

Communication

Water Disinfection: Ferrate (VI) as the Greenest Chemical – A Review

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Abstract: Water shortage pushed water treatment specialists to search for green technology and chemicals for better drinking water quality. Based on iron, a healthy element, ferrate (VI) has known some successful applications through the lab-scale and industrial level. Simultaneously as a disinfectant, oxidant, and coagulant, this eco-friendly chemical merits more attention to enlarging its worldwide acceptance. This work focuses on its recent usages mainly as killing agent. During the last decade, an appreciable understanding has been summated mostly concerning synthesis, fresh rising microcontaminants, radionuclides, inorganic as well as organic contaminants and the pathway of ferrate role. During sewage remediation, literature established that ferrate (VI) is an outstanding oxidant and a coagulant; it decreased chemical oxygen demand by 30% while killing three orders of magnitude more bacteria than traditional chemicals. Ferrate (VI) injection conducted to algae elimination from lake water thanks to its binary features, i.e., as an oxidant and coagulant. Recent successful application of *in-situ* ferrate (VI) for enhanced seawater pretreatment promotes its large acceptance. As the greenest chemical used in water treatment, ferrate merits more interest in terms of laboratory research and large-scale application. However, technical problems related to preoxidation effects on decreasing coagulation efficiency and disinfection by-products problems remain to be first taken into account besides to its industrial preparation.

Keywords: Ferrate, Wastewater Treatment, Drinking Water, Disinfection, Green Technology, Iron

1. Introduction

Water is a vital element of nature that is important for the continuity of life on earth [1]. During the last years, it is more and more mentioned the presence of different emerging contaminants (such as heavy metals, volatile organic carbons, pesticides, personal care products, pharmaceuticals, organics, and pathogens) that disturbed from one side to the other of all various parts of nature [2]. As a result, the deterioration of ground and surface water via different emerging contaminants is identified as a universal issue that remains in the search for low-cost and eco-technological solution [3, 4].

Iron (Fe) possesses a fundamental contribution in diverse bio-systems thanks to its implication in biochemical mechanisms, metabolic system, respiratory functions (as a

crucial constituent of hemoglobin) and essential action in DNA synthesis [5]. Moreover, Fe is an important element of living beings; therefore, it is really out of the question to comprehend any bio-system without comprehending the action of Fe. In addition to possessing a significant contribution in biochemical pathways, employing iron and its alloys as catalysts has conducted to technical progress in industrial fields and in synthetic organic chemistry [6]. In nature, iron is plentiful, for the most part in the forms of Fe(0), ferrous (Fe(II)), and ferric (Fe(III)) ions. In addition to such oxidation states, it may show higher oxidation states, i.e., Fe(IV), Fe(V), and Fe(VI), which are usually known as ferrates [4, 7].

Ferrate ($\text{Fe}^{\text{VI}}\text{O}_4^{2-}$) has obtained large regard thanks to its wanted chemical features like its extremely elevated

oxidizing power [4]. In this direction, ferrate ($\text{Fe}^{\text{VI}}\text{O}_4^{2-}$) has been employed as a green oxidant in diverse domains comprising usages in synthetic organic transformations, water oxidation catalysis, waste remediation, and high-capacity battery cathodes [8, 9]. Besides, ferrate(VI) has the potential to kill microbes, remove organic and inorganic pollutants (at least to a limited extent), and remove suspended/colloidal materials [10] thanks to its elevated oxidizing capacity to jointly produce ferric coagulating species. All this renders ferrate(VI) a performant substance for expanding ferrate-founded green techniques [11, 12] in diverse domains [13].

