Contents lists available at Science-Gate

International Journal of Advanced and Applied Sciences

Journal homepage: http://www.science-gate.com/IJAAS.html

Disinfection and DBPs removal in drinking water treatment: A perspective for a green technology

Djamel Ghernaout [1, 2, 3, *]

[1]Chemical Engineering Department, College of Engineering, University of Ha'il, PO Box 2440, Ha'il 81441, Saudi Arabia
[2]Binladin Research Chair on Quality and Productivity Improvement in the Construction Industry, College of Engineering, University of Ha'il, PO Box 2440, Ha'il 81441, Saudi Arabia
[3]Chemical Engineering Department, Faculty of Engineering, University of Blida, PO Box 270, Blida 09000, Algeria

A R T I C L E I N F O

Article history:
Received 2 October 2017
Received in revised form
15 December 2017
Accepted 20 December 2017

Keywords:
Chlorination by-products
Disinfection by-products
Natural organic matter
Trihalomethanes
Membrane processes

A B S T R A C T

The generation, monitoring, and health impacts of disinfection by-products (DBPs) in potable water are problems of worldwide worry. Several nations, besides the World Health Organization, possess regulations and/or guidelines on bearable levels of DBPs in water. Since drinking water is frequently remediated using a chemical killing agent, DBPs are pollutants to which several humans are unprotected. On account of the health impacts linked to subjection to chlorinated water and/or some DBPs, the water manufacturing has performed great endeavors to equilibrate killing pathogens and DBP monitoring. Large survey has been realized on rising DBPs of health and regulatory worry. In spite of the fact that the attention on DBPs was previously on chlorine- and bromine-containing carbonaceous DBPs, appearing DBPs comprise iodine-containing species, also halogenated and non-halogenated nitrogenous DBPs. In addition, latest toxicity experimentation has proposed that certain of the more recent PBPs are of more elevated toxicity than some of the regulated chemical products. Therefore, survey has been realized to better comprehend how to cost-effectively monitor a large interval of regulated and appearing DBPs. This comprises the usage of advanced remediation and killing pathogens methodologies. This paper shows certain of the newest research works at comprehending these significant DBP-related problems. Disinfection is killing microorganisms present in water; but, it is as well killing human beings drinking water by poisonous DBPs. Using chemicals for water treatment is finally a lost cause.

1. Introduction

Pure potable water is the most vital human health element (Singh et al., 2010; Ghernaout, 2013; 2017a; Ghernaout and Ghernaout, 2012a; Ghernaout et al., 2011). However, more than two billion people throughout the globe do not possess convenient provisions of protected potable water. Throughout the world, more than 20 million babies pass away each year because of waterborne diarrheal diseases like typhoid fever, dysentery, and cholera. Polluted water provisions and weak sanitation produce 80% of the diseases that trouble humans in the poorest nations. The maturation of municipal water purification in the last decades has authorized cities in the developed countries to be mostly without of waterborne diseases. Since the application of filtration and disinfection of potable water in the United States, waterborne diseases like cholera and typhoid have been almost removed (Bond et al., 2012; Weiner, 2012; Gopal et al., 2007; Liviac et al., 2011; Ghernaout et al., 2008; 2011; Ghernaout and Ghernaout, 2010).

Nevertheless, in 1974, it was detected that water disinfectants themselves enter in reactions with natural organic matter (NOM) (Sharp et al., 2006; Ghernaout et al., 2011) present in water to form unwanted disinfection by-products (DBPs) that constitute health hazards (Weiner, 2012; Liviac et al., 2011; Bellar et al., 1974; Ghernaout, 2017b). Trihalomethanes (THMs) DBPs (Huang et al., 2009; Zhang et al., 2009a; 2009b; Panyapinyopol et al., 2005) were regulated by EPA (1979).

Until now, many DBPs (bromodichloromethane, bromoform, chloroform, dichloroacetic acid, and bromate) have been proved to be carcinogenic in

* Corresponding Author.
Email Address: djamel_andalus@hotmail.com
https://doi.org/10.21833/ijaas.2018.02.018

laboratory animals at elevated doses (Plewa et al., 2008). Some DBPs (bromodichloromethane, chlorite, and some haloacetic acids (Karanfil et al., 2008) may as well produce unfavorable reproductive or developmental influences in laboratory animals. Being convinced by the fact that DBPs manifest a latent public health hazard, Environmental Protection Agency (EPA) published guidelines for reducing their generation (USEPA, 1997; 1999) and founded standards in 1998 for potable water levels of DBPs and disinfectant residuals (Weiner, 2012; Bull and Reckhow, 2008; Frierdich et al., 2009; Xu et al., 2009; Chen and Wang, 2014).

The initial aim of adding chemicals such as chlorine, chlorine dioxide, ozone, and chloramines, was to kill microorganisms; but, it has been proved that these agents are killing both microorganisms instantly and directly and human beings at long term and indirectly by forming poisonous DBPs. This paper reviews the actual situation concerning DBPs detecting and treating in the background of water treatment industry and in the perspectives of green technology.

2. Water sources

Potable water provisions are either from surface waters or groundwater. In the United States, groundwater sources (wells) provide about 53% of all potable water and surface water sources (reservoirs, rivers, and lakes) provide the residual 47%. Groundwater runs from underground aquifers, where wells are drilled to recuperate the water. Wells may be from tens to hundreds of meters deep (Weiner, 2012).

Groundwater is prone to be less polluted than surface water. It is generally more preserved from surface pollution and, since it runs more tardily, organic matter has sufficient contact period to be degraded by soil bacteria. The soil itself takes action like a filter; for this reason, less suspended solids is observed (Weiner, 2012; Reckhow et al., 2008).

Surface water runs from lakes, rivers, and reservoirs. Frequently, it contains more suspended solids than groundwater, and consequently needs more treatment to render it secure to consume. Surface waters are utilized for other motives as well drinking and usually begin to be contaminated by sewage, industrial, and recreational activities (Weiner, 2012).

3. Water treatment

Great modifications are producing in the water treatment technology, pushed by more and more rigorous water quality standards, a constant augmentation in the number of regulated drinking water pollutants (from ~ 5 in 1940 to ~ 100 in 1999), and recently developed regulations influencing disinfection and DBPs (Weiner, 2012; Roberson, 2008; Boucherit et al., 2015). Cities always look for improving their water treatment and give high-quality water by more economical techniques. A modern maturation in water treatment is the introduction of membrane filtration to potable water treatment (Rojas et al., 2008; Lin et al., 2006; Williams et al., 2012). Membrane filters have been revised to the level where, in some situations, they are appropriate as stand-alone remediation for small set-ups (Singh et al., 2010; Patsios et al., 2013; Oh et al., 2007; Doederer et al., 2014). To a greater extent, they are utilized in coupling with other treatment techniques to economically enhance the global quality of finalized potable water (Rachwal and Judd, 2006; Guo et al., 2016).

