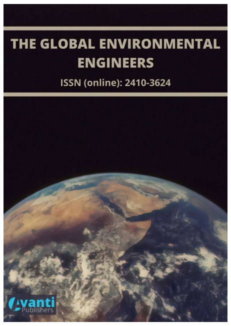
The Global Environmental Engineers, 2022, 60-102

Published by Avanti Publishers

The Global Environmental Engineers

ISSN (online): 2410-3624



Technologies for Halide Removal in Water Treatment – A State-of-the-Art Review

Elham Nariyan[1,2], Qiming Jimmy Yu[2], David Hamilton[3] and Qin Li[1,2,*]

[1]*Queensland Micro- and Nanotechnology Centre, Griffith University, Nathan, QLD 4111, Australia*
[2]*School of Engineering and Built Environment, Griffith University, Nathan, QLD 4111, Australia*
[3]*Australian Rivers Institute, Griffith University, Nathan, QLD 4111, Australia*

ARTICLE INFO

Article Type: Research Article

Keywords:
Iodide
Chloride
Bromide
Desalination
Disinfection-by-products

Timeline:
Received: November 15, 2022
Accepted: December 22, 2022
Published: December 27, 2022

Citation: Nariyan E, Yu QJ, Hamilton D, Li Q. Technologies for halide removal in water treatment – A state-of-the-art review. Glob Environ Eng. 2022; 9: 60-102.

DOI: https://doi.org/10.15377/2410-3624.2022.09.5

ABSTRACT

Halides (X=Cl, Br, I) are naturally present in water, and halide concentrations can be high in water sources that are impacted by high salinity. Halides are also present in wastewater streams from various industrial operations such as pulp and paper, oil and gas, and mining. Drinking water guideline limits have been established for halides, and halide removal from water is important in several ways. Chloride concentration in water is more related to salinity, and its removal from water matters because of adverse health effects, water scarcity, corrosion, and industrial needs. In drinking water treatment, disinfection is essential to improve water quality and prevent the spread of water born pathogens. However, disinfectants also produce harmful disinfection by-products (DBPs) from precursors such as halides and natural organic matter (NOM) in the source water. Removing halides in the source water before disinfection is a preferred option to increase the disinfection efficiency and avoid forming more toxic DBPs. Some industrial-made isotopes are radioactive and carcinogenic, and iodide produces iodinated DBPs. Bromide removal is important because it produces brominated DBPs. Halides also affect AOPs and can cause more active radicals such as OH. and SO4-. to transform into less active radicals. This paper aims to comprehensively review the sources of halides, the chemistry, and interaction in forming DBPs, current regulatory limits and state-of-art removal technologies available, and their challenges.

---

*Corresponding Author
Email: jimmy.yu@live.com.au
Tel: +(07) 373 55289

1. Introduction

Halide management is important in water treatment and desalination applications, specifically chloride, the most common precursor for disinfection by-product formation with natural organic matter (NOM). The existence of bromide and iodide during water purification with advanced oxidation processes can also produce hazardous disinfection by-products. Even with the removal of NOM from water, brominate can form, which is related to male infertile [1]. Some iodine isotopes have radioactive properties. This paper aims to provide a comprehensive review of the importance of halide removal, sources of halides in water, the chemistry and interaction in forming DBPs, current regulatory limits, and state-of-art removal technologies available. The removal technologies' effectiveness, advantages, and disadvantages are compared in depth. The challenges of halide removal are also discussed.

1.1. Importance of Halide Removal

1.1.1. Chloride

The majority of water on Earth is seawater (59%) and brackish water (22%) [2]. Seawater desalination for agricultural, domestic, and industrial water purposes has been increasingly used in arid and semi-arid regions such as the Middle East [3, 4], Spain, and Australia [4]. Seawater desalination for irrigation is critically involved with chloride removal because chloride constitutes more than half of the seawater salts. The other ions in seawater, such as Ca^{2+}, Mg^{2+}, and SO_4^{2-}, can be desirable for plant nutrition in agriculture [4]. Excessive chloride has significant negative impacts on crops and infrastructure lifetime. The corrosiveness of chloride ions has a far-reaching negative impact on infrastructure sustainability; chlorides corrode metallic pipes, concrete, electrodes used to extract metals from ores, heat exchangers, and Kraft recovery furnaces, amongst others [5-11]. Without chloride removal, significant operational disruptions and financial damages can occur to industries and communities [5, 12-14]. For example, bridge corrosion by chloride was estimated to cost USD 275.7 billion/per year and USD 123 billion in the USA in 1998 [12] and 2017, respectively [15]. Such infrastructure in contact with seawater or de-icing brines is highly prone to be corroded [16].

1.1.2. Iodide

Iodine can be produced via pharmaceutical industry wastes. Different isotopes of iodine are also produced within the plutonium and uranium fission reactions. Exposure to these iodine isotopes can lead to thyromegaly, leukemia, thyroid cancer, and metabolic disorders [17-20]. Moreover, in the context of nuclear energy systems, it is critical to ensure the safe handling and storage of radioiodine, such as ^{129}I and ^{131}I. Because of the long half-life of iodine (^{129} I = 15.7 million years), it is critical to regulate its discharge to waterways [18, 21] and minimizes human and environmental exposure [19, 20]. The most common chemical forms of I in nuclear wastes are iodide (I^-) and iodate (IO_3^-) [22-24], and iodide concentrations have been recorded to be up to 42 mg/L in leachate from radioactive waste [24].

Until 1998, 2360 kg of ^{129}I was released into seawater by Sellafield Ltd (UK) and at La Hague (France). In addition, from 1944-1972, plutonium production at the Hanford Site (Washington) released 266 kg of ^{129}I into the air [21]. The Chornobyl (Ukraine) and Fukushima (Japan) nuclear disasters released high amounts of iodine into the environment [25-27]. Water released from the Fukushima disaster contained 6.9-52 % ^{131}I. The Chornobyl disaster released 1,760 Petabecquerel (PBq) ^{131}I and other isotopes of iodinem, including 1,040 PBq $^{132}Te/^{132}I$, 910 PBq ^{133}I, 250 PBq ^{135}I, and 25 PBq ^{134}I [28]. Digestion or inhaling of ^{131}I can result in thyroid diseases such as goiter, autoimmune thyroiditis, and thyroid cancer [25, 29, 30], and iodine concentrations >0.1 mg/L can irritate the eyes and lungs, and cause bronchitis, diarrhea, weight loss, and tremors [31].

Water discharges from mines for iodine [32], uranium [23, 24], gold, and silver [33, 34] contain iodine, and uncontrolled discharges to the environment need to be avoided [35].

Disinfection by-products (DBPs) associated with the chlormination of drinking water treatment contain iodide. Iodinated DBPs are more genotoxic and cytotoxic than chlorinated and brominated DBPs, and strict public health regulations for iodide are therefore in place [36, 37].

1.1.3. Bromide

Bromide affects the taste and odor of water [38]. It also produces brominated DPBs (Br_2, HOBr, and OBr^-) when it reacts to natural organic matter (NOM) [37, 38] and halo acetic acids (HAAs) [39]. The toxicity index of brominated DBPs is $>10^4$ times greater than that of chlorinated counterparts. Also, brominated DBPs are more reactive than their chlorinated counterparts (Table **1**), aggravating the situation [36]. At elevated bromide concentration (500 µg/L), broform ($CHBr_3$) concentrations can be 70-174 µg/L [39].

Bromide and iodide removal prior to disinfection can reduce highly toxic DBPs [38]. Furthermore, the absence of bromide and iodide makes applying other kinds of disinfectant feasible because the oxidation of the iodide/bromide would not be a problem [38]. In addition, water treatment's capital and operational cost would decrease [40].

1.2. Effect of Halides on the Advanced Oxidation Processes (AOPs)

Halides can affect the water treatment processes, including desalination. Two-step desalination with RO became mandatory in Australia to ensure no bromide was left [41]. The most concern of halides in the water treatment processes lay in the advanced oxidation processes.

Halides can affect AOPs by decreasing the activity of free radicals, altering kinetic reactions, and therefore affecting DBP formation. AOP in saline water can be human-made to avoid membrane biofouling in reverse osmosis [42]. Also, in seawater, AOP can happen naturally, in which solar radiation can make hydroxyl (OH•) or dissolved organic matter (DOM•) radicals in seawater. Then these radicals react to halide and make halide radicals, leading to AOP occurring naturally [43].

The water matrix should be considered when applying AOP [44]. AOP in high saline waters such as seawater has a different effect than wastewater, and considerations should be taken [44, 45]. The high chloride content in seawater could decrease the mass transfer of oxidants. This leads to lower disinfectant concentration in seawater than in drinking water [44]. Also, high salinity in seawater can change the solubility of gaseous oxidants. The effect is called the salt-in and salt-out effect [46]. Chloride accelerates AOPs (mostly from $OH^\bullet$ and $SO_4^\bullet$) but forms toxic chlorinated intermediates [47]. It suppresses mineralization rates and accumulates absorbable organic halides (AOXs) [48].

Elevated halide concentrations inhibit the degradation of free radicals acting as radical scavengers above a certain level [45]. Degradation of acid orange 7, benzoic acid, phenol, and couramin with persulfate does not inhibit 0-0.2 mM bromide [45]. An increase of halide concentration leads to a change in the more active radicals ($OH^\bullet$, $SO_4^{\bullet-}$, $Cl^\bullet$) to less active radicals ($Br_2^{\bullet-}$, $Cl_2^{\bullet-}$, $BrCl^{\bullet-}$) [49-51], which may degrade more slowly, but the lower rate radical loss lead to reach higher radical concentrations [49, 50, 52, 53].

The effect of halide on various disinfectant materials of persulfate, hydrogen peroxide, UV, and Cl_2/HOCl is explained here.

Persulfate is one of the oxidants being used for disinfection. Persulfate is not suitable for advanced oxidation in highly saline water [47], especially for water with low pH [47, 54], because high chloride concentrations increase AOXs, which leads to increases in chlorinated DBPs and acute toxicity [47]. Unless halide concentrations in water are small, halide reduces persulfate removal efficiency [55-65]. For example, low concentrations of chloride and bromide enhance the degradation efficiency of AO7 with persulfate [54]. $Cl_2^{\bullet-}$ is the primary oxidant of acid orange 7 (AO7) in the presence of chloride [45, 54], while $SO_4^{-\bullet}$, $Br^\bullet$, and $Br_2^{-\bullet}$ are primary oxidants for AO7 degradation with persulfate [45] in the presence of bromide. In acidic conditions, $Cl^\bullet$ is formed from advanced persulfate oxidation, but $Cl_2^{\bullet-}$ is formed at neutral pH and plays a vital role in the degradation of AO7. In alkaline conditions, $ClOH^\bullet$ is formed, which is not stable and is converted to $OH^\bullet$, which also plays a vital role in the degradation of AO7 [54].

Hydrogen peroxide form bromate based on OH radical mechanism. Hydrogen peroxide reacts with bromide forming BrO_2^- which reacts with hydroxyl radical, forming bromate [66]. However, at very high bromide concentrations (e.g., 158 mg/L), OH radicals are scavenged (>90%) by halides to produce halide radicals [44, 67-69], and no bromate is formed [44]. The increases in concentrations of $Br_2^{\bullet -}$ and $BrCl^{\bullet -}$ are almost 3-4 times higher than concentrations of $OH^{\bullet}$ [49, 52, 70]. Bromide in seawater is a scavenger for hydroxyl radicals, while chloride is not. Because bromide reacts with hydroxyl radicals to form $BrOH^{\bullet -}$, which is transformed into $BrCl^{\bullet -}$ (efficiency 73%) and $Br^{\bullet}$ (efficiency 3%). When chloride reacts with hydroxyl radicals, it forms $ClOH^{\bullet -}$. However, it is not stable, and 99.98% of it converts to its initial form of $OH^{\bullet}$ and Cl^-. Bromide plays a key role in scavenger hydroxyl radicals [67, 71].

High salinity can affect the AOP and disinfection efficacy where UV radiation is used for disinfection because of decreases in the optical pathway of irradiation [44]. Alternatively, UV is the best disinfection method in high saline water because UV quenches chlorine and does not produce DBPs [42]. However, chloride has a negative impact on the H_2O_2/ UV [72] and UV/TiO_2 advanced oxidations [73].

Ozone reacts with bromide in seawater to produce OBr^- and HOBr at neutral pH values [74, 75]. OBr^- and HOBr are transformed into BrO_3^- in nonacidic conditions and low ammonia concentrations. Bromate is classified as carcinogenic by WHO and USEPA [42] and is the main reason for DBP formation [66].

Disinfectants chlorine and HOCl convert to each other depending on the pH aqueous. The application of chlorine and HOCl should be considered carefully when applying in different water matrices (e.g., bromide). With the application of chlorine in drinking water, chloroform is the primary concern for DBP formation, while in seawater, bromoform is more dominant than chloroform [44]. Chloroform forms with the application of chlorine for drinking water disinfection, while chlorine application in seawater forms bromoform majorly than chlroform [44]. Another concern in seawater with the application of chlorine is bromate formation. Because in seawater, chlorine oxidizes bromine to form BrO^- and HOBr. This causes bromate and DBPs formation [44]. One of the examples is brackish water (with 35 mg/L Br_2), in which 85-100% of THMs formed contain bromine [44]. AOP with HOCl affects by the presence of bromide in the water matrix. For example, the reactivity changes with bromide in the AOP process with UV/HOCl [50, 53]. HOCl transforms to HOBr, and $ClBr^{\bullet -}$and loses the hydroxyl radical [53], and with HOCl conversion to HOBr, the degradation of organic substrates increases [50, 53].

In saline waters, $OH^{\bullet}$ and $SO_4^{\bullet -}$ scavenge the chloride and bromide. General reactions of halides that can inhibit or enhance the AOP are presented below (Eq. 1-Eq. 7) [52, 54, 73, 76, 77].

$$SO_4^{\cdot -} + Cl^- \rightarrow SO_4^{2-} + Cl^{\cdot}\ k = (3.2 \pm 0.2) \times 10^{8}\mathrm{M}^{-1}\mathrm{S}^{-1} \qquad \text{Eq. 1}$$

$$Cl^{\cdot} + Cl^- \rightarrow Cl_2^{\cdot -}\ k = 6.5 \times 10^{9}\mathrm{M}^{-1}\mathrm{s}^{-1} \qquad \text{Eq. 2}$$

$$Cl^{\cdot} + OH^- \rightarrow ClOH^{\cdot -}\ k = (4.3 \pm 0.4) \times 10^{9}\mathrm{M}^{-1}\mathrm{s}^{-1} \qquad \text{Eq. 3}$$

$$ClOH^{\cdot -} \rightarrow Cl^- + OH^{\cdot}\ k = 6.1 \times 10^{9}\mathrm{M}^{-1}\mathrm{s}^{-1} \qquad \text{Eq. 4}$$

$$ClOH^{\cdot -} + Cl^- \rightarrow Cl_2^{\cdot -} + OH^-\ k = 1.0 \times 10^{5}\mathrm{M}^{-1}\mathrm{s}^{-1} \qquad \text{Eq. 5}$$

$$ClOH^{\cdot -} + \ H^+ \rightarrow Cl^{\cdot} + H_2O\ k = (2.6 \pm \ 0.6) \times 10^{10}\mathrm{M}^{-1}\mathrm{s}^{-1} \qquad \text{Eq. 6}$$

$$Br^- + SO_4^{\cdot -} \rightarrow Br^{\cdot} + SO_4^{2-}\ k = 3.5 \times 10^{9}\mathrm{M}^{-1}\mathrm{s}^{-1} \qquad \text{Eq. 7}$$

Zhang and Parker (2018) have developed a comprehensive computational modeling procedure for the kinetics of halide radicals [43]. The reactivity of halogen radicals with different organic substrates is shown in Table **1**.

2. Sources of Halides in Water

2.1. Chloride

Seawater intrusion (3-3.8% NaCl) and de-icing of roads (20-30% NaCl/$CaCl_2$ de-icing brines) are the primary sources of chloride release into water and damage the infrastructures by their corrosion [16]. Other sources of

Table 1: Kinetic rate of X radicals and HOX/OX$^-$ with organic materials. X=Cl, Br, I.

	k **(M^{-1} s^{-1})**	**Reference**
	Saturated aliphatic compounds	
$Cl^{\bullet}$	**10^7-10^9**	[78-81]
$Cl_2^{\bullet -}$	**10^3-10^7**	[82, 83]
$Br^{\bullet}$	**10^4-10^8**	[83]
$Br_2^{\bullet -}$,	**Below 10^6**	[43]
$I_2^{\bullet -}$	**Below 10^6**	[43]
	Olefinic compounds	
All halogen radicals except $I^{\bullet}$ and $I_2^{\bullet -}$	10^6-10^9	[83-85]
	Aromatic compounds	
Halogen radicals	< 10^5-10^{10}	[82-84, 86-90]
	Organosulfur species	
Halogen radicals	< 10^6-10^{10}	[82, 88, 91-93]
	organic substrates	
HOCl and HOBr rate constants	< 10^{-2}-10^7	[94-96]
OCl^-, OBr^-	Reacts slowly 10^{-2}-10^7	
	Aromatic	
HOCl and HOBr	10^{-2}-10^7	
	Amino substrate	
	10^1-10^6	
	Olefinic substrate	
	~ 10^0-10^6	
	Organosulfur substrate	
	10^5-10^8	

chloride are the kraft pulping process which turns wood into wood pulp. Chloride comes from electrostatic precipitator catch or dust (ESP dust), which consists of 1-10% wt chloride [97]. Chloride would be released from ESP because chlorine is one of the process elements which enters the kraft pulping process with wood and other chemicals and will accumulate [98]. The boiler burns the black liquor containing organic and inorganic materials such as chloride [99]. Chloride concentration from the inland mill is 0.1-0.8% of the liquor dry solid, while for the coastal mill, chloride concentration could be as high as 3-5%, and in the closed process, chloride concentration could be even higher [99]. Mining water also could contain high chloride concentrations, depending on the geological location, dissolved metals, and deposit characterizations in contact with water. The mines that release a large quantity of chloride into water are radio-nucleolus uranium and coal mines [100]. However, they have a different chemistry from each other. In particular, coal mine water is usually neutral, with an elevated TDS, high electrical conductivity, and high chloride concentration, which will turn into saline mine water [100]. Other than that, if the water is in contact with the tailings containing chloride, called tailing water, it would have high chloride concentrations due to the leaching of chloride into water [100]. For example, Polish mine water drainage contributed 6,500 tonnes of chloride in the Wisla and Odra rivers, which disqualified the water from being suitable for drinking or agriculture. Also, this leads to increased corrosion of pipes [101]. Most of Upper Hunter Valley's open pits have saline mine water (chloride concentration from 3100-6580 mg/L), used chiefly for coal washing and dust suppression [102]. In Kent Coalfield (UK), chloride concentration was 318,000 tonnes (up to 5000 mg/L) in mine drainage water [103]. If not addressed, this degree of salination caused by mined water would result in heavy penalties for the mining industries [101]. The produced water (the resultant water after the oil and gas activities) also contains high chloride concentrations [104-106]. Chloride concentration in produced water could reach 250,000 mg/L [105]. For example, chloride concentrations in the water produced from Louisiana and Texas platforms were reported to have 37,000-110,000 and 28,000-73,000 mg/L, respectively [107]. Josephine Brine Treatment in Pennsylvania had 80542 mg/L of chloride in the effluent. Moreover, the chloride concentration in Blacklick Creek was 55 000 and 98 000 mg/L [108].

The produced water from the extraction of shale gas (SG) and tight gas (TG), or conventional natural gas, is saline (>30 g/L chloride) and hypersaline (> 40 g/L chloride), respectively. Wastewater from hydraulic fracturing during oil and gas extraction contains very high levels of halide concentration and requires treatment processes precisely to remove halides to avoid toxic DBP formation [109]. However, coalbed methane (CBM) produced waters have less than 30 mg/L chloride ions [104]. Chloride concentration in the produced water from the oil field, gas field, steam gravity drainage (SAGD), and coal gas steam (CGS) reaches 152,750 mg/L, 2,300 mg/L,4,800 mg/L, and 3,100 mg/L, respectively [110]. The coal seam water has a high concentration of sodium, chloride, and bicarbonate (salinity 1,500-10,000 mg/L) [111, 112]. Australian (QLD) coal seam water contains more chloride (500-2000 mg/L) than bicarbonate [111, 113]. The coal seam water in Queensland, Australia, has < 5910 mg/L chloride [114], whereas in New Zealand and the USA chloride concentration is lower, in the range of 49.3-146 mg/L [114]. Chloride concentrations in produced water and some coal seam gas water are presented in Table **2**. Salt concentration becomes more critical when oil/gas operations occur onshore [105]. At a higher amount of chloride, corrosion and fracture in reactors and vessels will happen. Therefore, keeping chloride concentration as low as possible is necessary for feeding oil [115]. The offshore produced water will be released into the sea, which might endanger aquatic life [105]. If produced, water leaks to surface water could damage the ecosystem drastically [113].

Table 2: Chloride concentration in produced and seam gas water [104, 114, 116].

Produced Water (Coalbed Methane)		**Produced Water (Shale Gas)**				**Reference**
min	**max**	**Min**	**Max**			
0.7	70100	48.9	212700			[104]
Tight Gas		**Conventional Natural Gas**		**Flowback Water (Marcellus Shale)**		
min	max	Min	Max	min	max	
52	216000	1400	190000	32000	148000	[104]
Seam Gas Water						
Southern tenements (Surat) –WB – 56 wells		**Moranbah area (Bowen) –WB – Blackwater Group coal formation – 58 wells**				
min	max	Min	Max			
28	5870	1151	4500			[116]
Coal Seam Gas, Surat Basin, Queensland						
Field A (54 wells)		**Field B (73 wells)**		**Field C (23 wells)**		
min	max	Min	Max	min	max	
471	4390	875	2930	823	5910	[114]

2.2. Iodide

Human activities also can lead to iodine in the water, such as the liquid crystal display (LCD) polarizing films industry, which could release very high amounts of iodine/iodide in their wastewater, such as 10.2 g/L or (1-1.5 wt%) of I^- [20, 117, 118], with the flow rate of 100-300 m^3/day [119]. Typical wastewater treatment plants cannot treat the wastewater produced by the TFT-LCD industry due to the possibility of a biocidal effect on microorganisms [117, 118]. Nuclear fission is the other way that iodine (mostly iodide and iodate) enters the water [22, 118, 120]. Moreover, mining activities and produced water from gas production could also cause the release of iodine into waterways [31, 117, 121, 122]. A small spill of shale gas wastewater increased iodide up to 28 mg/L in the surface water [123]. Iodine was found in the Oko uranium deposit in Gabon. As a result of the fission reaction, the heavy elements (Kr, Xe, Rb, Cs, Sr, Ba, Mo) and I are very mobile [124]. The migration of ^{129}I in four uranium ore deposits of the Alligator Rovers region, Northern Territory, Australia, was reported by Fabryka-Martin et al. [125]. The weathering of the deposits contains iodine. In the case of Alligator Rovers region deposits, the -FeOH groups in ores, such as goethite FeO(OH), were likely the groups where iodide sorption occurred. The weathering of deposits resulted in a robust partitioning of ^{129}I in the groundwater, which depends on the distance to the ore place [125]. These iodine extractions lead to water contamination for the people who live near the mining site, which urged the local population to use the desalination plant treatment [122]. Another example is Southeastern Nigeria's abandoned mine sites, where iodide concentrations were found at 0.013-0.05 mg/L [126].