Through a long pH span, four ferrate(VI) species may be existing [14]. Both in acidic and basic solutions, $\text{Fe}(\text{VI})$ is a strong oxidizing agent with redox potentials of + 2.2 and + 0.7 V, respectively (Table 1) [4]. In acidic pH, the redox potential of ferrate(VI) ions (2.2 V) is top to else oxidants/disinfectants (for example, it is bigger than that of ozone (2.0 V)), which renders ferrate(VI) a better, i.e., “greener”, substance for water/wastewater implementations

[13]. In aqueous solutions, ferrate(VI) presents a typical red-violet color. The $[\text{FeO}_4]^{2-}$ ion has a tetrahedral form identical to its covalently bound geometry in the solid-state [13, 15]. In 1958, Wood [16] published the thermodynamic constants of ferrate(VI) salt (potassium ferrate). In the main, volumetric titration and spectroscopic methods have been employed to describe ferrate(VI) salts [13]. As an illustration, an aqueous solution of ferrate ions shows distinctive absorption peaks at 500 and 800 nm in the visible domain along with many absorption peaks in the near-infrared (IR) zone. Frequently, ultraviolet-visible (UV-vis), X-ray diffraction (XRD), X-ray absorption spectroscopy (XAS) and scanning electron microscopy (SEM) are employed to categorize made ferrate ($\text{Fe}^{\text{VI}}\text{O}_4^{2-}$) with elevated purity as contrasted to commercialized forms. Moreover, Fe *k*-edge X-ray absorption near edge spectrum (XANES) is a very successful instrument for examining its molecular construction and distinguishing the speciation of ferrate(VI) salts [17].

Table 1. Redox potential for the oxidants/disinfectants employed in water and wastewater treatment [13, 18-20].

Oxidant	Reaction	E^0 (V)
Chlorine	$\text{Cl}_{2(\text{g})} + 2\text{e}^- \rightarrow 2\text{Cl}^-$	1.358
	$\text{ClO}^- + \text{H}_2\text{O} + 2\text{e}^- \rightarrow \text{Cl}^- + 2\text{OH}^-$	0.841
	$\text{HClO} + \text{H}^+ + 2\text{e}^- \rightarrow \text{Cl}^- + \text{H}_2\text{O}$	1.482
	$\text{HClO} \leftrightarrow \text{H}^+ + \text{ClO}^-$ $pK_a = 7.48$ (20°C)	
Chlorine dioxide	$\text{ClO}_{2(\text{aq})} + \text{e}^- \rightarrow \text{ClO}_2^-$	0.954
Ozone	$\text{O}_3 + 2\text{H}^+ + 2\text{e}^- \rightarrow \text{O}_2 + \text{H}_2\text{O}$	2.076
	$\text{O}_3 + \text{H}_2\text{O} + 2\text{e}^- \rightarrow \text{O}_2 + 2\text{OH}^-$	1.24
Hydroxyl radical	$^*\text{OH} + \text{H}^+ + \text{e}^- \leftrightarrow \text{H}_2\text{O}$	2.80
	$^*\text{OH} + \text{e}^- \leftrightarrow \text{OH}^-$	1.89
Hydrogen peroxide	$\text{H}_2\text{O}_2 + 2\text{H}^+ + 2\text{e}^- \leftrightarrow 2\text{H}_2\text{O}$	1.78
	$\text{H}_2\text{O}_2 + 2\text{e}^- \leftrightarrow 2\text{OH}^-$	0.88
Hypochlorite	$\text{HClO}^- + \text{H}^+ + 1\text{e}^- \rightarrow \text{Cl}^- + \text{H}_2\text{O}$	1.48
	$\text{ClO}^- + \text{H}_2\text{O} + 2\text{e}^- \rightarrow \text{Cl}^- + 2\text{OH}^-$	0.84
Perchlorate	$\text{ClO}_4^- + 8\text{H}^+ + 8\text{e}^- \rightarrow \text{Cl}^- + 4\text{H}_2\text{O}$	1.39
Dissolved oxygen	$\text{O}_2 + 4\text{H}^+ + 4\text{e}^- \rightarrow 2\text{H}_2\text{O}$	1.23
	$\text{MnO}_4^- + 4\text{H}^+ + 3\text{e}^- \rightarrow \text{MnO}_2 + 2\text{H}_2\text{O}$	1.679
Permanganate	$\text{MnO}_4^- + 8\text{H}^+ + 5\text{e}^- \rightarrow \text{Mn}^{2+} + 4\text{H}_2\text{O}$	1.507
	$\text{MnO}_4^- + 2\text{H}_2\text{O} + 3\text{e}^- \rightarrow \text{MnO}_2 + 4\text{OH}^-$	0.59
	$\text{HMnO}_4 \leftrightarrow \text{H}^+ + \text{MnO}_4^-$ $pK_a = -2.25$ (20°C)	
Ferrate(VI)	$\text{FeO}_4^{2-} + 8\text{H}^+ + 3\text{e}^- \rightarrow \text{Fe}^{3+} + 4\text{H}_2\text{O}$	2.20
	$4\text{K}_2\text{FeO}_4 + 10\text{H}_2\text{O} \rightarrow 4\text{Fe}(\text{OH})_3 + 8\text{KOH} + 3\text{O}_2$	0.70
	$\text{H}_2\text{FeO}_4 \leftrightarrow \text{H}^+ + \text{HFeO}_4^-$ $pK_{a1} = 3.5$ (20°C)	
	$\text{HFeO}_4^- \leftrightarrow \text{H}^+ + \text{FeO}_4^{2-}$ $pK_{a2} = 7.23$ (20°C)	

