around the world. But, two main AOPs are described in this chapter that includes ozone along with H_2O_2 addition and UV radiation along with H_2O_2 accumulation. AOPs may have numerous advantages in water management technology, for instance, oxidation of artificial organic chemicals, taste, color, and odor inducing agents, sulfide, various minerals (Fe, Mn) and demolition of DBP precursors before chlorine addition (Sirés et al., 2014).

4.5.1 Ozone With H_2O_2 Addition

The addition of H_2O_2 with ozonated water is simple technique having a powerful reaction of H_2O_2 with molecular ozone, which enhances the formulation rate of OH. Due to this reason, an ozone-H_2O_2 purification system is greatly used to improve the absorption of hydroxide radicals that have a strong oxidizing potential compared to molecular ozone, and so quickly results in molecular ozone reduction. That is why H_2O_2 is highly recognized for its usage in the process of ozonation rather than disinfection (Hey et al., 2014). The added ozone-H_2O_2 method is used for the extinction of off odors, color elimination, and micropollutants damage, such as volatile biological mixtures, pesticides, and herbicides (Wang et al., 2014). Stoichiometric investigation proposes that optimal H_2O_2 to ozone ratio is around 0.3:1 (mg/mg). Nevertheless, detailed studies have proposed that best ratio is greater in the range of 0.5:1–0.6:1 mg/mg (Afzal et al., 2015). The typical mechanism in which ozone is added with H_2O_2 involves incorporation of influents water as a constituent of the system and ozone as intense gas, which is bubbled finely from the bottom of the water tank by diffusing technology (Hey et al., 2014). The complicated reaction chemistry involved among ozone, H_2O_2, normal biological constituents, and added ingredients from water, it is not clearly evident that either such traditional structure is considered to be the best design for an ozone-H_2O_2 management method. By various future research studies and recent advances in engineering design technology, its efficiency could be significantly improved by the reduced level of ozone and H_2O_2.

4.5.2 UV Irradiation With H_2O_2 Addition

UV irradiation in the presence of H_2O_2 deteriorates the constitute OH. Adding H_2O_2 to UV irradiation influents is recently employed for the demolition of groundwater micropollutants, but at the same time, it possibly serves as a basic component for reactions as in other AOPs, thus ensures better taste, odor, and the color of the water. Various reactions among UV and H_2O_2 for the formation of OH operate at much slower rate than the reactions carried out between ozone and H_2O_2 (Fujioka et al., 2017). Although in numerous water purification strategies, UV irradiation is considered to be the better option than ozone generation system due to the complexity of the process and feeding system. Conversely, a high concentration of H_2O_2 (5–20 mg/L H_2O_2) residues are required due to slow OH manufacturing reactions in UV-H_2O_2 systems (Oh et al., 2014). Consequently, the implication of this method in drinking water purification, both by the process modification to use less H_2O_2 and a management method should be connected to reduce the H_2O_2 components to required levels (<0.5 mg/L) prior to water incorporation in supply system (Fujioka et al., 2017). The numerous possibilities offered for reducing the H_2O_2 residuals comprises of using thiosulfate, chlorine, granular-activated carbon, or sulfites (Fatta-Kassinos et al., 2011).

4.6 Ion-Exchange Technology

Ion exchange, which is abbreviated as IX technology, is being employed in various biochemical and ecological manufacturing areas for extended periods. But, nowadays its use in water softening is very common, which involves the removal of Mg^{2+} and Ca^{2+} ions from hard water, either at water purification plant or by implying proper time for using a treatment procedure and also for industrial applications, for example, the formulation of pure demineralized water (Atalay and Ersöz, 2016). Although, with various limitations being related to numerous inorganic compounds, ion-exchange treatment gains considerable interest for water improvements system. Some of the most important components or pollutants removed with ion-exchange technology are arsenic, nitrate, barium, selenium, radium, lead, chromate, and fluoride. Early studies carried out in the 1980s proved that almost 400 societies have considerably greatest amount of nitrate up to maximum concentration level of 10 mg/L as nitrogen and 400 societies near the sea have an excess of fluoride content that is maximum concentration level of 4 mg/L (Jacob, 2007). Recently, new contaminants detected in groundwater are perchlorate ($C1O_4^-$) ions that are a significant constituent of rocket fuels. The California Department of Health Services has accepted a perchlorate action near of 18 g/L, and considered exchange technology as a perfect system for the perchlorate ion exclusion from polluted water (Fox et al., 2014).

