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Article

# Total Dissolved Solids and Their Removal Techniques

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**Abstract:** Total dissolved solids (TDS) due to both geogenic and anthropogenic contaminations, is one of the preliminary as well as essential parameters among others to describe water quality. It includes organic and inorganic components, heavy metals, salts, other dissolved substances, and others due to indiscriminate disposal of untreated domestic and industrial effluents, urban and/or agricultural runoff which exists in the form of micro or nano level in nature. Higher TDS levels in water severely impact health and the environment. For instance, it causes gastrointestinal, cardiovascular, genotoxic, respiratory, skin, and hepatic effects in humans. High TDS level (> 500 ppm) results in excessive scaling in household appliances (e.g., pipes, heaters, and boilers) thereby reducing their efficiency. Therefore, the removal of TDS from various water matrices is taking paramount importance to minimize its impact on health and the environment. Various TDS removal technologies based on the membrane, ion, and temperature gradient are employed to treat water. In this review paper, several TDS removal technologies for instance reverse osmosis, nanofiltration, distillation, ultrafiltration, forward osmosis, precipitation, desalination, ion exchange, electrochemical techniques, electrodialysis, electrolysis, electrocoagulation, and adsorption are discussed in detail.

**Keywords:** Total dissolved solids, Reverse osmosis, Adsorption, Electrocoagulation, Nanofiltration

## 1. Introduction

Total dissolved solids (TDS) are one of the important chemical parameters in water quality monitoring. It refers to the sum of total organic and inorganic substances in water, which consists of both cations (e.g., calcium, magnesium, potassium, and sodium) and anions (e.g., carbonates, nitrates, bicarbonates, chloride, and sulfates). Both natural and anthropogenic activities are the sources of TDS. Natural sources include seawater intrusion, mineral springs, salts, and carbonate deposits, and anthropogenic sources include sewage, urban runoff, industrial wastewater, and chemicals in the water and wastewater treatment process. According to the Indian standard, the permissible limit of TDS in drinking water is 500 and 2000 ppm if there are no other sources of water available. It causes harmful effects in an aquatic environment if the concentration is higher than 2000 ppm [1]. Water with a low concentration of TDS is also unacceptable because of its flatness and lack of taste. Gravimetric analysis has been used to determine TDS accurately that involves the evaporation of solvent or water followed by the measurement of residual mass left after the complete evaporation. Conductivity measurement has also been used to determine TDS using a conductivity probe, which is directly dependent on the concentration of dissolved solids in water. The elevated level of TDS in water is an indicator of pollution. A higher TDS level results in undesirable taste, which could be salty, bitter, or metallic, and water look turbid. It also causes various health effects including gastrointestinal, cardiovascular, genotoxic, respiratory, skin, and hepatic diseases [2]. The mineral content of water also influences TDS characteristics, where the constant amount of minerals in the water is essential for aquatic life. The significant difference in TDS levels may be fatal to aquatic life. In previous studies, it was mentioned that the mortality rate of aquatic species (e.g., *dugesia gonocephala*) is correlated to higher TDS concentration, which has calcium, magnesium, sulfate, chloride, fluoride, and others [3]. It also has effects, for instance, encrustation, and corrosion on the environment. TDS above 500 ppm cause scaling in water heaters, boilers, pipes, and so on, thereby increasing energy requirements as well as maintenance costs for their proper functioning [4].

Due to the adverse effects of TDS on the environment and health, it is necessary to identify the sources of TDS, which is helpful in the restoration of water bodies. Several methods have been employed for the removal of TDS from the drinking and contaminated water (e.g., textile industry, pharmaceutical industry, synthetic water, and produced water), which are generally classified into three categories: membrane-based operations, ion-based operations, and temperature gradient-based operations [5]. Membrane-based operations are usually driven by concentration, pressure, and electric potential gradients [6]. Reverse osmosis

(RO), nanofiltration, and distillation are the conventional methods for the removal of TDS from water [7,8]. Desalination, ion exchange, adsorption, extraction, forward osmosis, electro-chemical removal, electro-coagulation, electrodialysis, and electrolysis are the currently existing methods for the removal of TDS [6]. RO and nanofiltration are the most commonly used and well-established techniques for the removal of TDS, as shown in Fig. 1 [9]. They provide high-quality, purified water with better efficiency by using a semi-permeable membrane. Forward osmosis is also used for the removal of TDS [10]. Ionic contaminants in water are purified by deionization techniques, and the deionized water is passed through a RO membrane for the removal of non-ionic contaminants [11]. Activated alumina, activated charcoal, and limestone are the common and efficient adsorbents for the removal of TDS from water [12]. Crystallization techniques based on separation and evaporation were used in wastewater treatment. They require, however, energy for the separation of contaminants. Chemical precipitation was found to be more effective in the treatment of sewage water [13]. TDS from textile and pharmaceutical wastewater is removed by the ion-exchange technique, which has been considered a low-cost and efficient method [14]. However, it yields a less quantity of purified water than that of a RO method [15]. Certain methods are employed for water treatments, which are chemical-free and they solely depend on an electric potential gradient that includes electro-chemical, electro-coagulation, electrodialysis, and electrolysis techniques [16,17]. Colloidal particles with a smaller size range were formed upon the use of these techniques, which is, however, removed readily from treated water matrices. From previous studies, it is better understood that the above-mentioned techniques have various advantages and disadvantages. In the current scenario, it is necessary to develop a novel technique and/or modification of the currently existing techniques are required for the better removal of TDS from water to produce purified water in a larger quantity through a sustainable approach.

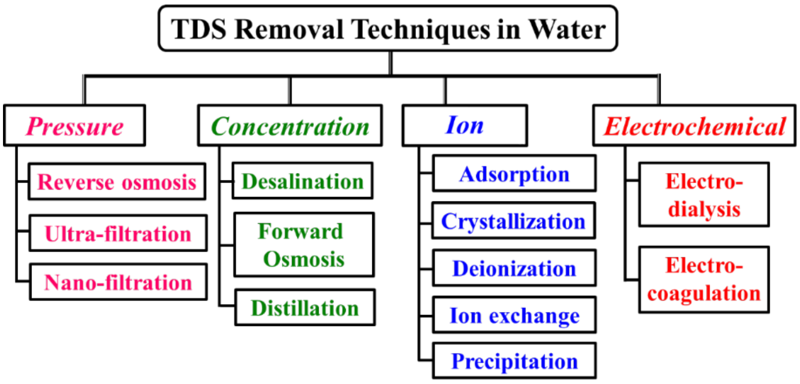


**Fig. 1.** Pictorial representation for TDS removal techniques.

## 2. TDS Removal Technologies

### *2.1. Reverse Osmosis Technology for TDS Removal*

RO has been used to purify water, where external energy is required to move the water molecules from a higher concentration to a lower concentration through a semi-permeable membrane [18]. In this technique, the produced water must be pure and contains no or fewer contaminants compared to that of feed water. It is capable to remove dissolved salts, colloids, organics, pathogens, and others from feed water. It has a higher removal efficiency (95−99%) for the removal of TDS. The performance of TDS removal by a RO method is strongly dependent on two distinct factors. One such distinct factor is the removal of ionic impurities. The impurities removal other than ions by ultrafiltration is another distinct factor, where small pores act as a molecular filter [19]. The cut-off molecular size of ultrafiltration is approximately 14−20 nm and impurities of the size above this would be rejected. RO is applied both at a larger and smaller scale. This technique seems to be useful in the treatment of groundwater, surface water, brackish water, and industrial wastewater (pharmaceutical, textile, dye, food, and beverages) [20]. The salt rejection in a RO system is expressed by the ratio between the differences in the conductivity of feed and permeate water and the conductivity of feed water [21].