The last but not least way of entering iodine into waterways through human activity is the chemical wastes of x-ray, disinfection, and medical (nuclear medicine) dumps, because of iodine application in these industries [22, 120].

2.3. Bromide

Today, bromine is used in flame retardants [127] and biocide in various waters, including pool water, cooling water, industrial water treatment [127], and photo industries [127]. All of these industries would release bromide into the waters. Road salts and some fertilizers also bring bromide into water [128]. Textile industries that produce flameproof fabrics use brominated compounds, which would lead to bromide release into water [128].

Scrubbers in coal-fired power plants [128, 129], incinerations [130], mining activities [131], and gas extractions industries, including hydraulic fracturing in natural gas extraction, release a massive amount of brines containing a high concentration of halides [108, 109, 123, 127].

Coal-fired power plants release bromide into their wastewater within 2 pathways. One is coal that has bromide from 1-2 mg/L in sub-bituminous coal to bituminous coal with 20 mg/L [132]. Secondly, bromide salt is added to the flu gas to make mercury more soluble and more accessible to be removed. However, in the end, bromide would accumulate into wastewater of flue gas. Therefore, for making 1 MW of electricity, 0.23-2.8kg/day of bromide is released into the wastewater [128]. A coal fire plant has increased bromide in the Allegheny River-Pennsylvania up to 410 µg/L [133].

In Switzerland, the chemical industry (50%) and municipal waste incarnation (20%) contributed most to bromide release into water [134].

Mining water from potash deposits in Saskatchewan, Canada, showed 28500 mg/L bromide [131].

Gas extractions produce flow backs and produce waters that are highly brine, and their bromide concentration would be very high. Josephine facility in Pennsylvania USA, a brine facility in Pennsylvania for hydraulic fracturing water treatment, showed had 601- 8,290 mg/L bromide with a flow rate of 155,000 gal/day [128]. The oil and gas industry (produced water) can release a significant amount of bromide into the water, such as 3070 mg/L in USA shale [131].

When bromide concentration is less than 0.1 mg/L, it was shown that the number of DBPs produced would be considerably lower [135]. Nonetheless, even bromide concentration from 50-100 µg/L would lead to the formation of hazardous DBP [136].

The summary of bromide concentration in various water substrates has been presented (Table **3**) [37, 40, 136-141].

Human activities that lead to excess halide release into the environment have been summarized below (Fig. **1**).

Table 3: Bromide concentration in various water substrates.

Substrate	Bromide Concentration	Additional Information	Reference
Natural Waters	100–3000 µg/L	Br: I 10:1, Cl: Br 100-200	[37, 138-140]
Brackish Water (study)	1, 5, 10 mg/L		[136]
Freshwater	0.5 mg/L		[137]
Sea Water	65-80 mg/L	Cl: 18980 mg/L to over 23000 mg/L	[141]
Desalinated Water	1 mg/L		[137]
Moderate Bromide Concentration	0.5-1.2 mg/L		[40]

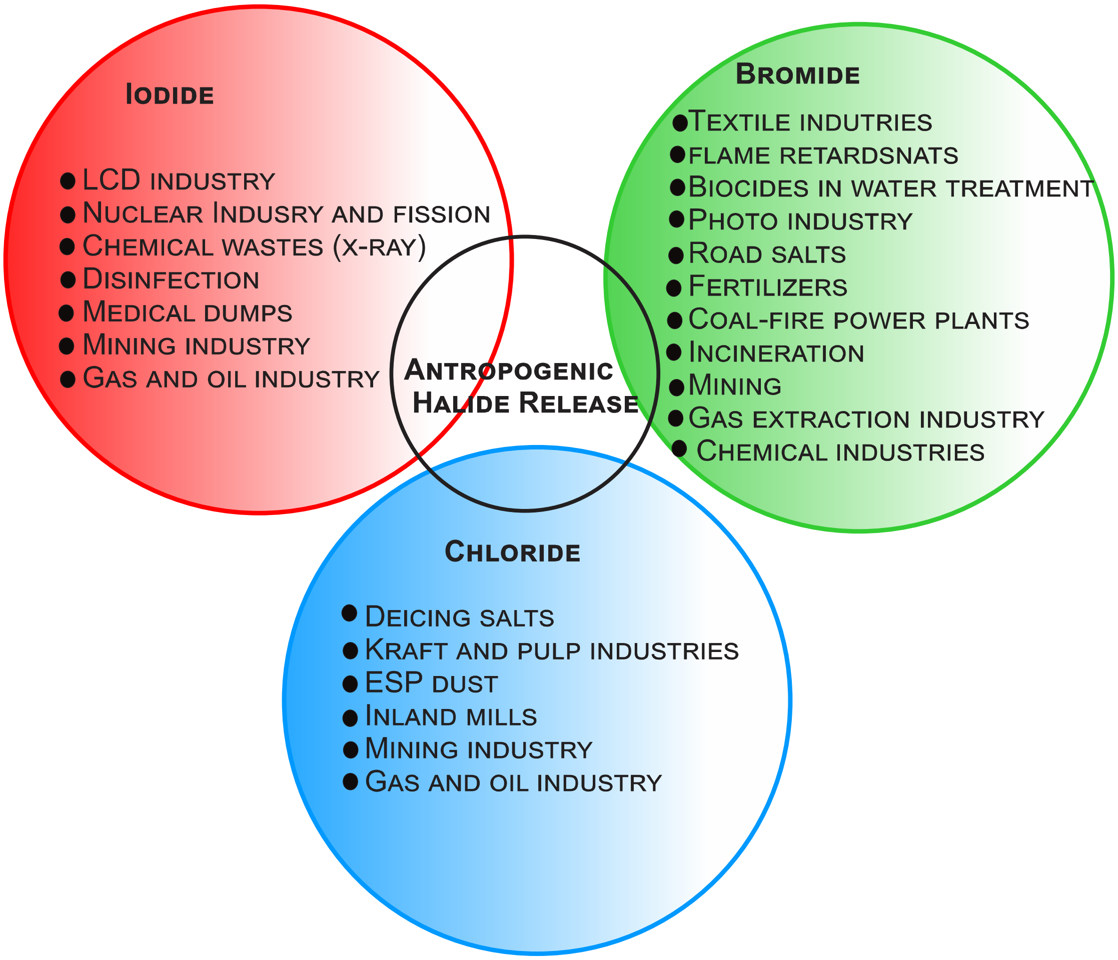


Figure 1: Summary of anthropogenic activities that lead to halide release into the environment.

3. Chemistry of Halides

Iodine to iodide conversion requires +0.54 V (standard reduction potential), while Cl_2/Cl^- standard reduction is +1.36 V, and Br_2/Br^- has the standard reduction potential of 1.09 V (Eq. 8, Eq. 9, Eq. 10). Also, the first ionization energy for Cl, Br, and I are 1251, 1140 kJ, and 1008 kJ/mol, respectively. This depicts that oxidizing power follows $Cl_2>Br_2>I_2$ [31].

The oxidation power of halogen radicals ($X^{\cdot}$) gets higher than halogen gas (X_2). Reduction potentials for halide radicals are as follows $Cl^{\cdot}$ (2.5 V), $Cl_2^{\cdot -}$ (2.2 V), $Br^{\cdot}$ (2 V), $Br_2^{\cdot -}$ (1.7 V), $I^{\cdot}$ (1.4 V), $I_2^{\cdot -}$ (1.1 V) [142].

$$I_{2(s)} + 2e^- \rightarrow 2I^-_{(aq)}\ E^o(volts) = 0.54 \quad \text{Eq. 8}$$

$$Br_{2(l)} + 2e^- \rightarrow 2Br^-_{(aq)}\ E^o(volts) = 1.09 \quad \text{Eq. 9}$$

$$Cl_{2(l)} + 2e^- \rightarrow 2Cl^-_{(aq)}\ E^o(volts) = 1.36 \quad \text{Eq. 10}$$

Halogen gas (X_2=Cl_2, Br_2, I_2) reacts with water, produces hypohalous acid and halide, and makes the water acidic. Previously, the rate constants of halogen gas dissolution in water and other related halides reaction had been calculated (Table **4**). Halogen gas reaction with water undergoes the reaction shown in Table **4** and Fig. **2**) [118, 143, 144].

Table 4: Halid reactions and their rate constants.

Reaction Number	Reaction	*K*	Reference
		Rate Constant $M^{-1}s^{-1}$	
1	$H^+ + OCl^- \rightarrow HOCl$	5.0×10^{10}	[145]
2	$HOCl \rightarrow H^+ + OCl^-$	1.6×10^{3}	
3	$Cl_2 + Cl^- \rightarrow Cl_3^-$	2.0×10^{4}	[146]
4	$Cl_3^- \rightarrow Cl_2 + Cl^-$	1.1×10^{5}	
5	$Cl_2 + H_2O \rightarrow Cl^- + HOCl + H^+$	22.3	[143]
6	$Cl^- + HOCl + H^+ \rightarrow Cl_2 + H_2O$	18.2±0.7	
7	$H^+ + BrO^- \rightarrow HBrO$	5.0×10^{10}	[145]
8	$HBrO \rightarrow H^+ + BrO^-$	7.9×10^{1}	
9	$Br_2 + Br^- \rightarrow Br_3^-$	9.6×10^{8}	[146]
10	$Br_3^- \rightarrow Br_2 + Br^-$	5.5×10^{7}	
11	$HBrO + Br^- \rightarrow Br_2OH^-$	5×10^{9}	[147]
12	$Br_2 + H_2O \rightarrow Br_2OH^- + H^+$	97±7	[144]
13	$Br_2OH^- + H^+ \rightarrow Br_2 + H_2O$	2×10^{10}	[147]
14	$Br_2OH^- \rightarrow HOBr + Br^-$	5×10^{9}	
15	$I_2 + H_2O \leftrightarrow I^- + H^+ + IOH$	4.3×10^{-13}	
16	$I_2 + I^- \leftrightarrow I_3^-$	830	
17	$IOH \leftrightarrow H^+ + IO^-$	2.3×10^{-11}	
18	$IO^- + I^- + H_2O \leftrightarrow I_2OH^- + OH^-$	0.13	
19	$H_2O + I_2 \leftrightarrow H_2O.I^+ + I^-$	1.2×10^{-11}	
20	$I_2 + H_2O \rightarrow OI^- + 2H^+ + I^-$	2.0×10^{-13}	[118]
21	$I_2 + 2OH^- \rightarrow I^- + H_2O$	30	
22	$3OI^- \rightarrow 2I^- + 3IO_3^-$	10^{20}	

As mentioned above, in the halogen group going down from chlorine to iodine, the halogens' oxidative activity would reduce [31], but OX^-/HOX (X=Cl, Br, I) acts differently. For example, the rate constant of HOBr with halophenolates and phenolate is 3000 times more than the reaction of these organic materials to HOCl [95].

Chloride is highly soluble under all pH and E_h values unless high voltage is being applied to oxidize chloride to ClO_4^-even in the case of ClO_4^- would still be soluble. Therefore, it shows that removing chloride would be a challenge due to its high solubility [148].

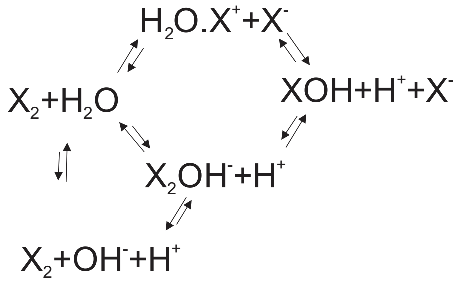


Figure 2: Halogen gas reaction with water [147].

Iodate and iodine are prevalent in low pH and high E_h values. In other conditions, iodide is common [149]. However, iodine in water will react and produce iodide and hypoiodite (OI^-) [118]. Likewise chloride, bromide is also very soluble in various conditions of E_h-pH [148]. Therefore, bromide removal is also challenging because of its high solubility.

4. Limits and Regulations

A summary of halide concentrations in different water applications has been provided Table 5. More regulations are set for chloride than for the rest of the halides. Unfortunately, no regulations have been set for bromide in water. Because bromide is not considered toxic, industries do not need to report its concentration [128]. However, the safe concentration of bromide in water by various studies has been indicated (Table **5**). Australian water regulation suggested having a bromide concentration below 0.1 mg/L because of bromate formation in the oxidation process. Specifically, they suggested that if bromide is less than 0.1 mg/L in water, it would contain less than 0.02 mg/L bromate, with Australian regulation alignment. However, they did not set any

Table 5: Various levels of halides regulations and suggestions for different applications.

-	Concentration	Regulated Organization	Comments	Ref.
Chloride	250 mg/L	Australian guidelines and WHO	drinking water	[150-152]
	500 mg/L	IEPA	surface water	[153]
	94 mg/L	NA.	below risk limits for the ecosystem	[154]
	< 105 mg/L	NA.	Water for agricultural application	[3]
	2000 mg/L	Qld. regulation	livestock consumption	[114]
	< 0.4% by mass of cement in acid-soluble, <0.15% by mass of cement in water-soluble environments	-	reinforced concretes in Europe and North America	[7]
Bromide	< 60 µg/L	NA.	Low risk	[40]
	60-500 µg/L	NA.	Moderate risk	
	> 500 µg/L	NA.	High risk	
	< 50 µg/L	NA.	Low risk	[38]
	110 µg/L	NA.	Moderate risk	
	76-540 µg/L	NA.	Moderate to high risk	
	~700 µg/L	NA.	Very high v	
	> 100 µg/L	NA.	Will cause bromate	[150]
Iodide/Iodine	4-18 µg/L (Iodine)	WHO	USA drinking water	[155, 156]
	0.5 mg/L (Iodide)	Australian guidelines	drinking water	[150]

direct regulations for bromide itself [150]. When bromide concentration increases by 50 µg/L, the bladder cancer risk would increase by 10^{-4}-10^{-3} due to THM formation [129].

The effect of halide on DBPs formation is significant. A summary that shows regulated DBPs with their risks is shown in Table **6**. This signifies why halide removal matters.

Table 6: Summary of regulated DBPs during and their health issues.

Class of DBPs		**Compounds**	**Health Effects**	**Occurrence**	**Genotoxicity**	**Carcinogenicity**	**WHO Guideline Value µg/L**	**USEPA µg/L**	**Australia µg/L**	**Ref.**
Total THM	Trihalomethanes (THM)	Chloroform	Cancer, liver, kidney, and reproductive effects	low- to mid µg/L	-	+	200	Total THM 80	Total THM 250	[157-159]
		Dibromochloromethane	The nervous system, liver, kidney, and reproductive effects				60			[157-159]
		Bromodichloromethane	Cancer, liver, kidney, and reproductive effects	low µg/L	+	+	60			[157-159]
		Bromoform	Cancer, liver, kidney, and reproductive effects	low µg/L	+	+	100			[157, 159]
Trihalomethanes (THM)		Chlorodibromomethane	chromosomal aberrations or sister chromatid exchanges, hepatocellular tumors	low µg/L	+	+	100		-	[158, 160]
Haloacetonitrile (HAN)		Trichloroacetonitrile	Cancer, mutagenic and clastogenic effects	sub- to low-µg/L levels	+					[157]
		Dichloroacetonitrile	No data yet	sub- to low-µg/L levels	+		20			[158].
		Dibromoacetonitrile	No data yet	sub- to low-µg/L levels	+		70			[158].
Halogenated aldehydes and ketones		Formaldehyde	Mutagenic	sub- to low-µg/L levels	+	+	900		500	[157-159]
Haloacetic acids (HAA)		Dibromoacetic acid	hepatocellular tumors, lung tumors, mesothelioma, Leukaemia	low- to mid µg/L	+	+		Total HAAs 60		[158, 161]
		Bromoacetic acid	No cancer studies performed	sub- to low-µg/L levels	+					[158, 159]
		Chloroacetic acid		sub- to low-µg/L levels	+	-			150	[158, 159]
		Dichloroacetic acid	Cancer and reproductive and developmental effects	low- to mid µg/L	+	+	50		100	[157-159]
		Trichloroacetic acid	Liver, kidney, spleen, and developmental effects	low- to mid µg/L	-	+	100		100	[157, 159]
Halocarbonyl compounds		Chloral hydrate	Skin allergy, carcinogenic,	low µg/L	+	+	10		100	[157-159, 162]
Oxyhalides		Bromate	Renal tumors	sub- to low-µg/L levels	+	+	10	10	20	[158, 159, 163-166]

5. Technologies for Removing Halides

5.1. Chloride

There are various technologies for removing chloride (desalination). Selection of a suitable process for chloride removal depends on the ease of operation, its effect on the environment/plant location, the amount of investment, and the cost of maintenance and operations [10, 167]. Various methods have been employed for chloride removals, such as chemical precipitation, electrochemical remediation technology, membrane technologies (non-thermal like RO and thermal like MD), adsorption, and ion exchange.

Chemical/electrochemical precipitation with UHLA produces insoluble minerals of double-layered Friedel salt. The disadvantage is that existing of other anions, including sulfate, decreases chloride removal efficacy [168-170]. Chloride precipitation with silver nitrate is expensive because the silver loss in this process is inevitable [171]. Produced waters with high chloride concentrations will use RO and thermally driven technologies such as MD for chloride removal [104]. ZDL will be used to recover brine for zero discharge pollutants [105].

Primary desalination treatments are happening with RO at 58.65%, MSF at 26.95%, and MED at 9.51% (Fig. **3**). Maximum capacity of various technologies' desalination is shown in Fig. (**3** and **4**). Data related to the graphs are presented in Table **7** and Table **7**. The CAPEX and OPEX of leading technologies for a typical treatment capacity are shown in Fig. (**5**). Here, we separated RO, MSF, MED, and ED as major desalination technologies and the rest as non-major desalination technologies. This category was made based on the technologies' capacities. From Fig. (**5**), RO has the highest OPEX and lowest CAPEX. Nonetheless, MED and MSF have higher CAPEX and lower OPEX. Therefore, selecting the technology should be based on preference and considering which outweighs the OPEX or CAPEX. Unfortunately, information about ED CAPEX was not found. On the other hand, the CAPEX of those technologies (MSF and MED) are higher than RO. CAPEX of RO is 1313, MSF is 1598, and MED is 1,860 US $/m^3/day (Fig. **5a**). OPEX of RO could be varied from 0.2-12.99 US$/m^3, while other technologies costs are less comparatively. For example, MSF 0.2-1.75, MED 1.36-1.6, ED 0.015-1.05 US $/m^3 (Fig. **5b**).

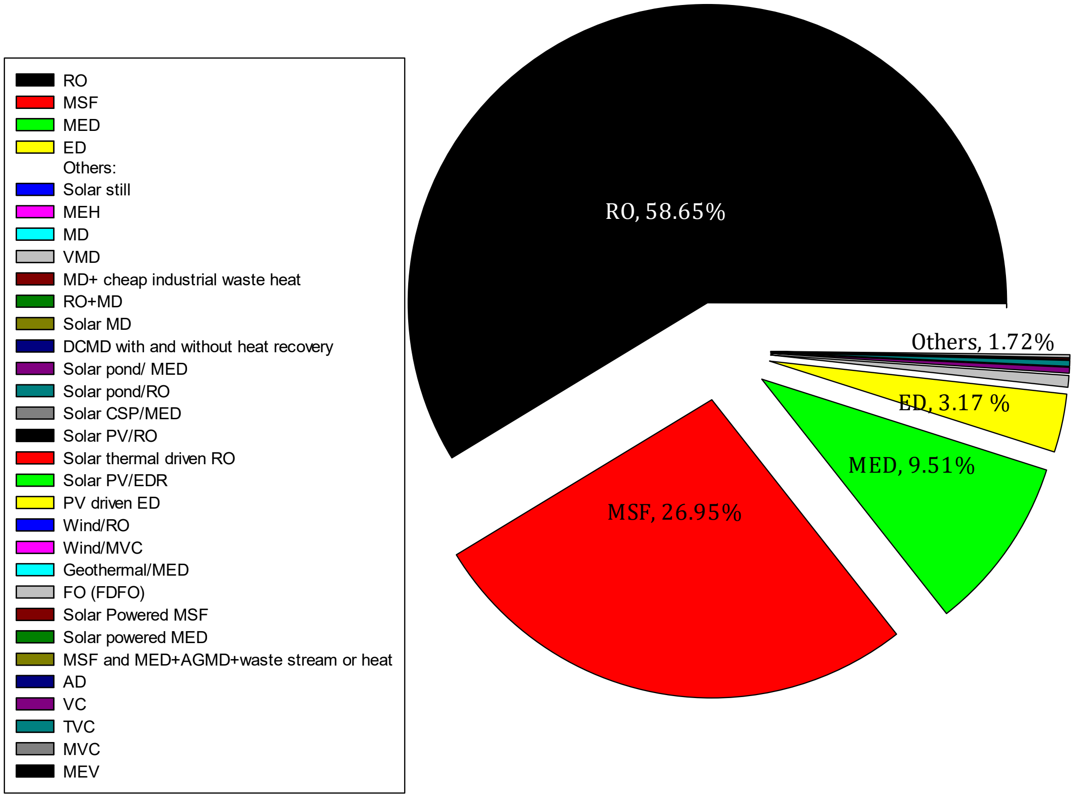


Figure 3: Maximum capacity of desalination plants details of data are presented in Table **8**.