While using ion-exchange technology, the knowledge-based process is usually planned as a fixed-bed procedure for packing of synthetic resins. Therefore, during water passage through the resin bed, potential contaminants existing in water are replaced with resin ions on surfaces, thus eliminating the contaminant ions from the water by directing them on the resin. The resin is normally redeveloped to eradicate the contaminant from the resin surface and replace it with different interchangeable ions (Mazur et al., 2016). There are four main categories of ion exchange resins: strong acid cationic (SAC) resin, weak acid cationic (WAC) resin, strong base anionic (SBA) resin, and weak base anionic (WBA) resin (Nikoloski et al., 2015). The details for these resins are presented in Table 4.2 that presents different ions which can be screened out with the help of different resin type, the resin renewal requirements. The terminologies used in the table designate as SAC and WAC resins are employed for the removal of positive ions from contaminated water (e.g., Ra^{2+}, Ba^{2+}, Pb^{2+}, Ca^{2+}, Mg^{2+}), whereas SBA and WBA resins are formulated for the removal of negative ions (anions) from contaminated water (e.g., ClO_4^-,NO_3^-,$HASO_4^{2-}$,SeO_3^{2-},SO_4^{2-}, etc.).

SAC resins mostly activate over a widespread pH values ranges 1–14, while WAC resins can merely function at pH >7. During water softening applications, SAC resins may eradicate together carbonated and noncarbonated firmness, while WAC resins can first eliminate carbonate hardness. In addition, WAC resins are preferred over SAC because of their easy regeneration, and not resulted in sodium enhancement compared to SAC (Fries et al., 2017). Furthermore, the additional cost of ion-exchange technology is less as compared to added inorganic exclusion procedures, for example, lime softening techniques, high pH ppt, and high-pressure membranes (RO membranes). For instance, the total rates of ion-exchange technology for the exclusion of nitrate ions from groundwater is valued to 0.4 t–0.5$/gpd (Bergquist et al., 2016). However, commercial applications of ion-exchange technology at large scale are challenging because of the high level of waste production from purification process. Although, the volume of waste produced by this process is not so large and can only account 2%–5% of the total treated water yet the waste produced, encompasses a high level of acid (HCl), base (NaOH), or salt (NaCl). In addition, the waste stream may also hold higher levels of pollutants (e.g., NO_3^-,$HASO_4^{2-}$,Pb_2^+, etc.) that should be treated before the wastewater is disposed of in sea (Alzahrani and Mohammad, 2014). Therefore, the removal of waste components from water is considered as a principal application of ion-exchange technique at commercialized water purification plants whereas treatment systems present in areas which are near to sea and ponds may have the choice of waste disposal into nearby oceans. Conversely, for the inland plants there exists no cost-effective procedure for the removal of the waste stream (Manos and Kanatzidis, 2012).

4.7 Biological Filtration

Various techniques as mentioned above are based on many physiochemical working principles. However, the water purification industries not only influenced by physical and chemical procedures to properly achieve the water purification and quality standards. Advancement in various biochemical methods in water purification is reported and now being adopted in water treatment plants. This technology is gaining popularity due to increased incidences of infectious out breaks and safety concerns about the existence of microorganisms in water (Kvartenko et al., 2016). Among these biological processes, biological filtration is recognized as foremost an important operative method to produce pure water free from biological contaminations. This was especially compelled by concerning the enhancement of biodegradable organic matter (BOM) absorption, because of natural water ozonation. Moreover, there is great concern regarding increased BOM levels that may results in higher organic contaminants recreation in the circulation arrangements. Therefore, by the implementation of biological filtration technique, various water treatment plants result in a reduction of BOM absorptions in the pure water, which is already present into the circulations plant (Xie et al., 2015).