Copper and cadmium from synthetic wastewater are removed by the RO method. TDS concentration was reduced from 500 to 3 ppm and the removal efficiency was found to be 99.4% by this method [22]. The produced water thus is reusable which reduces the stress on the conventional water resources significantly. Kumar et al. studied the wastewater treatment process of the Charminar brewery industry by RO. The TDS removal efficiency was in the range of 90.52 and 94.2%. It was also found that the aeration process has a less effect on the TDS removal, and the treated water from the wastewater treatment plant met the effluent discharge standards of WHO and also satisfies the 4R concepts of ‘reduce, reuse, recycle, replenish’ [23]. The water produced from Shale gas has a higher concentration of various substances including organic and inorganic salts and particulate. Higher TDS concentration can induce scaling in the wells and pollution of adjacent water bodies as well as soil [24]. The performance of RO is affected significantly by the TDS concentration of feed water. It was suggested that RO is used as a pre-treatment technique for the removal of TDS.

The removal of boron from seawater was examined using a hybrid technology comprising ion exchange and a membrane (e.g., nanofiltration (NF)/RO membrane) for desalination applications. NF/RO membrane showed significant removal of boron and TDS and its removal efficiency is about 90%. Fundamental research is needed further to improve the scientific understanding of this technique [25]. RO-based method for the removal of higher nitrate ions as the constituent of TDS from drinking water showed a much higher removal performance. This method is applied both at a full and pilot scale. The efficiency of this method depends on the types of membrane and their pore size [26]. The removal of contaminants from groundwater in Chandrapur, India using a polyamide membrane was examined, which showed the removal efficiency of 98% for sulfate, iron, fluoride, and others thereby achieving the WHO standards. TDS removal performance, the recovery ratio of water, and others are increased with the increase of temperature that alters the viscosity of feed water. As a result, the permeation rate of water through a membrane also increased. The efficiency of a RO membrane is strongly dependent upon the pH of inlet water, pressure, and temperature [27]. Bonnélye et al. developed a treatment method containing seven stages including an RO treatment system for the removal of boron from seawater. Both TDS and boron were removed from Curacao drinking water and the final concentration of TDS was found to be below 150 ppm. Although the developed method is a time-consuming process, the quality of treated water was following expected values [28].

Tomaszewska et al. assessed the potential of RO using a low-pressure brackish water RO membrane not only to reduce TDS but also to remove boron, iron, fluoride, and arsenic (As). Both TDS and boron were removed about 7 g and 10 mg per liter of feed water, respectively, by the developed desalination system. 84–97% of TDS was removed at pH 5 [29]. Techno-economic feasibility studies were conducted to treat water from Placerita Canyon Oil Field by RO technology. It was found that more than 95% of TDS was removed and suggested that RO technology is viable after the incorporation of structural modifications [30]. Taniguchi et al. developed a seawater reverse osmosis (SWRO) membrane, which exhibited excellent boron and TDS removal performance along with high water production. Post-treatment loading is reduced significantly, which decreases the production cost of drinking water. 20% of overall cost reduction was achieved by this developed membrane when compared with a conventional membrane. Its combination with an alkali brackish reverse osmosis (BWRO) membrane showed an enhanced TDS removal at a reasonable cost [31]. Rahmawati et al. studied the removal efficiency of both boron and TDS from red seawater (brackish water) using SWRO and BWRO membranes. It was found that the TDS removal performance of membranes was not altered significantly with the change in pH. The average TDS rejection of membranes tested was in a range between 96 and 85%, respectively. It was also found that salts rejection by all membranes used in this study was relatively constant during the operation [32].

The removal of boron from seawater was performed using SWRO membranes made of polyamide thin film composite [33]. The selected membranes showed TDS removal performance and its permeate flux increased with the increase of pressure in the pH range of 7.0–7.5. The influence of TDS, pH on boron rejection, and permeate flux were examined using an SWRO membrane and a synthetic solution and seawater. The presence of higher TDS in seawater results in concentration polarization. Although kinetics for the removal of TDS is slower, a higher removal of TDS was achieved. The performance of RO membranes was examined using a simulated water mixture that contains dye and salts and the selected membrane showed 99.99% removal performance. It was also observed that salt rejection was decreased with the increase of dye concentration from 500 to 1000 ppm at all operating pressures [34]. Three systems comprising RO and distillatories were developed for the removal of As and TDS from groundwater. Two types of point-of-use purification devices and one RO device were used for removal studies using synthetic groundwater. 90% of removal efficiency was achieved by the developed systems, and it was found that TDS removal efficiency was directly proportional to the removal efficiency of As. Their removal efficiency at point-of-use systems was in the range of 88−96%, where the concentration of TDS in feed water was 1100 ppm, which was reduced up to 10−60 ppm after treatment. It was also observed that TDS removal efficiency is the same for both synthetic water and groundwater. However, it is significantly different for As [35]. A combined membrane bioreactor and RO system (MBR-RO) was developed for the removal of TDS and found that the developed system showed an efficiency of 95−99% in RO permeate. This system is used for the effective treatment of municipal and industrial wastewater with more than 90% metal removal efficiency. Although the developed bioreactor showed enhanced metal removal performance for Cu, Pb, and Zn from RO concentrate, Ni removal was realized however, only at the initial stage of column operations [36]. The summary of various types of RO membranes used for the removal of TDS is listed in Table 1.