4. Fundamental potable water treatment

The first objective of water treatment is (1) to render water secure to consume by making certain that it is without of pathogens and poisonous compounds; (2) the second target is to render it a desirable drink by eliminating unpleasant turbidity, tastes, colors, and odors (Weiner, 2012).

Classical potable water treatment deals with both of these objectives. It consists of four stages (Weiner, 2012):

1. Primary settling
2. Aeration
3. Coagulation
4. Disinfection

In a general manner, not all four of the fundamental stages are required in each treatment factory. Specially, groundwaters frequently require much less remediation than surface waters. Groundwaters may require no settling, aeration, or coagulation. For pure groundwaters, only a small chlorine dose (~ 0.16 mg/L) is injected to conserve the water during its passage through the distribution framework (Weiner, 2012; Warton et al., 2006).

4.1. Primary settling

Water, which has been roughly winnowed to eliminate big particulate matter, is conducted into a big holding tank to let finer particulates to settle. Chemical coagulants can be injected to constitute flocs. Lime may be injected at this level to encourage clarification if pH < 6.5. The flocs settle by gravity, eliminating solids bigger than about 25 μm (Weiner, 2012).

4.2. Aeration

The clarified water is mixed with air. This process encourages oxidation of any readily oxidizable compounds, i.e., those which are powerful reducing agents. Chlorine will be introduced subsequently. If chlorine was injected at this level and reducing agents were still in the water, they may reduce the chlorine and render it powerless as a disinfectant (Weiner, 2012).

Ferrous iron (Fe^{2+}) is a specifically difficult reducing agent. It can emerge from the water running across iron pyrite (FeS_2) or iron carbonate ($FeCO_3$) minerals. Whether dissolved oxygen is present, Fe^{2+} is oxidized to Fe^{3+}, which precipitates in the form of ferric hydroxide, $Fe(OH)_{3(s)}$, at pH bigger than 3.5. $Fe(OH)_{3(s)}$ provides a metallic taste to the water and produces the unpleasant red-brown stain usually observed in sinks and toilets in iron-rich areas. The stain is effortlessly eliminated with weak acid solutions, like vinegar (Weiner, 2012).

4.3. Coagulation

The thinnest residues, like pollen, spores, bacteria, and colloidal minerals, have not the ability to settle out in the first settling stage. For the finished water to appear net and effervescent, these thin residues have to be eliminated. Hydrated aluminum (Walton, 2007) sulfate, $Al_2(SO_4)_3 \bullet 18H_2O$, usually named alum, injected with lime, $Ca(OH)_2$, is the most frequent filtering chemical product utilized for secondary settling (Weiner, 2012; Liu et al., 2012):

$$Al_2(SO_4)_3 + Ca(OH)_2 \rightarrow Al(OH)_{3(s)} + CaSO_4 \quad (1)$$

At pH 6-8, $Al(OH)_{3(s)}$ is produced as a light, fluffy, gelatinous flocculant possessing a greatly wide surface area that attracts and traps thin suspended particles, carrying them to the bottom of the basin as the precipitate slowly settles. In this pH interval, $Al(OH)_3$ is close to its minimum solubility and very little Al^{3+} is left in suspension (Weiner, 2012).

4.4. Disinfection

Eliminating bacteria and viruses is the most significant side of water treatment. Appropriate disinfection gives a remaining disinfectant degree that exists across the distribution framework. This not only eliminates microorganisms that run across filtration and coagulation at the treatment factory, but it as well stops reinfection while the period the water is in the distribution framework. In a big city, water may stay in the framework for 5 days or more before it is utilized. Five days is long sufficiently for any bypassed microorganisms to expand (Weiner, 2012).

As a consequence of worries concerning DBPs, EPA and the water treatment industry are putting more value on the usage of disinfectants other than chlorine, which nowadays is the most frequently utilized water disinfectant. An additional manner to decreasing the likelihood of DBP generation is by eliminating DBP precursors (NOM) from water before disinfection (Ghernaout and Naceur, 2011). Nevertheless, usage of other disinfectants has also been observed to form DBPs and present regulations attempt to stabilize the hazards between microbial pathogens and DBPs. DBPs comprise the following (Weiner, 2012):

- Halogenated organic compounds, such as THMs, haloacetic acids, haloketones, and other halogenated compounds that are produced firstly while chlorine or ozone (in the presence of bromide ion) are utilized as disinfectant (Bougeard et al., 2008; Xie et al., 2015; Ye et al., 2012; Kanokkantapong et al., 2006; Navalon et al., 2009; Aydin et al., 2012; Rincón et al., 2001).
- Organic oxidation by-products, such as aldehydes, ketones, assimilable organic carbon, and biodegradable organic carbon. The latter two DBPs follow from big organic molecules being oxidized to smaller molecules, which are more accessible to microbes, plant, and aquatic life as a nutrient reservoir. Oxidized organics are generated while powerful oxidizing chemical products (ozone, permanganate, chlorine dioxide, or hydroxyl radical) are utilized (Guo et al., 2014; Lou et al., 2009; Tian et al., 2014).
- Inorganic compounds, like chlorate, chlorite, and bromate ions, produced while chlorine dioxide and ozone disinfectants are utilized (Guo et al., 2014; Lou et al., 2009; Tian et al., 2014).

Gopal et al. (2007) presented a list of chlorination by-products (CBPs) and their toxicities (Table 1). They as well listed the guideline values in drinking water for CBPs (Table 2).

4.5. Disinfection manners

Most disinfectants are powerful oxidizing agents that interact with organic and inorganic oxidizable compounds in water. In some situations, the oxidant is generated as a reaction by-product; hydroxyl radical is produced in this manner. More than destroying pathogens, disinfectants are as well utilized for reduction of distasteful tastes, odors, and color (Weiner, 2012).

The most frequently utilized water treatment microorganisms killing agent is chlorine. It was primarily employed on a methodical rule in Belgium in the early 1900s. Additional disinfectants occasionally utilized are ozone, chlorine dioxide (Guo et al., 2014), and ultraviolet (UV) radiation. Among these chemical products, only chlorine and chlorine dioxide possess remaining killing agent capacity (Guo et al., 2014). For chlorine or chlorine dioxide, injection of a small surplus of disinfectant keeps conservation of the potable water across the delivery framework. As a rule, remaining chlorine or chlorine dioxide dose of ~0.2-0.5 mg/L is requested. Killing agents that do not possess remaining conservation are usually accompanied by a weak injection of chlorine to maintain the disinfection capacity across the delivery framework (Weiner, 2012; Guo et al., 2014).