The overall development in the design of organic filtrates is to encompass a thin sand layer (6–12 in) below the granular activated carbon (GAC) or anthracite media (Sierra et al., 2017). Sometimes this layer of sand confronted with major problems during the filtration process. Biological filters also have some problems in the filtration so we can overcome this problem with the help of dual filtration method, by ensuring the exclusion of chlorine or chloramine that they should not present in the final pure treated water. But, there are many queries which need more advanced research and study to improve the process of biofilters. Furthermore, various water purification systems had recognized the importance of incorporation of chlorine (4–5 mg/L) to contaminated water during washing. This addition of chlorine significantly improves the biological resistance of filtrates, inhibits the multicellular organism initiation and progression in filters, and filters routes length enhancement by lowering frequency of headless buildups. However, more advanced research studies are required for addressing various problems regarding biofiltration functionality. Biofilters are also in use for the treatment of drinking water to reduce these contam-

Table 4.2 Types and Characteristics of Ion Exchange Resins

Resin Type	Functional Group	Ions Removed	Regeneration	Reference
Strong acid cationic (SAC) resin	Sulfonate RSO_3^-	Total hardness, Mg^{2+}, Ra^{2+}, Ba^{2+}, Pb^{2+}, etc.	Regenerated with HCl or NaCl	Millar et al. (2015)
Weak acid cationic (WAC) resin	Carboxylate $RCOO^-$	Carbonate hardness, Mg^{2+}, Ra^{2+}, Ba^{2+}, Pb^{2+}, etc.	Regenerated with HCl	Al-Samadi (2014)
Strong base anionic (SBA) resin	Quaternary amine $RN(CH_3)_3^+$	$NO_3^-, SO_4^{2-}, ClO_4^-, HAsO_4^{2-}, SeO_3^{2-}$, etc.	Regenerated with NaOH or NaCl	Bazri et al. (2016)
Weak base anionic (WBA) resin	Tertiary amine $RN(CH_3)_2H^+$	$ClO_4^-, HAsO_4^{2-}, SeO_3^{2-}, NO_3^-, SO_4^2$, etc.	Regenerated with NaOH, or $Ca(OH)_2$	Fries et al. (2017)

inants. Biofilters also reduce the many inorganic contaminants such as bromate, perchlorate, chlorate, nitrate, and selenite (Mimura et al., 2017). But the use of this method still needs many types of research for using this method at the large scale.

4.8 Biosorption

This method can remove the toxic substances from the water by using the physiochemical pathways (Kabir and Chowdhury, 2017). This is the relatively new method which is more extensively used for exclusion of heavy metals from contaminated water. Biosorption is obtained from the nonliving biomass such as lignin bark, shrimp wastes, algal, and microbial mass, for example, bacteria, fungi, and yeasts. Algae have evidenced to be potential heavy metal biosorbents (He and Chen, 2014). The significant advantages of biosorption compared to prevalent treatment methods have reasonable cost, high efficiency, no further nutrients necessities, biosorbents recreation, reduction of biochemical by-products, and enough metals reduction probability (Ngo et al., 2015). However, the disadvantages of biosorption are initial saturation, less chance of biological development since the cells are not significantly metabolized and numerous complexities regarding alteration of metals valency (Gaur et al., 2014).

Normal materials like chitosan, clay, zeolites, and certain waste goods are known as fewer rate adsorbents. Chitosan has recognized as an important metal binder and has a very low-cost stimulated carbon (Wang and Chen, 2014). Activated carbon is the most widely used adsorbent in the world but it is a very affluent material so it cannot be used on large scale due to cost inefficiency. Shrimp, lobster, and crab shells are used to produce chitosan in countries which have a huge marine product such as Japan. These wastes can be got from fishery industries at very low cost (Anastopoulos et al., 2017). Clay is a good substitute for activated carbon. It is a significant inorganic constituent in the soil. Clay also have the higher surface area, thus providing more adsorbent surface to bind with impurities in water, this makes it potential biosorbent for water treatment plants. However, the negative charges on clay minerals are responsible for attracting positive toxic heavy metal ions (Liu et al., 2014). Zeolites have better ion exchangeability. Massive sediments of zeolites in various regions include Mexico Iran, Jordan, and Italy that offer decent possibilities for the removal of heavy metallic ions from wastewater at less cost (Dinu and Dragan, 2014).