**Table 1.** Reverse osmosis for TDS removal techniques.

| Type of Feed Water | Type of Membrane | Removal Efficiency | Advantage | Disadvantage |
|---|---|---|---|---|
| Urban sewagewater, sea water, industrial wastewater [20] | Cellulose acetate, Polysulfone hollow fiber, PS,PAN, PSA, PP, PE, PVDF | Removal rate of particulate matter is up to99.9%, Removes pathogenicmicroorganism | Low energy consumption, simple structure, convenient operation | 14-20 nm impurityparticle size would be rejected, membrane fouling, operation and maintenance costs is high |
| Copper andcadmium (industry wastewater) [22] | Polyamide spiralwound | TDS concentrationreduced from 500 ppm to3 ppm (99.4%). 98% and 99% for copper andcadmium removal | Reuse of industrialwastewater containing heavy metals | High costs high rejection of water |
| Charminar brewery industry [23] | RO | TDS removal rangebetween 90.52 and 94.2% | Satisfying the 4Rconcepts (reuse, recycle, reduce,replenish) | Aeration process has aless effect on theTDS removal |
| Sea water (Boron and TDS) [24] | Brackish ROmembrane, Seawater RO membrane, Polyhexamethyl ene biguanide coated seawaterRO membrane | Boron and TDS removal efficiency was about 90% | Used for various separation techniques, High efficiency | Membrane fouling |
| Well water (Nitrate) [26] | Tubular membrane Polyamide, Cellulose acetate | Nitrate concentration reduced from 100 ppm to50 ppm and also removalefficiency depends on the types of membrane used and their pore size | This method applied for both full and pilotscale, Easy membraneexchange, rejection of suspended particles and organiccompounds | Very sensitive againstScaling |
| Groundwater Contaminant [27] | Polyamidemembrane | Removal efficiency 95- 98% for sulphate, iron, fluoride, , and also it depends on the pH of the inlet water, pressure, temperature | Recycling therejected water, inorganic pollutantalso removed | Reject water |

**Table 1.** *cont.*

| | | | | |
|---|---|---|---|---|
| Seawater (boron and TDS) [28] | During first passSodium bisulfite injected in upstream, Second pass Caustic soda used on the reverse osmosis membrane | Final concentration of TDS and boron found to be 150 ppm and 0.3 ppm. Removal efficiency 50-95% depending on the membrane type and the pretreatment (pH, Temp, Time ) | Inorganic andorganic pollutants is removed simultaneously | Time consuming process |
| Geothermal waters (boron, TDS) [29] | Spiral wound polyamide thin-film compositemembrane, BWRO membrane | Low pressure membrane removes TDS up to 7 g/Land boron concentration of up to 10 mg/L. Percentage of removal efficiency was 84-97% atpH 5 and also removes boron | Low energy required,low cost | Low water recoveries |
| Oilfield- Produced water [30] | Polymeric ultrafiltration membrane | Removal efficiency of TDS was 98 % and boron 80% | Less energy ascompared to other technology | Capital cost, labor, waste disposal,chemicals |
| Sea water (Boron, TDS) [31] | SWRO membrane(TM820A) combination with alkali BWRO membrane | 94-96% boron removalwith high TDS rejection and high water productivity | Lower drinking Water production cost, cost effective | Low flow rates expected high saline concentrations in influent |
| Textile industrial wastewater (color, TDS) [34] | Nanofiltration and thin film composite polyamide (spherical wound configuration) | Salt rejectiondecreased with the increase of dye concentration from 500 to 1000 ppm. 99.80% of color removaland 99.99% TDS removal efficiency | Produce the potable water, Removing the unwanted ions, less sensitive to fouling | Outlet water is waste |
| Synthetic groundwater and groundwater (arsenic) [35] | Two types of point of use purification andone RO device (thin filmcomposite membrane) | 1100 ppm of feed water TDS reduced to 10-60 ppm. The percentage of removal efficiency was 90% | The process is electrically driven hence it is readily adaptable to powering solar plants | Replacement of filtersand membrane |
| Municipal wastewater and industrial wastewater [36] | Combined membrane bioreactor (thin film composite polyamide) | 95-99% of TDS and 90% metal removal efficiency | Production of high-quality treated effluent, Good disinfection capability, compactness, and Flexibility in operation | Membrane fouling |

*2.2. Nanofiltration Methods for TDS Removal*

Nanofiltration is a process of removing contaminants from water by forcing it through porous media. Nanofiltration is a pressure-driven membrane operation for the separation of molecules and ionic species, where nanofillers have a pore size of ~0.001 µm. It offers a higher flux rate and uses less energy than RO in the recycling process.

The mechanism of nanofiltration is more or less similar to RO, however, a nanofiltration membrane, used for this purpose is not as tight as RO. It operates at a lower feed water pressure than a filtration membrane. The fouling of a membrane is lower as compared to the RO system due to its pressure. It does not remove, however, monovalent ions effectively from water compared with RO membrane [37]. It is capable of removing 50−90% of contaminants. This technology is efficient for the removal of di- and trivalent ions as well as hardness. Nanofiltration is employed as a cost-effective water treatment method for the rejection of di- and trivalent ions, bacteria, viruses, and organic substances. It also removes almost 90% of monovalent ions from water. In addition to water treatment, it is often employed for the treatment of industrial effluents of pharmaceutical, dairy products, and textiles. Two types of nanofiltration membranes, namely spiral and tubular/straw are employed for the treatment of water, where the former is cheaper than the latter. However, the former is more vulnerable to fouling, which reduces its performance steeply at earlier stages.

The other application of nanofiltration systems includes softening, recycling, and reduction of salt contents. The micropollutants like herbicides, insecticides, and low molecular components like colorants and sugars is removed efficiently using nanofiltration membranes. Major advantages of this process are lower discharge volume, reduction of salts content, (TDS and metals), reduction in colors, tannins, and turbidity [38]. It is a chemical-free method for disinfection. The requirement of higher energy consumption for pretreatment, limited retention of salts, and less removal performance for monovalent ions is the noticeable demerit in this process. The membranes of nanofilters are sensitive to free chlorine.

A thin composite nanofiltration membrane was developed for the removal of As from the drinking water. 99% of As removal was achieved with TDS removal at the optimum pressure range of 40−50 bar. The merit of this operation is a requirement of lower operating pressure and showed relatively less vulnerability towards fouling. However, its efficiency is strongly dependent upon the pH of the water and the presence of other ions, which requires continuous monitoring and frequent maintenance. It has been proven that this methodology is capable of producing potable quality water along with the removal of As, and turbid matters from water [39]. The higher TDS removal efficiency of 97.4% was realized through a nanofiltration process, where TDS concentration is significantly reduced from 500 ppm to 13 ppm [40].

Spiral, nanofiltration membrane based on composite was prepared for the removal of color, COD, and TDS due to the presence of di-salts mixture in a solution from textile industries. The performance of the membrane was evaluated using simulated water under various pressure and concentration. TDS removal performance was increased with increasing pressure [41]. Nanofilters working at an ultra-low pressure range were fabricated using a low-energy membrane for the treatment of color, organic matter, and hardness in the drinking water. A large number of contaminants including 90−95% of total trihalomethanes, 80−95% of hardness, and 70% of monovalent ions were removed with the use of these filters. It is capable of purifying the water under specific conditions with an operating pressure of 70−100 psi and has importance in water conservation and groundwater treatment [42].