Side of the disinfection manner implicates reducing DBP precursors; mostly total organic carbon (TOC), by coagulation, water softening, or filtration (Ji et al., 2008; Ghernaout and Ghernaout, 2012b). An elevated TOC level (more than 2.0 mg/L) points out an elevated capacity for DBP generation.

Table 1: CBPs and their health effects (Gopal et al., 2007)

Class of DBPs	Compounds	Health effects
Trihalomethanes (THMs)	Chloroform	Cancer, liver, kidney and reproductive effects
	Dibromochloromethane	Nervous system, liver, kidney and reproductive effects
	Bromodichloromethane	Cancer, liver, kidney and reproductive effects
	Bromoform	Cancer, liver, kidney and reproductive effects
Haloacetonitrile (HAN)	Trichloroacetonitrile	Cancer, mutagenic and clastogenic effects
Halogenated aldehydes and ketones	Formaldehyde	Mutagenic
Halophenol	2-Chlorophenol	Cancer and tumor promoter
Haloacetic acids (HAA)	Dichloroacetic acid	Cancer and reproductive and developmental effects
	Trichloroacetic acid	Liver, kidney, spleen and developmental effects

Table 2: CBPs and their guideline values in drinking water (Gopal et al., 2007)

Chlorination by-products (CBPs)		WHO guideline value (μg/L)
Trihalomethanes (THMs)	Chloroform ($CHCl_3$)	200
	Bromodichloromethane ($CHBrCl_2$)	60
	Bromoform ($CHBr_3$)	100
	Dibromochloromethane ($CHBr_2Cl$)	100
Haloacetic acids	Dichloroacetic acid ($Cl_2CHCOOH$)	50
	Trichloroacetic acid (Cl_3CCOOH)	100
Haloacetonitriles	Dichloroacetonitrile (Cl_2CHCN)	90
Halocarbonyl compounds	Chloral (CCl_3CHO, H_2O)	10

5. DBPs and disinfection residuals

The main precursor of organic DBPs is NOM which is frequently evaluated as TOC or dissolved organic carbon (DOC) (Wang et al., 2012; Chang and Wang, 2013). Usually, ~90% of TOC is constituted by DOC which is known as the portion of TOC that travels across a 0.45 μm. Halogenated organic by-products are generated in water if NOM interacts with free chlorine (Cl_2) or free bromine (Br_2) (Hua and Reckhow 2008; Kim and Yu, 2007). Free chlorine may be formed when chlorine gas, chlorine dioxide, or chloramines are injected for microorganisms killing. Free bromine is a product of the oxidation by disinfectants of bromide ion previously existing in the fountainhead water (Weiner, 2012; Echigo et al., 2008; Wang et al., 2014).

Reactions of powerful oxidants with NOM as well produce nonhalogenated DBPs, especially if nonchlorine oxidants such as ozone and peroxone are utilized. Frequent nonhalogenated DBPs comprise aldehydes, ketones, organic acids, ammonia, and hydrogen peroxide (Weiner, 2012; Zhang et al., 2011).

Bromide ion (Br^-) may be existent, particularly where geothermal waters affect surface and groundwaters, and in coastal areas where saltwater incursion is happening. Ozone or free chlorine oxidizes Br^- to generate brominated DBPs, like bromate ion, bromoform, cyanogen bromide, bromopicrin, and brominated acetic acid (Weiner, 2012; Pope and Speitel Jr 2008).

6. Strategies for monitoring DBPs

The instant produced, DBPs are hard to eliminate from a water provision. Consequently, DBP monitoring is paid particular attention to avoiding their generation. The main monitoring means for DBPs are:

- Decreasing NOM levels in source water using coagulation and settling, filtering, and oxidation (Iriarte-Velasco et al., 2007; Xiao et al., 2010; Gerrity et al., 2009; Ghernaout and Boucherit, 2015; Ghernaout et al., 2014; 2015a, b).
- Utilizing sorption on granulated activated carbon to eliminate DOC (Fabris et al., 2008; Drikas et al., 2008; Tan et al., 2008).
- Displacing the disinfection stage later in the treatment chain, therefore it arrives following all techniques that reduce NOM.
- Reducing chlorine to avoid remaining disinfection, following primary disinfection with ozone, chlorine dioxide, chloramines, or UV radiation.
- Preservation of source water from bromide ion (Weiner, 2012; Guo et al., 2014).

As mentioned above, Weiner (2012) focused on the significance of displacing the disinfection step later at the end of the treatment chain, i.e., post-disinfection. Indeed, several authors have shown that pre-chlorination induced DOC and DBPs Formation from NOM and algae in treatment processes (Chiu and Wang, 2008; Zong et al., 2013; Zhou et al., 2014; Ghernaout et al., 2009; 2010; 2015c).

As an example, (Chiu and Wang, 2008) studied the influence of pre-chlorination on the THMs and haloacetic acids (HAAs) formation from *Microcystis aeruginosa*. They cultivated *M. aeruginosa* under both batch and chemostat modes and harvested it at various development stages. They evaluated the formation of DBPs from the algal suspensions and extracellular organic matter in the water treatment processes with and without pre-chlorination. Their findings established that pretreatment with 4 mg/L of chlorine augmented chloroform formation potential by 62-113 μg/L and 12-23 μg/L from M. *aeruginosa* cultivated in batch culture and in chemostat, respectively. Following classical treatment techniques, the pre-chlorination terminated in 10-50% reduction in total DBPs precursor removal. When 0.5 mg/L of bromide was spiked into the algal suspension, the DBPs formation displaced from chlorinated to brominated species. In addition, the findings of THM formation potential experiments illustrated that the algae cultivated at the lower temperature water released less intracellular organic matter and less amounts of THMs precursors after pre-chlorination than that cultivated at the higher temperature water.

7. Chlorine disinfection method

Chlorine is a corrosive and toxic yellow-green gas at ambient temperature, with a powerful irritating odor. It is stored and shipped as liquefied gas. Chlorine is the most largely utilized water treatment disinfectant due to its several pleasing characteristics (Weiner, 2012; Liviac et al., 2011):

- It is efficient versus a large domain of pathogens frequently observed in water, especially bacteria and viruses.
- It quits a remaining that stabilizes water in delivery frameworks towards reinfection.
- It is economical and simply evaluated and monitored.
- It has been utilized for a long period and shows a well-comprehended remediation applied science. It keeps a superb security record regardless of the risks of manipulating chlorine gas.
- Killing microorganisms using chlorine is obtainable from sodium and calcium hypochlorite salts, as well as from chlorine gas. Hypochlorite solutions are probably more economical and appropriate than chlorine gas for small remediation set-ups.