4.8.1 Biosorption Mechanism

The biosorption method includes two phases as subsequent liquid phase (solvent) and solid phase (biosorbent), which has a capacity to absorb specific substances from the relative classes to be sorbed (metal ions). Moreover, there are numerous methods for metal uptake by different cells because of complex microorganism's structure. Therefore, the biosorption mechanism is the very complex procedure. Regarding the cell metabolism, biosorption can be categorized into two types that are metabolism dependent and nonmetabolism dependent. This process has three subclasses based on the metal removal site in solution, for example, intracellular accumulation, extracellular accumulation, and cell surface precipitation (Li et al., 2015). Intracellular accumulation is the outcome of transverse metal transportation by the cell membrane that greatly associated with cell metabolism. Besides, this situation reveals that such sort of biosorption could happen only with feasible cells. Indeed, the biosorption, in this case, is not considered to be much faster because of more time required for relative microbial reactions. The various connections between the heavy metal and cells functional groups significantly result in a cell surface sorption based on physical adsorption, ion exchange, and complexation, which is independent to the metabolism (Ramrakhiani et al., 2016). Cell walls of microbial by-products are most commonly composed of various polysaccharides, proteins, and lipids, which have several metal binders functional groups exemplified as carboxyl, sulfate, phosphate, and amino groups. Nonmetabolic biosorption is comparatively quick and could be effectively reversed (Wang and Chen, 2014). During precipitation, the heavy metals absorption can occur both in solution and on the cell surface (Ramrakhiani et al., 2016). In these processes, the precipitation may not eventually recognize to be cell reliant, if it occurs after metal and cell interactions.

4.8.2 Transport Across Cell Membrane

Transport between cell membrane is associated with cell metabolism. Biosorbent examination of higher metal absorptions was not carried out due to the toxicity of some elements. Indeed, there is less evidential research data regarding this type of adsorption process. Moreover, transportation of heavy metals could be facilitated by the identical procedure used to supply metabolically momentous ions, for example, K^+, Mg^{2+}, and Na^+. There is also confusion regarding the existence of heavy metal ions having identical charges and ionic radius of critical ions (Ramrakhiani et al., 2016). Furthermore, it is not connected with metabolic activity. Biosorption by biotic microorganisms fundamentally consists of two stages. First, independent metabolic binding that the metals are bound to anywhere in relevant cells and second, dependent metabolic intracellular uptake, where the metal ions are replaced by the cell membrane into the cell (Pokethitiyook and Poolpak, 2016).

4.8.3 Physical Adsorption

Physical adsorption can occur by Van der Waals interactions, radionuclides which predominantly prevail in aquatic environments like sea are grouped by water microbes (Thommes and Cychosz, 2014). A study about this mechanism demonstrates that uranium and thorium biosorption by various fungal strains of *Rhizopus arrhizus* found by physical adsorption in chitin cell-wall arrangement (Fomina and Gadd, 2014). Electrostatic interfaces are accountable to copper biosorption by bacterial spp. *Zoogloea ramigera* and algal *Chlorella vulgaris*. While, physical adsorption is accountable for zinc, cadmium, copper, nickel, and lead biosorption by *Rhizopus arrhizus* (Fomina and Gadd, 2014).

4.8.4 Ion Exchange

Ion exchange methods have extensively been used to eliminate heavy metal ions from waste polluted water regarding their elimination, effectiveness, and effectual kinetics. Conversely, several researchers have proposed that ion exchange is not the only single effective method used for metal biosorption (Fomina and Gadd, 2014). The existence of low-molecular-weight ions in cell walls and membranes such as Na^{+1}, Ca^{2+}, K^{+1}, and Mg^{2+} could be replaced by metal cations such as Cu^{2+}, Cd^{2+}, Co^{2+}, and Zn^{2+}, subsequently result in bio sorptive absorption of metals. The gram-positive bacteria, from largely the genus and from members of *Bacillus* genre, had improved capacity for metal binding due to its substantial negative charge density (Gupta et al., 2015).