The mechanism of As and TDS removal was examined using a negatively charged, porous nanofiltration membrane, and conductivity measurement as a tool for knowing its removal performance. Only 50% of removal was realized due to larger pore size, a higher permeability, and performance. The rate is improved further upon the modification of membrane characteristics. The TDS removal performance of a nanofiltration membrane was tested using synthetic and surface water. The efficiency for TDS removal, total hardness, and conductivity were 75, 88, and 75%, respectively [43].

Nanofilter membranes (e.g., NF-300) were developed for the removal of TDS, dissolved organics, and As. Although the developed NF-300 membrane showed a better removal performance for the TDS removal in the presence of dissolved organics, it did not show a significant influence on As [44]. Both capital costs as well as maintenance cost due to the formation of fouling on a membrane surface, are the strong setbacks for using this type of membrane. Removal performance was not strongly dependent on transmembrane pressure, cross-flow velocity, and temperature. NF membrane was used for the removal of color and TDS. The selected membrane showed more than 99% removal performance along with resistance toward the formation of fouling. The membrane filters based on NF and RO were employed at a household level to treat As as well as TDS. The selected filters showed a better performance and they were not produced any solid waste materials. High operational costs, as well as maintenance costs due to scaling and fouling issues, are the major limitations of the selected membranes [45].

### *2.3. Distillation Process for TDS Removal*

Distillation is a point-of-use system, as one of the conventional methods of water treatment that shows a better treatment efficiency. This method can remove bacteria and inorganic and organic substances from water. The distillation process involves boiling water, capturing the steam followed by condensing it in a different container. The distillation process is strongly dependent on the evaporation of water and large-sized nonvolatile, organic, and inorganic molecules that do not evaporate remain in untreated water. This method effectively removes inorganic compounds such as metals (e.g., lead), and nitrates. Distillation units generally consist of a boiling chamber, condensing coils, and a storage tank. They require proper maintenance periodically, which increases the cost of operation. The most common methods of distillation are solar distillation and multi-storage flash distillation.

Membrane distillation (MD) technology was developed to purify the seawater collected from Arabian Gulf using five different MD membranes. The TDS removal rate was higher than 99.99% by the developed MD technology. MD membranes are capable of reducing the salinity of highly saline seawaters. Fouling issues were, however, observed in MD membranes. Therefore, further studies are needed to improve the efficiency of MD membranes [46].

### *2.4. Ultrafiltration Methods for TDS Removal*

Ultra-filtration (UF) is a pressure-driven operation to remove particles (e.g., solids, bacteria, and viruses ) from water, which uses a hydrostatic force to pass water through a semipermeable membrane. The basic operating principle of ultrafiltration is a pressure-induced separation of solutes from solvent through a semipermeable membrane. The pore size of a membrane is usually in the range between 103 and 106 Daltons. It is a membrane filtration process like RO. The hollow fiber characteristics of UF membranes can filter water from inside. An efficient UF membrane has fine characteristics for instance less pore size, and a larger surface area. The pre-treatment of a filter is required for the removal of multi organics and contaminants. UF filters operate generally at a low-pressure range. UF filters keep essential minerals in the filtered water. The operation of UF filters is comparatively easier than that of other filtration systems, and there is almost no or little waste generation in UF treatment systems. UF filters possess 90−95% of the water recovery rate to produce reusable water. It is worth mentioning here that the UF treatment process is an environment-friendly process, where they do not require any chemicals for the water treatment. A forward ultrafiltration technique using an ultrafiltration membrane having a membrane size range of 20 and 50 Daltons was developed for the treatment of textile effluents that contain higher TDS. 90 and 50% of turbidity and color removal were achieved, respectively, by the developed method. In addition, 30 and 20% of the improvement in TDS and conductivity, respectively, were achieved when UF 20 membrane was used [47]. It was also observed that UF 20 and UF 50 membranes showed better permeation characteristics. The promising results obtained from this study lead to the possibility of using a multistage process for water treatment applications.

### *2.5. Forward Osmosis Process for TDS Removal*

Forward osmosis is a membranous process that purifies wastewater using a semipermeable membrane via the use of osmotic pressure differences generated in feed water. It has been widely used for water treatment due to its relatively less energy requirement, low fouling tendency of a membrane, and high water recovery. Internal concentration polarization (ICP) induces fouling, and reverse salt diffusion, and limits the performance of the forward osmosis. The asymmetrical structure of a forward osmosis membrane causes ICP, which impacts a water flux significantly [48].

Forward osmosis membranes are typically designed for the selective separation of the water molecules from feed water that has contaminants. The driving force for a forward osmosis process is the development of pressure difference due to a concentration gradient of water molecules on both sides of a membrane. The main difference between FO and RO membrane is that the RO membrane requires energy-intensive hydraulic pressure for an operation but the FO membrane requires only osmotic pressure. It is the most promising technique for water treatment that produces high-quality water after the treatment and has relatively less issues with membrane fouling. A hybrid forward osmosis system was developed for the desalination of seawater and the reuse of wastewater [49]. It has various advantages, for instance, low capital and O&M cost. The pipe maintenance cost is reduced due to the production of high-quality water by the proposed hybrid system that has sustainable flexible treatment units. Certain polymers that had semipermeable characteristics were used for this system to permeate solely the water molecules but not the dissolved solids. Forward osmosis technology has yet to become a commercially viable technology. The development of high flux membranes at a lower cost is a pivotal step to realize this as a viable technology in the future. This technique is capable of removing salts in water with minimum internal polarization effects pertinent to concentration. This technique is relatively cost-effective, allows further recirculation of rejected water, and improves water recovery.

Dual-stage forward osmosis (FO) and pressure retarded osmosis (PRO) techniques were developed to purify a hypersaline solution and generate power simultaneously. The permeation of water in a system is increased with the increase of the flow rate of the inlet water. The advantage of this method is a significant reduction of salts in a hypersaline solution and the treated water is further purified by a conventional process or the post-treated water is discharged properly to sea. The performance of PRO-FO series is higher than that of the FO-PRO series in water purification. No significant improvement in the performance was observed when increasing the flow rate of feed water in the developed PRO-FO system [50,51].

### *2.6. Precipitation Methods for TDS Removal*

Precipitation is one of the most common methods for the treatment of heavy metals from water. It is used as a pre-treatment method, in which precipitates are formed as a result of the reaction between the metal ions present in water and precipitating agents.