Moreover than disinfection, chlorination is utilized for (Weiner, 2012; Nikolaou et al., 2004):

- Taste and odor monitoring, comprising destruction of hydrogen sulfide.
- Color bleaching.
- Monitoring algal development.
- Precipitation of soluble iron and manganese.
- Sterilizing and maintaining wells, water mains, distribution pipelines, and filter systems.

Issues with chlorine employing comprise (Weiner, 2012; Lyon et al., 2014):

- Not efficient versus *Cryptosporidium* and restricted efficiency versus *Giardia lamblia* protozoa.
- Interactions with NOM conduct to the generation of unwanted DBPs.
- The risks of manipulating chlorine gas need distinctive apparatus and security guides.
- If site conditions need elevated chlorine levels, taste and odor issues can emerge.

Chlorine may be dissolved in water by the following equilibrium reactions (Weiner, 2012):

$$Cl_{2(g)} \leftrightarrow Cl_{2(aq)} \quad (2)$$

$$Cl_{2(aq)} + H_2O \leftrightarrow H^+_{(aq)} + Cl^-_{(aq)} + HOCl_{(aq)} \quad (3)$$

$$HOCl_{(aq)} \leftrightarrow H^+_{(aq)} + OCl^-_{(aq)} \quad (4)$$

At pH values below 7.5, hypochlorous acid (HOCl) is the controlling dissolved chlorine species (Fig. 1). Above pH 7.5, chlorite anion (OCl^-) is controlling. The formation of H^+ shows that chlorination decreases total alkalinity (Weiner, 2012).

The energetic disinfection species, Cl_2, HOCl, and OCl^-, are named the total free available chlorine, in spite of the fact that Cl_2 is insignificant above pH 2. All these species are oxidizing agents; however, chloride ion (Cl^-) is not. HOCl is approximately 100 times more efficient as a microorganisms' killer than OCl^-; since, as a neutral molecule, it can penetrate into cell membranes of microorganisms more easily than can OCl^-.

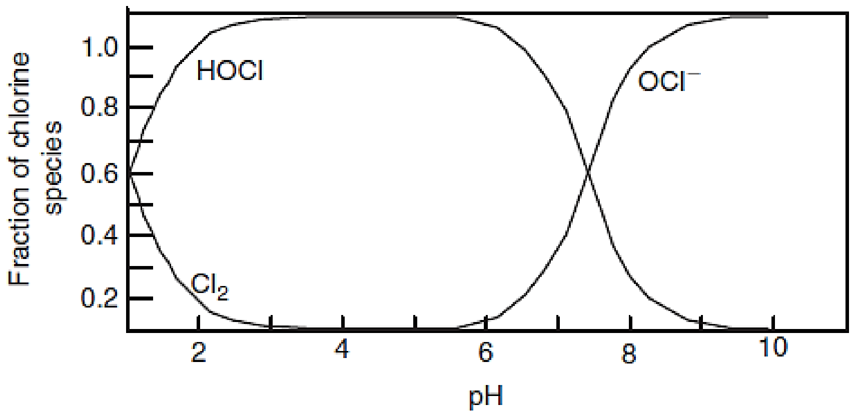

Fig. 1: Distribution diagram for dissolved chlorine species. Free chlorine molecules, Cl_2, exist only below about pH 1 (at pH 7.5, [HOCl] = [OCl^-]) (Weiner, 2012)

Therefore, the quantity of chlorine needed for a certain degree of disinfection is function of the pH. More elevated doses are required at more elevated pH. At pH 8.5, approximately 8 times as much chlorine must be utilized as at pH 7.0 for the equal degree of disinfection (Weiner, 2012).

If chlorine gas is introduced to a water recipient, it dissolves following Eqs. 2 to 4. All compounds existing in the water that are oxidizable by chlorine form the chlorine demand (Fig. 2).

Until oxidation of these matters is total, all the injected chlorine is expended; the net dissolved chlorine dose stays zero as chlorine is introduced. When no chlorine-oxidizable matter is allowed to remain, i.e., the chlorine demand has been satisfied, the dissolved chlorine concentration (chlorine residual) augments in direct proportion to the added level (Weiner, 2012).

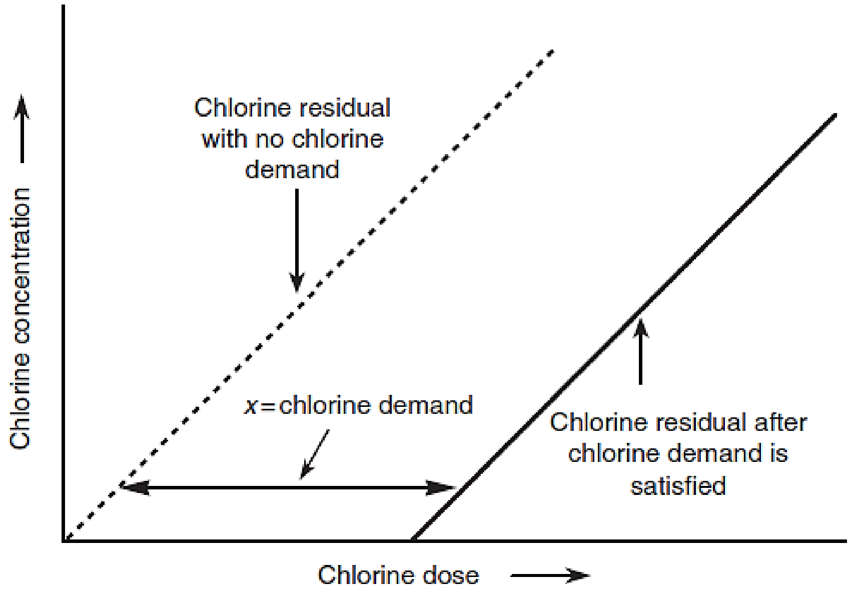

Fig. 2: Relationships between chlorine dose, chlorine demand, and chlorine residual (Weiner, 2012)

If chlorine demand is zero, the residual chlorine always equals the dose, and the plot is a straight line of slope = 1, passing across the origin (Fig. 2). Since the boiling point of molecular chlorine is -35°C at 1 atm pressure, chlorine is provided and kept in reserve as the bulk liquid under pressure. The total residence period of water in the chlorine disinfection basin is usually 20-60 min. A typical level of residual chlorine in the finished water is less than 1 mg/L (Weiner, 2012).