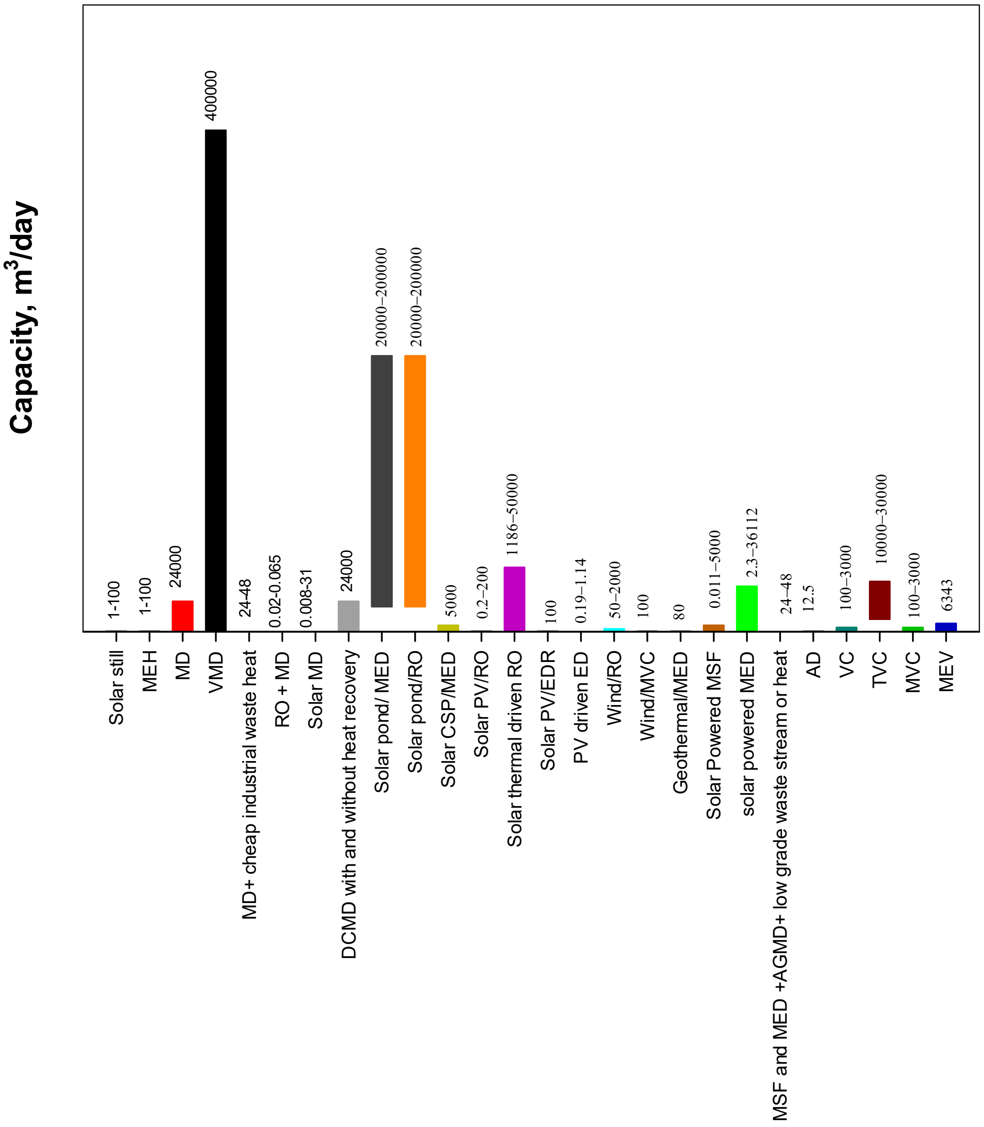


Figure 4: Capacities of other technologies (non-major technologies) for desalination/ chloride removal-related data are presented in Table **7**.

Fig. (**6**) [172-185] presents desalination costs for significant technologies Fig. **5**. Non-major desalination technologies costs are shown in Figure 6) [172, 174, 177, 178, 183, 184, 186-192]. Non-significant technologies that are hybrids of other technologies have less capacity than the major technologies; therefore, their applications are less than the major ones. They can be used in small-scale applications and are cheaper than the major technologies.

Due to the high importance of the leading desalination technologies (RO, MSF, MED, and ED), the amount of their energy consumption is presented in Table **8** [172, 174, 175, 179, 185, 186]. Some of these technologies work with electrical energy, and some need electrical and thermal energy. For example, RO and ED work with electrical energy, while MSF and MED work with electrical and thermal energy (more thermal basis than electrical basis energy consumer) (Table **8**).

Adsorption and CDI are considered cheap technologies for chloride removal at low concentrations. The capacity adsorbents and CDI are presented (Table **9** and Fig. **7**).

Table 7: Maximum capacity of desalination plants.

Desalination Plant	Capacity	Reference
RO	37 million m^3/day	[174]
MSF	17 million m^3/day	
MED	6 million m^3/day	
ED	2 million m^3/day	
Solar still	100 m^3/day	[172]
MEH	100 m^3/day	
MD	24000 m^3/day	[183]
VMD	400000 m^3/day	[175]
MD+ cheap industrial waste heat	48 m^3/day	[187]
RO+MD	0.065 m^3/day	[193]
Solar MD	31 m^3/day	[189]
DCMD with and without heat recovery	24000 m^3/day	[183]
Solar pond/ MED	200000 m^3/day	[172]
Solar pond/RO	200000 m^3/day	
Solar CSP/MED	5000 m^3/day	
Solar PV/RO	200 m^3/day	[189]
Solar thermal driven RO	50000 m^3/day	
Solar PV/EDR	100 m^3/day	[172]
PV driven ED	1.14 m^3/day	[189]
Wind/RO	2000 m^3/day	[172]
Wind/MVC	100 m^3/day	
Geothermal/MED	80 m^3/day	
FO (FDFO)	100000 m^3/day	[184]
Solar Powered MSF	5000 m^3/day	[189]
Solar powered MED	36112 m^3/day	
MSF and MED +AGMD+ low-grade waste stream or heat	48 m^3/day	[187]
AD	12.5 m^3/day	[174]
VC	3000 m^3/day	[172]
TVC	30000 m^3/day	
MVC	3000 m^3/day	
ME	6343 m^3/day	[177]

Table 8: Main technologies used for desalination and their energy consumption.

Technology	Electrical Energy Needed (kWh/m^3)	Thermal Energy Needed (kWh/m^3)	Total Energy Needed (kWh/m^3)
RO	0.5-10	0	14.29
MSF	2.5-5	15.83-78.3	19.58-57.14
MED	2-21.5	40.3-63.9	43.21
ED	0.7-8	0	0.7-8

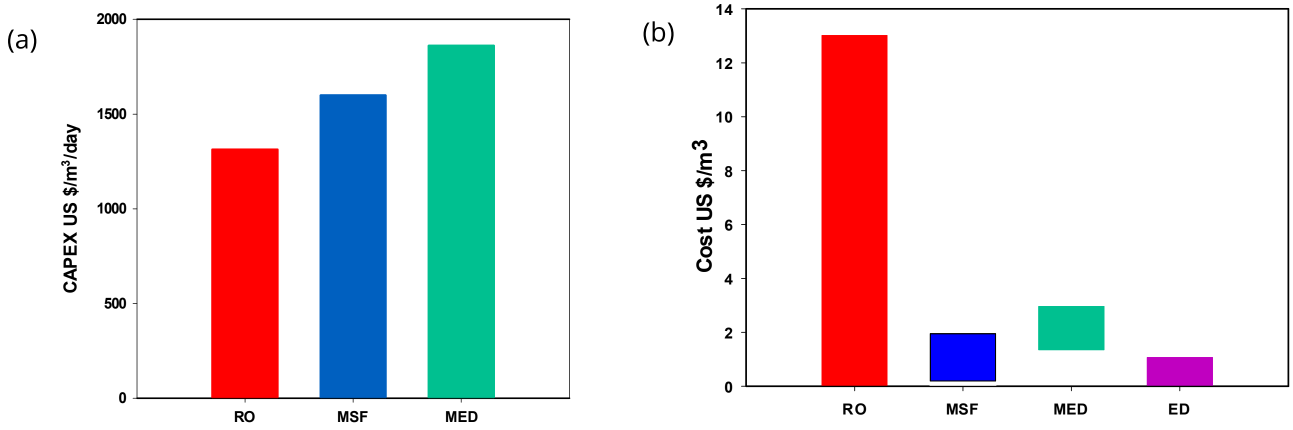


Figure 5: Main technologies for desalination (chloride removal); (a) CAPEX and (b) OPEX (for capacity of 37850 m^3/day).

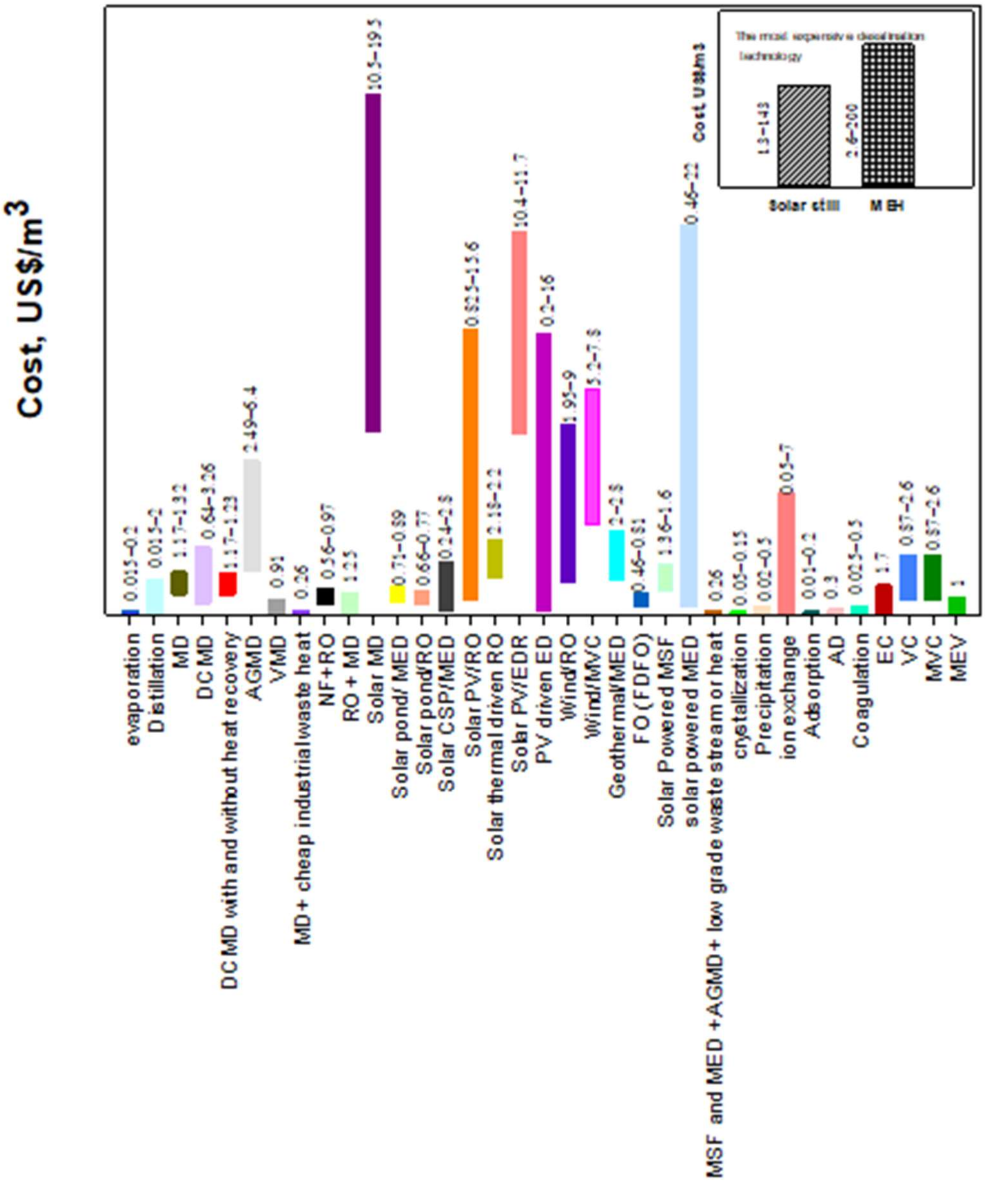


Figure 6: Cost of other technologies (non-main technologies) for desalination/chloride removal.

Table 9: Comparison of the maximum capacity of various adsorbents for chloride removal.

Adsorbent	Capacity (Q_m) mg/g	Reference
Cement (silicate hydrate (C-S-H))	21.27 mg/g (0.6 mmol/g)-172	[194-196]
Friedel's salt	70.91- 514.07 mg/g (2-14.5 mM)	[197]
Calcium kaolinite	3 m. equivalent (me)/100 g	[198, 199]
Natal soil	0.4 me%-1.0 me% (1.4 -3.5 mg/g)	[199]
Kent sand	more than 0.4 me% (more than 1.4 mg/g)	[199]
Gibbsite	approx. 2.48 mg/g	[200]
ɣ-alumina- modified with sodium oxide	11.25 mg/g	[201]
Goethite	50 µmole/g	[200]
Tripoli	30 mg/g	[202]
Pozzolana	12.07 mg/g	[203]
zeolite	9.23 mg/g	[203]
Anthracite coal	98.559 mg/g	[204]
Dolomite	3.139 mg/g	[204]
Limestone	93.795 mg/g	[204]
Pozzolan	55.153 mg/g	[204]
FF	106 mmol/g (3758.02 mg/g)	[205]
FS	373 mmol/g (13223.97 m/g)	[205]
DI-60	105 mmol/g (3722.565 mg/g)	[205]
RH	49 mmol/g (1737.2 mg/g)	[205]
Activated carbon modified with carboxyl groups	3.082 mg/ g	[206]
Parthenium sp.	340000mg/g	[207]
Parthenium sp. leaf biomass and assistance of sugar	8000 mg/g	[208]

Other technologies which have been studied for chloride removal (selective technologies) are coagulation and electrocoagulation (UHLA-ultra-high lime aluminum technology), chemical precipitation, ion exchange, adsorption desalination (AD), and adsorption, which their pros and cons are presented in Table **10**. Chloride removal by biological treatment is also less effective [223, 224].

5.2. Iodide

Generally speaking, iodide can be removed via various methods, such as ion exchange [149], adsorption [18, 22, 156, 225-243], membrane separation [244, 245], and chemical precipitation [246, 247]. Membrane-assisted technologies, electrochemical and adsorption as the leading technologies for removing iodide and bromide from water, have shown their removal efficacies, pros, and cons (Table **11** and Table **12**).

I^- shown to co-precipitate with hydroxides such as Zr, U, and Th at pH 4, pH 8, and pH 7. In addition, iodide has shown a high affinity towards $Bi(OH)_3$ [19]. Other adsorbents for iodide are iron zero-valent, illite, activated aerogels impregnated with silver ions, and Mg-Al LDH/Mg-Al (NO_3) LDH [118, 119]. Alternative technologies for iodine removal are ion exchanges of Amberlite 400 and DOW 21K XLT [121], permeation, and chemical desorption (PCD) [117]. Some ion exchanges need iodide oxidation, forming iodate and then passing through the resin. It is clear that this process also deals with the oxidating agent, which is not very environmentally friendly [117].

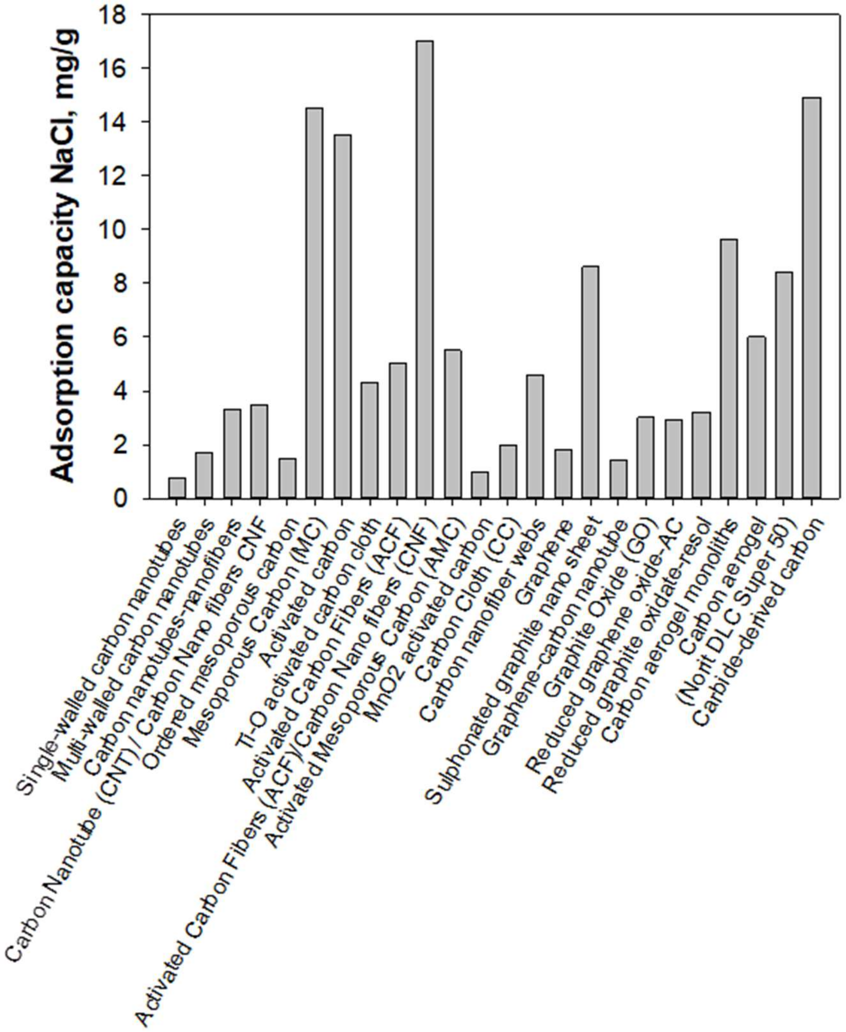


Figure 7: Capacity of CDI electrode for removing sodium chloride [209-222].

5.3. Bromide

Membrane desalination and electrochemical methods are energy extensive, and the membrane is prone to fouling and scaling [40]. Therefore, if these technologies are used just for bromide removal are more expensive than other technologies [40]. Electrochemical technologies such as electrolysis can oxidize bromide to HBrO, BRO^- and Br_2, which would limit their application on a large scale due to the possibility of the formation of brominated DBPs [40]. Adsorption is another technology used for bromide removals, such as xerogels and hydrogels, with a removal efficiency of 9-80%. Nonetheless, xerogels and hydrogels are not effective in the presence of NOM for bromide removal. Because they have more affinity towards the organic than inorganic species [40], other adsorbents, such as aluminum chloride and LDH, but these adsorbents have limited application due to their efficiency decrease in the presence of other inorganic anions and organic species. Silver integrated into the adsorbent has the disadvantage of silver leaching into the water and is expensive [40].

6. Challenges of Halide Removal

6.1. Chloride

Chloride in chemical compounds such as NaCl is very stable and soluble in water [145-148]. The solubility of NaCl, the most commonly used chloride salt, is 35.7 g/100 g at 0 °C in water. When a chemical species (chloride) is very soluble in water, it tends to be in its ionic form (Cl^-) [353]. Chloride is considered an inert chemical that would not be removed by bioremediation techniques and could not be easily precipitated [354]. Conversion of chloride to hydrochloric acid is not a good long-term option as it would be only changing chloride form [10]. Also, the oxidation of chloride to chlorine gas by various oxidants, such as potassium permanganate, is very dangerous for the workplace and could form DBPs [355]. Another challenge of chloride removal is that it is usually the less preferred species by the substrate in adsorption and ion exchange processes. Generally, the selectivity of an ion would get higher if its charge is much higher than its hydration radius (i.e., smaller ions with more charges have more selectivity than the bigger ions with smaller charges) [356]. For example, fluoride has a smaller hydrated radius with the same charge as chloride; therefore, fluoride would have more preference to be adsorbed than chloride [293]. The preference for chloride over bromide and iodide for removal is due to the hydration radius, as they have the same charge affinity [293, 357].

Table 10: Summary of other technologies just used for chloride removal.

Technology		Advantage	Disadvantage	Remarks	Reference
Chemical precipitation	**Silver nitrate**	Can be used on an industrial scale	Precipitation with silver nitrate is expensive and is mainly used in hydrometallurgy processes. Silver loss in this process is inevitable.	Silver nitrate was used to remove chloride from hydrometallurgical solutions, and silver was regenerated again. The regeneration of silver was carried out by using zinc in the solution. Zinc would alter silver chloride to zinc chloride, regenerating silver. Subsequently, the metallic silver would contact acid nitrate to convert it to silver nitrate. Silver nitrate is considered suitable for hydrometallurgy processes.	[171]
	Copper slag	Can be used on an industrial scale	Copper slag is toxic (due to the application of zinc) and is suitable and limited to hydrometallurgy. It needs high acidity and high sulfate.	Copper oxide process is considered more environmentally friendly than copper slag with zinc because it does not need zinc to reduce copper (II) to (I), and zinc is not environmentally friendly.	[171, 336]
Membrane assisted technology	**MD**	High chloride rejection. It can reject 99–100% of salts (chloride) and produce water with very high quality (less than 10 mg/L). Feed water quality, and salt concentration, have minimal effect on the performance. It works with small /no pressure. The membrane used in this process does not need very good mechanical properties (fewer requirements on the membrane). It also has a large contact area per unit of equipment volume. Finally, it can also work in low temperatures, like when used in a vacuum. The process heat could be gained from renewable energies or industrial waste/ residual heat.	It is energy-intensive technology (more than RO and less than evaporation and crystallization). It has a lower permeate flux due to mass transfer resistance than RO. There are few designs made for membrane/ membrane modules. Water needs pre-treatment to avoid scaling and fouling of membranes. For example, fouling is possible if the membrane gets wetted using a hydrophobic membrane.	It is more suitable for brine (from desalination plants) treatment. Using plastic materials to avoid corrosion was suggested, especially at high chloride concentrations. The cost of this process has yet to be discovered and depends on the type of energy source.	[175, 186, 249, 250, 337]

(Table 10) Contd....

Technology		Advantage	Disadvantage	Remarks	Reference
Thermal	**MSF**	It is a robust technology that deals with low-quality water and adverse conditions. It produces high-quality water with less than 10 mg/L pollutants/TDS.	It needs high temperatures of 90-110 °C as primary energy. The final water should be mixed with cold water. It has low water recovery. Even after dilution, the high salinity of concentrate would be very high, even 15% higher than feed water.	2nd, a desalination process in the world after RO. Today, the share of RO plants in desalination capacity in the world is 59%, while the thermally driven desalination methods have only 27%.	[172, 176, 186, 338]
	MED	It produces water with high quality of 10 mg/L of pollutants/TDS. Its advantage over MSF is that it is more flexible, less plausible to scale, and works at a lower temperature of 70 °C as primary energy.	This process is more suitable for limited-capacity plants because it works at a partial load of MSF.		[172, 186]
	Solar still	simple with less maintenance.	Low productivity. It needs large areas of land and is mainly suitable for low capacity.	In the pure thermal process, solar/dam needs 0.63 kWh/m^3 as electrical energy, and the thermal is 475.01 kWh/m^3.	[174, 189]
	Evaporation ponds	It is cheap, the operation is simple, and it is used in industries. Also, there is a possibility of salt recovery.	It needs a large area of land.		[175]
	Evaporation and crystallization systems	The technology is available and is being used on an industrial scale.	It is an expensive technology, and CAPEX and OPEX are both high.	It needs new developments to decrease its energy consumption.	[175]
	VC (MVC, TVC)	It produces water with high quality, TDS almost 10 mg/L. It is relatively cheap, especially if it is combined with heat waste.	Its capacity is limited to small to medium-sized plants (100-30000 m^3/day).	This technology is based on vapor compression, which can be achieved by mechanical or thermal vapor compression. MVC uses electricity, while TVC uses the steam jet for pressurizing the water. TVC has a higher capacity than MVC.	[172]
AD		It consumes a small amount of energy. It can also work with a low-temperature heat source or solar heat. It has low maintenance and low evaporative temperature, fouling, and scaling in the evaporators. Finally, it is cheap (low payable cost) if it uses the waste heat of renewable energies.	The data available for this technology is only known at the pilot or demonstration scale. Its economic aspect is questionable if it is not using heat from cheap sources, such as renewable energies or heat waste. Finally, the robustness of silica gel absorber beds has yet to be discovered.		[174, 249]

Table 11: Summary of technologies for halide removal.