Soluble particles convert into insoluble particles in water. Carbonates, sulfates, sulfides, lime, and hydroxides have been used as precipitants, which are mostly fine in nature that help to form suspensions in water. This technique is used as a complementary technique for coagulation and flocculation techniques. It can also be used for removing salts, production of pigments, water treatment, and qualitative inorganic analysis. Chemical precipitation can aid in the removal of TDS by altering the solubility of ions. This method is efficient, and requirements (equipment and chemicals) for this method are readily available. The method demands low capital investments and maintenance costs. Although a precipitation method is used for the removal of metals from water, the simultaneous removal of multiple metals may be difficult by this method. The waste generated from this method is another problem, which has to be addressed.

The removal performance of As, Se and V from refinery wastewater was examined by a precipitation method using three precipitants namely $Fe_2(SO_4)_3$, Nalmet 1689 and MetClear. 91–99% of V, 60–73% of As and 50–55% of Se were removed upon the use of $Fe_2(SO_4)_3$. However, 55% of Se, 36% of V and no As were removed when MetClear was used and 45% Se, 6% V and no As were removed when Nalmet 1689 was used. The precipitation using ferric sulphate followed by reactive filtration is more efficient for the removal of heavy metals tested in this study. However, further studies are required to understand its techno-economic benefits by the inclusion of certain parameters, for instance, requirements of energy and chemicals, and waste generation [52].

*2.7. Desalination Techniques for TDS Removal*

Desalination is a desalting process of water, which is converted into potable water, where the sources of feed water are seawater, brackish water, wells, rivers, streams, and wastewater. This technology is capable of removing salts and minerals from feed water. The desalination of seawater has the potential to produce enough potable water to support a larger population located near a coastal area. The produced water after desalination is used for municipal, industrial and commercial needs. In a desalination process, two streams of feed water are obtained after treatment, including treated potable water and concentrate or brine. The treated potable water consists of a less amount of salts and minerals. Whereas, a concentrate or brine has a higher concentration of salts and minerals when compared with original feed water. It is one of the cost-effective technologies as it works based on thermal, electric, and pressure principles [53].

Up-flow microbial desalination cell (UMDC) containing air cathode was developed for the removal of salts under a continuous operation mode. This cell removes not only TDS at a rate of 7.5 $g \cdot l^{-1} d^{-1}$ but also produces bio-electricity. The charge-transfer performance of UMDC was measured by the ratio between the amounts of NaCl removed from feed water and the electrons produced. The developed UMDC showed the power density of 30.8 $W/m^3$ along with 99% removal of NaCl. This study enabled us to develop improved processes for desalination and wastewater treatment applications [54].

Microbial capacitive desalination cell (MCDC) based on a biological and membrane process was developed for the simultaneous generation of energy and the removal of organic matters and salt. All three chambers of MCDC are used to remove both organic and inorganic contaminants. The developed method is cost-effective and possesses a better energy output. MCDC was capable of removing TDS and COD at a rate of 2760 and 170 $mg \cdot l^{-1} h^{-1}$, respectively, which is significantly higher than that of a conventional microbial desalination cell [55]. The removal performance of organics and TDS was investigated using a multi-chamber microbial desalination cell (MCDC) that contains five compartments for an anode, a cathode, one compartment for desalination and two compartments for concentrate, which are separated by a membrane. MDC may be a suitable pre-treatment method prior to a RO treatment method. It was successfully demonstrated that power is generated simultaneously along with the removal of organic matter and salts. The simultaneous removal of phenol and TDS from industrial wastewater using a multi-chambered microbial desalination cell was performed. An anaerobic sludge and pure culture of *P. aeruginosa* as inoculum were used in a cell, which showed the effective removal of phenol and TDS. The degradation of phenol up to 95% was achieved in wastewater. Thus, MDC based method is a sustainable and economical solution for the treatment of phenol and TDS from wastewater [56].

Desalination technique was developed for the removal of TDS from concentrated saline water produced by Shale gas. Membrane and thermal desalination methods are used for the removal of a majority of contaminants and TDS from the wastewater generated from oil and gas-based industries [57]. This method is effective at a higher temperature range and wastewater contains high molecular weight compound and polar compounds such as polycyclic aromatic hydrocarbons (PAH) but it is not effective when wastewater contains low molecular weight compounds and nonpolar organic molecules. Fouling issues in a membrane and distillation equipment were observed when the concentration of organic carbon exceeds 1000 ppm in the wastewater generated from the Shale gas.

*2.8. Ion Exchange Technology for TDS Removal*

Ion exchange is a chemical treatment technology, which has been commonly used for water softening and demineralization. Resins used in this technology are natural or synthetic, as they contain small microporous beads that are insoluble in water and organic solvents. Ion exchange is also capable of removing other ionic substances from contaminated water. It can also be used as a part of other processes such as de-alkalization and disinfection. It is one of the efficient technologies for removing toxic metals and dissolved organic ions from water. It requires a low initial capital investment when compared with other TDS removal technologies. The maintenance cost of this technology is relatively low as a few steps are required solely to regenerate resins. However, pathogens (e.g., bacteria) from water cannot be removed by this technology. The efficiency of ion exchange technology depends on the affinity between ions present in a resin and a solution.

The removal of TDS that contains boron from seawater was examined by ion exchange technology. TDS concentration was reduced from the original concentration of 40,000 to 79 ppm. The performance of ion exchange resins in terms of water yield was not affected by operating conditions such as temperature, pH, and salinity. It was capable of removing all minerals from water. The combination of RO and ion exchange technologies is recommended to reduce the salinity of seawater to produce the drinking water at a lower cost than a RO system [58]. An electrochemical ion exchange process was used for the removal of TDS using ruthenium dioxide-coated titanium plates ($RuO_2$/Ti) and stainless plates as anode and cathode, respectively. Both cations (e.g., $Fe^{2+}$ and $Mg^{2+}$) and anions (e.g., $Cl^-$, $SO4^{2-}$, and $PO4^{3-}$) from synthetic water were removed at a laboratory scale. Almost all ions are removed by one or two operating steps [59].

The removal of As and TDS from groundwater was examined using alumina media by ion exchange technology. The results obtained from this study showed that the selected ion exchange systems are not economically attractive for water containing a higher TDS (> 500 ppm) or sulfate (> 150 ppm). The low concentrations of TDS, sulfate, and total As have remained for the first 24 min during backwash and the initial stage of brine generation. Although the formation of fouling at electrodes is one of the major disadvantages of this technology for small-scale water treatment plants due to its ease of operations and a lower maintenance cost [60].

The removal of organic matter and TDS from wastewater was investigated by the development of MDC containing anion- and cation-exchange membranes, which were placed at respective electrodes. Although the developed system showed improved performance for TDS and COD removal, studies on designing and operating parameters are necessary to improve the performance further in terms of power generation as well as wastewater treatment. A larger inter-membrane distance prevents a system to achieve its maximum desalination performance [61].