8. Membrane filtration for water treatment

Membrane filters are being utilized to treat groundwater, surface water, and reclaimed wastewater (Singh et al., 2010). Membrane filtration is a physical separation process and eliminates undesirable matters from water without employing chemical products that may conduct to unwanted secondary products (Patsios et al., 2013; Shetty et al., 2003; Rana et al., 2014, 2012; Narbaitz et al., 2013; Bolong et al., 2010). The interval of membrane filters accessible is illustrated in Fig. 3, along with frequent matters that may be eliminated by filtration. Even though membranes occasionally serve as a stand-alone treatment, they are more frequently coupled with additional treatment techniques. As an illustration, at the present time accessible microfiltration (MF) and ultrafiltration (UF) membranes are not very efficient in eliminating DOC, some synthetic organic compounds, or THM precursors (Bougeard et al., 2008). Their functioning in these regards is enhanced by adding powdered adsorbent material to the wastewater flow. Pollutants that may pass across the filters are adsorbed on the bigger adsorbent particles and refused by the filters (Singh et al., 2010; Weiner, 2012; Patsios et al., 2013).

Organic membrane filters are produced from many different organic polymer layers usually generated as a thin film on a supporting woven or nonwoven fabric. Inorganic membrane filters are produced from ceramics, glass, or carbon. They are usually composed of a more porous supporting film on which a thin microporous film is chemically deposited. Inorganic membranes resist more elevated pressures, a large pH interval, and more utmost temperatures than perform organic membranes. Their main disadvantages are bigger weight and expense (Weiner, 2012; Patsios et al., 2013).

9. Fecal contamination: Coliform and streptococci bacteria

Identifying and banning fecal pollution is of crucial significance for all potable water systems and recreation water managers. Fecal wastes can carry enteric pathogens (disease-causing organisms from the intestines of warm-blooded animals) such as viruses, bacteria, and protozoans (which include *Cryptosporidium* and *Giardia*). Fecal-polluted water is a frequent source of gastrointestinal illness, comprising diarrhea, dysentery, ulcers, fatigue, and cramps. It as well can hold pathogens that produce a host of other dangerous diseases like cholera, typhoid fever, hepatitis A, meningitis, and myocarditis (Weiner, 2012).

Analyzing water directly for single pathogenic organisms is, until now, unsuitable for many causes (Weiner, 2012):

- There are so numerous varying types of pathogens that a complete test would be very costly and laborious, while time is of the importance for pathogen find.
- Pathogens may be hazardous at low levels, which need big sample volumes for test. This combines to the time and cost of test.
- Credible analytical techniques for numerous significant pathogens are hard or not even accessible. Furthermore, not all waterborne pathogenic microorganisms are recognized.
- A favorable choice is accessible, namely, the identification of "indicator" species that are simple to count and are frequently existing with enteric pathogens.

Consequently, awareness of possible pollution by enteric pathogens is founded on observing the more simply detected "indicator" species, whose presence shows that fecal pollution may have occurred (Weiner, 2012).

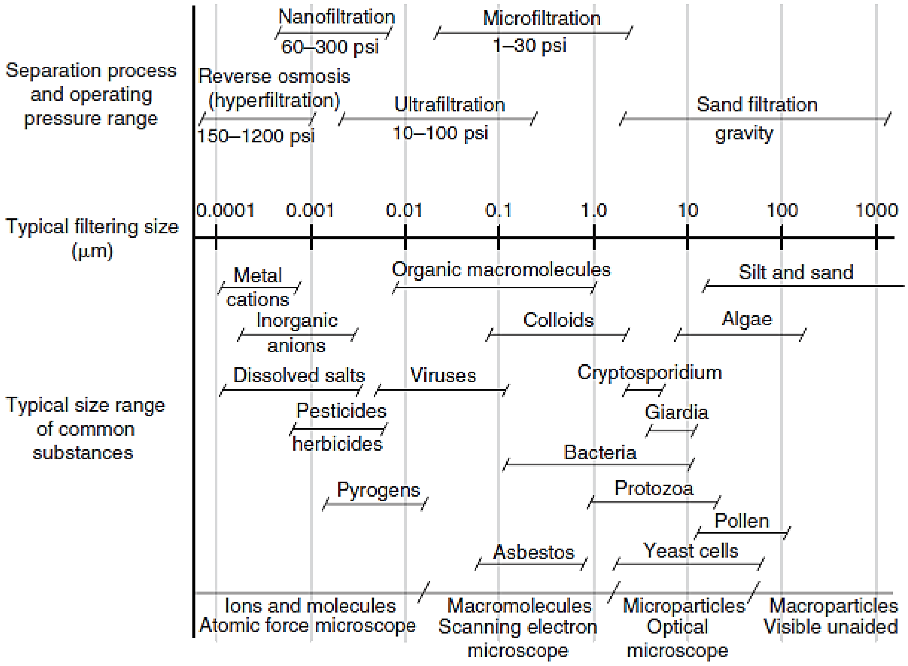

Fig. 3: Comparison of filter processes and size ranges (Weiner, 2012)

10. Conclusion

The main points drawn from this review may be drawn as:

- Considered as the latest technique, disinfection is extremely crucial for the classical potable water treatment. Its target is to kill microorganisms that can cause disease in water to make certain the potable water security. But, the quality of the fountainhead water becomes worse and worse due to rising natural and artificial water contaminations. DBPs are generated at what time disinfectants (chlorine, chlorine dioxide, chloramines or ozone) interact with NOM, anthropogenic contaminants, bromide, and iodide in the potable water treatment chain. As well the regulated DBPs (such as THMs, HAAs, bromate and chlorite), several additional unregulated DBPs have been detected. Nitrosoamines are the elements of these new DBPs, which are strongly carcinogenic, mutagenic, and teratogenic.
- The first objective of water treatment is to render water secure to consume by making certain that it is without of pathogens and poisonous compounds; the second target is to render it a desirable drink by eliminating unwanted turbidity, tastes, colors, and odors. Considering the first objective render water without pathogens and toxic matters, it is obvious that disinfecting by injecting chemicals is an impossible compromise since disinfection kills microorganisms but forms DBPs. Consequently, injecting chemical products into water must be avoided even if the mentioned reason is disinfecting water.
- Instead of chemical therapy, sure techniques such as physical processes like distillation and membrane processes should be urgently adopted to remove pathogens and organic compounds.