4.8.5 Complexation

The biosorption of heavy metal ions from respective solutions might arise through the composite development on the cell surface after various interrelations among heavy metal ions and activated binding places. Metallic ions could be fixed to the single related ligand through chelation (metal ion formulation by ring structure). Besides complexation might occur by either covalent or electrostatic interaction (Fomina and Gadd, 2014).

4.8.6 Precipitation

The precipitation mechanism in several cases describes the development of insoluble inorganic metal precipitates; sometimes precipitates may also be formed in organic metal biosorption process. Precipitation may sometime show its dependence on cellular metabolism (Pokethitiyook and Poolpak, 2016). In case of metal biosorption metabolism, it is frequently linked with an effective defensive microbial system. These mostly show quick reactions in the presence of toxic metallic ions, significantly result in compounds formulation that supports the precipitation progression. Whereas, in case of metabolic independent mechanism, it might result in chemical relations between the metal and cell surfaces (Hansda and Kumar, 2016).

4.8.7 Factors Influencing Biosorption

Literatures showed that there are four important factors affecting biosorption. These are temperature, solution pH, biomass concentration, and occurrence of other metal ions.

Temperature: Temperature in the range of 20–35°C does not seem to affect the biosorption efficiency (Ramrakhiani et al., 2016).

Solution pH: The pH is the most vital factor in the biosorption process due to its effect on the functional group's activity of biomass, the solution chemistry and competitive metallic ions and heavy metals interactions (Ramrakhiani et al., 2016).

Biomass concentration: Biomass concentration in related formulations seems to be more effective on the particular uptake. Specific uptake rises as biomass concentration is reduced (Ramrakhiani et al., 2016).

Presence of other metal ions: In various cases, biosorption is discerning. Biosorption is commonly used for reducing the definite quantity of heavy metal in wastewater and elimination of this specific heavy metal may affect existence of other heavy metals. Thorium adsorption by *Rhizopus arrhizus* is unchanged due to the existence of further ions like Fe^{2+} and Zn^{2+} in solution whereas Uranium adsorption with *Rhizopus arrhizus* is affected by the occurrence of Fe^{2+} and Zn^{2+} (Gupta et al., 2015).

4.8.8 Comparison Between Low-Cost Adsorbents and Active Carbon

4.8.8.1 Chitosan

Chitin is a structural polysaccharide of crustaceans, insects, and some fungi and produced by numerous living organisms. Thus, it is considered to be second most commonly occurred biopolymer after cellulose (Boddu et al., 2003). Fungal cell walls comprise chitin and chitosan, which have been verified through researchers to sequest metal ions. It was claimed that *Rhodotorula* sp., which is a type of fungus, contained chitin as a cell-wall polysaccharide (Franco et al., 2004). Chitosan, which had a similarity in molecular structure to cellulose, is formed by alkaline N-deacetylation of chitin. Chitosan is a low-cost material with resulting characteristics: nontoxic, fine mechanical power, hydrophilic nature, good bonding properties, etc. Thus, chitosan is used as a chelating polymer for metals elimination (Franco et al., 2004). Contrary to natural chitosan, synthetic polymers have high reactivity and process capability due to it fixed molecular structure and polycationic nature (Wang and Chen, 2014). The occurrence of various amino and hydroxyl groups in chitosan may substantially play a role as active sites; this makes chitosan a beneficial adsorbent to eradicate heavy metals ions and coloring compounds (Boddu et al., 2003). Chitosan constituents recognized to have a good adsorption capability that resists acidic environment (Wang and Chen, 2014). Chitosan found to be very responsive to changing pH because it forms gels with different characteristics depending on pH values of solution (Mcafee et al., 2001). Cross-linking reagents such as glutar aldehyde, glyoxal, formaldehyde, epichlorohydrin, ethylene glycon diglycidyl ether, and isocyanates have extensively been used in order to enhance chitosan's efficiency to remove impurities from water (Saifuddin and Kumaran, 2005).