Ion exchange technology is used for the treatment of specific ions rather than the reduction of overall salinity but cannot be used as an economically viable option for the water that contains a higher TDS. This technology has been used for water softening for the removal of Ca and Mg. The regeneration of salty wastewater (1−5% of the total volume) and its associated higher maintenance cost are the shortcomings of this technology. Ion exchange technology is used for the treatment of perchlorates present in the groundwater that has a higher TDS, alkalinity, and hardness, and 90% of TDS removal was achieved. Sulfate and chloride were removed consistently in this study [62].

*2.9. Electrochemical Technologies for TDS Removal*

Electrochemical technology has been used to remove pollutants from various water bodies and reduce TDS and hardness effectively without using any salts. The introduction of negatively or positively charged electrodes in a water treatment system can remove the oppositely charged particles in water. Electrochemical based technologies are one of the potential solutions for the treatment of water. These technologies can operate at a relatively lower voltage range and provide the treated water along with less residual impurities compared to that of conventional technologies. The O&M cost of the component involved in these technologies is relatively low as they require minimum steps for water treatment. It comprises electro-dialysis, electro-coagulation, and reverse electrode dialysis (RED). Electro-dialysis technology is the second most widely used membrane-based desalination technology for a wide range of industrial applications.

*2.10. Electrocoagulation Technology for TDS Removal*

Electrocoagulation (EC) technology is an eco-friendly technology to remove pollutants up to 98%, for instance, total suspended solids, TDS, heavy metals, emulsified oils, bacteria and other contaminants from water at a low cost [63]. The performance of EC depends on pH, coagulation dose, coagulant type, and a number of electrodes. EC technology is used to remove any specific contaminant or multiple contaminants at a time from wastewater. The selection of electrode materials, residence time, and current density play a pivotal role in removal of pollutants via EC technology [64]. Multiple reactions (e.g., generation of metal ions, the formation of $H_2$ gas and hydroxyl groups on the surface of cathode) take place in an EC cell when water passes in it. The flow of free-electrons in an EC cell alters the surface charges of suspended solids and emulsifies oils that result in a large-sized floc, which is removed eventually from the water via the separation and filtration process [65]. EC technology has been used for several industrial applications like diaries, metal plating, oil and gas, food processing, mining, washings automobiles, and drinking water treatment [66].

Electrochemical technology has been used for the removal of metals from leachate based on sewage. EC was more efficient and economical than conventional precipitation, as it showed 98% removal efficiency with calcium or sodium hydroxide as a precipitant for conventional precipitation methods. This technology seems to be useful for the separation of suspended solids. The produced water must be pure that contains no contaminants. TDS removal performance using an EC reactor was examined at 1.75 A as a function of coagulation. Although this method seems to be efficient, the cost for the TDS removal is relatively higher than that of the other methods [67].

Farhadi et al. investigated the removal of TDS from pharmaceutical wastewater. TDS removal efficiency was examined by EC, peroxy electrocoagulation and peroxy photo-electrocoagulation process. TDS concentration was reduced from 755 to 474 ppm and 490 to 460 ppm by each process after 90 min of treatments. Electric and light energy has been considered as the main inputs for the process [68]. EC method has been used to remove organics and divalent cations, which induces scaling. TDS was removed at a lower energy consumption from the shale gas-produced water through hydraulic fracturing by increasing a current at a set voltage. This process has been considered as a viable method to encourage the treatment and reuse of wastewater produced by shale gas. It is also an environmentally friendly method and the performance of EC method is strongly dependent on the amounts of dissolved salts including chloride ions, and the pH of wastewater in wastewater [69].

Coagulation plays a pivotal role in textile industries and a different combination of coagulants (e.g., $FeSO_4$ and CaO) was selected for the removal of colour and sludge [70]. The coagulation method is used for the removal of TDS with improved efficiency at a lower cost. The pH and colour of the solution were influenced by the use of coagulants, where the pH of the solution is decreased by more than 33%. A pilot study was conducted to remove TDS, hardness, $NO_3^-$, color, and turbidity from water using pipes, and pots made from clay, which showed excellent efficacy in the removal of turbidity (≥ 90%) and color (≥ 60%). Clay filters are not, however, capable of complete removal of hardness, electrical conductivity, and TDS [71,72]. The summary of electrocoagulation techniques used for TDS removal in wastewater are listed in Table 2.

**Table 2.** Electrocoagulation for TDS removal in wastewater.

| Type of feedwater | Type of electrodematerial | Removalefficiency | Advantage | Disadvantage |
|---|---|---|---|---|
| Wastewater (total suspended solids, TDS, heavy metals,emulsified oils,bacteria andother contaminants [63] | Al-Al, Fe-Fe, Al-Fe, Mg-Fe,Carbon steel, MS-Al, Al-Aircathode, SS-Zn,Cu-Fe, Graphite-Ti | It can remove pollutants up to 98%. | Less external chemicals, easier installation, lowersecondary pollutants formation, odor and colour removal, lower residence time | High electricityconsumption due to the formation of oxide film on the surface of electrode |
| Industry Wastewater[64] | Sacrificialaluminumelectrodes | It removes 99% of colorand turbidity from discharged wastewater. | Compact size, low sludge generation, high water recovery and easy operation | High initial investment, sacrificial electrodesare dissolved in wastewater |
| Oil removal from wastewater [65] | Aluminum and iron electrodes | Large sized floc removedfrom separation and filtration process | Simple equipment, use of less or no chemicals | Low efficiency, long processing time,secondary pollution, high cost |

**Table 2.** *cont.*

| | | | | |
|---|---|---|---|---|
| Leachate basedsewage [67] | Aluminum and iron electrodes | The produced water must be pure with no contaminants. 98% removal efficiency | Low energyconsumption, | TDS removal cost isrelatively higher than that of other methods. |
| Wastewater (Pharmaceutical) [68] | Iron electrodes | TDS concentrationreduced from 755 to 474 ppm and 490 and 460 ppm after 90 mins | Simple set-up, No chemicals, Produces the highly stable sludge | Selection of electrodeand overall Maintenance of this process is not easy |
| Wastewater (Organic and divalent cations) [69] | Iron electrodes | Due to high conductivity of shale gas wastewater having high currents for an applied voltage results higher contaminant removal at lower electricity consumption | Economically viablemethod, Environmentally friendly technology | High conductivity of wastewater suspensionis required |
| Industrial wastewater treatment (TDS, pH, Turbidity, nitrate) [71] | Clay | Excellent removalefficiency of turbidity (90%), and colour (60%) | Low cost method | Clay filters not capableof complete removal of Hardness and TDS |

### *2.11. Electrodialysis Process for TDS Removal*

Electrodialysis is a membrane process in which ions are passed through a semipermeable membrane when electric charges are applied [73]. A system drives ions through a membrane instead of water using a voltage gradient. Electrodialysis systems typically consist of stacks of ion-exchange membranes, which are selective towards cations and anions. Although pretreatment methods, for instance, filtration, and flocculation are necessary sometimes before applying electrodialysis technique for water treatment. It is used, however, to remove ions from water. Large-sized anions, colloids, and oxides- of Fe and Mn can neutralize membranes and, therefore these substances can interfere with the performance of ion-exchange membranes [74, 75].