Technology	-	Advantage	Disadvantage	Remarks	Reference
Membrane assisted technology	RO	Effective Br rejection >90.6% and iodide rejection>89% Can reject chloride with high concentrations up to 10000 mg/L. Recently, RO has improved its efficiency and reduced its energy consumption and footprint by Modifying membrane modules, using a semi-batch process, and combining RO with NF reduce energy consumption. Semi-batch RO has high to medium membrane recovery, depending on the feed water quality (recovery%: 55% seawater and 95% brackish water desalination). Two-stage RO will increase the water recovery.	Generally, it has a high cost, Concentrate disposal and management is tricky, Scaling and fouling concentration polarization is an accumulation of particulate and dissolved material near the membrane. This will affect the RO performance by higher salt flux and rejection decline, decrease the water flux because of the higher osmotic pressure, precipitation on the membrane surface would be more plausible, and cake formation on the membrane by the particulates. The osmotic pressure and viscosity would decrease RO performance. Semi-batch RO is known very little; data is available for only pilot and demonstration scales. The effect of high cross flow and brine circulation on membrane life is unknown. Two-stage RO needs high reagent dosage, which will increase the process expenses.	1st, the desalination process in the world. Rejections are as follows Cl>Br>I. This is because of the higher hydration energy of chloride, then bromide, and finally, the iodide. Electrostatic forces play the primary role in the rejection of halide ions. The removal of halides increases with increasing the pressure to the threshold limit. Above the threshold limit, the rejection of halides decreases. Spiral-wound and fine hollow fiber is the most commonly used membranes for RO. RO, with modular construction, has a small footprint. Also, semi-batch RO consumes lower energy (no energy recovery devices) and reduces footprint, fouling, membrane elements, and pre-treatment. Semi-batch RO has high crossflow velocity, higher water flux (more than 30%), and higher rejection of salts (90%) for the brackish and wastewater. Can produce water with a total TDS of 400-500 mg/L from seawater Increasing halogen content in the DBP molecule and substituting smaller chlorine-containing DBPs with larger molecular size bromine-containing DBPs achieve greater rejection by RO membrane. Poor rejection of low molecular weight uncharged compounds.	[172, 175, 182, 186, 188, 248-252]

(Table 11) Contd....

Technology	-	Advantage	Disadvantage	Remarks	Reference
	FO	It has simple technology. It is an osmotically driven process. This does not need hydraulic pressure or works with low pressure with lower energy consumption. Lower fouling potential due to lack of applied pressure. It has high feed water recovery and lesser pre-treatment needed. Good for desalination of highly saline water. It has high salt rejection, which would hardly be affected by the feed water contaminants. It can recover feed water with a wide range of 500-175000 mg/L as TDS.	Full-scale installation is limited, and more development is needed in FO membrane technology. It is more suitable as a pre-treatment. Recovery of clean water and draw solution regeneration would require a suitable combination of other technologies like RO—reverse diffusion of solute from draw to feed solution present.	FO, as pre-treatment, can reduce the cost of RO. The cost of FO/RO for desalination of seawater is lower than RO due to less electrical consumption. Its hybridization with RO is a perfect approach. FO/RO recycles 76% of water. FO costs depend on the application of the technology. For example, for FO draw solution recovery/reconcentration, the direct cost will be energy requirement. It can utilize waste heat sources for the regeneration of the draw solution. High iodide rejection 98.4% from LCD wastewater. $MgCl_2$ and cetyltrimethylammonium bromide as draw solution. Needs more studies for iodide and bromide removal.	[175, 186, 249, 250, 253]
	NF	Efficient, lower capital and operational costs compared to RO, lower working pressure, producing less concentrate compared to RO.	medium to high energy consumption. Needs pre-treatment has scaling and, fouling, brine disposal problems. It is not practical to remove chloride from mining water.	Membranes are charged, and electrostatic forces are important in the rejection part. Polyvalent ions are more readily rejected than monovalent ions, such as halides. The removal of halides increases with increasing the pressure to the threshold limit. Above the threshold limit, the rejection of halides decreases. Operating conditions are significant in the selectivity of halide rejection. Usually, chloride has more selectivity than iodide to be rejected due to the hydration energy. However, it was shown that if the operational pressure gets less than optimal conditions	[250, 254-265]

(Table 11) Contd....

Technology	-	Advantage	Disadvantage	Remarks	Reference
				(pressure in which iodide has more rejection), iodide would have more selectivity over chloride. Tight NF-45 has similar mass transfer to RO properties and is a good option for halide rejection. NF membranes with higher molecular weight could reject higher amounts of halides.	
Electrochemical assisted	ED and EDR	Tests in pilot scales show that it can have 80% bromide removal. ED, compared to RO, has lower energy, chemical consumption, pre-treatment requirements, operational costs, and water recovery. ED does not need pressure, despite RO. EDR has a higher membrane lifetime than RO. ED and EDR can produce high-quality water with TDS 150-500 mg/L (80-94% water recovery). ED can reduce chloride to 200 mg/L in brackish water (97-98% recovery).	They are not conventional technologies in drinking water treatment. For example, EDR has technical and economic limitations such as high capital costs and energy consumption. In ED, precipitant can build up on the concentrate sides because no current reversing exists despite EDR. ED is prone to scaling and fouling of the membrane Possibility of oxidation chloride to toxic chlorine gas, mainly if the stainless steel is used as an electrode. It has high CAPEX and OPEX.	Generally, ED and EDR are suitable technologies for halide removals. In this technology, hydraulic and electrical staging is used for halide removal. ED is cost-effective technology suitable for medium concentrations (NaCl up to 10 g/L) or TDS ≤ 4000 mg/L. At higher TDS>4000 mg/L is better to apply RO as a more cost-effective technology. EDR is better than ED in aspects of longer electrode lifetime and cleaner membranes due to reversing current.	[7, 172, 175, 249, 250, 266-270]
	Electrolysis	Conversion of halogen to the gaseous form can give disinfection properties.	In the case of bromide, the gas conversion can make hypobromous acid. Then hypobromous acid reacts with NOM in water and produces DBPs. Electrolysis was not used on a large scale and needed more studies to make its pilot scale more feasible.	It is based on oxidation and conversion of halide to halogen gas. pH and the species in water, such as carbon dioxide (a role in pH decline), can convert hypobromite to hypobromous acid. Therefore, a need to control pH and species in water. Electrode corrosion is an issue. Parameters such as current density, type of electrode, time of electrolysis, the ratio of halides in water, conductivity of water, and electrodes' distance will affect the process of halide removal and energy consumption.	[271-275]

(Table 11) Contd….

Technology	-	Advantage	Disadvantage	Remarks	Reference
	CDI	Does not need extra pressure despite RO. It has low pre-treatment, minimum scaling and fouling, low maintenance, low energy requirement, and more stability than RO. Regeneration is possible and easy by reversing the current polarity. More cost-effective than RO and EDR.	It needs more study to be implemented on a large scale, especially for brackish water. Q_e is small—for example, maximum sorption capacity (NaCl) of almost 18 mg/g of the electrode, approximately. Competitive anions can reduce chloride removal from water. Electrodes' efficiency needs optimization, in which limited data is available.	suitable for low salinity feed water sources (TDS < 15,000 mg/L). Activated carbon and carbon aerogels are electrode candidates for this technology. Removal efficiency of halides depends on the electrode properties such as pore structures in electrodes, surface area and chemical composition of the electrode (affinity towards halides), and electrostatic forces. Order of removal is Cl^- <Br^-< I^-because the charge transfer in iodide is more than the other halides. Likewise, of other electrochemical technologies, the current density, electrode surface area, and conductivity of the solution impact removal and energy consumption. Polarity reversal will give self-cleaning of electrodes. This technology is suitable for brackish water treatment from mining and gas industries and recovery of iodide.	[172, 175, 212, 249, 250, 276-285]
	MCDI	Higher removal efficiency than CDI. This is because ion exchange membranes prevent adsorbed ions from leaving the electrode region.	Difficulties in scale-up. That is because we must find cheap aerogels to make them commercially applicable. Membrane scaling and fouling in MCDI would be possible.	More studies, especially for halide removal. Need more investigations to make it practical on a large scale.	[286-288]
Adsorption	Adsorption- LDH	It is a cheap, universal, fast, and flexible technology with low maintenance and is easy to design and operate. Regenerate the sorbent is possible. Useful for iodide and bromide removal from drinking water.	LDH materials, such as Mg-Al-Cl LDH, are affected by the exiting of other anions. For example, the removal of iodide decreased with increasing chloride concentrations. The existence of bicarbonate can reduce bromide removal, and sulfate and bicarbonate .	Depending on the adsorbent type, the adsorption capacity could be low to high. Applying metals in the LDH structures with affinity to halides such as Cu^{2+} would enhance the iodide/other halide removals.	[194, 199, 202, 289-298]

(Table 11) Contd....

Technology	-	Advantage	Disadvantage	Remarks	Reference
			can reduce iodide removal. Removal of chloride with adsorbents (like C-S-H) in the existence of other anions (such as nitrate, carbonate, bromate, and sulfate) would favor other anions. Existence of NOM and high alkalinity is not suitable for bromide removal. They can be as effective as commercial resins in the right place of usage. Adsorption depends on the pH and isoelectric of the adsorbent. halide leaching after adsorption is possible. The cost of the whole process considering continuous dosing adsorbent could be high due to finite adsorbent capacity. CO_3^{2-}, SO_4^{2-}, OH^-, and F^- have more preference for sorption than chloride in LDH and CLDH.	Parameters such as calcination/non-calcination, time and temperature of calcination, type of metal being used in the system, and metal ratio can affect the LDH materials' sorption.	
	Coal and activated carbon	Cheap and high usage in water treatment processes.	Has low removal for iodide removal.	The oxidation of iodide can increase the removal efficiency of iodide to iodine. Not being tested for bromide removal.	[299]
	Silver-impregnated and silver chloride-impregnated activated carbon.	Impregnation of silver into the carbon active has an extensive application in drinking water treatment. Cheap technology in according with no need for big infrastructures. Silver gives antibacterial properties.	Silver leaching.	Applying a proper impregnation process could prevent silver from leaching under acidic conditions. For example, impregnating silver chloride instead of silver significantly reduces silver leaching in acidic conditions.	[300, 301]
	Silver impregnated Carbon Aerogels	Higher adsorption capacity than activated carbon for halides.	High cost and not applicable on an industrial scale. Existing chloride would reduce bromide and iodide removal. Preferring	Increasing silver concentration on the aerogel increases the macropores and mesopores.	[302-305]

(Table 11) Contd….

Technology	-	Advantage	Disadvantage	Remarks	Reference
			for halide removal is Cl^- > Br^- > I^-. This is because the larger ion size, like iodide, is disadvantaged. NOM and competing anions reduce the halide removal efficiency.	By activation and carbonization, the surface area increases. This increases the iodide and bromide removal efficiency. Therefore, carbonization and activation of aerogels are highly suggested.	
	Soil	Cheap and available.	Limited functionality, especially in complex water matrices, has a low capacity for iodide and chloride removal. Other anions and organic materials can reduce halide removal significantly. No study for the bromide, and it does not have the capability for bromide removal.	Iron oxide in the soil showed better iodide removal than in soils than contain aluminum oxide. For example, iodide has better removal efficiency with hematite than kaolinite. However, chloride is better removed in soils that have aluminum minerals.	[306-316]
Coagulation and electrocoagulation	Coagulation with aluminum	Cheap and conventional water treatment method. Capable of being pilot scale. Coagulation with UHLA is used for chloride removal and can be used on an industrial scale. UHLA's aluminum source can be from the aluminum electrode (EC), sludges containing aluminum, or alum. UHLA with alum has advantages such as compact instrumentation, simplicity, automation, and versatility. It produces less sludge over chemical coagulation and has smaller footprints. Chloride removal efficiency with UHLA 84%.	No studies for iodide with Coagulation with alum. No studies for iodide and bromide removal with UHLA. Coagulation with alum is sensitive to pH and other existing ions and humic acids on bromide removal. In UHLA, chloride removal would be less with the existence of other anions, such as silica and sulfate, and it is suitable for chloride concentrations higher than 100mM. Finally, aluminum in the feed should be monitored. Alum alone is not efficient for chloride removal, while when calcium salt is added would be very effective (UHLA). In the case of EC, aluminum electrodes are costly.	Conventional coagulation, sedimentation, and filtration are unsuitable for halide removal and higher molecular weight, hydrophobic fractions of natural organic materials. Only low molecular weight, hydrophilic fractions are removed. Increases the halide-to-organic ratio, leading to increased halide incorporation in halogenated DBPs. Coagulation alone needs a high dosage of aluminum chloride if there are competitive ions and organic materials in water. UHLA for chloride removal (alum and calcium salt chemical coagulation) Cl-chemical coagulation needs Ca:Al: Cl ratio of 10:0:4: 1 (for Freidel's salt). In UHLA technology and the application of EC, cathode passivation is plausible because calcium salt precipitation on the cathode is possible, which can be avoided by applying stainless steel.	[113, 169-171, 298, 317-321]

(Table 11) Contd....

Technology	-	Advantage	Disadvantage	Remarks	Reference
			Expensive for iodide and bromide removal. Because iodide and bromide concentrations are lower than chloride. However, it is more economical for chloride than other halides and resin's function is sensitive to the water conditions such as alkalinity (bicarbonate) and competing ion concentrations in MIEX®. Lower capacity for bromide sorption after regeneration MIEX®.	Strong anion-exchange resin with polystyrene functional groups can remove iodide and bromide. Amine groups, especially quaternary amine functional groups in the resins, are highly capable of removing iodide and bromide.	
	Resins	This method is good for the low concentration of chloride. It would be comparatively cheap because of lower power consumption, minimal brine production, and low capital cost. Therefore, it is still cheaper in low and high salinity, even if we consider the chemicals needed to regenerate resins. It is selective towards chloride. The capacity of the anion resins (for chloride) is 1-1.3 q/L for the strong base anion resins.	Metal incorporated into the resins is susceptible to metal leaching. Weak base resins (WBA) need acidic conditions for removing chloride. Ion exchangers are made of toxic materials, which is suggested for lower chloride concentration. Generally, ions with a smaller hydrated radius and higher valence have a higher permeability in an ion exchange membrane than ions with a larger hydrated radius and lower valence. Therefore, $I^- > NO_3^- > Br^- > Cl^- > SO_4^{2-} > F^-$. Specifically, in strong base resins I^-, NO_3^-, Br^-, ClO_4-, SO_4^{2-}, HPO_4^{2-}, CO_3^{2-} have preference for sorption more than chloride. Weak base resins OH^- has the most preference for sorption. Regeneration of IX columns is costly.	Lack of studies on iodide removal with resins because most studies are about bromide removal. Need to find a cheaper resin. Regeneration cost of resins could be decreased; as a result, the cost of comprehensive technology, by applying core-shell arrangement in the resins. Shallow shell ion exchanges, which are the ones that provide core-shell arrangements, have the advantage of regenerating more quickly than normal ones. These resins also reduce the volumes of rinsing and increase running times.	[113, 191, 293, 298, 322-335]

6.2. Iodide

Ion exchangers have limited applications for removing iodide from water because of their limited removal efficiency and cost [358]. Some natural minerals and sediments have been shown with iodide/iodine removal capacity, but their removal rates needed to be increased, too [20, 22].

Technologies which have been routinely employed to remove iodide (RO, NF, ED/EDR, electrolysis, CDI, resins) are expensive, and adsorption, which is cheaper (except silver-contained adsorbents) is not practical all the time such as activated carbon [37, 247]. Another challenge of iodide removal is that most of the adsorbents for iodide removal possess slow reaction kinetics. In a nuclear disaster, it would be desirable to have an absorbent to quickly and effectively remove iodide from water [17].

6.3. Bromide

Bromide removal is challenging and is less effective with common water treatment technologies (coagulation/flocculation) [158]. It is expensive to be removed by membrane-assisted technologies such as RO and NF. Bromide oxidation is also not a good strategy to remove bromide from water, especially if there is any NOM in water, then brominated DBPs would be produced [37]. Another challenge of bromide removal is that bromide adsorption on adsorbents or resins in the presence of NOM or alkalinity would decrease. NOM could block the adsorption sites, and bromide removal would decrease [40, 135]. For example, MIEX® showed removal of 49% and 20% for alkalinity in water 11 mg/L and 95 mg/L, respectively [135].

Table 12: Technologies for iodide and bromide removal and their efficiencies.

	Material Type (membrane/ adsorbent)	Bromide (mg/L)	Iodide (mg/L)	Competitive Anions	Type of Water	Removal Br %	Removal I %	pH	Temperature (°C)	Ref.
RO	Composite Polyamide	64.4-71	-	Yes	Seawater and natural water	99.34-99.8	-	7.9-8	20-25.1	[312]
	NS		0.0358 - 0.0511	Yes	Seawater and natural water	-	89	7.1-7.6	26.1-38.5	[339]
	Thin-Film Composite (TFC) ® Polyamide	51.3	49.9	Yes	Natural water, oilfield water	90.7	92	6	11±1	[340]
	Polyamide Membrane	3995	6345	No	seawater	99.6	99.4	6.8	25	[341]
NF	Polyamide TFC [NF-90 (200 Da)	1030	1	Yes	Synthetic water	94-97	84-91	7.8 - 9.8	20	[254]
	NF-90	51.3	49.9	Yes	Natural water	80	78.3	6	25	[340]
	NF70-2540 (Polyamide)	-	719.5-2538	No	Synthetic water		56.785-80	-	20	[252, 257] [261]
	ESNA	51.3	49.9	Yes	Natural water	-	55.6	6	25	[340]
ED/EDR	Mark III to Mark IV type	0.5–1.2		Yes	Natural water	75-80	-	6.5-7.3	25	[266]
	AR204-SZRA and CR67- HMR	0.185	-	Yes	Natural water	72	-	7.6	25	[342]
	DE81	-	1.2 - 12.7	No	Synthetic water	-	92–97	-	25	[343]
Electrolysis	-	0.200	-	Yes	Natural water	>99	-	-	-	[273]
	-	0.461		Yes	Synthetic water	79	-	~7.5	-	[275]

(Table 12) Contd....

	Material Type (membrane/ adsorbent)	Bromide (mg/L)	Iodide (mg/L)	Competitive Anions	Type of Water	Removal Br %	Removal I %	pH	Temperature (°C)	Ref.
CDI	-	~75	~30	Yes	Natural water	62.5	77	7.5-9.1	23	[279]
	-	191.8	304.56	No	Synthetic water	0.108 mmol/g	0.154 mmol/g	-	25	[280]
Adsorption	Mg–Al-(NO_3) LDH	-	342	Yes	Natural water, wastewater	-	59	9.2	25	[119]
	Mg-Al (molar ratio of 4, calcined at 500°C) LDH	100	100	No	Synthetic water	94	96.5	-	30	[344, 345]
	Zn-AlLDH	-	330	No	Synthetic water	-	60	7	-	[346]
	$Fe_2O_3{\cdot}Al_2O_3{\cdot}xH_2O$	120	-	Yes	Synthetic water	80	-	-	22	[347]
	Sub-bituminous coal	-	1.3	Yes	Synthetic water	-	46	6.2	25	[348]
	Merck activated carbon	-	1269	Yes	Synthetic water	-	21	7	-	[289]
	Silver-impregnated activated carbon (20 wt % of Ag)	-	0.127	Yes	Synthetic water	-	98	-	20	[349]
	Silver-impregnated activated carbon	-	1.0 – 200.5	No	Synthetic water	-	3.10-153.7 (μmol/g)	5,7,8	-	[350]
	Activated silver-doped aerogels	0.15	0.15	No	Synthetic water	5.78 (μmol/g)	5.03 (μmol/g)	7	25	[302, 304, 305, 351]
Resins	MIEX®	0.076-0.900	-	Yes	Synthetic water, Natural water	17-83	-	6.6-8.1	15-26	[322-325, 328]
	MIEX®+Alum	0.0137-0.540	-	Yes	Natural water	0-94	-	6.1-8.2	20,25	[324, 326]
	Indion-850	2876.4	5.1	Yes	Synthetic water	66.6	57.5	-	25	[352]
	Duolite A-113	3403.7	5.3	No	Synthetic water	54	45.3	-	25	[327]
	DOWEX MARATHON MSA					90	-			[322]
Coagulation	Aluminum coagulation	0.2-2	-	Yes	Synthetic water and natural water	30.4-98.8	-	6-8	-	[317, 318]
Soil	Udic Ferrisols	-	4	No	Synthetic water	-	57.5	5.05	25	[314]

7. Conclusion

A state-of-the-art review on halide removal has been carried out. This review highlights the importance of halide removal, the sources of excessive halide concentrations in water, and the technologies available for halide removal in water treatment. The review also presents how halide presence affects oxidation processes such as AOP through scavenging active radicals, especially in saline water. In AOPs, bromide scavenges the hydroxyl and sulfate radicals. Bromide also affects the ozonation and chlorination processes and will lead to the formation of bromoform and bromate. However, chloride would affect sulfate radicals. Bromide plays a key role in oxidation in high saline waters such as seawater with high chloride concentrations. The $ClOH^{\bullet-}$ is not stable and transforms to $OH^{\bullet}$ and Cl^{-}. Increasing halide concentration formation of $BrCl^{\bullet-}$ and $Br_2^{\bullet-}$ is more likely. The best strategy to use AOP in high-saline waters is the application of UV. It does not have much efficiency, but DBPs production is less likely. Also, removing iodide and bromide from water is as important as chloride because they will produce DBPs in the oxidation process.

Chloride concentration in water is highly regulated compared to other halides, such as bromide and iodide, which can cause environmental and health issues due to more toxic DBPs formation. The halides in water can be engineered to enhance the AOP. Halide management is very critical as unwanted DBPs can be produced. One of the techniques to have less dangerous DBPs in water is to remove their main formation precursors, bromide and iodide, prior to any water purification or oxidation.

Using adsorbents and ion exchange to remove halide could be advantageous with a fast kinetic rate, and there is ample scope for further research and development. However, the presence of other ions in water poses a challenge to its removal. For example, resins and adsorbents' active sites could be clogged by the associated natural organic matter in water, making iodide and bromide removal less effective. There needs to be further studies on affordable absorbent/ion exchanger development with high affinity and fast kinetic reaction. This will make absorption a more potent technology that can be used in water purification at lower costs. Electrochemical capacitive deionization is another potential technology that can be studied to selectively target bromide removal from source waters undergoing disinfection to reduce brominated DBP formation.

Alternate treatment methods, such as using biomass and industrial wastes for halide removal, have yet to be investigated thoroughly. Flora such as Lolium rigidum (forage grass in southern Australia), Aaicennia marinia, Avicennia, Aegialitis and Aegiceras, Fourwing saltbushes, and low Cl- excluder plant K51-40 should be further researched as natural halide management techniques. However, these plants could have a low kinetic rate of removal. However, case studies have shown that some flora, such as Corymbia maculate Hook, Eucalyptus botryoides Smith, E. tereticornis Smith, and E. occidentalis Endl, can be used for rehabilitation of post-mining lands in NSW, Australia. However, they were not used for water treatment.

Halides are removed as total dissolved solids by membrane-assisted technologies with less selectivity. For example, current commercial membrane processes are suitable for bromine removal. However, much of its energy is utilized for the removal non targeted dissolved solids in water instead of selectively removing bromide. When applying these technologies, the costs should be considered along with the environmental outcomes. Integrating renewable energies such as geothermal and waste heat with membrane technologies could reduce the total operating costs. The research in this area seems bright. Membranes can be engineered to reduce their fouling and selectivity. For example, the designed cross-linked matrix of polymers and engineered nanoparticles could be widely applied in future membranes.