As a rising domain may be categorized the application of ferrates in environmental remediation [4]. Potassium ferrate was discussed by some researchers [13, 14]. In fact, their surveys were mainly restricted to oxidation [21] and coagulation capacity in waste/wastewater treatment [22-27]. Moreover, Li et al. [28], and Ghernaout and Naceur [20] concentrated on chemical and electrochemical techniques for producing ferrate, respectively. Appreciable progress was recorded in the comprehension of ferrate chemistry and its multipurpose usages. On the other hand, Jiang [29] assessed the implementation of ferrate and its environmental utilizations. During the last decade, a large span of new understanding has been summated, mostly concerning synthesis, fresh rising microcontaminants, radionuclides,

inorganic as well as organic contaminants and the pathway of ferrate role [30, 31].

Even if this method has been scientifically well accepted, Rai et al. [4] presented a thorough examination and actualized data about ferrate preparation, the removal of a large variety of contaminants employing ferrate, its route of contribution, and its restrictions. This work focuses on the reactivity of ferrate with microbes in the remediation of polluted water.

2. Preparation of Ferrate

Diverse man-made formulas for ferrate(VI) comprising wet chemical, electrochemical, and thermal methods have

been suggested and optimized. Preparing ferrate(VI) has been completely revised by several researchers [13, 20, 32]. Usually, ($\text{Fe}^{\text{VI}}\text{O}_4^{2-}$) ions complex with alkali (Li, Na, K, and Rb) and alkaline (Ca, Sr, and Ba) metals; however, most attempts have concentrated on preparing sodium and potassium salts of Fe(VI) (Na_2FeO_4 and K_2FeO_4) due to their simplicity and stability [4]. Such techniques may be classified as (a) dry oxidation by heating/melting of various iron oxide-containing minerals under strong alkaline and oxygen flow conditions [33], (b) electrochemical approaches that use anodic oxidation employing iron or an alloy as the anode and NaOH or KOH as the electrolyte [20, 34], and (c) wet oxidation of a Fe(III) salt under strong alkaline conditions employing hypochlorite or chlorine as the oxidant [13, 35].

Through the preceding techniques, dry oxidation is the most frequent approach to preparing ferrate salts [4]. Nevertheless, this way appears to be unsuitable since the usual synthetic circumstances may conduct to detonations at high temperatures [13].

The fundamental base of the electrolytic technique is to prepare ferrate(VI) salts via employing cast iron as an anode [4]. The anode is dissolved and then oxidized to generate K_2FeO_4 employing highly-concentrated KOH (10 M) as an electrolyte [13, 20]. In the electrochemical approach, iron rods (Fe(0)), Fe(II) salts, and oxides/salts of Fe(III) were employed as precursors for producing ferrates. Several synthesis circumstances like temperature, the composition of iron precursors, and the power of the alkaline solution were completely studied to attain the maximum yield of ferrate salts production [36]. However, the potentials of the oxidation of Fe(III) to Fe(VI) and the oxygen emergence reaction interfere, and this may hardly impact the yield and purity of ferrates. Nevertheless, this inconvenient has been controlled via doping the electrodes with boron and employing molten hydroxides to inhibit the oxygen liberation [37]. Ferrate(VI) salts (particularly Na_2FeO_4 and K_2FeO_4) are largely employed as “green cleaners” for wastewater treatment. Even so, K_2FeO_4 is a preferable ferrate for wastewater treatment thanks to the hard stages implicated in the production of solid Na_2FeO_4 [13].