As a recent development in electrodialysis, for instance, a facility to change the polarity of electrodes and a reverse option to tune hydraulic channels can clean a membrane. Another recent advancement in a membrane technology is the possibility of rejection of monovalent and divalent ions present in the system. Electrodialysis is much more tolerant to inorganic scaling and requires a less pre-treatment. The removal of inorganic trace contaminants from bore well water was examined using an electrodialysis technique under various electric potential conditions. TDS removal performance becomes higher when 12 V was applied to the system when compared with 18 V. The fouling of the electrodialysis membrane was observed due to the deposition of trace contaminants on its surface, which affected the electrodialysis process. This technique was effective and the concentration of chloride, fluoride, sodium and sulfate ions was reduced to below than a guidelines value [76]. Electrodialysis as an emerging method was employed for the improved removal of TDS from brackish water and TDS concentration was decreased up to 80 ppm. The cost of this technique is increased substantially with the increase of salinity or TDS. The limited removal of non-charged constituents (e.g., organic molecules, silica, boron, and microorganisms) is the disadvantage of this process [77]. A pilot study was conducted to evaluate nitrate removal performance from the drinking water that contains 18−25 ppm of nitrate, 43 ppm of sulfate, and 530 ppm of TDS by electrodialysis method, which showed a higher removal performance and reduced the TDS concentration to below than 10 ppm [78]. Electrodialysis was used as a part of perchlorate treatment to remove chlorides and TDS effectively from groundwater [79].

### *2.12. Adsorption Technology for TDS Removal*

Adsorption technology has been played an important role in water treatment technologies and used mainly for the removal of organic and inorganic particles. In an adsorption process, matters are transferred from aqueous phases to solid surfaces. Adsorptive removal is strongly dependent on the types of adsorbents, their pore size, adsorption capacity, and contact time. Among various water purification and recycling technologies, adsorption is fast, simple, affordable, effective in a wide range of pH, and easy to operate. It has been widely used for water treatment applications, for instance, wastewater treatment, and groundwater remediation.

However, selectivity for the target pollutants is one of the major issues, which has to be addressed. Activated carbon and its various forms have been used as adsorbents for the purification of water.

**Table 3.** Adsorption methods for TDS removal in industrial wastewater.

| Type of feedwater | Type of membrane | Removalefficiency | Advantage | Disadvantage |
|---|---|---|---|---|
| Industrial wastewater [80] | Activated alumina, activated carbon, steel slag and Limestoneaggregate | 44.28, 47.68, 45.94, and 76.76% respectively. | Established technology, adsorbents readilyavailable | High electricityconsumption due to the formation of oxide film on the surface of the electrode |
| Textile effluent [81] | Water hyacinth,water lily, bark of plantain plants | Plantain plants reducethe TDS by 3.7% | Cheaper, less energy required, completely natural system and very easy toregenerate. | Plants obtain poisonous effect after treating theeffluent |
| Industrial effluent [82] | Cyclodextrinated,sulfonated, aminated form of nanocomposite were developedusing carbon nanotube, gumArabic, chitosan | Aminated adsorbents showed the removal rateof 93.48 and 99.8%. and that of Sulphonatedmembrane is 87.9 and83.2% | Eco sustainable method, lower cost | Most TDS ions areonly adsorbed to a limited extent. |

Various adsorbents have been used to examine their performance for the removal of TDS from synthetic industrial wastewater. Limestone aggregate was the most effective adsorbent, which showed 76.76% removal of TDS. However, other adsorbents, for instance, steel slag, activated alumina, and activated carbon showed the TDS removal performance of 45.94, 44.28, and 47.68%, respectively, which is comparatively lower than that of limestone. Further studies, for instance, optimization of parameters (dose, temperature, and kinetics) and the nature of wastewater are therefore needed to increase the removal efficiency of the adsorbents [80].

Various adsorbents and coagulants that include aquatic and non-aquatic plants were selected for the effective treatment of textile effluents. Water hyacinth, water lily, and the bark of plantain plants were used as adsorbents, which showed the effective removal of TDS. Although the proposed adsorbents are cheaper, the handling of contaminated plants and sludge is a serious issue to be addressed. It is suggested that the use of contaminated plants as fuel be one of the practical solutions to address this issue [81]. Cyclodextrinated, sulfonated, and aminated forms of nano biocomposites were developed as a bead or membrane using carbon nanotubes, gum arabic, and chitosan for the treatment of TDS from tap water. Both beads and membrane showed the highest TDS removal performance at pH 6. Aminated adsorbents showed the highest removal rate of 93.48 and 99.8% followed by sulphonated membranes (87.9 and 83.2%). Its removal efficiency is enhanced with the increase of bio-sorbent dosage. The reuse studies of nanobiocomposite were also performed to examine its applicability for consecutive cycles. This methodology is an eco-sustainable method for the treatment of TDS at a lower cost and suggested that this method can also be an alternative to RO technology [82]. Various adsorbents used for TDS removal in industrial wastewater are listed in Table 3.

Zero valent iron and its supported form were developed for the removal of As from water. As removal mechanism on the iron surface was examined for various As contaminated water matrices [83]. In addition, iron-oxides (e.g., $Fe_3O_4$ and $Fe_2O_3$) were developed for the treatment of pesticides (e.g., Chlorpyrifos) in water. A manuscript is under preparation to report the obtained results. We are currently using TDS as one of the screening parameters to monitor the water quality of lakes, rivers, sewage treatment plants.

### *2.13. Crystallization Methods for TDS Removal*

Crystallization is also known as brine treatment. It is an energy-efficient water treatment method in nature and one of the most commonly used methods for wastewater treatment in particular for industries. There are two stages including nucleation and growth available in this method. This technique was used for the removal of TDS from the contaminated water produced by Shale gas and more than 99% of TDS removal performance was achieved [84]. This method is effective for bleaching plants and water with a higher TDS. This method can also be used as a reclamation method for the treatment of liquid hazardous suspensions, wastewater treatment, draft tube bottles, coal-fired/gas-fired utility boilers, and treatment of pulps of paper industries.