4.8.8.2 Zeolites

Zeolites are recognized as most commonly occurring hydrated alumina silicate minerals with a cage-like structure and these from the class of tectosilicates. Its structure consists of 3-dimensional framework of SiO^{4+} and AlO^{4+} tetrahedral (Lameiras et al., 2008). Moreover, various zeolitic compounds are formulated by modification of glass-rich volcanic rocks (tuff) along with fresh water in different lakes or by seawater (Blanchard et al., 1984). There is Al^{3+} ion surrounded by the tetrahedron structure of four oxygen atoms and a negative charge is produced in the lattice by the isomorphus replacement of Si^{4+} by Al^{3+}. The total negative charge is well adjusted by replaceable cations, which in numerous formulations containing Pb, Zn, Mg, and Cd are exchangeable with positive cations (Lameiras et al., 2008). These ions (Na^{+1}, Ca^{2+}, and K^{+1}) are relatively nontoxic which makes them especially convenient to remove toxic heavy metals. Zeolites are specially used in order to remove and purify cesium and strontium radioisotopes (Chojnacki et al., 2004). Clinoptiolite is the most abundant mineral among the different known type of zeolites which belongs to the HEU-type zeolite group. Many researchers investigated the ion-exchange capacity of clinoptilolite. It was observed that clinoptilolite obtained from diverse areas exhibit changed behaviors in ion-exchanging process (Baskan and Pala, 2014).

4.8.8.3 Clay

Clays are hydrous aluminosilicates and broadly defined as those minerals that make up the colloid fraction (<2 μm) of soil, sediments, rocks, and water (Álvarez-Martín et al., 2016). Usually, clay is known as the materials that become plastic when mixed with small amount of water. There are three basic types of clays: aremicas (such as montmorillonite), smectite, and kaolinite (such as illite). Clays always exhibit transferable cations and anions on its external area. Clay may uptake heavy metal cations because of its total negative charges on its surface, thus positively charged cations can neutralize the negative charge. The greater surface area of clays (up to 800 m^2/g) may result in high adsorption capability (Olu-Owolabi et al., 2016). Montmorillonite clays have smallest crystalline compounds, biggest surface area, and maximum cation exchange capacity (CEC). Therefore, montmorillonite clays have the high sorptive capacity. For example, exclusion of mercury by montmorillonite was five times larger than possess by kaoline. Moreover, clays can be altered to expand its adsorption capability (Belhaine et al., 2016). There are two prevalent methods for clay modification: intercalation and pillaring and acid activation.

4.8.8.4 Activated Carbon

Activated carbon is produced from environmental wastes with high carbon content. Lignocellulosic and coal materials have been used as raw materials planned for manufacturing of activated carbons. There are two approaches for preparing activated carbon that can be used in water purification processes: physical activation and chemical activation. Activated carbon has good potential for adsorbing heavy metals because of its greater surface area, microporous ability, and chemical complexity of its external area. There are two forms of stimulated active carbon: H-type and L-type (Zelmanov and Semiat, 2014). The H-type carbon adopts positive charges, when introduced into water or treated with strong acids and is characterized as hydrophobic in nature. The L-type carbon is a stronger solid acid than the H-type carbon which assumes a negative charge in water which neutralizes strong bases and is hydrophilic. Activated carbon is categorized into four basic classes based on its physical appearance. Powders (PAC), granular (GAC), fibrous (ACF), and clothe (ACC). Nowadays, commercialized activated carbon (CAC) has more extensively used worldwide (Mudakavi and Puttanna, 2016).

4.9 Conclusion

Great advancements observed in purification processes of water in recent years. Various water treatment industries have been adopting modern technologies but at a slow incremental pace. From the last 20 years, there has been increasing development in the occurrence of new technologies that remaining to be introduced, established, and demonstrated, into the municipal water purification. Most of these modern technologies comprise of UV irradiation, membrane filtration, advanced oxidation, ion exchange, and biological filtration. Advancement of water purification industry is not limited to these technologies. Although these technologies have potential market value due to their applicability and reliability to large-scale municipal water treatment plants, for example, costs of these treatments continually are going down that result in increasing applications at the industrial level. Today due to technological advancement, each and every physiochemical and biological impurities from water can be excluded during water treatment, but application mainly depends on the cost of the process. With growing population across this globe, more resources are required to invest in water purification research to provide safe, clean, and wholesome water to every person on this globe.

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