During the wet chemical method, iron salts (FeCl_3 and $\text{Fe}(\text{NO}_3)_3$) are oxidized using highly alkaline hypochlorite (OCl^-), to endure very soluble Na_2FeO_4 [13]. It was found that K_2FeO_4 is much less soluble than Na_2FeO_4 , and elevated purity (98%) K_2FeO_4 salt may be achieved via injecting KOH into soluble Na_2FeO_4 [4]. Even if the preparation of Na_2FeO_4 may be performed via the permutation of hypochlorite (OCl^-) with ozone, the yield of ferrate was extremely low employing this technique [31]. Throughout the wet oxidation procedure, washing with dry methanol is a fundamental stage for eliminating ionic impurities like hydroxides, chlorides, and nitrates, producing a 90% pure ferrate(VI) product [17, 38]. As methanol is cost-effective, its employment in the washing stage is well-accepted [17]. A successful method of synthesizing high purity (99%) ferrate(VI) salt (K_2FeO_4) with a high yield

(50-70%) is published [28].

Throughout the thermal approach, a mixture of iron(III) oxides and KNO_3 salts was heated above 1100°C to form K_2FeO_4 with low purity (~30%). This finding points out that this technique might be an unsuitable approach to synthesizing K_2FeO_4 . To conquer this practical drawback, Na_2FeO_4 was produced by decreasing the temperature to 600°C employing an amalgamation of iron(III) oxide and Na_2O_2 . The formed solid K_2FeO_4 was stable for long periods at particular circumstances. This technique gives a solution to handle the worry concerning long term storage of ferrate(VI) salts. However, there are scarce investigations on the long-term storage problems of ferrate(VI) following generation [4].

3. Ferrate as a Killing Agent of Microorganisms

Not long ago, ferrate was found to be a performant killing agent in demobilizing diverse microorganisms from both soil and groundwater [4]. As a result, it was employed to avoid different by-products of traditional chemical methods. Microbes are a varied group of organisms that are closely related to sewage contamination and human health. The efficiency of potassium ferrate(VI) was contrasted to additional substances for demobilizing *Escherichia coli*, comprising sodium hypochlorite, ferric sulfate, and aluminum sulfate [39]. Demobilizing *E. coli* happened at very small concentrations and lower residence periods. Moreover, the demobilization method was not touched considerably by pH, and a more elevated disinfection percentage of ferrate was noted as contrasted to sodium hypochlorite [39, 40]. Lately, Li et al. [41] focused on the relative impact of ferrate(VI) and chlorine during treating polluted water on bacterial community dynamics. They established that these chemical products could possess diverse killing routes. They employed quantitative polymerase chain reactions and pyrosequencing of 16S rRNA genes to estimate viable and nonviable bacterial populations following injection of ferrate(VI) and chlorine. During sewage remediation, ferrate(VI) was an outstanding oxidant and a coagulant; it decreased chemical oxygen demand by 30% while killing three orders of magnitude more bacteria than traditional chemicals. Protozoan parasites such as *Cryptosporidium parvum* and *Giardia lamblia* are famous to induce waterborne disease outbreaks and the frequent technique of chlorine disinfection is mostly impotent because of the maximum resistance of such parasites [30]. More investigations studied additional solutions for microbial removal without considerable triumph, which drove them to adopt ferrate as a green solution [30, 42].