### *2.14. Deionization Technology for TDS Removal*

Deionization technology has been used to remove ions from water by applying an electrical potential gradient between the electrodes. In this technology, charged ions (cations and anions) attract on the surface of polarized electrodes, which facilitate the removal of charged particles from water. The major application of this technology is the desalination of brackish water at a lower cost compared with the other water purification technologies. It does not require a high temperature or pressure. It is a useful and effective method for the treatment of brackish water. This technology is an effective and viable alternative for the treatment of TDS. The disadvantage of this technology is the use of chemicals followed by their discharges into an environment.

The membrane capacitive deionization method as an alternative to SWRO was developed for the removal of bromide and TDS from seawater, which showed 90 and 97.4% removal performance, respectively [85]. The performance was increased significantly up to 90% when the electric potential is increased to 12 V, where the initial performance was 78.4% at 1 V. The desalination efficiency of the capacitive deionization process is strongly dependent on initial TDS concentration, where ions are stored temporarily on the surface of an electrode. The total adsorption capacity of electrodes is increased further by the formation of a thick electrical double layer, thereby increasing TDS removal performance. The concept of capacitive deionization for the removal of TDS, nitrates, and ammonium ions has been developed, which showed much improved performance at a power consumption range of 0.45 and 5.35 kWh/$m^3$, where the concentration of TDS was in the range between 150 and 3000 ppm. No chemical treatment is needed for the reuse of electrodes [86].

An electrostatic charging system based on capacitive deionization technology was developed to demineralize water that contains carbon electrodes for the removal of As and TDS from potable water resources. 98.5% of As was removed, and the volume of rejected water was found to be 3% [87]. This technology is effective for the treatment of As from groundwater at a lower cost than conventional technologies. The advantages of this technology include low energy consumption, low maintenance costs, and no requirement for additives. Fouling issues at electrodes over a long run is one of the limitations of this method. TDS removal performance is decreased with the increase of TDS concentration due to the accumulation of ions on the surface of electrodes. A capacitive deionization system at a bench-scale level (total electrode surface area of a single cell is 0.7 $m^2$ and flow rate range of 300 to 500 ml/min) was developed for the treatment of water and wastewater streams including seawater desalination applications. More than 98% water recovery and 99% ion removal rate were achieved by the developed system. The application of this system was limited to the water containing a low ionic strength (< 300 ppm of TDS) due to the high pore volume and surface area characteristics of carbon electrode material [88].

The capacitive deionization technique is used to achieve higher TDS removal efficiencies under various operational conditions. TDS removal study was conducted using synthetic water containing sodium chloride with the initial TDS concentration of 1000 ppm, which was decreased to 90 ppm after each treatment. Improved efficiency with lower energy consumption, lower environmental pollution, and low-fouling potential is the noticeable advantages of this method. Its efficiency and operational stability almost remained constant up to the tested 72 cycles [89].

## 3. Conclusion

TDS as one of the preliminary chemical parameters is used to understand the extent of pollution in water matrices. A high TDS level in water impacts both health and the environment, and therefore TDS has to be removed below the permissible limits from the contaminated water matrices. In this review paper, various TDS removal technologies based on a membrane, ion, and temperature gradient for water treatment are discussed in detail. RO, nanofiltration, distillation, ultrafiltration, forward osmosis, and precipitation techniques have been used conventionally for the removal of TDS from water. RO is used for the treatment of ground, surface, brackish water, and industrial wastewater. Hybrid technologies, for instance, ion exchange and membrane, RO and membrane, seem to be promising for the removal of TDS from water. Nanofiltration technology is used for the removal of di- and trivalent ions, hardness, organics, and pathogens at a lower cost due to the requirement of lower operating pressure and comparatively fewer fouling issues. Ultrafiltration is an environment-friendly technology that has been developed for the removal of TDS from water due to its ease of operation, little waste generation, higher water recovery, and no or less requirement for chemicals. Although forward osmosis possesses several advantages, for instance, less energy requirement and higher water recovery, membrane fouling, lower flux and reverse salt diffusion, as a result of internal concentration polarization, limit the forward osmosis performance. The development of a high flux membrane at a low cost is a key to using this as a viable technology on a commercial scale. Precipitation as a complementary step for coagulation and flocculation is used to remove heavy metals and soluble compounds, which are converted into insoluble compounds in water. The simultaneous removal of multiple contaminants is achieved by the precipitation method.

Desalination, ion exchange, electrochemical techniques, and adsorption are used currently for the removal of TDS. Desalination is one of the cost-effective technologies that has been developed for TDS treatment, which works based on thermal, electric, and pressure principles. Ion exchange technology using resins that depend on the affinity between resins and ions has been developed for water softening and demineralization. Although this technology is used for the removal of toxic metals, ions, and organic ions, it cannot be used to remove any pathogens. This technology is used solely for the removal of selective ions rather than the reduction of the overall TDS of water. The electrochemical-based technologies are a potential option for the removal of TDS due to their ease of operation at a lower voltage range, less O&M cost, and no requirement for chemicals. EC technology is used to remove any specific or multiple contaminants at a time. Its performance is, however, strongly dependent upon the selection of pH, types, the number of electrodes, coagulation dose and its types, residence time, and current density. Deionization technology (e.g., capacitive deionization) that works based on an electric potential gradient between the electrodes, is used for the effective removal of charged pollutants from water. This technology is used to purify brackish water at a lower cost without using any chemical additives. Among various water treatment technologies, adsorption is fast, simple, affordable, and effective at a wider pH range. However, its application for removal of the specific pollutants removal in water may pose challenges. Although various TDS removal technologies have been developed to purify water, the issues pertinent to the sludge management, and hazardous waste, generated after water treatment are serious and have to be addressed in the future.

The development of RO membranes with less or no fouling issues, and high throughput is essential for the effective removal of TDS from various water matrices at a lower cost. Composite-based RO membranes may address fouling issues during TDS treatment. By considering the existing water reserves, the water rejection rate of RO-based technology needs to be reduced significantly without compromising the water purification performance. Advancement in materials designing and engineering is required further to increase TDS removal performance, which offers to obtain safe drinking water at a reasonable cost. The development of nanofilters specific to monovalent ions is required for the effective treatment of TDS. The development of porous materials with a desired porous range and tolerance towards free chlorine is required to fabricate nanofilters targeting to remove monovalent ions. The development of low-cost electrodes with a tunable polarity is needed further to treat water having a higher TDS range. Functionalized adsorbents with a high adsorption capacity need to be developed to treat water having a higher TDS range. TDS treatment technologies and/or their combination need to be selected based on water characteristics in order to increase TDS removal performance at a lower cost. The issues with toxic sludge generated after TDS treatment technologies need to be addressed, which poses serious threats to both health and the environment.

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