References

[1] Elsheikh AS, Fadul TF, Aboagla EM-E, Rahim Gameel AA. Effects of potassium bromate on male rat growth and testicular histology. Asian Pacific Journal of Reproduction. 2016; 5(5):376-80. https://doi.org/10.1016/j.apjr.2016.07.001

[2] Burn S, Hoang M, Zarzo D, Olewniak F, Campos E, Bolto B, *et al.* Desalination techniques - a review of the opportunities for desalination in agriculture. Desalination. 2015; 364:2-16. https://doi.org/10.1016/j.desal.2015.01.041

[3] Shaffer DL, Yip NY, Gilron J, Elimelech M. Seawater desalination for agriculture by integrated forward and reverse osmosis: Improved product water quality for potentially less energy. Journal of Membrane Science. 2012; 415-416:1-8. https://doi.org/10.1016/j.memsci.2012.05.016

[4] Martínez-Alvarez V, Martin-Gorriz B, Soto-García M. Seawater desalination for crop irrigation - a review of current experiences and revealed key issues. Desalination. 2016; 381:58-70. https://doi.org/10.1016/j.desal.2015.11.032

[5] Tsutsumi Y, Nishikata A, Tsuru T. Pitting corrosion mechanism of type 304 stainless steel under a droplet of Chloride Solutions. Corrosion Science. 2007; 49(3):1394-407. https://doi.org/10.1016/j.corsci.2006.08.016

[6] Jang S-Y, Karthick S, Kwon S-J. Investigation on durability performance in early aged high-performance concrete containing GGBFS and FA. Advances in Materials Science and Engineering. 2017; 2017:1-11. https://doi.org/10.1155/2017/3214696

[7] Yodsudjai W, Saelim W. Influences of electric potential and electrolyte on electrochemical chloride removal in reinforced concrete. Journal of Materials in Civil Engineering. 2014; 26(1):83-9. https://doi.org/10.1061/(ASCE)MT.1943-5533.0000777

[8] Kameda T, Shoji C, Fukushima S, Grause G, Yoshioka T. Removal of chloride from ethylene glycol solution using alumina/zeolite membrane as a physical boundary between the organic and aqueous phases. Journal of Material Cycles and Waste Management. 2013; 15(3):404-8. https://doi.org/10.1007/s10163-013-0119-8

[9] Lito PF, Aniceto JP, Silva CM. Removal of anionic pollutants from waters and wastewaters and materials perspective for their selective sorption. Water, Air, & Soil Pollution. 2012; 223(9):6133-55. https://doi.org/10.1007/s11270-012-1346-7

[10] Pfromm PH. Low effluent processing in the pulp and paper industry: Electrodialysis for continuous selective chloride removal. Separation Science and Technology. 1997; 32(18):2913-26. https://doi.org/10.1080/01496399708000787

[11] Şahin FÇ, Derin B, Yücel O. Chloride removal from Zinc Ash. Scandinavian Journal of Metallurgy. 2000; 29(5):224-30. https://doi.org/10.1034/j.1600-0692.2000.d01-26.x

[12] Cramer SD, Covino, Jr. BS, Bullard SJ, Holcomb GR, Russell JH, Ziomek-Moroz M, *et al.* Prevention of chloride-induced corrosion damage to bridges. ISIJ International. 2002; 42(12):1376-85. https://doi.org/10.2355/isijinternational.42.1376

[13] Jiao L, Li M, Zeng T, Zhu D. Study on corrosion performance of Cu-Te-Se alloys in a 3.5% sodium chloride solution. Journal of Materials Engineering and Performance. 2015; 24(11):4333-9. https://doi.org/10.1007/s11665-015-1741-5

[14] Blagojevic A, Fennis S, Walraven JC. mpact of cracks on chloride-induced corrosion and durability of reinforced concrete structures - a literature review. Espoo, Finland: VTT Technical Research Centre; 2012; p. 80-91.

[15] ASCE The American Society of Civil Engineers. 2017 Infrastructure Report Card. Reston, Virginia: ASCE; 2017.

[16] Marcos-Meson V, Michel A, Solgaard A, Fischer G, Edvardsen C, Skovhus TL. Corrosion resistance of steel fibre reinforced concrete - a literature review. Cement and Concrete Research. 2018; 103:1-20. https://doi.org/10.1016/j.cemconres.2017.05.016

[17] Liu Y, Gu P, Jia L, Zhang G. An investigation into the use of cuprous chloride for the removal of radioactive iodide from Aqueous Solutions. Journal of Hazardous Materials. 2016; 302:82-9. https://doi.org/10.1016/j.jhazmat.2015.09.045

[18] 18] Rong J, Zhao Z, Jing Z, Zhang T, Qiu F, Xu J. High-specific surface area hierarchical Al2O3 Carbon fiber based on a waste paper fiber template: Preparation and adsorption for iodide ions. Journal of Wood Chemistry and Technology. 2017; 37(6):485-92. https://doi.org/10.1080/02773813.2017.1347684

[19] Liu Y, Guten HR, Migration chemistry and behaviour of iodine relevant to geological disposal of radioactive wastes-a literature review with a compilation of sorption data, in Technischer Bericht 88-29. Paul Scherrer Institut, Wuerenlingen: Switzerland. 1988; p. 183.

[20] Majidnia Z, Idris A. Photocatalytic reduction of iodine in radioactive waste water using maghemite and Titania nanoparticles in PVA-alginate beads. Journal of the Taiwan Institute of Chemical Engineers. 2015; 54:137-44. https://doi.org/10.1016/j.jtice.2015.03.005

[21] Hu Q, Moran JE, Blackwood V. Geochemical Cycling of Iodine Species in Soils. In: Lawrence Livermore National Laboratory: The Comprehensive Handbook on Iodine, Geochemical Cycling of Iodine Species in Soils. New York City, New York: Academic Press; 2007. p. 99-107.

[22] Li D, Kaplan DI, Sams A, Powell BA, Knox AS. Removal capacity and chemical speciation of groundwater iodide (I−) and iodate (IO3−) sequestered by organoclays and granular activated carbon. Journal of Environmental Radioactivity. 2018; 192:505-12. https://doi.org/10.1016/j.jenvrad.2018.08.008

[23] Freitas Mdo, Vieira BJ, Pacheco AMG. Levels of iodine and other elements in drinking water across rural counties adjoining a former uranium mining and milling works, through short-time activation analysis. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment. 2007; 579(1):514-7. https://doi.org/10.1016/j.nima.2007.04.113

[24] Kozai N, Ohnuki T, Iwatsuki T. Characterization of saline groundwater at Horonobe, Hokkaido, Japan by Sec-UV-ICP-MS: Speciation of uranium and iodine. Water Research. 2013; 47(4):1570-84. https://doi.org/10.1016/j.watres.2012.12.017

[25] Ten Hoeve JE, Jacobson MZ. Worldwide health effects of the Fukushima Daiichi Nuclear Accident. Energy & Environmental Science. 2012; 5(9):8743-57. https://doi.org/10.1039/c2ee22019a

[26] Hou X, Povinec PP, Zhang L, Shi K, Biddulph D, Chang C-C, *et al.* Iodine-129 in seawater offshore Fukushima: Distribution, inorganic speciation, sources, and Budget. Environmental Science & Technology. 2013; 47(7):3091-8. https://doi.org/10.1021/es304460k

[27] Papastefanou C, Manolopoulou M, Charalambous S. Radiation measurements and radioecological aspects of fallout from the Cherbonyl Reactor Accident. Journal of Environmental Radioactivity. 1988; 7(1):49-64. https://doi.org/10.1016/0265-931X(88)90041-0

[28] Foreman MR. An introduction to serious nuclear accident chemistry. Cogent Chemistry. 2015; 1(1):1049111. https://doi.org/10.1080/23312009.2015.1049111

[29] UNSCEAR United Nations Scientific Committee on the Effects of Atomic Radiation. Annexes C, D and E: Sources and Effects of Ionizing . New York: United Nations; 2008.

[30] Liu H, Cui Y, Zhang B. Effects of Iodine and Fluorine in Drinking Water on Human Health, in Encyclopedia of Environmental Health (Second Edition), Nriagu J, Editor. Elsevier: Oxford. 2019; p. 256-263. https://doi.org/10.1016/B978-0-12-409548-9.10990-X

[31] Kaiho T. Iodine Chemistry and Applications. In: Iodine chemistry and applications. Hoboken, NJ: Wiley; 2014; 9781118466292: 636. https://doi.org/10.1002/9781118909911

[32] Muramatsu Y, Fehn U, Yoshida S. Recycling of iodine in fore-arc areas: Evidence from the iodine brines in Chiba, Japan. Earth and Planetary Science Letters. 2001; 192(4):583-93. https://doi.org/10.1016/S0012-821X(01)00483-6

[33] Konyratbekova SS, Baikonurova A, Ussoltseva GA, Erust C, Akcil A. Thermodynamic and kinetic of iodine-iodide leaching in gold hydrometallurgy. Transactions of Nonferrous Metals Society of China. 2015; 25(11):3774-83. https://doi.org/10.1016/S1003-6326(15)63980-2

[34] Guo X, Qin H, Tian Q, Zhang L. The efficacy of a new iodination roasting technology to recover gold and silver from refractory gold tailing. Journal of Cleaner Production. 2020; 261:121147. https://doi.org/10.1016/j.jclepro.2020.121147

[35] Northey SA, Mudd GM, Saarivuori E, Wessman-Jääskeläinen H, Haque N. Water footprinting and mining: Where are the limitations and opportunities? Journal of Cleaner Production. 2016; 135:1098-116. https://doi.org/10.1016/j.jclepro.2016.07.024

[36] Plewa MJ, Wagner ED, Richardson SD. Tic-Tox: A preliminary discussion on identifying the forcing agents of DBP-mediated toxicity of disinfected water. Journal of Environmental Sciences. 2017; 58:208-16. https://doi.org/10.1016/j.jes.2017.04.014

[37] Ateia M, Erdem CU, Ersan MS, Ceccato M, Karanfil T. Selective removal of bromide and iodide from natural waters using a novel AgCl-SPAC Composite at environmentally relevant conditions. Water Research. 2019; 156:168-78. https://doi.org/10.1016/j.watres.2019.03.028

[38] Gruchlik Y, Tan J, Allard S, Heitz A, Bowman M, Halliwell D, Gunten U, *et al.* Impact of bromide and iodide during drinking water disinfection and potential treatment processes for their removal or mitigation. Water. 2014; 41(8):38-43

[39] Ates N, Yetis U, Kitis M. Effects of bromide ion and natural organic matter fractions on the formation and speciation of chlorination by-products. Journal of Environmental Engineering. 2007; 133(10):947-54. https://doi.org/10.1061/(ASCE)0733-9372(2007)133:10(947)

[40] Rajaeian B. Removal of Bromide from Drinking Water Sources using Silver impregnated activated carbon (SIAC) understanding Br-SIAC interactions, in Department of Civil Engineering, Curtin University. 2017.

[41] Dorji P, Kim DI, Hong S, Phuntsho S, Shon HK. Pilot-scale membrane capacitive deionisation for effective bromide removal and high water recovery in seawater desalination. Desalination. 2020; 479:114309. https://doi.org/10.1016/j.desal.2020.114309

[42] Kim D, Jung S, Sohn J, Kim H, Lee S. Biocide application for controlling biofouling of SWRO membranes - an overview. Desalination. 2009; 238(1-3):43-52. https://doi.org/10.1016/j.desal.2008.01.034

[43] Zhang K, Parker KM. Halogen radical oxidants in natural and engineered Aquatic Systems. Environmental Science & Technology. 2018; 52(17):9579-94. https://doi.org/10.1021/acs.est.8b02219

[44] Kornmueller A. Review of fundamentals and specific aspects of oxidation technologies in marine waters. Water Science and Technology. 2007; 55(12):1-6. https://doi.org/10.2166/wst.2007.379

[45] Yang F, Sheng B, Wang Z, Yuan R, Xue Y, Wang X, *et al.* An often-overestimated adverse effect of halides in heat/persulfate-based degradation of wastewater contaminants. Environment International. 2019; 130:104918. https://doi.org/10.1016/j.envint.2019.104918

[46] Battino R, Rettich TR, Tominaga T. The solubility of oxygen and ozone in liquids. Journal of Physical and Chemical Reference Data. 1983; 12(2):163-78. https://doi.org/10.1063/1.555680

[47] Fang C, Xiao D, Liu W, Lou X, Zhou J, Wang Z, *et al.* Enhanced AOX accumulation and aquatic toxicity during 2,4,6-trichlorophenol degradation in a CO(II)/peroxymonosulfate/CL− System. Chemosphere. 2016; 144:2415-20. https://doi.org/10.1016/j.chemosphere.2015.11.030

[48] Yuan R, Ramjaun SN, Wang Z, Liu J. Effects of chloride ion on degradation of Acid Orange 7 by sulfate radical-based advanced oxidation process: Implications for formation of chlorinated aromatic compounds. Journal of Hazardous Materials. 2011; 196:173-9. https://doi.org/10.1016/j.jhazmat.2011.09.007

[49] Yang Y, Pignatello JJ, Ma J, Mitch WA. Comparison of halide impacts on the efficiency of contaminant degradation by sulfate and hydroxyl radical-based advanced oxidation processes (AOPS). Environmental Science & Technology. 2014; 48(4):2344-51. https://doi.org/10.1021/es404118q

[50] Sun P, Lee W-N, Zhang R, Huang C-H. Degradation of DEET and caffeine under UV/chlorine and simulated sunlight/chlorine conditions. Environmental Science & Technology. 2016; 50(24):13265-73. https://doi.org/10.1021/acs.est.6b02287

[51] Yang Y, Pignatello JJ, Ma J, Mitch WA. Effect of matrix components on UV/H2O2 and UV/S2O82− advanced oxidation processes for trace organic degradation in reverse osmosis brines from municipal wastewater reuse facilities. Water Research. 2016; 89:192-200. https://doi.org/10.1016/j.watres.2015.11.049

[52] Grebel JE, Pignatello JJ, Mitch WA. Effect of halide ions and carbonates on organic contaminant degradation by hydroxyl radical-based advanced oxidation processes in Saline Waters. Environmental Science & Technology. 2010; 44(17):6822-8. https://doi.org/10.1021/es1010225

[53] Cheng S, Zhang X, Yang X, Shang C, Song W, Fang J, *et al.* The multiple role of bromide ion in ppcps degradation under UV/chlorine treatment. Environmental Science & Technology. 2018; 52(4):1806-16. https://doi.org/10.1021/acs.est.7b03268

[54] Yuan R, Wang Z, Hu Y, Wang B, Gao S. Probing the radical chemistry in UV/persulfate-based saline wastewater treatment: Kinetics modeling and byproducts identification. Chemosphere. 2014; 109:106-12. https://doi.org/10.1016/j.chemosphere.2014.03.007

[55] Chawla OP, Fessenden RW. Electron spin resonance and pulse radiolysis studies of some reactions of peroxysulfate (SO4.1,2). The Journal of Physical Chemistry. 1975; 79(24):2693-700. https://doi.org/10.1021/j100591a020

[56] McElroy WJ. A laser photolysis study of the reaction of sulfate(1-) with chloride and the subsequent decay of chlorine(1-) in aqueous solution. The Journal of Physical Chemistry. 1990; 94(6):2435-41. https://doi.org/10.1021/j100369a044

[57] Yu X-Y, Bao Z-C, Barker JR. Free radical reactions involving Cl•, and Cl2-•, and SO4-• in the 248 nm photolysis of aqueous solutions containing S2O82- and Cl-. The Journal of Physical Chemistry A, 2004; 108(2): 295-308. https://doi.org/10.1021/jp036211i

[58] Wine PH, Tang Y, Thorn RP, Wells JR, Davis DD. Kinetics of aqueous phase reactions of the SO4− radical with potential importance in cloud chemistry. Journal of Geophysical Research. 1989; 94(D1):1085-94. https://doi.org/10.1029/JD094iD01p01085

[59] Huie RE, Clifton CL, Neta P. Electron transfer reaction rates and equilibria of the carbonate and sulfate radical anions. International Journal of Radiation Applications and Instrumentation Part C Radiation Physics and Chemistry. 1991; 38(5):477-81. https://doi.org/10.1016/1359-0197(91)90065-A

[60] Buxton GV, Bydder M, Arthur Salmon G. The reactivity of chlorine atoms in aqueous solution part ii.the equilibrium SO4-+Cl-CLNSBD+SO42-. Physical Chemistry Chemical Physics. 1999; 1(2):269-73. https://doi.org/10.1039/a807808d

[61] Liu L, Lin S, Zhang W, Farooq U, Shen G, Hu S. Kinetic and mechanistic investigations of the degradation of sulfachloropyridazine in heat-activated persulfate oxidation process. Chemical Engineering Journal. 2018; 346:515-24. https://doi.org/10.1016/j.cej.2018.04.068

[62] Khan S, He X, Khan JA, Khan HM, Boccelli DL, Dionysiou DD. Kinetics and mechanism of sulfate radical- and hydroxyl radical-induced degradation of highly chlorinated pesticide Lindane in UV/Peroxymonosulfate System. Chemical Engineering Journal. 2017; 318:135-42. https://doi.org/10.1016/j.cej.2016.05.150

[63] Xu X, Chen J, Qu R, Wang Z. Oxidation of tris (2-chloroethyl) phosphate in aqueous solution by UV-activated peroxymonosulfate: Kinetics, water matrix effects, degradation products and reaction pathways. Chemosphere. 2017; 185:833-43. https://doi.org/10.1016/j.chemosphere.2017.07.090

[64] Wang Z, Yuan R, Guo Y, Xu L, Liu J. Effects of chloride ions on bleaching of azo dyes by Co2+/oxone regent: Kinetic analysis. Journal of Hazardous Materials. 2011; 190(1-3):1083-7. https://doi.org/10.1016/j.jhazmat.2011.04.016

[65] Yang F, Huang Y, Fang C, Xue Y, Ai L, Liu J, *et al.* Peroxymonosulfate/base process in saline wastewater treatment: The fight between alkalinity and chloride ions. Chemosphere. 2018; 199:84-8. https://doi.org/10.1016/j.chemosphere.2018.02.023

[66] von Gunten U, Oliveras Y. Advanced oxidation of bromide-containing waters: bromate formation mechanisms. Environmental Science & Technology. 1998; 32(1):63-70. https://doi.org/10.1021/es970477j

[67] Mopper K, Zhou X. Hydroxyl radical photoproduction in the sea and its potential impact on Marine Processes. Science. 1990; 250(4981):661-4. https://doi.org/10.1126/science.250.4981.661

[68] Zafiriou OC, True MB, Hayon E. Consequences of oh radical reaction in sea water: Formation and decay of Br2- ion radical. ACS Symposium Series. 1987; 89-105. https://doi.org/10.1021/bk-1987-0327.ch007

[69] Zhou X, Mopper K. Determination of photochemically produced hydroxyl radicals in seawater and freshwater. Marine Chemistry. 1990; 30:71-88. https://doi.org/10.1016/0304-4203(90)90062-H

[70] Parker KM, Mitch WA. Halogen radicals contribute to photooxidation in coastal and estuarine waters. Proceedings of the National Academy of Sciences, 2016. 113(21): p. 5868-73. https://doi.org/10.1073/pnas.1602595113

[71] Zafiriou OC. Sources and reactions of oh and daughter radicals in seawater. Journal of Geophysical Research. 1974; 79(30):4491-7. https://doi.org/10.1029/JC079i030p04491

[72] Liu W, Fang C, Huang Y, Ai L, Yang F, Wang Z, *et al.* Is UV/CE(iv) process a chloride-resistant AOPs for organic pollutants decontamination? RSC Advances. 2016; 6(96):93558-63. https://doi.org/10.1039/C6RA21682J

[73] Yuan R, Ramjaun SN, Wang Z, Liu J. Photocatalytic degradation and chlorination of azo dye in saline wastewater: Kinetics and Aox Formation. Chemical Engineering Journal. 2012; 192:171-8. https://doi.org/10.1016/j.cej.2012.03.080

[74] von Gunten U, Hoigne J. Bromate Formation during ozonization of bromide-containing waters: Interaction of ozone and hydroxyl radical reactions. Environmental Science & Technology. 1994; 28(7):1234-42. https://doi.org/10.1021/es00056a009

[75] Hoigné J. Chemistry of Aqueous Ozone and Transformation of Pollutants by Ozonation and Advanced Oxidation Processes. In: Quality and Treatment of Drinking Water II, J. Hrubec, Editor. Springer Berlin: Heidelberg. 1988; p. 83-141. https://doi.org/10.1007/978-3-540-68089-5_5

[76] Baycan N, Thomanetz E, Sengül F. Influence of chloride concentration on the formation of AOX in UV oxidative system. Journal of Hazardous Materials. 2007; 143(1-2):171-6. https://doi.org/10.1016/j.jhazmat.2006.09.010

[77] Ramjaun SN, Yuan R, Wang Z, Liu J. Degradation of reactive dyes by contact glow discharge electrolysis in the presence of Cl− ions: Kinetics and AOX formation. Electrochimica Acta. 2011; 58:364-71. https://doi.org/10.1016/j.electacta.2011.09.052

[78] Gilbert BC, Stell JK, Peet WJ, Radford KJ. Generation and reactions of the chlorine atom in aqueous solution. Journal of the Chemical Society, Faraday Transactions 1: Physical Chemistry in Condensed Phases. 1988; 84(10):3319-30. https://doi.org/10.1039/f19888403319

[79] Buxton, GV, Bydder, M, Salmon GA, Williams JE. The reactivity of chlorine atoms in aqueous solution. part III. the reactions of Cl• with solutes. Physical Chemistry Chemical Physics. 2000; 2(2):237-45. https://doi.org/10.1039/a907133d

[80] Buxton GV, Wang J, Arthur Salmon G. Rate constants for the reactions of NO3•, SO4•- and Cl• Radicals with formate and acetate esters in aqueous solution. Physical Chemistry Chemical Physics. 2001; 3(13):2618-21. https://doi.org/10.1039/b101932p

[81] Wicktor F, Donati A, Herrmann H, Zellner R. Laser based spectroscopic and kinetic investigations of reactions of the cl atom with oxygenated hydrocarbons in aqueous solution. Physical Chemistry Chemical Physics. 2003; 5(12):2562-72. https://doi.org/10.1039/b212666d

[82] Adams GE, Aldrich JE, Bisby RH, Cundall RB, Redpath JL, Willson RL. Selective free radical reactions with proteins and enzymes: Reactions of inorganic radical anions with amino acids. Radiation Research. 1972; 49(2):278-89. https://doi.org/10.2307/3573267 https://doi.org/10.2307/3573266

[83] Hasegawa K, Neta P. Rate constants and mechanisms of reaction of chloride (Cl2-) radicals. The Journal of Physical Chemistry. 1978; 82(8):854-7. https://doi.org/10.1021/j100497a003

[84] Alfassi ZB, Huie RE, Marguet S, Natarajan E, Neta P. Rate constants for reactions of iodine atoms in solution. International Journal of Chemical Kinetics. 1995; 27(2):181-8. https://doi.org/10.1002/kin.550270208

[85] Guha SN, Schoneich C, Asmus KD. Free radical reductive degradation of Vic-Dibromoalkanes and reaction of bromine atoms with polyunsaturated fatty acids: Possible involvement of br. in the 1,2-dibromoethane-induced lipid-peroxidation. Archives of Biochemistry and Biophysics. 1993; 305(1):132-40. https://doi.org/10.1006/abbi.1993.1402