Acknowledgment

This study was supported by the Saudi Ministry of Education under the framework of the National Initiative on Creativity and Innovation in Saudi Universities. The author gratefully acknowledges the support of his research program.

Abbreviations

CBPs	Chlorination by-products
DBPs	Disinfection by-products

DOC	Dissolved organic carbon
EPA	Environmental Protection Agency
HAAs	Haloacetic acids
HAN	Haloacetonitrile
MF	Microfiltration
NOM	Natural organic matter
THMs	Trihalomethanes
TOC	Total organic carbon
UF	Ultrafiltration
UV	Ultraviolet

Acknowledgment

This study was supported by the Saudi Ministry of Education under the framework of the National Initiative on Creativity and Innovation in Saudi Universities. The author gratefully acknowledges the support of his research program.

References

Aydin E, Yaman FB, Genceli EA, Topuz E, Erdim E, Gurel M, and Pehlivanoglu-Mantas E (2012). Occurrence of THM and NDMA precursors in a watershed: Effect of seasons and anthropogenic pollution. Journal of Hazardous Materials, 221: 86-91.

Bellar TA, Lichtenberg JJ, and Kroner RC (1974). The occurrence of organohalides in chlorinated drinking waters. Journal American Water Works Association, 66(12): 703-706.

Bolong N, Ismail AF, Salim MR, Rana D, Matsuura T, and Tabe-Mohammadi A (2010). Removal of endocrine disruption compound by hollow fiber polyethersulfone membrane modified by charged surface modifying macromolecule. Separation and Purification Technology, 73: 92-99.

Bond T, Goslan EH, Parsons SA, and Jefferson B (2012). A critical review of trihalomethane and haloacetic acid formation from natural organic matter surrogates. Environmental Technology Reviews, 1(1): 93-113.

Boucherit A, Moulay S, Ghernaout D, Al-Ghonamy AI, Ghernaout B, Naceur MW, and Elboughdiri NA (2015). New trends in disinfection by-products formation upon water treatment. Journal of Research and Developments in Chemistry, 2015: 1-27.

Bougeard CM, Janmohamed IH, Goslan EH, Jefferson B, Watson JS, Morgan GH, and Parsons SA (2008). Parameters affecting haloacetic acid and trihalomethane concentrations in treated UK drinking waters. ACS Publications, Washington, USA.

Bull RJ and Reckhow DA (2008). Use of chemical models and structure—activity relationships to identify novel disinfection by-products of potential toxicological concern. ACS Publications, Washington, USA.

Chang H and Wang G (2013). Fractionation of nitrogen-enriched dissolved organic matter in water. Separation and Purification Technology, 117: 89-97.

Chen KC and Wang YH (2014). The effects of Fe–Mn oxide and TiO 2/α-Al 2 O 3 on the formation of disinfection by-products in catalytic ozonation. Chemical Engineering Journal, 253: 84-92.

Chiu CA and Wang GS (2008). Pre-chlorination induced DOC and DBPs formation from microcystis aeruginosa in treatment process. ACS Publications, Washington, USA.

Doederer K, Farré MJ, Pidou M, Weinberg HS, and Gernjak W (2014). Rejection of disinfection by-products by RO and NF membranes: Influence of solute properties and operational parameters. Journal of Membrane Science, 467: 195-205.

Drikas M, Dixon M, and Morran JY (2008). Removal of trihalomethane precursors using the MIEX® dissolved organic carbon process in combination with granular activated carbon. ACS Publications, Washington, USA.

Echigo S, Itoh S, and Ando R (2008). Contribution of organic bromines to the genotoxicity of chlorinated water: A combination of chromosomal aberration test and total organic bromine analysis. ACS Publications, Washington, USA.

EPA (1979). Nationalinterimprimary drinking water regulations; control of trihalomethanes in drinking water. Environmental Protection Agency US, Federal Register, 44: 68624-68707.

Fabris R, Chow CW, and Drikas M (2008). Combined treatments for enhanced reduction of trihalomethane precursors. ACS Publications, Washington, USA.

Frierdich AJ, Joseph CE, and Strathmann TJ (2009). Catalytic reduction of N-nitrosodimethylamine with nanophase nickel–boron. Applied Catalysis B: Environmental, 90(1): 175-183.

Gerrity D, Mayer B, Ryu H, Crittenden J, and Abbaszadegan M (2009). A comparison of pilot-scale photocatalysis and enhanced coagulation for disinfection byproduct mitigation. Water Research, 43(6): 1597-1610.

Ghernaout B, Ghernaout D, and Saiba A (2010). Algae and cyanotoxins removal by coagulation/flocculation: a review. Desalination and Water Treatment, 20(1-3): 133-143.

Ghernaout D (2013). The best available technology of water/wastewater treatment and seawater desalination: Simulation of the open sky seawater distillation. Green and Sustainable Chemistry, 3(02): 68-88.

Ghernaout D (2014). The hydrophilic/hydrophobic ratio vs. dissolved organics removal by coagulation–A review. Journal of King Saud University-Science, 26(3): 169-180.

Ghernaout D (2017a). Environmental principles in the holy koran and the sayings of the prophet muhammad. American Journal of Environmental Protection, 6(3): 75-79.

Ghernaout D (2017b). Microorganisms' electrochemical disinfection phenomena. EC Microbiology, 9: 160-169.

Ghernaout D and Boucherit A (2015). Review of coagulation's rapid mixing for NOM removal. Journal of Research and Developments in Chemistry, 2015: Article ID 926518, 32 pages. https://doi.org/10.5171/2015.926518

Ghernaout D and Ghernaout B (2010). From chemical disinfection to electrodisinfection: The obligatory itinerary?. Desalination and Water Treatment, 16(1-3): 156-175.

Ghernaout D and Ghernaout B (2012a). On the concept of the future drinking water treatment plant: algae harvesting from the algal biomass for biodiesel production—a review. Desalination and Water Treatment, 49(1-3): 1-18.

Ghernaout D and Ghernaout B (2012b). Sweep flocculation as a second form of charge neutralisation: A review. Desalination and Water Treatment, 44(1-3): 15-28.

Ghernaout D and Naceur MW (2011). Ferrate (VI): In situ generation and water treatment–A review. Desalination and Water Treatment, 30(1-3): 319-332.

Ghernaout D, Al-Ghonamy AI, Boucherit A, Ghernaout B, Naceur MW, Messaoudene NA, and Elboughdiri NA (2015a). Brownian motion and coagulation process. American Journal of Environmental Protection, 4(5-1): 1-15.