In the group of various microalgae, cyanobacteria give rise to remarkable odor issues in potable water, and this necessitates an inexpensive chemical solution [4, 43-46]. Ferrate(VI) injection conducted to algae elimination from

lake water thanks to its binary features, i.e., as an oxidant and coagulant [47]. Employing an integration of ferrate(VI) and alum, the elimination percentage of cyanobacteria was greatly augmented comparatively with pure alum as a coagulant [30, 48]. On the other hand, ferrate(VI) as well efficiently demobilized bacteriophage MS2, which is a human enteric virus that is detected in potable water [30, 49]. Besides, investigations have shown that deterioration to both the capsid protein and the genome of MS2 augmented as ferrate(VI) entrance to the inside of the virion augmented, and this conducted to elevated demobilization. Consequently, the harm to both the capsid protein and the genome induced by the offensive of ferrate(VI) may participate in phage demobilization [30, 49]. With a view to prove the demobilization of microorganisms via ferrate, the demobilization kinetics of MS2 coliphage by ferrate(VI) were assessed employing individual batch tests by a Chick–Watson model with first-order dependences on disinfectant and infective phage concentrations [49]. Ferrate manifested the greatest demobilization (99.99%) percentage constant k_i at a ferrate injection of 1.23 mg/L (pH 7.0, 25°C). Moreover, Hu et al. [49] affirmed the MS2 demobilization via matrix-assisted laser desorption mass spectrometry (MALDI-MS) and qRT-PCR analyses. Via molecular analyses of the MS2 capsid protein, it was shown that there was a quick diminution in the signals of intact capsid protein molecules, which points out the total demobilization of the virus (Figure 1a). As illustrate in Figure 1b, the decomposition of the intact capsid protein was proved throughout the appearance of a product peak at $m/z = 4888$ Da. This mass peak was assigned to the protein fragment arising from backbone segmentation between residues Cys46 and Ser47. This indicates that ferrate(VI) may launch segmentation among Cys46 and Ser47, which proves that both capsid protein and genome destruction augmented with augmenting virus demobilization. Further, the oxidative characteristics of ferrate efficiently demobilize pathogens [4]. Oxidizing the microbial cell membrane may happen thanks to the formation of reactive oxygen species (ROS), which may elevate the cell permeability, conducting to demobilization (Figure 2). More researches would clarify the route of work of ferrate on pathogens.

Away from its application as a killing agent for demobilization of diverse bacteria (*E. coli*, *Salmonella*, *Staphylococcus aureus*, *Bacillus sp.*, *Pseudomonas sp.*, *Enterococcus faecalis*) in water [50, 51], ferrate has as well appeared as a fresh disinfectant chemical for attractive usages like demobilizing fish parasites (*Ichthyophthirius multifiliis*) [51] and eliminating harmful cyanobacteria (like *Microcystis aeruginosa*) [52] and viruses [49]. Publications illustrated that the disinfection potential of ferrate augmented greatly at pH degrees less than 8.0 thanks to protonated ferrate species. This indicates that ferrate possesses the capacity to demobilize most of the microorganisms cited previously

employing concentrations as small as 1 mg/L [53]. Articles have as well established that ferrate as well acts as a killing agent during the demobilization of viruses and bacteria [30, 54, 55].