[86] Alegre ML, Geronés M, Rosso JA, Bertolotti SG, Braun AM, Mártire DO, *et al.* Kinetic study of the reactions of chlorine atoms and cl2•- radical anions in aqueous solutions. 1. reaction with benzene. The Journal of Physical Chemistry A. 2000; 104(14):3117-25. https://doi.org/10.1021/jp9929768

[87] Mártire DO, Rosso JA, Bertolotti S, Le Roux GC, Braun AM, Gonzalez MC. Kinetic study of the reactions of chlorine atoms and Cl2•- radical anions in aqueous solutions. II. toluene, benzoic acid, and chlorobenzene. The Journal of Physical Chemistry A. 2001; 105(22):5385-92. https://doi.org/10.1021/jp004630z

[88] Neta P, Huie RE, Ross AB. Rate constants for reactions of inorganic radicals in aqueous solution. Journal of Physical and Chemical Reference Data. 1988; 17(3):1027-284. https://doi.org/10.1063/1.555808

[89] Merenyi G, Lind J. Reaction mechanism of hydrogen abstraction by the bromine atom in water. Journal of the American Chemical Society. 1994; 116(17):7872-6. https://doi.org/10.1021/ja00096a050

[90] Alfassi ZB, Huie RE, Neta P, Shoute LC. Temperature dependence of the rate constants for reaction of inorganic radicals with organic reductants. The Journal of Physical Chemistry. 1990; 94(25):8800-5. https://doi.org/10.1021/j100388a011

[91] Hiller K-O, Asmus K-D. Oxidation of methionine by X in aqueous solution and characterization of some three-electron bonded intermediates. A pulse radiolysis study. International Journal of Radiation Biology and Related Studies in Physics, Chemistry and Medicine. 1981; 40(6):583-95. https://doi.org/10.1080/09553008114551571

[92] Szabó L, Tóth T, Takács E, Wojnárovits L. One-electron oxidation of molecules with aromatic and thioether functions: CL2−/BR2− and oh induced oxidation of penicillins studied by pulse radiolysis. Journal of Photochemistry and Photobiology A: Chemistry. 2016; 326:50-9. https://doi.org/10.1016/j.jphotochem.2016.04.025

[93] Caregnato P, Rosso JA, Soler JM, Arques A, Mártire DO, Gonzalez MC. Chloride anion effect on the advanced oxidation processes of methidathion and dimethoate: Role of Cl2− radical. Water Research. 2013; 47(1):351-62. https://doi.org/10.1016/j.watres.2012.10.018

[94] Deborde M, von Gunten U. Reactions of chlorine with inorganic and organic compounds during water treatment-kinetics and mechanisms: A critical review. Water Research. 2008; 42(1-2):13-51. https://doi.org/10.1016/j.watres.2007.07.025

[95] Heeb MB, Criquet J, Zimmermann-Steffens SG, von Gunten U. Oxidative treatment of bromide-containing waters: Formation of bromine and its reactions with inorganic and organic compounds - a critical review. Water Research. 2014; 48:15-42. https://doi.org/10.1016/j.watres.2013.08.030

[96] Criquet J, Rodriguez EM, Allard S, Wellauer S, Salhi E, Joll CA, *et al.* Reaction of bromine and chlorine with phenolic compounds and natural organic matter extracts - electrophilic aromatic substitution and oxidation. Water Research. 2015; 85:476-86. https://doi.org/10.1016/j.watres.2015.08.051

[97] Rapp H-J, Pfromm PH. Electrodialysis for chloride removal in low effluent kraft pulp production. Membrane Technology. 1997; 1997(89):7-11. https://doi.org/10.1016/S0958-2118(00)89225-3

[98] Rapp H-J, Pfromm PH. Electrodialysis field test for selective chloride removal from the chemical recovery cycle of a Kraft Pulp Mill. Industrial & Engineering Chemistry Research. 1998; 37(12):4761-7. https://doi.org/10.1021/ie980376+

[99] Ferreira LM, Amaral L, Machado L. Removal of chloride in the Kraft chemical recovery cycle of pulp mills using the ion-exchange process. Industrial & Engineering Chemistry Research. 2004; 43(22):7121-8. https://doi.org/10.1021/ie030862j

[100] Lottermoser BG. Mine Water. In: Mine wastes characterization, treatment and environmental impacts. Heidelberg: Springer; 2010. p. 83-41. https://doi.org/10.1007/978-3-642-12419-8

[101] Ericsson B, Hallmans B. Treatment of saline wastewater for zero discharge at the Debiensko coal mines in Poland. Desalination. 1996; 105(1-2):115-23. https://doi.org/10.1016/0011-9164(96)00065-3

[102] Mercuri AM, Duggin JA, Grant CD. The use of saline mine water and municipal wastes to establish plantations on rehabilitated open-cut coal mines, Upper Hunter Valley NSW, Australia. Forest Ecology and Management. 2005; 204(2-3):195-207. https://doi.org/10.1016/j.foreco.2004.09.008

[103] Banks D, Younger PL, Arnesen R-T, Iversen ER, Banks SB. Mine-water chemistry: The good, the bad and the ugly. Environmental Geology. 1997; 32(3):157-74. https://doi.org/10.1007/s002540050204

[104] Silva TLS, Morales-Torres S, Castro-Silva S, Figueiredo JL, Silva AMT. An overview on exploration and environmental impact of unconventional gas sources and treatment options for produced water. Journal of Environmental Management. 2017; 200:511-29. https://doi.org/10.1016/j.jenvman.2017.06.002

[105] Jiménez S, Micó MM, Arnaldos M, Medina F, Contreras S. State of the art of produced water treatment. Chemosphere. 2018; 192:186-208. https://doi.org/10.1016/j.chemosphere.2017.10.139

[106] Booth DW, Anderson, TL. Booth, D.W. and T.L. Anderson, Method and system for removing NaCl from production water or fracking water produced in an oil well operation, or other wastewater, using CaCl2. St Albans, West Virgina, USA: Clean Water LLC, USA; 2017.

[107] Middleditch BS. Ecological effects of produced water effluents from offshore oil and gas production platforms. Ocean Management. 1984; 9(3-4):191-316. https://doi.org/10.1016/0302-184X(84)90003-9

[108] Warner NR, Christie CA, Jackson RB, Vengosh A. Impacts of shale gas wastewater disposal on water quality in Western Pennsylvania. Environmental Science & Technology. 2013; 47(20):11849-57. https://doi.org/10.1021/es402165b

[109] Parker KM, Zeng T, Harkness J, Vengosh A, Mitch WA. Enhanced formation of disinfection byproducts in shale gas wastewater-impacted drinking water supplies. Environmental Science & Technology. 2014; 48(19):11161-9. https://doi.org/10.1021/es5028184

[110] Adham S, Hussain A, Minier-Matar J, Janson A, Sharma R. Membrane applications and opportunities for water management in the Oil & Gas Industry. Desalination. 2018; 440:2-17. https://doi.org/10.1016/j.desal.2018.01.030

[111] Millar GJ, Couperthwaite SJ, Papworth S. Ion exchange of sodium chloride and sodium bicarbonate solutions using strong acid cation resins in relation to coal seam water treatment. Journal of Water Process Engineering. 2016; 11:60-7. https://doi.org/10.1016/j.jwpe.2016.03.003

[112] Vedelago R, Millar GJ. Process evaluation of treatment options for high alkalinity coal seam gas associated water. Journal of Water Process Engineering. 2018; 23:195-206. https://doi.org/10.1016/j.jwpe.2018.04.005

[113] Millar GJ, Couperthwaite SJ, Moodliar CD. Strategies for the management and treatment of coal seam gas associated water. Renewable and Sustainable Energy Reviews. 2016; 57:669-91. https://doi.org/10.1016/j.rser.2015.12.087

[114] Rebello CA, Couperthwaite SJ, Millar GJ, Dawes LA. Coal seam water quality and the impact upon management strategies. Journal of Petroleum Science and Engineering. 2017; 150:323-33. https://doi.org/10.1016/j.petrol.2016.12.022

[115] Ikura M, Stanciulescu M. Process for removing chlorides from crude oil. Canada Minister of Energy Mines and Resources Canada; 1995.

[116] Mallants D, Jeffrey R, Zhang X, Wu B, Kear J, Chen Z, *et al.* Review of plausible chemical migration pathways in Australian coal seam gas basins. International Journal of Coal Geology. 2018; 195:280-303. https://doi.org/10.1016/j.coal.2018.06.002

[117] Kim HI, Wijenayake JJ, Mohapatra D, Rout PC. A process to recover high purity iodine in wastewater from liquid crystal display (LCD) manufacturing industry. Hydrometallurgy. 2018; 181:91-6. https://doi.org/10.1016/j.hydromet.2018.09.004

[118] Madrakian T, Afkhami A, Zolfigol MA, Ahmadi M, Koukabi N. Application of modified silica coated magnetite nanoparticles for removal of iodine from water samples. Nano-Micro Letters. 2012; 4(1):57-63. https://doi.org/10.1007/BF03353693

[119] Kentjono L, Liu JC, Chang WC, Irawan C. Removal of boron and iodine from optoelectronic wastewater using MG-al (NO3) layered double hydroxide. Desalination. 2010; 262(1-3):280-3. https://doi.org/10.1016/j.desal.2010.06.015

[120] Theiss FL, Ayoko GA, Frost RL. Iodide removal using LDH Technology. Chemical Engineering Journal. 2016; 296:300-9. https://doi.org/10.1016/j.cej.2016.02.039

[121] Fruit JT, Xu P, Hoppe-Jones C, Cath TY. Recovery of Iodine from Produced Water Through Anion Resin Exchange, in 2011 Research Experiences for Undergraduates posters and presentations. 2011, Advanced Water Technology Center (AQWATEC) Colorado School of Mines, 1500 Illinois street, Golden, CO 80401.

[122] Ordóñez JI, Moreno L, González JF, Cisternas LA. Use of discharged brine from reverse osmosis plant in heap leaching: Opportunity for caliche mining industry. Hydrometallurgy. 2015; 155:61-8. https://doi.org/10.1016/j.hydromet.2015.04.008

[123] Harkness JS, Dwyer GS, Warner NR, Parker KM, Mitch WA, Vengosh A. Iodide, bromide, and ammonium in hydraulic fracturing and oil and Gas Wastewaters: Environmental implications. Environmental Science & Technology. 2015; 49(3):1955-63. https://doi.org/10.1021/es504654n

[124] Walton RD, Cowan GA. Relevance of nuclide migration at Oklo to the problem of geologic storage of radioactive waste. In: IAEA International symposium on the OKLO phenomenon. Libreville, Gabon; 1975. p. 499.

[125] Fabryka Martin June T, Airey PL, Elmore D, Kubik PW. Redistribution of Natural 129I among Mineral Phases and Ground Water in the Koongarra Uranium Ore Deposit, N.T., Australia, in Natural Analogues In: Radioactive Waste Disposal, B. Côme and N.A. Chapman, Editors. Dordrecht: Springer Netherlands; 1987. p. 374-85. https://doi.org/10.1007/978-94-009-3465-8_33

[126] Okogbue CO, Ukpai SN. Evaluation of trace element contents in groundwater in Abakaliki Metropolis and around the abandoned mine sites in the southern part, Southeastern Nigeria. Environmental Earth Sciences. 2013; 70(7):3351-62. https://doi.org/10.1007/s12665-013-2401-4

[127] Vainikka P, Hupa M. Review on bromine in solid fuels - part 2: Anthropogenic occurrence. Fuel. 2012; 94:34-51. https://doi.org/10.1016/j.fuel.2011.11.021

[128] McTigue NE, Cornwell DA, Graf K, Brown R. Occurrence and consequences of increased bromide in drinking water sources. Journal - American Water Works Association. 2014; 106(11):E492-E508. https://doi.org/10.5942/jawwa.2014.106.0141

[129] Regli S, Chen J, Messner M, Elovitz MS, Letkiewicz FJ, Pegram RA, *et al.* Estimating potential increased bladder cancer risk due to increased bromide concentrations in sources of disinfected drinking waters. Environmental Science & Technology. 2015; 49(22):13094-102. https://doi.org/10.1021/acs.est.5b03547

[130] Morf LS, Schenk K, Fahrni H-P. Chemische Zusammensetzung Verbrannter Siedlungsabfälle. MÜLL und ABFALL. 2007; (4):169-75. https://doi.org/10.37307/j.1863-9763.2007.04.06

[131] Winid B. Bromine and water quality - selected aspects and future perspectives. Applied Geochemistry. 2015; 63:413-35. https://doi.org/10.1016/j.apgeochem.2015.10.004

[132] Buschmann J, Lindau L, Vosteen BW. [Internet]. The KNX™ Coal Additive Technology: A Simple Solution for Mercury Emissions Control. 2005; [cited 2023Feb16]. Available from: https://www.vosteen-consulting.de/fileadmin/user_upload/Publikationen/2005/2005_12_Vosteen_Consulting_KNX_TM_Coal_Additive_Technology_PowerGen_USA.pdf

[133] Good KD, VanBriesen JM. Current and potential future bromide loads from coal-fired power plants in the Allegheny River basin and their effects on downstream concentrations. Environmental Science & Technology. 2016; 50(17):9078-88. https://doi.org/10.1021/acs.est.6b01770

[134] Soltermann F, Abegglen C, Götz C, von Gunten U. Bromide sources and loads in Swiss surface waters and their relevance for Bromate Formation during wastewater Ozonation. Environmental Science & Technology. 2016; 50(18):9825-34. https://doi.org/10.1021/acs.est.6b01142

[135] Farré1 MJ, Knight N. Assessment of Regulated and Emerging Disinfection By-Products in South East Queensland Drinking Water. Brisbane, Qld: Urban Water Security Research Alliance ; 2012. (Technical Report No. 90).

[136] Dorji P, Choi J, Kim DI, Phuntsho S, Hong S, Shon HK. Membrane capacitive deionisation as an alternative to the 2nd pass for seawater reverse osmosis desalination plant for bromide removal. Desalination. 2018; 433:113-9. https://doi.org/10.1016/j.desal.2018.01.020

[137] World Health Organization. Bromide in drinking-water. Background Document for Development of WHO Guidelines for Drinking-water Quality. Geneva, Switzerland; 2009.

[138] Amy G. Nation-wide survey of bromide ion concentrations in drinking water sources. In: Proceedings of Annual Conference of American Water Work Association. 1993. p. 1-19.

[139] Weinberg HS, Krasner SW, Richardson SD, Thruston AD. The Occurrence of Disinfection By-Products (DBPs) of Health Concern in Drinking Water: Results of a Nationwide DBP Occurrence Study. Athens, GA: National Exposure Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency ; 2002.

[140] Jones DB, Saglam A, Song H, Karanfil T. The impact of bromide/iodide concentration and ratio on iodinated trihalomethane formation and speciation. Water Research. 2012; 46(1):11-20. https://doi.org/10.1016/j.watres.2011.10.005

[141] Al-Mutaz I. Water desalination in the Arabian Gulf Region. Water Purificaton. 2000; 2:245-65.

[142] Wardman P. Reduction potentials of one-electron couples involving free radicals in aqueous solution. Journal of Physical and Chemical Reference Data. 1989; 18(4):1637-755. https://doi.org/10.1063/1.555843

[143] Wang TX, Margerum DW. Kinetics of reversible chlorine hydrolysis: Temperature dependence and general-acid/base-assisted mechanisms. Inorganic Chemistry. 1994; 33(6):1050-5. https://doi.org/10.1021/ic00084a014

[144] Beckwith RC, Wang TX, Margerum DW. Equilibrium and kinetics of Bromine hydrolysis. Inorganic Chemistry. 1996; 35(4):995-1000. https://doi.org/10.1021/ic950909w

[145] Matthew BM, Anastasio C. A chemical probe technique for the determination of reactive halogen species in aqueous solution: Part 1 - bromide solutions. Atmospheric Chemistry and Physics. 2006; 6(9):2423-37. https://doi.org/10.5194/acp-6-2423-2006

[146] Ershov BG, Kelm M, Janata E, Gordeev AV, Bohnert E. Radiation-chemical effects in the near-field of a final disposal site: Role of bromine on the radiolytic processes in NaCl-Solutions. Radiochimica Acta. 2002; 90(9-11):617-22. https://doi.org/10.1524/ract.2002.90.9-11_2002.617

[147] Eigen M, Kustin K. The kinetics of halogen hydrolysis. Journal of the American Chemical Society. 1962; 84(8):1355-61. https://doi.org/10.1021/ja00867a005

[148] National Institute of Advanced Industrial Science and Technology Research Center for Deep Geological Environments Naoto TAKENO. Atlas Eh-pH Diagrams Intercomparison of thermodynamic databases Geological Survey of Japan Open File Report No.419. 2005.

[149] Decamp C, Happel S. Utilization of a mixed-bed column for the removal of iodine from radioactive process waste solutions. Journal of Radioanalytical and Nuclear Chemistry. 2013; 298(2):763-7. https://doi.org/10.1007/s10967-013-2503-1

[150] NHMRC and NRMMC. National water quality management strategy Australian drinking water guidelines 6 national water quality management strategy, 3.5 edition. Canberra: National Health and Medical Research Council, National Resource Management Ministerial Council, Commonwealth of Australia; 2011.

[151] The Council of European Union. Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption. Official Journal of the European Communities. 1998; :L 330/32-L 330/54.

[152] World Health Organization. Guidlines for drinking water quality, 4th edition. Gutenberg, Switzerland; 2011.

[153] Walton KR, Panno SV, Hackley K. Sources, distribution, and trends of chloride in the waters of Illinois. Champaign, IL: Illinois State Water Survey, Prairie Research Institute, University of Illinois at Urbana-Champaign; 2012.

[154] Verbruggen EMJ. In: Afleiding van Milieurisicogrenzen voor chloride in oppervlaktewater, grondwater, bodem en waterbodem (Derivation of environmental risk limits for chloride in surface water, groundwater, soil and sediment). Bilthoven, Nederland: RIVM; 2008. Rapport 711701075, p. 76.

[155] World Health Organization. Iodine in drinking-water, in: M. Sheffer (Ed.), Background Document for Development of WHO Guidelines for Drinking-water Quality. Geneva, Switzerland; 2003.

[156] Yu F, Chen Y, Wang Y, Liu C, Ma W. Enhanced removal of iodide from aqueous solution by ozonation and subsequent adsorption on Ag-AG2O modified on carbon spheres. Applied Surface Science. 2018; 427:753-62. https://doi.org/10.1016/j.apsusc.2017.08.089

[157] Gopal K, Tripathy SS, Bersillon JL, Dubey SP. Chlorination byproducts, their toxicodynamics and removal from drinking water. Journal of Hazardous Materials. 2007; 140(1-2):1-6. https://doi.org/10.1016/j.jhazmat.2006.10.063

[158] Richardson S, Plewa M, Wagner E, Schoeny R, Demarini D. Occurrence, genotoxicity, and carcinogenicity of regulated and emerging disinfection by-products in drinking water: A review and roadmap for research. Mutation Research/Reviews in Mutation Research. 2007; 636(1-3):178-242. https://doi.org/10.1016/j.mrrev.2007.09.001

[159] Liew D. Australian disinfection by-product research: identifying impacts on the water industry Impact Study - disinfection by-product research. 2015. Water Research Australia (WRA). 2015.

[160] National Toxicology Program. NTP Toxicology and Carcinogenesis Studies of Chlorodibromomethane (CAS No. 124-48-1) in F344/N Rats and B6C3F1 Mice (Gavage Studies) (Gavage Studies). National Toxicology Program Technical Report Series. 1985; 282:1-174.

[161] Melnick RL, Nyska A, Foster PM, Roycroft JH, Kissling GE. Toxicity and carcinogenicity of the water disinfection byproduct, dibromoacetic acid, in rats and mice. Toxicology. 2007; 230(2-3):126-36. https://doi.org/10.1016/j.tox.2006.11.006

[162] Aronson JK. In: Meyler's side effects of drugs: The International Encyclopedia of Adverse Drug Reactions and interactions. Amsterdam: Elsevier Science; 2016. p. 226-8.

[163] DeAngelo AB, George MH, Kilburn SR, Moore TM, Wolf DC. Carcinogenicity of potassium bromate administered in the drinking water to male B6C3F1 mice and F344/N Rats. Toxicologic Pathology. 1998; 26(5):587-94. https://doi.org/10.1177/019262339802600501

[164] Kurokawa Y, Takayama S, Konishi Y, Hiasa Y, Asahina S, Takahashi M, *et al.* Long-term in vivo carcinogenicity tests of potassium bromate, sodium hypochlorite, and sodium chlorite conducted in Japan. Environmental Health Perspectives. 1986; 69:221-35. https://doi.org/10.1289/ehp.8669221

[165] Kurokawa Y, Aoki S, Matsushima Y, Takamura N, Imazawa T, Hayashi Y. Dose-response studies on the carcinogenicity of potassium bromate in F344 rats after long-term oral administration. JNCI: Journal of the National Cancer Institute. 1986; 77(4):977-82.

[166] Kurokawa Y, Hayashi Y, Maekawa A, Takahashi M, Kokubo T, Odashima S. Carcinogenicity of potassium bromate administered orally to F344 rats. JNCI: Journal of the National Cancer Institute. 1983; 71(5):965-72.

[167] Hirich A, Choukr-Allah R, Rami A, El-Otmani M. Feasibility of using desalination for irrigation in the Souss Massa region in the south of Morocco. Recent Progress in Desalination, Environmental and Marine Outfall Systems. 2015; 189-203. https://doi.org/10.1007/978-3-319-19123-2_13

[168] Duan J, Gregory J. Coagulation by hydrolysing metal salts. Advances in Colloid and Interface Science. 2003; 100-102:475-502. https://doi.org/10.1016/S0001-8686(02)00067-2

[169] Abdel-Wahab, A.I.A. AIA. The ultra-high lime with aluminum process for removing chloride from recirculating cooling water [thesis]. 2003. https://doi.org/10.2175/193864703784679323

[170] Abdel-Wahab A, Batchelor B. Effects of ph, temperature, and water quality on chloride removal with ultra-high lime with aluminum process. Water Environment Research. 2006; 78(9):930-7. https://doi.org/10.2175/106143005X72821

[171] Bodson FJJ. Process for the elimination of chloride from zinc sulphate solutions US Patent 4005174A. 1977.