Ghernaout D, Al-Ghonamy AI, Naceur MW, Boucherit A, Messaoudene NA, Aichouni M, and Elboughdiri NA (2015b). Controlling coagulation process: From zeta potential to streaming potential. American Journal of Environmental Protection, 4(5-1): 16-27.

Ghernaout D, Badis A, Kellil A, and Ghernaout B (2008). Application of electrocoagulation in Escherichia coli culture and two surface waters. Desalination, 219(1-3): 118-125.

Ghernaout D, Benblidia C, and Khemici F (2015c). Microalgae removal from Ghrib Dam (Ain Defla, Algeria) water by electroflotation using stainless steel electrodes. Desalination and Water Treatment, 54(12): 3328-3337.

Ghernaout D, Ghernaout B, and Kellil A (2009). Natural organic matter removal and enhanced coagulation as a link between coagulation and electrocoagulation. Desalination and Water Treatment, 2(1-3): 203-222.

Ghernaout D, Ghernaout B, and Naceur MW (2011). Embodying the chemical water treatment in the green chemistry: A review. Desalination, 271(1): 1-10.

Ghernaout D, Moulay S, Messaoudene NA, Aichouni M, Naceur MW, and Boucherit A (2014). Coagulation and chlorination of NOM and algae in water treatment: A review. International Journal of Environmental Monitoring and Analysis, 2: 23-34.

Ghernaout D, Naceur MW, and Aouabed A (2011). On the dependence of chlorine by-products generated species formation of the electrode material and applied charge during electrochemical water treatment. Desalination, 270(1): 9-22.

Ghernaout D, Naceur MW, and Ghernaout B (2011). A review of electrocoagulation as a promising coagulation process for improved organic and inorganic matters removal by electrophoresis and electroflotation. Desalination and Water Treatment, 28(1-3): 287-320.

Gopal K, Tripathy SS, Bersillon JL, and Dubey SP (2007). Chlorination byproducts, their toxicodynamics and removal from drinking water. Journal of Hazardous Materials, 140(1): 1-6.

Guo W, Shan Y, and Yang X (2014). Factors affecting the formation of iodo-trihalomethanes during oxidation with chlorine dioxide. Journal of Hazardous Materials, 264: 91-97.

Guo Y, Xu B, and Qi F (2016). A novel ceramic membrane coated with MnO 2–Co 3 O 4 nanoparticles catalytic ozonation for benzophenone-3 degradation in aqueous solution: Fabrication, characterization and performance. Chemical Engineering Journal, 287: 381-389.

Hua G and Reckhow DA (2008). Relationship between brominated THMs, HAAs, and total organic bromine during drinking water chlorination. ACS Publications, Washington, USA.

Huang J, Graham N, Templeton MR, Zhang Y, Collins C, and Nieuwenhuijsen M (2009). A comparison of the role of two blue–green algae in THM and HAA formation. Water Research, 43(12): 3009-3018.

Iriarte-Velasco U, Alvarez-Uriarte JI, and González-Velasco JR (2007). Enhanced coagulation under changing alkalinity-hardness conditions and its implications on trihalomethane precursors removal and relationship with UV absorbance. Separation and Purification Technology, 55(3): 368-380.

Ji Q, Liu H, Hu C, Qu J, Wang D, and Li J (2008). Removal of disinfection by-products precursors by polyaluminum chloride coagulation coupled with chlorination. Separation and Purification Technology, 62(2): 464-469.

Kanokkantapong V, Marhaba TF, Panyapinyophol B, and Pavasant P (2006). FTIR evaluation of functional groups involved in the formation of haloacetic acids during the chlorination of raw water. Journal of Hazardous Materials, 136(2): 188-196.

Karanfil T, Hong Y, and Song H (2008). HAA Formation and Speciation during Chloramination. ACS Publications, Washington, USA.

Kim HC and Yu MJ (2007). Characterization of aquatic humic substances to DBPs formation in advanced treatment processes for conventionally treated water. Journal of Hazardous Materials, 143(1): 486-493.

Lin YL, Chiang PC, and Chang EE (2006). Reduction of disinfection by-products precursors by nanofiltration process. Journal of Hazardous Materials, 137(1): 324-331.

Liu H, Liu R, Tian C, Jiang H, Liu X, Zhang R, and Qu J (2012). Removal of natural organic matter for controlling disinfection by-products formation by enhanced coagulation: A case study. Separation and Purification Technology, 84: 41-45.

Liviac D, Creus A, and Marcos R (2011). Genotoxic evaluation of the non-halogenated disinfection by-products nitrosodimethylamine and nitrosodiethylamine. Journal of Hazardous Materials, 185(2): 613-618.

Lou JC, Chang TW, and Huang CE (2009). Effective removal of disinfection by-products and assimilable organic carbon: An advanced water treatment system. Journal of Hazardous Materials, 172(2): 1365-1371.

Lyon BA, Cory RM, and Weinberg HS (2014). Changes in dissolved organic matter fluorescence and disinfection byproduct formation from UV and subsequent chlorination/ chloramination. Journal of Hazardous Materials, 264: 411-419.

Narbaitz RM, Rana D, Dang HT, Morrissette J, Matsuura T, Jasim SY, and Yang P (2013). Pharmaceutical and personal care products removal from drinking water by modified cellulose acetate membrane: Field testing. Chemical Engineering Journal, 225: 848-856.

Navalon S, Alvaro M, and Garcia H (2009). Ca 2+ and Mg 2+ present in hard waters enhance trihalomethane formation. Journal of Hazardous Materials, 169(1): 901-906.

Nikolaou AD, Lekkas TD, and Golfinopoulos SK (2004). Kinetics of the formation and decomposition of chlorination by-products in surface waters. Chemical Engineering Journal, 100(1): 139-148.

Oh BS, Jang HY, Jung YJ, and Kang JW (2007). Microfiltration of MS2 bacteriophage: Effect of ozone on membrane fouling. Journal of Membrane Science, 306(1): 244-252.

Panyapinyopol B, Marhaba TF, Kanokkantapong V, and Pavasant P (2005). Characterization of precursors to trihalomethanes formation in Bangkok source water. Journal of Hazardous Materials, 120(1): 229-236.

Patsios SI, Sarasidis VC, and Karabelas AJ (2013). A hybrid photocatalysis–ultrafiltration continuous process for humic acids degradation. Separation and Purification Technology, 104: 333-341.

Plewa MJ, Wagner ED, Muellner MG, Hsu KM, and Richardson SD (2008). Comparative mammalian cell toxicity of N-DBPs and C-DBPs. ACS Publications, Washington, USA.