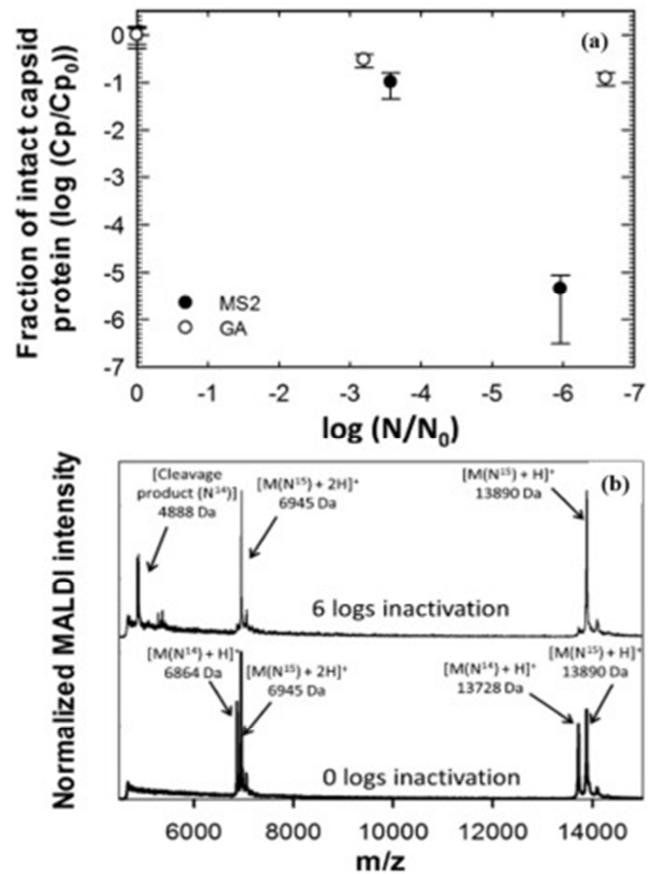


Figure 1. (a) Damage to individual capsid proteins (Cp) of MS2 and GA phages corresponding to varying levels of inactivation achieved during ferrate(VI) treatment. (b) MALDI spectra of the full MS2 capsid protein, showing the disappearance of the intact native (N^{14}) capsid peak ($m/z = 13,728$ and 6864 Da) and the appearance of a cleavage product ($m/z = 4888$ Da) after 6- \log_{10} inactivation of MS2 [4, 49].

In addition, ferrate has been employed as a strong killing agent for various bacterial species like *Bacillus cereus*, *Streptococcus bovis*, *Staphylococcus aureus*, *Shigella flexneri*, *Streptococci faecalis*, and *Salmonella typhimurium* in water [56]. Moreover, ferrate has present convenient viricidal activity in raw water and wastewater towards F-specific RNA coliphage, Qb as a viral model [57] and f2 virus [58]. The disinfection pathway of ferrate implies genome demolition and destruction to the oxidant-sensitive cysteine residues of viruses that are existent in the capsid proteins of viruses. All these findings propose that ferrate remains an encouraging killing agent for demobilizing a large span of microorganisms and rising toxins comprising diverse chlorine-resistant organisms.

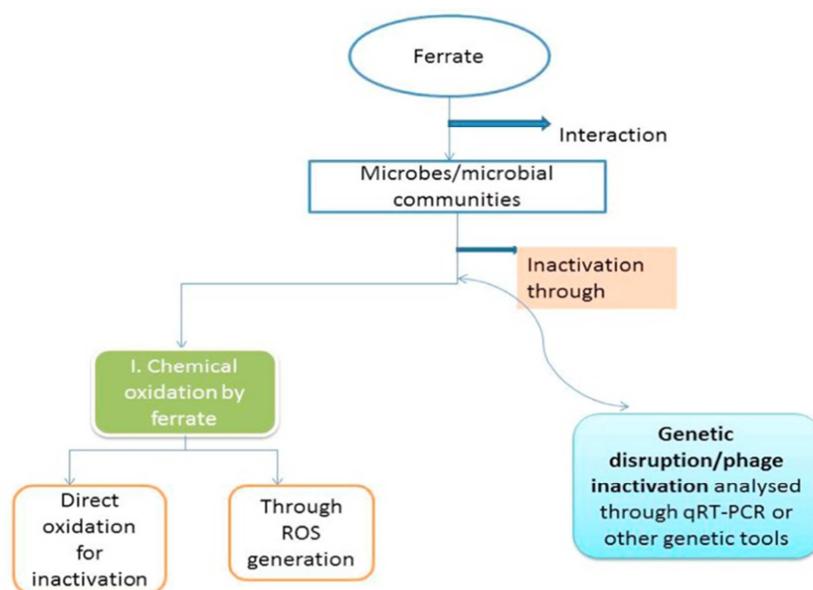


Figure 2. Possible pathway of the work of ferrate on microbes/microbial communities [4].