[172] Al-Karaghouli A, Kazmerski LL. Energy consumption and water production cost of conventional and renewable-energy-powered desalination processes. Renewable and Sustainable Energy Reviews. 2013; 24:343-56. https://doi.org/10.1016/j.rser.2012.12.064

[173] Avlonitis SA. Operational water cost and productivity improvements for small-size ro desalination plants. Desalination. 2002; 142(3):295-304. https://doi.org/10.1016/S0011-9164(02)00210-2

[174] Ng KC, Thu K, Kim Y, Chakraborty A, Amy G. Adsorption desalination: An emerging low-cost thermal desalination method. Desalination. 2013; 308:161-79. https://doi.org/10.1016/j.desal.2012.07.030

[175] Morillo J, Usero J, Rosado D, El Bakouri H, Riaza A, Bernaola F-J. Comparative study of brine management technologies for desalination plants. Desalination. 2014; 336:32-49. https://doi.org/10.1016/j.desal.2013.12.038

[176] Shahzad MW, Ng KC, Thu K, Saha BB, Chun WG. Multi effect desalination and adsorption desalination (Medad): A hybrid desalination method. Applied Thermal Engineering. 2014; 72(2):289-97. https://doi.org/10.1016/j.applthermaleng.2014.03.064

[177] Zhou Y, Tol RS. Evaluating the costs of desalination and Water Transport. Water Resources Research. 2005; 41(3). https://doi.org/10.1029/2004WR003749

[178] Gupta VK, Ali I, Saleh TA, Nayak A, Agarwal S. Chemical Treatment Technologies for waste-water recycling-an overview. RSC Advances. 2012; 2(16):6380-8. https://doi.org/10.1039/c2ra20340e

[179] Sarai Atab M, Smallbone AJ, Roskilly AP. An operational and economic study of a reverse osmosis desalination system for potable water and land irrigation. Desalination. 2016; 397:174-84. https://doi.org/10.1016/j.desal.2016.06.020

[180] Malaeb L, Ayoub GM. Reverse osmosis technology for water treatment: State of the art review. Desalination. 2011; 267(1):1-8. https://doi.org/10.1016/j.desal.2010.09.001

[181] Glater J, Cohen Y. Brine disposal from land based membrane desalination plants: a critical assessment. Prepared for the Metropolitan Water District of Southern California. Los Angeles, CA: University of California; 2003.

[182] Fritzmann C, Löwenberg J, Wintgens T, Melin T. State-of-the-art of reverse osmosis desalination. Desalination. 2007; 216(1-3):1-76. https://doi.org/10.1016/j.desal.2006.12.009

[183] Al-Obaidani S, Curcio E, Macedonio F, Diprofio G, Alhinai H, Drioli E. Potential of membrane distillation in seawater desalination: Thermal efficiency, sensitivity study and cost estimation. Journal of Membrane Science. 2008; 323(1):85-98. https://doi.org/10.1016/j.memsci.2008.06.006

[184] Kim JE, Phuntsho S, Chekli L, Hong S, Ghaffour N, Leiknes TO, *et al.* Environmental and economic impacts of fertilizer drawn forward osmosis and nanofiltration hybrid system. Desalination. 2017; 416:76-85. https://doi.org/10.1016/j.desal.2017.05.001

[185] Kesieme UK, Milne N, Aral H, Cheng CY, Duke M. Economic Analysis of desalination technologies in the context of carbon pricing, and opportunities for membrane distillation. Desalination. 2013; 323:66-74. https://doi.org/10.1016/j.desal.2013.03.033

[186] González D, Amigo J, Suárez F. Membrane distillation: Perspectives for sustainable and improved desalination. Renewable and Sustainable Energy Reviews. 2017; 80:238-59. https://doi.org/10.1016/j.rser.2017.05.078

[187] Hanemaaijer JH, van Medevoort J, Jansen AE, Dotremont C, van Sonsbeek E, Yuan T, *et al.* Memstill membrane distillation - a future desalination technology. Desalination. 2006; 199(1-3):175-6. https://doi.org/10.1016/j.desal.2006.03.163

[188] Macedonio F, Curcio E, Drioli E. Integrated Membrane Systems for seawater desalination: Energetic and exergetic analysis, economic evaluation, experimental study. Desalination. 2007; 203(1-3):260-76. https://doi.org/10.1016/j.desal.2006.02.021

[189] Zhang Y, Sivakumar M, Yang S, Enever K, Ramezanianpour M. Application of solar energy in water treatment processes: A Review. Desalination. 2018; 428:116-45. https://doi.org/10.1016/j.desal.2017.11.020

[190] Moussa DT, El-Naas MH, Nasser M, Al-Marri MJ. A comprehensive review of electrocoagulation for water treatment: Potentials and challenges. Journal of Environmental Management. 2017; 186:24-41. https://doi.org/10.1016/j.jenvman.2016.10.032

[191] Strathmann H. Electrodialytic membrane processes and their practical application. Studies in Environmental Science. 1994; :495-533. https://doi.org/10.1016/S0166-1116(08)70563-6

[192] Ali I, Gupta VK. Advances in water treatment by adsorption technology. Nature Protocols. 2006; 1(6):2661-7. https://doi.org/10.1038/nprot.2006.370

[193] Kubota S, Ohta K, Hayano I, Hirai M, Kikuchi K, Murayama Y. Experiments on seawater desalination by membrane distillation. Desalination. 1988; 69(1):19-26. https://doi.org/10.1016/0011-9164(88)80003-1

[194] Hirao H, Yamada K, Takahashi H, Zibara H. Chloride binding of cement estimated by binding isotherms of hydrates. Journal of Advanced Concrete Technology. 2005; 3(1):77-84. https://doi.org/10.3151/jact.3.77

[195] Zhou Y, Hou D, Jiang J, Liu L, She W, Yu J. Experimental and molecular dynamics studies on the transport and adsorption of chloride ions in the nano-pores of calcium silicate phase: The influence of calcium to silicate ratios. Microporous and Mesoporous Materials. 2018; 255:23-35. https://doi.org/10.1016/j.micromeso.2017.07.024

[196] Nakamura A, Sakai E, Nishizawa K, Ohba Y, Daimon M. Sorption of chloride-ion, sulfate-ion and phosphate-ion in calcium silicate hydrates. Nippon Kagaku Kaishi. 1999; (6):415-20. https://doi.org/10.1246/nikkashi.1999.415

[197] Birnin-Yauri UA, Glasser FP. Friedel's Salt, Ca2Al(OH)6(Cl,OH)·2H2O: Its solid solutions and their role in chloride binding. Cement and Concrete Research. 1998; 28(12):1713-23. https://doi.org/10.1016/S0008-8846(98)00162-8

[198] QUIRK JP. Negative and positive adsorption of chloride by kaolinite. Nature. 1960; 188(4746):253-4. https://doi.org/10.1038/188253a0

[199] Sumner ME, Reeve NG. The effect of iron oxide impurities on the positive and negative adsorption of chloride by kaolinites. Journal of Soil Science. 1966; 17(2):274-9. https://doi.org/10.1111/j.1365-2389.1966.tb01473.x

[200] Hingston FJ, Posner AM, Quirk JP. Anion adsorption by goethite and gibbsite. Journal of Soil Science. 1972; 23(2):177-92. https://doi.org/10.1111/j.1365-2389.1972.tb01652.x

[201] Gerami M, Halladj R, Biriaei R, Askari S, Nazari M. Adsorption of chloride ions from aqueous solution on γ-alumina modified by sodium oxide: An equilibrium and kinetics study. Desalination and Water Treatment. 2017; 58:249-57. https://doi.org/10.5004/dwt.2017.0958

[202] Al-Rawajfeh A, Al-Whoosh K, Al D, Al-Maaberah A, Tarawneh A. Pre-treatment of desalination feed seawater by Jordanian Tripoli, Pozzolana, and feldspar: Batch experiments. Chemical Industry and Chemical Engineering Quarterly. 2011; 17(2):163-71. https://doi.org/10.2298/CICEQ100827066A

[203] Al-Rawajfeh AE, Al-Shamaileh EM, Al-Whoosh K, Al-Ma'abrah A, Al-Zorqan R, Zanoon R, *et al.* Adsorption desalination of chloride ions on composite natural-synthetic materials: An approach for the reduction of chlorine corrosion in electrodeionization units. Journal of Industrial and Engineering Chemistry. 2013; 19(6):1895-902. https://doi.org/10.1016/j.jiec.2013.02.035

[204] de Santiago-Martín A, Michaux A, Guesdon G, Constantin B, Despréaux M, Galvez-Cloutier R. Potential of anthracite, dolomite, limestone and Pozzolan as reactive media for de-icing salt removal from road runoff. International Journal of Environmental Science and Technology. 2016; 13(10):2313-24. https://doi.org/10.1007/s13762-016-1085-1

[205] Iakovleva E, Mäkilä E, Salonen J, Sitarz M, Sillanpää M. Industrial products and wastes as adsorbents for sulphate and chloride removal from synthetic alkaline solution and Mine Process Water. Chemical Engineering Journal. 2015; 259:364-71. https://doi.org/10.1016/j.cej.2014.07.091

[206] Sun Z, Chai L, Shu Y, Li Q, Liu M, Qiu D. Chemical bond between chloride ions and surface carboxyl groups on activated carbon. Colloids and Surfaces A: Physicochemical and Engineering Aspects. 2017; 530:53-9. https://doi.org/10.1016/j.colsurfa.2017.06.077

[207] Apte SS, Apte SS, Kore VS, Kore SV. Chloride removal from wastewater by biosorption with the plant biomass. Universal Journal of Environmental Research and Technology. 2011; 1(4):416-22.

[208] Hazra S. Removal of chloride from water, in enersciences practical science at work. Lafayette, LA: 1424 S. Hugh Wallis Road; 2013.

[209] Li H, Pan L, Lu T, Zhan Y, Nie C, Sun Z. A comparative study on electrosorptive behavior of carbon nanotubes and graphene for capacitive deionization. Journal of Electroanalytical Chemistry. 2011; 653(1-2):40-4. https://doi.org/10.1016/j.jelechem.2011.01.012

[210] Dai K, Shi L, Fang J, Zhang D, Yu B. NaCl adsorption in multi-walled carbon nanotubes. Materials Letters. 2005; 59(16):1989-92. https://doi.org/10.1016/j.matlet.2005.01.042

[211] Wang XZ, Li MG, Chen YW, Cheng RM, Huang SM, Pan LK, *et al.* Electrosorption of NaCl solutions with carbon nanotubes and nanofibers composite film electrodes. Electrochemical and Solid-State Letters. 2006; 9(9):E23-E26. https://doi.org/10.1149/1.2213354

[212] AlMarzooqi FA, Al Ghaferi AA, Saadat I, Hilal N. Application of capacitive deionisation in water desalination: A Review. Desalination. 2014; 342:3-15. https://doi.org/10.1016/j.desal.2014.02.031

[213] Ryoo M-W, Seo G. Improvement in capacitive deionization function of activated carbon cloth by Titania modification. Water Research. 2003; 37(7):1527-34. https://doi.org/10.1016/S0043-1354(02)00531-6

[214] Yang J, Zou L, Song H, Hao Z. Development of novel MNO2/Nanoporous Carbon Composite Electrodes in capacitive deionization technology. Desalination. 2011; 276(1-3):199-206. https://doi.org/10.1016/j.desal.2011.03.044

[215] Wang G, Pan C, Wang L, Dong Q, Yu C, Zhao Z, *et al.* Activated carbon nanofiber webs made by Electrospinning for capacitive deionization. Electrochimica Acta. 2012; 69:65-70. https://doi.org/10.1016/j.electacta.2012.02.066

[216] Li H, Lu T, Pan L, Zhang Y, Sun Z. Electrosorption behavior of graphene in NaCl Solutions. Journal of Materials Chemistry. 2009; 19(37):6773-9. https://doi.org/10.1039/b907703k

[217] Jia B, Zou L. Wettability and its influence on graphene nansoheets as electrode material for Capacitive Deionization. Chemical Physics Letters. 2012; 548:23-8. https://doi.org/10.1016/j.cplett.2012.06.016

[218] Zhang D, Yan T, Shi L, Peng Z, Wen X, Zhang J. Enhanced capacitive deionization performance of graphene/carbon nanotube composites. Journal of Materials Chemistry. 2012; 22(29):14696-704. https://doi.org/10.1039/c2jm31393f

[219] Li H, Pan L, Nie C, Liu Y, Sun Z. Reduced graphene oxide and activated carbon composites for Capacitive Deionization. Journal of Materials Chemistry. 2012; 22(31):15556-61. https://doi.org/10.1039/c2jm32207b

[220] Wang Z, Dou B, Zheng L, Zhang G, Liu Z, Hao Z. Effective desalination by capacitive deionization with functional graphene nanocomposite as novel electrode material. Desalination. 2012; 299:96-102. https://doi.org/10.1016/j.desal.2012.05.028

[221] Suss ME, Baumann TF, Bourcier WL, Spadaccini CM, Rose KA, Santiago JG, *et al.* Capacitive desalination with flow-through electrodes. Energy & Environmental Science. 2012; 5(11):9511. https://doi.org/10.1039/c2ee21498a

[222] Porada S, Weinstein L, Dash R, van der Wal A, Bryjak M, Gogotsi Y, *et al.* Water desalination using capacitive deionization with microporous carbon electrodes. ACS Applied Materials & Interfaces. 2012; 4(3):1194-9. https://doi.org/10.1021/am201683j

[223] Skaisgirienė A, Janutėnienė J, Vaitiekūnas P. Modelling of chloride influence upon activated sludge community growth. Journal of Environmental Engineering and Landscape Management. 2009; 17(2):114-20. https://doi.org/10.3846/1648-6897.2009.17.114-120

[224] Kyser S, Doucette E. Alternatives for addressing chloride in wastewater effluent-MPCA analyzes treatment options for salty parameters, J. Holstad, Editor. Saintt Paul, MN: Minnesota Pollution Control Agency; 2018 p. 1-41.

[225] Ma X-X, Li Z-S. The effect of oxygen molecule adsorption on lead iodide perovskite surface by first-principles calculation. Applied Surface Science. 2018; 428:140-7. https://doi.org/10.1016/j.apsusc.2017.09.073

[226] Zhang A, Tie X, Zhang J, An Y, Li L. Adsorption of iodide and iodate on colloidal silver surface. Applied Surface Science. 2008; 255(5):3184-7. https://doi.org/10.1016/j.apsusc.2008.09.016

[227] Kubota T, Fukutani S, Ohta T, Mahara Y. Removal of radioactive cesium, strontium, and iodine from natural waters using bentonite, zeolite, and activated carbon. Journal of Radioanalytical and Nuclear Chemistry. 2012; 296(2):981-4. https://doi.org/10.1007/s10967-012-2068-4

[228] Osmanlioglu AE. Treatment of radioactive liquid waste by sorption on natural zeolite in Turkey. Journal of Hazardous Materials. 2006; 137(1):332-5. https://doi.org/10.1016/j.jhazmat.2006.02.013

[229] Zhao X, Han X, Li Z, Huang H, Liu D, Zhong C. Enhanced removal of iodide from water induced by a metal-incorporated porous metal-organic framework. Applied Surface Science. 2015; 351:760-4. https://doi.org/10.1016/j.apsusc.2015.05.186

[230] Liu S, Wang N, Zhang Y, Li Y, Han Z, Na P. Efficient removal of radioactive iodide ions from water by three-dimensional ag2o-AG/Tio2 composites under visible light irradiation. Journal of Hazardous Materials. 2015; 284:171-81. https://doi.org/10.1016/j.jhazmat.2014.10.054

[231] Choung S, Kim M, Yang J-S, Kim M-G, Um W. Effects of radiation and temperature on iodide sorption by surfactant-modified bentonite. Environmental Science & Technology. 2014; 48(16):9684-91. https://doi.org/10.1021/es501661z

[232] Warchoł J, Misaelides P, Petrus R, Zamboulis D. Preparation and application of organo-modified zeolitic material in the removal of chromates and Iodides. Journal of Hazardous Materials. 2006; 137(3):1410-6. https://doi.org/10.1016/j.jhazmat.2006.04.028

[233] Choung S, Um W, Kim M, Kim M-G. Uptake mechanism for iodine species to black carbon. Environmental Science & Technology. 2013; 47(18):10349-55. https://doi.org/10.1021/es401570a

[234] Zhang C, Wen H, Huang Y, Shi W. Adsorption of anionic surfactants from aqueous solution by high content of primary amino crosslinked chitosan microspheres. International Journal of Biological Macromolecules. 2017; 97:635-41. https://doi.org/10.1016/j.ijbiomac.2017.01.088

[235] Mao P, Liu Y, Jiao Y, Chen S, Yang Y. Enhanced uptake of iodide on ag@cu2o nanoparticles. Chemosphere. 2016; 164:396-403. https://doi.org/10.1016/j.chemosphere.2016.08.116

[236] Faghihian H, Ghannadi Maragheh M, Malekpour A. Adsorption of radioactive iodide by natural zeolites. Journal of Radioanalytical and Nuclear Chemistry. 2002; 254(3):545-50. https://doi.org/10.1023/A:1021698207045

[237] Ikeda Y, Sazarashi M, Tsuji M, Seki R, Yoshikawa H. Adsorption of I ions on cinnabar for ^{129}I waste management. Radiochimica Acta Acta. 1994; 65(3):195-8. https://doi.org/10.1524/ract.1994.65.3.195

[238] Theiss FL, Ayoko GA, Frost RL. Leaching of iodide (I−) and iodate (IO3−) anions from synthetic layered double hydroxide materials. Journal of Colloid and Interface Science. 2016; 478:311-5. https://doi.org/10.1016/j.jcis.2016.06.024

[239] Bors J, Dultz S, Gorny A. Sorption of iodide, cesium and strontium on organophilic bentonite. Radiochimica Acta. 1998; 82(s1):269-74. https://doi.org/10.1524/ract.1998.82.special-issue.269

[240] Zhang H, Gao X, Guo T, Li Q, Liu H, Ye X, *et al.* Adsorption of iodide ions on a calcium alginate-silver chloride composite adsorbent. Colloids and Surfaces A: Physicochemical and Engineering Aspects. 2011; 386(1-3):166-71. https://doi.org/10.1016/j.colsurfa.2011.07.014

[241] Hoskins JS, Karanfil T, Serkiz SM. Removal and sequestration of iodide using silver-impregnated activated carbon. Environmental Science & Technology. 2002; 36(4):784-9. https://doi.org/10.1021/es010972m

[242] Sadasivam S, Rao SM. Characterization of silver-kaolinite (AGK): An adsorbent for long-lived 129i species. SpringerPlus. 2016; 5(1), p.142. https://doi.org/10.1186/s40064-016-1855-8

[243] Sánchez-Polo M, Rivera-Utrilla J, Salhi E, von Gunten U. Removal of bromide and iodide anions from drinking water by silver-activated carbon aerogels. Journal of Colloid and Interface Science. 2006; 300(1):437-41. https://doi.org/10.1016/j.jcis.2006.03.037

[244] Ensafi AA, Eskandari H. Efficient and selective extraction of iodide through a liquid membrane. Microchemical Journal. 2001; 69(1):45-50. https://doi.org/10.1016/S0026-265X(00)00188-0

[245] Liu Y, Gu P, Yang Y, Jia L, Zhang M, Zhang G. Removal of radioactive iodide from simulated liquid waste in an integrated precipitation reactor and membrane separator (PR-MS) system. Separation and Purification Technology. 2016; 171:221-8. https://doi.org/10.1016/j.seppur.2016.07.034

[246] Mao P, Qi L, Liu X, Liu Y, Jiao Y, Chen S, *et al.* Synthesis of Cu/CU2O hydrides for enhanced removal of iodide from water. Journal of Hazardous Materials. 2017; 328:21-8. https://doi.org/10.1016/j.jhazmat.2016.12.065

[247] Polo AMS, Velo-Gala I, Sánchez-Polo M, van Gunten UG, López-Peñalver JJ, Rivera-Utrilla J. Halide removal from aqueous solution by novel silver-polymeric materials. Science of The Total Environment. 2016; 573:1125-31. https://doi.org/10.1016/j.scitotenv.2016.08.071

[248] Fakhru'l-Razi A, Pendashteh A, Abdullah LC, Biak DR, Madaeni SS, Abidin ZZ. Review of technologies for oil and gas produced water treatment. Journal of Hazardous Materials. 2009; 170(2-3):530-51. https://doi.org/10.1016/j.jhazmat.2009.05.044

[249] Subramani A, Jacangelo JG. Emerging desalination technologies for water treatment: A critical review. Water Research. 2015; 75:164-87. https://doi.org/10.1016/j.watres.2015.02.032

[250] Kucera J. In: Desalination: Water from water. Hoboken, NJ, USA: John Wiley & Sons, Inc.; 2019. p. 1-37. https://doi.org/10.1002/9781119407874.ch1

[251] Naaktgeboren AJ, Snijders GJ, Gons J. Characterization of a new reverse osmosis composite membrane for industrial application. Desalination. 1988; 68(2-3):223-42. https://doi.org/10.1016/0011-9164(88)80057-2

[252] Pontie M, Buisson H, Diawara CK, Essis-Tome H. Studies of halide ions mass transfer in nanofiltration - application to selective defluorination of brackish drinking water. Desalination. 2003; 157(1-3):127-34. https://doi.org/10.1016/S0011-9164(03)00391-6

[253] Chang H-M, Chen S-S, Cai Z-S, Chang W-S, Ray SS, Nguyen NC, *et al.* Iodide recovery and boron removal from thin-film transistor liquid crystal display wastewater through forward osmosis. Journal of Cleaner Production. 2020; 258:120587. https://doi.org/10.1016/j.jclepro.2020.120587

[254] Harrison CJ, Le Gouellec YA, Cheng RC, Childress AE. Bench-scale testing of nanofiltration for seawater desalination. Journal of Environmental Engineering. 2007; 133(11):1004-14. https://doi.org/10.1061/(ASCE)0733-9372(2007)133:11(1004)

[255] Tanninen J, Nyström M. Separation of ions in acidic conditions using NF. Desalination. 2002; 147(1-3):295-9. https://doi.org/10.1016/S0011-9164(02)00555-6

[256] Qin J-J, Oo MH, Lee H, Coniglio B. Effect of feed ph on permeate ph and ion rejection under acidic conditions in NF process. Journal of Membrane Science. 2004; 232(1-2):153-9. https://doi.org/10.1016/j.memsci.2003.12.010

[257] Lhassani A. Selective demineralization of water by nanofiltration application to the defluorination of brackish water. Water Research. 200; 35(13):3260-4. https://doi.org/10.1016/S0043-1354(01)00020-3

[258] Hilal N, Al-Zoubi H, Mohammad AW, Darwish NA. Nanofiltration of highly concentrated salt solutions up to seawater salinity. Desalination. 2005; 184(1-3):315-26. https://doi.org/10.1016/j.desal.2005.02.062

[259] Al-Zoubi H, Hilal N, Darwish NA, Mohammad AW. Rejection and modelling of sulphate and potassium salts by nanofiltration membranes: Neural network and Spiegler-Kedem model. Desalination. 2007; 206(1-3):42-60. https://doi.org/10.1016/j.desal.2006.02.060

[260] Bougen A, Rabiller-Baudry M, Chaufer B, Michel F. Retention of heavy metal ions with nanofiltration inorganic membranes by grafting chelating groups. Separation and Purification Technology. 2001; 25(1-3):219-27. https://doi.org/10.1016/S1383-5866(01)00105-8

[261] Diawara CK, Lô SM, Rumeau M, Pontie M, Sarr O. A phenomenological mass transfer approach in nanofiltration of halide ions for a selective defluorination of brackish drinking water. Journal of Membrane Science. 2003; 219(1-2):103-12. https://doi.org/10.1016/S0376-7388(03)00189-3

[262] Amy GL, Siddiqui MS. Strategies to control Bromate and bromide. Denver, CO: AWWA Research Foundation and American Water Works Association; 1999.