Pope PG and Speitel Jr GE (2008). Reactivity of bromine-substituted haloamines in forming haloacetic acids. ACS Publications, Washington, USA.

Rachwal T and Judd S (2006). A synopsis of membrane technologies in UK municipal potable water treatment: History, status and prospects. Water and Environment Journal, 20(3): 110-113.

Rana D, Narbaitz RM, Garand-Sheridan AM, Westgate A, Matsuura T, Tabe S, and Jasim SY (2014). Development of novel charged surface modifying macromolecule blended PES membranes to remove EDCs and PPCPs from drinking water sources. Journal of Materials Chemistry A, 2(26): 10059-10072.

Rana D, Scheier B, Narbaitz RM, Matsuura T, Tabe S, Jasim SY, and Khulbe KC (2012). Comparison of cellulose acetate (CA) membrane and novel CA membranes containing surface modifying macromolecules to remove pharmaceutical and personal care product micropollutants from drinking water. Journal of Membrane Science, 409: 346-354.

Reckhow DA, Makdissy G, and Rees PS (2008). Disinfection by-product precursor content of natural organic matter extracts. ACS Publications, Washington, USA.

Rincón AG, Pulgarin C, Adler N, and Peringer P (2001). Interaction between E. coli inactivation and DBP-precursors—dihydroxybenzene isomers—in the photocatalytic process of drinking-water disinfection with TiO 2. Journal of Photochemistry and Photobiology A: Chemistry, 139(2): 233-241.

Roberson JA (2008). The evolution of disinfection by-products regulations: Past, present, and future. ACS Publications, Washington, USA.

Rojas JC, Moreno B, Garralón G, Plaza F, Pérez J, and Gómez MA (2008). Potabilization of low NOM reservoir water by ultrafiltration spiral wound membranes. Journal of Hazardous Materials, 158(2): 593-598.

Sharp EL, Jarvis P, Parsons SA, and Jefferson B (2006). Impact of fractional character on the coagulation of NOM. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 286(1): 104-111.

Shetty GR, Malki H, and Chellam S (2003). Predicting contaminant removal during municipal drinking water nanofiltration using artificial neural networks. Journal of Membrane Science, 212(1): 99-112.

Singh G, Rana D, Matsuura T, Ramakrishna S, Narbaitz RM, and Tabe S (2010). Removal of disinfection byproducts from water by carbonized electrospun nanofibrous membranes. Separation and Purification Technology, 74(2): 202-212.

Tan Y, Kilduff JE, and Karanfil T (2008). Natural dissolved organic matter removal and subsequent disinfection by-product formation: A comparison of ion exchange and activated carbon. ACS Publications, Washington, USA.

Tian FX, Xu B, Zhang TY, and Gao NY (2014). Degradation of phenylurea herbicides by chlorine dioxide and formation of disinfection by-products during subsequent chlor (am) ination. Chemical Engineering Journal, 258: 210-217.

USEPA (1997). Small systems compliance technology list for the surface water treatment rule (EPA 815-R-97–002). United States Environmental Protection Agency, Washington, USA.

USEPA (1999). Alternative disinfectants and oxidants guidance manual (EPA 815-R-99–014). United States Environmental Protection Agency, Washington, USA.

Walton JR (2007). A longitudinal study of rats chronically exposed to aluminum at human dietary levels. Neuroscience Letters, 412(1): 29-33.

Wang X, Goual L, and Colberg PJ (2012). Characterization and treatment of dissolved organic matter from oilfield produced waters. Journal of Hazardous Materials, 217: 164-170.

Wang Z, Xu B, Lin YL, Hu CY, Tian FX, Zhang TY, and Gao NY (2014). A comparison of iodinated trihalomethane formation from iodide and iopamidol in the presence of organic precursors during monochloramination. Chemical Engineering Journal, 257: 292-298.

Warton B, Heitz A, Joll C, and Kagi R (2006). A new method for calculation of the chlorine demand of natural and treated waters. Water Research, 40(15): 2877-2884.

Weiner ER (2012). Applications of environmental aquatic chemistry: A practical guide. CRC press, Florida, USA.

Williams MD, Ravindran V, and Pirbazari M (2012). Modeling and process evaluation of membrane bioreactor for removing biodegradable organic matter from water. Chemical Engineering Science, 84: 494-511.

Xiao F, Zhang X, Zhai H, Yang M, and Lo IM (2010). Effects of enhanced coagulation on polar halogenated disinfection byproducts in drinking water. Separation and Purification Technology, 76(1): 26-32.

Xie P, Ma J, Liu W, Zou J, and Yue S (2015). Impact of UV/persulfate pretreatment on the formation of disinfection byproducts during subsequent chlorination of natural organic matter. Chemical Engineering Journal, 269: 203-211.

Xu B, Chen Z, Qi F, Ma J, and Wu F (2009). Rapid degradation of new disinfection by-products in drinking water by UV irradiation: N-Nitrosopyrrolidine and N-nitrosopiperidine. Separation and Purification Technology, 69(1): 126-133.

Ye T, Xu B, Lin YL, Hu CY, Xia SJ, Lin L, and Gao NY (2012). Formation of iodinated disinfection by-products during oxidation of iodide-containing water with potassium permanganate. Journal of Hazardous Materials, 241: 348-354.

Zhang H, Liu H, Zhao X, Qu J, and Fan M (2011). Formation of disinfection by-products in the chlorination of ammonia-containing effluents: significance of Cl 2/N ratios and the DOM fractions. Journal of Hazardous Materials, 190(1): 645-651.

Zhang L, Gu P, Zhong Z, Yang D, He W, and Han H (2009b). Characterization of organic matter and disinfection by-products in membrane backwash water from drinking water treatment. Journal of Hazardous Materials, 168(2): 753-759.

Zhang Q, Kuang WF, Liu LY, Li K, Wong KH, Chow AT, and Wong PK (2009a). Trihalomethane, haloacetonitrile, and chloral hydrate formation potentials of organic carbon fractions from sub-tropical forest soils. Journal of Hazardous Materials, 172(2): 880-887.

Zhou S, Shao Y, Gao N, Zhu S, Li L, Deng J, and Zhu M (2014). Removal of microcystis aeruginosa by potassium ferrate (VI): Impacts on cells integrity, intracellular organic matter release and disinfection by-products formation. Chemical Engineering Journal, 251: 304-309.

Zong W, Sun F, and Sun X (2013). Evaluation on the generative mechanism and biological toxicity of microcystin-LR disinfection by-products formed by chlorination. Journal of Hazardous Materials, 252: 293-299.