4. Quantifying DBPs Following Ferrate(VI) Pre-treatment and Chlorination of Blue-green Algae

Cyanobacterial bloom is omnipresent in lakes, rivers, and reservoirs. It begins to be worldwide trouble for potable water supplies [59-62]. Through the decease of algae, unwanted organic matters, like algal toxins and algal organic matter (AOM), are liberated into the surface water, producing odor and taste [63-67]. This constitutes a serious dare to the quality of potable water [68]. AOM is the result of cell waste and cell disintegration. It comprises carbohydrate, amino acids, and proteinaceous compounds, which are categorized as extracellular organic matter (liberated by living cells), and intracellular organic matter (from cell disintegration) [69-71]. It was established that the AOM in the water participate in the generation of disinfection by-products (DBPs) during chlorination (or chloramination) of potable water [72-74]. DBPs comprise carbonaceous DBPs (CDBPs) and nitrogenous DBPs. The DBPs' yields and speciation are influenced by the species of AOM and the water parameters (especially pH) [59, 69, 75].

It was found that both chlorination and chloramination of algae in bromide-containing potable water might produce bromo-DBPs [59, 76-78]. Bromo-DBPs are importantly more poisonous than their chloro-analogues [79, 80]. As a result, it is indispensable to comprehend the generation of AOM-derived DBPs (particularly bromo-DBPs) throughout the chlorination of eutrophic water [81, 82]. As the fundamental treatment method, traditional coagulation remains employed for decreasing algae in potable water [83-85]. Nevertheless, the reduction is not satisfactory because of the electrostatic repulsion and steric impacts [86]. Several investigations have mentioned that pretreating water using oxidants like ozone and chlorine dioxide may improve

the coagulation technique to eliminate algae cells [84, 87-89]. Dong et al. [59] focused on the study of pre-treating algae cells employing ferrate(VI) ($\text{Fe}^{\text{VI}}\text{O}_4^{2-}$, Fe(VI)).

As pre-oxidant, Fe(VI) may be used thanks to its powerful reduction potential of +2.2 V in the acid and +0.7 V in the base [16]. Moreover, Fe(VI) is environmentally friendly and may be employed as oxidant and coagulant for handling water without forming side contamination [90]. It has been proved that pre-oxidizing *M. aeruginosa* (freshwater cyanobacteria) via Fe(VI) diminished the production of trihalomethanes (THMs) and haloacetic acids (HAAs) throughout the following chlorination [91]. At the present time, little details are found about the impacts of pH and bromide on the generation of N-DBPs and bromo-DBPs during the Fe(VI) preoxidation and next chlorination stage was implemented to the blue-green algae carrying water. Dong et al. [59] carried out Fe(VI) pre-treatment/chlorination method on two chosen blue-green algal species, *Chlorella sp.* and *Pseudanabaena limnetica* (*P. limnetica*). Such species are the most regularly observed green algae and blue algae species in Taihu Lake, one of the biggest freshwater lakes in China [92, 93].

Dong et al. [59] established that Fe(VI) eliminated the algal cells via inducing cell death, apoptosis, and lost integrity, and diminished AOM (in terms of total organic carbon) in water throughout oxidation and coagulation [94-97]. Chlorination of the Fe(VI) pre-oxidized algal water samples formed halogenated DBPs (comprising THMs, HAAs, halo ketones, chloral hydrate, haloacetonitriles, and trichloronitromethane); however, the concentrations of DBPs were lower than those produced in the chlorinated samples without pre-treatment using Fe(VI) . More important Fe(VI) dose, longer oxidation time, and alkaline pH were useful in controlling DBPs. In bromide-containing algal solutions, negligible quantity of bromo-DBPs was formed in the Fe(VI) pre-oxidation, and halogenated DBPs were mostly produced

in the following chlorination.

5. *In-situ* Ferrate(VI) for Enhanced Seawater Pretreatment

Harmful algal blooms (HABs) are regarded as the main menace for seawater reverse osmosis (SWRO) plants. The existence of HABs in the raw feed water may augment chemical consumption inside the desalination plant, elevate membrane fouling [98, 99] percentage and might conduct to plant closure. Eliminating AOM throughout the pretreatment will assist in elevating the membrane existence, diminish functioning cost and augment the plant reliability [100-102]. Alshahri et al. [103] assessed the performance of liquid

ferrate and ferric chloride throughout coagulation on eliminating AOM. The liquid ferrate was produced in-situ via wet oxidation of ferric iron employing hypochlorite in a caustic medium (Figure 3). They used two seawater models, the first one includes 10 mg c/L of sodium alginate and the second one comprises 10 mg c/L of *Chaetoceros affinis* (CA) algae. Throughout the advanced coagulation, liquid ferrate manifested to be more efficient in reducing AOM than ferric chloride, with a global dissolved organic carbon elimination of 90%, allowing 100% algal elimination and the demobilization of 99.99% of the microorganisms. These findings prove the performance of liquid ferrate as seawater pretreatment over the HABs occurrences [103].