[263] Chellam S. Effects of nanofiltration on trihalomethane and haloacetic acid precursor removal and speciation in waters containing low concentrations of bromide ion. Environmental Science & Technology. 2000; 34(9):1813-20. https://doi.org/10.1021/es991153t

[264] Chellam S, Krasner SW. Disinfection byproduct relationships and speciation in chlorinated nanofiltered waters. Environmental Science & Technology. 2001; 35(19):3988-99. https://doi.org/10.1021/es010775n

[265] Turek M, Dydo P, Klimek R. Salt production from coal-mine brine in NF - evaporation - crystallization system. Desalination. 2008; 221(1-3):238-43. https://doi.org/10.1016/j.desal.2007.01.080

[266] Valero F, Arbós R. Desalination of Brackish River water using electrodialysis reversal (EDR). Desalination. 2010; 253(1-3):170-4. https://doi.org/10.1016/j.desal.2009.11.011

[267] Valero F, Barcelo A, Arbos R. Electrodialysis technology - theory and applications. Desalination, Trends and Technologies. 2011; https://doi.org/10.5772/14297

[268] Strathmann H. Electrodialysis, a mature technology with a multitude of new applications. Desalination. 2010; 264(3):268-88. https://doi.org/10.1016/j.desal.2010.04.069

[269] Seneviratne M. A practical approach to water conservation for commercial and Industrial Facilities. Oxford: Butterworth Heinemann; 2008.

[270] Aponte VM, Colón G. Sodium chloride removal from urine via a six-compartment ed cell for use in Advanced Life Support Systems (part 2: Limiting current density behavior). Desalination. 2001; 140(2):133-44. https://doi.org/10.1016/S0011-9164(01)00363-0

[271] Hale AJ. Applications of electrolysis in chemical industry. Charleston, South Carolina: BiblioBazaar Nabu Press; 2008.

[272] Black & Veatch Corporation. White's Handbook of Chlorination and alternative disinfectants 5th edition. Hoboken, NJ: Wiley; 2009. https://doi.org/10.1002/9780470561331

[273] Kimbrough DE, Suffet IH. Electrochemical removal of bromide and reduction of THM formation potential in drinking water. Water Research. 2002; 36(19):4902-6. https://doi.org/10.1016/S0043-1354(02)00210-5

[274] Kogel JE. Industrial Minerals & Rocks: Commodities, markets, and uses. Littleton: Society for Mining, Metallurgy, and Exploration; 2006.

[275] Bo, L., Electrolytic cell and process for removal of bromide ions and disinfection of source waters using silver cathode and/or dimensionally stable anode (DSA): a process for the reduction of disinfectant/disinfection byproducts in drinking water. US Patent 7384564B2. 2006.

[276] Gabelich CJ, Tran TD, Suffet IH. Electrosorption of inorganic salts from aqueous solution using carbon aerogels. Environmental Science & Technology. 2002; 36(13):3010-9. https://doi.org/10.1021/es0112745

[277] Welgemoed TJ, Schutte CF. Capacitive deionization technology™: An Alternative Desalination Solution. Desalination. 2005; 183(1-3):327-40. https://doi.org/10.1016/j.desal.2005.02.054

[278] Yang K-L, Ying T-Y, Yiacoumi S, Tsouris C, Vittoratos ES. Electrosorption of ions from aqueous solutions by Carbon Aerogel: an electrical double-layer model. Langmuir. 2001; 17(6):1961-9. https://doi.org/10.1021/la001527s

[279] Xu P, Drewes JE, Heil D, Wang G. Treatment of brackish produced water using Carbon Aerogel-based Capacitive Deionization Technology. Water Research. 2008; 42(10-11):2605-17. https://doi.org/10.1016/j.watres.2008.01.011

[280] Ying T-Y, Yang K-L, Yiacoumi S, Tsouris C. Electrosorption of ions from aqueous solutions by nanostructured Carbon Aerogel. Journal of Colloid and Interface Science. 2002; 250(1):18-27. https://doi.org/10.1006/jcis.2002.8314

[281] Tran TD, Lenz DJ. Tran, T.D. and D.J. Lenz, Alternating-polarity operation for complete regeneration of electrochemical deionization system. US Patent 6346187. 2002.

[282] Bouhadana Y, Avraham E, Noked M, Ben-Tzion M, Soffer A, Aurbach D. Capacitive deionization of NaCl solutions at non-steady-state conditions: Inversion functionality of the carbon electrodes. The Journal of Physical Chemistry C. 2011; 115(33):16567-73. https://doi.org/10.1021/jp2047486

[283] Lee J-B, Park K-K, Eum H-M, Lee C-W. Desalination of a thermal power plant wastewater by Membrane Capacitive Deionization. Desalination. 2006; 196(1-3):125-34. https://doi.org/10.1016/j.desal.2006.01.011

[284] Hou CH, Huang CY, Hu CY. Application of capacitive deionization technology to the removal of sodium chloride from aqueous solutions. International Journal of Environmental Science and Technology. 2013; 10(4):753-60. https://doi.org/10.1007/s13762-013-0232-1

[285] Porada S, Zhao R, van der Wal A, Presser V, Biesheuvel PM. Review on the Science and Technology of Water Desalination by capacitive deionization. Progress in Materials Science. 2013; 58(8):1388-442. https://doi.org/10.1016/j.pmatsci.2013.03.005

[286] Oren Y. Capacitive deionization (CDI) for desalination and water treatment - past, present and future (a review). Desalination. 2008; 228(1-3):10-29. https://doi.org/10.1016/j.desal.2007.08.005

[287] Biesheuvel PM, van der Wal A. Membrane capacitive deionization. Journal of Membrane Science. 2010; 346(2):256-62. https://doi.org/10.1016/j.memsci.2009.09.043

[288] Lee J-B, Park K-K, Eum H-M, Lee C-W. Desalination of a thermal power plant wastewater by Membrane Capacitive Deionization. Desalination. 2006; 196(1-3):125-34. https://doi.org/10.1016/j.desal.2006.01.011

[289] Kaufhold S, Pohlmann-Lortz M, Dohrmann R, Nüesch R. About the possible upgrade of bentonite with respect to iodide retention capacity. Applied Clay Science. 2007; 35(1-2):39-46. https://doi.org/10.1016/j.clay.2006.08.001

[290] Echigo S, Itoh S, Kuwahara M. Bromide removal by hydrotalcite-like compounds in a continuous system. Water Science and Technology. 2007; 56(11):117-22. https://doi.org/10.2166/wst.2007.817

[291] Curtius H, Kattilparampil Z. Sorption of iodine on Mg-al-layered double hydroxide. Clay Minerals. 2005; 40(4):455-61. https://doi.org/10.1180/0009855054040183

[292] Pless JD, Benjamin Chwirka J, Krumhansl JL. Iodine sequestration using delafossites and layered hydroxides. Environmental Chemistry Letters. 2006; 5(2):85-9. https://doi.org/10.1007/s10311-006-0084-8

[293] Kumar E, Bhatnagar A, Hogland W, Marques M, Sillanpää M. Interaction of inorganic anions with iron-mineral adsorbents in Aqueous Media - a review. Advances in Colloid and Interface Science. 2014; 203:11-21. https://doi.org/10.1016/j.cis.2013.10.026

[294] Frau F, Addari D, Atzei D, Biddau R, Cidu R, Rossi A. Influence of major anions on as(v) adsorption by synthetic 2-line ferrihydrite. kinetic investigation and XPS study of the competitive effect of bicarbonate. Water, Air, and Soil Pollution. 2009; 205(1-4):25-41. https://doi.org/10.1007/s11270-009-0054-4

[295] Elakneswaran Y, Nawa T, Kurumisawa K. Electrokinetic potential of hydrated cement in relation to adsorption of chlorides. Cement and Concrete Research. 2009; 39(4):340-4. https://doi.org/10.1016/j.cemconres.2009.01.006

[296] Mohapatra M, Rout K, Gupta SK, Singh P, Anand S, Mishra BK. Facile synthesis of additive-assisted Nano Goethite Powder and its application for fluoride remediation. Journal of Nanoparticle Research. 2009; 12(2):681-6. https://doi.org/10.1007/s11051-009-9779-7

[297] Acelas NY, Flórez E. Chloride adsorption on fe- and al-(hydr)oxide: Estimation of Gibbs Free energies. Adsorption. 2018; 24(3):243-8. https://doi.org/10.1007/s10450-018-9939-0

[298] Semblante GU, Lee JZ, Lee LY, Ong SL, Ng HY. Brine pre-treatment technologies for Zero Liquid Discharge Systems. Desalination. 2018; 441:96-111. https://doi.org/10.1016/j.desal.2018.04.006

[299] Maes N, Canniere P, Sillen X, Ravestyn L, Put M. DS 2.6 Migration of iodide in backfill materials containing an anion getter. Mol Belgian: Belgian Nuclear Research Centre; 2004.

[300] Marsh H, Reinoso Rodríguez Francisco. Activated carbon. Amsterdam: Elsevier; 2006.

[301] Karanfil T, Moro EC, Serkiz SM. Development and testing of a silver chloride-impregnated activated carbon for aqueous removal and sequestration of iodide. Environmental Technology. 2005; 26(11):1255-62. https://doi.org/10.1080/09593332608618595

[302] Sánchez-Polo M, Rivera-Utrilla J, Salhi E, von Gunten U. Removal of bromide and iodide anions from drinking water by silver-activated carbon aerogels. Journal of Colloid and Interface Science. 2006; 300(1):437-41. https://doi.org/10.1016/j.jcis.2006.03.037

[303] Sánchez-Polo M, Rivera-Utrilla J, Salhi E, von Gunten U. AG-doped carbon aerogels for removing halide ions in water treatment. Water Research. 2007; 41(5):1031-7. https://doi.org/10.1016/j.watres.2006.07.009

[304] Sánchez-Polo M, Rivera-Utrilla J, von Gunten U. Bromide and iodide removal from waters under dynamic conditions by AG-doped aerogels. Journal of Colloid and Interface Science. 2007; 306(1):183-6. https://doi.org/10.1016/j.jcis.2006.10.019

[305] Sánchez-Polo M, Rivera-Utrilla J, Salhi E, von Gunten U. AG-doped carbon aerogels for removing halide ions in water treatment. Water Research. 2007; 41(5):1031-7. https://doi.org/10.1016/j.watres.2006.07.009

[306] Couture RA, Seitz MG. Sorption of anions of iodine by iron oxides and kaolinite. Nuclear and Chemical Waste Management. 1983; 4(4):301-6. https://doi.org/10.1016/0191-815X(83)90055-4

[307] Muramatsu Y, Uchida S, Sriyotha P, Sriyotha K. Some considerations on the sorption and desorption phenomena of iodide and iodate on Soil. Water, Air, and Soil Pollution. 1990; 49(1-2):125-38. https://doi.org/10.1007/BF00279516

[308] Sheppard MI, Hawkins JL, Smith PA. Linearity of iodine sorption and sorption capacities for seven soils. Journal of Environmental Quality. 1996; 25(6):1261-7. https://doi.org/10.2134/jeq1996.00472425002500060014x

[309] Yoshida S, Muramatsu Y, Uchida S. Studies on the sorption of k (iodide) and IOU (iodate) onto Andosols. Water, Air, & Soil Pollution. 1992; 63(3-4):321-9. https://doi.org/10.1007/BF00475499

[310] Hu Q, Zhao P, Moran JE, Seaman JC. Sorption and transport of iodine species in sediments from the Savannah River and Hanford sites. Journal of Contaminant Hydrology. 2005; 78(3):185-205. https://doi.org/10.1016/j.jconhyd.2005.05.007

[311] Kaplan DI, Serne RJ, Parker KE, Kutnyakov IV. Iodide sorption to subsurface sediments and illitic minerals. Environmental Science & Technology. 1999; 34(3):399-405. https://doi.org/10.1021/es990220g

[312] Bartels CR, Rybar S, Andes K, Franks R. Optimized removal of boron and other specific contaminants by SWRO membranes. Proceedings of IDA World Congress; 2009 January 7-12; Dubai UAE.

[313] Sheppard MI, Thibault DH, McMurry J, Smith PA. Factors affecting the soil sorption of iodine. Water, Air, & Soil Pollution. 1995; 83(1-2):51-67. https://doi.org/10.1007/BF00482593

[314] Dai JL, Zhang M, Hu QH, Huang YZ, Wang RQ, Zhu YG. Adsorption and desorption of iodine by various Chinese soils: II. iodide and iodate. Geoderma. 2009; 153(1-2):130-5. https://doi.org/10.1016/j.geoderma.2009.07.020

[315] Dai J-L, Zhang M, Zhu Y-G. Adsorption and desorption of iodine by various Chinese soils. Environment International. 2004; 30(4):525-30. https://doi.org/10.1016/j.envint.2003.10.007

[316] Gu B, Schulz RK, Anion retention in soil: Possible application to reduce migration of buried technetium and iodine. California Univ., Berkeley, CA (United States). Dept. of Soil Science: Washington D.C. 1991. https://doi.org/10.2172/5980032

[317] Ge F, Zhu L. Effects of coexisting anions on removal of bromide in drinking water by coagulation. Journal of Hazardous Materials. 2008; 151(2-3):676-81. https://doi.org/10.1016/j.jhazmat.2007.06.041

[318] Ge F, Shu H, Dai Y. Removal of bromide by aluminium chloride coagulant in the presence of humic acid. Journal of Hazardous Materials. 2007; 147(1-2):457-62. https://doi.org/10.1016/j.jhazmat.2007.01.028

[319] Abdel-Wahab A, Batchelor B. Chloride removal from recycled cooling water using ultra-high lime with aluminum process. Water Environment Research. 2002; 74(3):256-63. https://doi.org/10.2175/106143002X139983

[320] Wang LP, Lee WH, Man Tseng S, Cheng TW. Removal of chloride ions from an aqueous solution containing a high chloride concentration through the chemical precipitation of Friedel's Salt. Materials Transactions. 2018; 59(2):297-302. https://doi.org/10.2320/matertrans.M2017273

[321] Fang P, Tang Z-jun, Chen X-bo, Huang J-hang, Tang Z-xiong, Cen C-ping. Chloride ion removal from the wet flue gas desulfurization and denitrification wastewater using Friedel's salt precipitation method. Journal of Chemistry. 2018; 2018:1-9. https://doi.org/10.1155/2018/5461060

[322] Humbert H, Gallard H, Suty H, Croué J-P. Performance of selected anion exchange resins for the treatment of a high DOC content surface water. Water Research. 2005; 39(9):1699-708. https://doi.org/10.1016/j.watres.2005.02.008

[323] Johnson CJ, Singer PC. Impact of a magnetic ion exchange resin on ozone demand and Bromate Formation during drinking water treatment. Water Research. 2004; 38(17):3738-50. https://doi.org/10.1016/j.watres.2004.06.021

[324] Boyer TH, Singer PC. Bench-scale testing of a magnetic ion exchange resin for removal of disinfection by-product precursors. Water Research. 2005; 39(7):1265-76. https://doi.org/10.1016/j.watres.2005.01.002

[325] Boyer TH, Singer PC. A pilot-scale evaluation of magnetic ion exchange treatment for removal of natural organic material and inorganic anions. Water Research. 2006; 40(15):2865-76. https://doi.org/10.1016/j.watres.2006.05.022

[326] Singer PC, Bilyk K. Enhanced coagulation using a magnetic ion exchange resin. Water Research. 2002; 36(16):4009-22. https://doi.org/10.1016/S0043-1354(02)00115-X

[327] Lokhande RS, Singare PU, Dole MH. Study on Ion Exchange Equilibrium for some uni-univalent and uni-divalent reaction systems using strongly basic anion-exchange resin Duolite A-113. Russian Journal of Physical Chemistry A. 2009; 83(13):2313-7. https://doi.org/10.1134/S0036024409130226

[328] Hsu S, Singer PC. Removal of bromide and natural organic matter by Anion Exchange. Water Research. 2010; 44(7):2133-40. https://doi.org/10.1016/j.watres.2009.12.027

[329] Singer PC, Schneider M, Edwards-Brandt J, Budd GC. Miex for removal of DBP Precursors: Pilot-Plant Findings. Journal - American Water Works Association. 2007; 99(4):128-39. https://doi.org/10.1002/j.1551-8833.2007.tb07913.x

[330] Singare P, Lokhande R. Behaviour of radioactive iodide and bromide ions from aqueous solution on ion exchange resins Amberlite IRA-400. Natural Science. 2009; 01(03):191-4. https://doi.org/10.4236/ns.2009.13025

[331] Wang Z, Liu H, Zhou K, Fu P, Zeng H, Qiu J. Effect of surface oxygen/nitrogen groups on hydrogen chloride removal using modified viscose-based activated carbon fibers. RSC Advances. 2015; 5(105):86006-12. https://doi.org/10.1039/C5RA11705D

[332] Gärtner RS, Witkamp GJ. Regeneration of mixed solvent by ion exchange resin: Selective removal of chloride and sulfate. Separation Science and Technology. 2005; 40(12):2391-410. https://doi.org/10.1080/01496390500267442

[333] Yun G, Colour and chloride removal from pulp mill effluent using ion-exchange. University of Alberta (Canada): Ann Arbor; 2001; 100.

[334] Kameda T, Yoshioka T, Mitsuhashi T, Uchida M, Okuwaki A. The simultaneous removal of calcium and chloride ions from calcium chloride solution using magnesium-aluminum oxide. Water Research. 2003; 37(16):4045-50. https://doi.org/10.1016/S0043-1354(03)00311-7

[335] Hann RA, Eyres R, Cottier D, Separation of Anions by Electrodialysis in Ion Exchange Membranes, Ellis Hotwood and Chichester, Editors. Elsevier; 1983; p. 31.

[336] Wei L, Method for removing chlorine in zinc sulfate solution with high chlorine content. 2012, Huludao Zinc Industry Co LTD: China.

[337] Ahmed M, Shayya WH, Hoey D, Mahendran A, Morris R, Al-Handaly J. Use of evaporation ponds for brine disposal in desalination plants. Desalination. 2000; 130(2):155-68. https://doi.org/10.1016/S0011-9164(00)00083-7

[338] Ahmed M, Shayya WH, Hoey D, Mahendran A, Morris R, Al-Handaly J. Use of evaporation ponds for brine disposal in desalination plants. Desalination. 2000; 130(2):155-68. https://doi.org/10.1016/S0011-9164(00)00083-7

[339] Duranceau SJ. Determination of the total iodide content in desalinated seawater permeate. Desalination. 2010; 261(3):251-4. https://doi.org/10.1016/j.desal.2010.06.039

[340] Drewes, JE, Multibeneficial use of produced water treatment through high pressure membrane treatment and capacitive deionization technology, in Reclamation - Managing Water in the West. 2009, Advanced Water Technology Center (AQWATEC) Environmental Science and Engineering Division Colorado School of Mines Golden, Colorado: Bureau of Reclamation.

[341] Pontié M, Diawara CK, Rumeau M. Streaming effect of single electrolyte mass transfer in nanofiltration: Potential application for the selective defluorination of brackish drinking waters. Desalination. 2003; 151(3):267-74. https://doi.org/10.1016/S0011-9164(02)01019-6

[342] van der Hoek JP, Rijnbende DO, Lokin CJA, Bonné PAC, Loonen MT, Hofman JAMH. Electrodialysis as an alternative for reverse osmosis in an integrated membrane system. Desalination. 1998; 117(1-3):159-72. https://doi.org/10.1016/S0011-9164(98)00086-1

[343] Inoue H, Kagoshima M. Removal of 125i from radioactive experimental waste with an anion exchange paper membrane. Applied Radiation and Isotopes. 2000; 52(6):1407-12. https://doi.org/10.1016/S0969-8043(99)00168-2

[344] Lv L, Wang Y, Wei M, Cheng J. Bromide ion removal from contaminated water by calcined and uncalcined mgal-CO3 layered double hydroxides. Journal of Hazardous Materials. 2008; 152(3):1130-7. https://doi.org/10.1016/j.jhazmat.2007.07.117

[345] Liang L, Li L. Adsorption behavior of calcined layered double hydroxides towards removal of iodide contaminants. Journal of Radioanalytical and Nuclear Chemistry. 2007; 273(1):221-6. https://doi.org/10.1007/s10967-007-0740-x

[346] Thomas N, Rajamathi M. Intracrystalline oxidation of thiosulfate-intercalated layered double hydroxides. Langmuir. 2009; 25(4):2212-6. https://doi.org/10.1021/la803402j

[347] Chubar NI, Samanidou VF, Kouts VS, Gallios GG, Kanibolotsky VA, Strelko VV, *et al.* Adsorption of fluoride, chloride, bromide, and bromate ions on a novel Ion Exchanger. Journal of Colloid and Interface Science. 2005; 291(1):67-74. https://doi.org/10.1016/j.jcis.2005.04.086

[348] Balsley SD, Brady PV, Krumhansl JL, Anderson HL. Anion Scavengers for Low-Level Radioactive Waste Repository Backfills. Journal of Soil Contamination. 1998; 7(2):125-41. https://doi.org/10.1080/10588339891334195

[349] Ho PC, Kraus KA. Adsorption on inorganic materials-VIII. Journal of Inorganic and Nuclear Chemistry. 1981; 43(3):583-7. https://doi.org/10.1016/0022-1902(81)80507-6

[350] Hoskins JS, Karanfil T, Serkiz SM. Removal and sequestration of iodide using silver-impregnated activated carbon. Environmental Science & Technology. 2002; 36(4):784-9. https://doi.org/10.1021/es010972m

[351] Sánchez-Polo M, Rivera-Utrilla J, von Gunten U. Metal-doped carbon aerogels as catalysts during ozonation processes in aqueous solutions. Water Research. 2006; 40(18):3375-84. https://doi.org/10.1016/j.watres.2006.07.020

[352] Lokhande RS, Singare PU, Patil AB. A study of ion exchange equilibrium for some uni-univalent and uni-divalent reaction systems using strongly basic anion exchange resin Indion-830 (type 1). Russian Journal of Physical Chemistry A. 2007; 81(12):2059-63. https://doi.org/10.1134/S0036024407120254

[353] Canadian Council of Ministers of the Environment (CCME), Canadian water quality guidelines for the protection of aquatic life, 2011; 1-16.

[354] Mayer T, Snodgrass WJ, Morin D. Spatial characterization of the occurrence of road salts and their environmental concentrations as chlorides in Canadian surface waters and benthic sediments. Water Quality Research Journal. 1999; 34(4):545-74. https://doi.org/10.2166/wqrj.1999.028

[355] Wu X, Liu Z, Liu X. Chloride ion removal from zinc sulfate aqueous solution by electrochemical method. Hydrometallurgy. 2013; 134-135:62-5. https://doi.org/10.1016/j.hydromet.2013.01.017

[356] Mossad M, Zou L. A study of the capacitive deionisation performance under various operational conditions. Journal of Hazardous Materials. 2012; 213-214:491-7. https://doi.org/10.1016/j.jhazmat.2012.02.036

[357] Ying T-Y, Yang K-L, Yiacoumi S, Tsouris C. Electrosorption of ions from aqueous solutions by nanostructured Carbon Aerogel. Journal of Colloid and Interface Science. 2002; 250(1):18-27. https://doi.org/10.1006/jcis.2002.8314

[358] Watson K, Farré MJ, Knight N. Strategies for the removal of halides from drinking water sources, and their applicability in disinfection by-product minimisation: A critical review. Journal of Environmental Management. 2012; 110:276-98. https://doi.org/10.1016/j.jenvman.2012.05.023