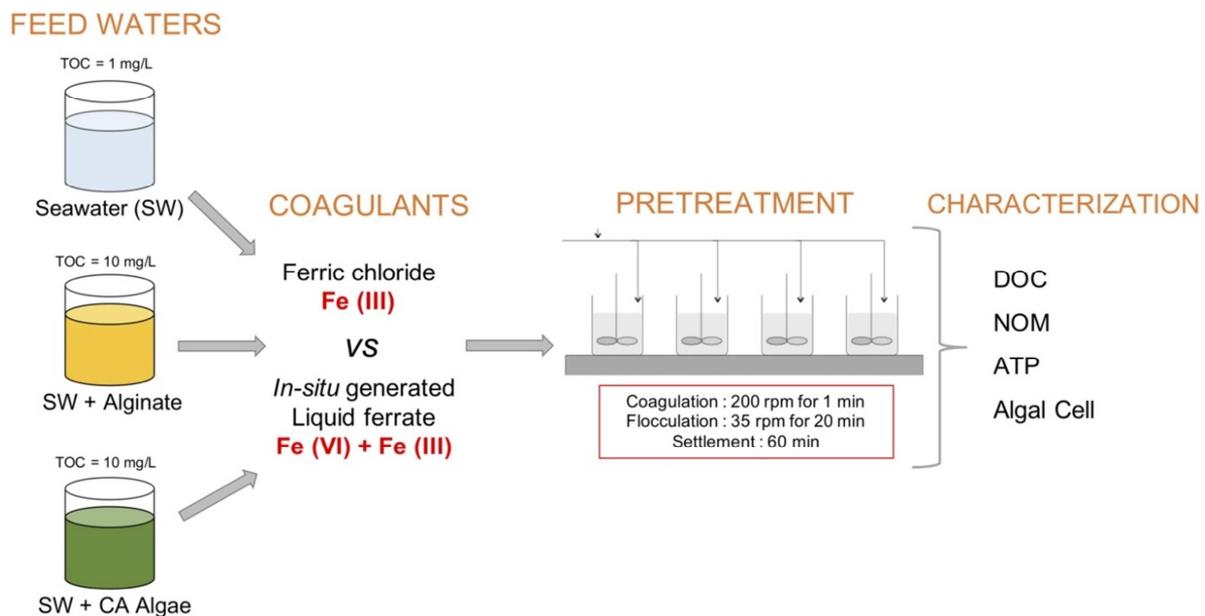


Figure 3. Experimental procedure for the pretreatment of seawater (SW), *Chaetoceros affinis* (CA), and algal organic matter (AOM) [103].

6. Preoxidation Improving Coagulation: Questions and Worries

Following some references, preoxidation has attracted specialists' interest thanks to its performance in improving coagulation [104, 105]. Xie et al. [104] reviewed the routes, disadvantages and implementations in the enhancement of coagulation. Preoxidation may destruct the organic coating on the surface of particles to modify the zeta potential, which is the main cause for enhancing coagulation. Co-existing metallic ions, like calcium, iron, and manganese, possess fundamental contributions in enhancing coagulation thanks to the generation of metal-humate complexes or the *in situ* formed coagulant. On the other hand, preoxidation may decompose organic matter from elevated molecular weight to low molecular weight and harm cell membrane of algae, inducing intracellular algal organic matter to liberate outside and forming hydrophilic functional groups to a certain degree, which possesses the capacity to decline the water quality.

Besides, DBPs generation is greatly influenced by modifying the features of the organic and inorganic precursors. Xie et al. [104] proposed several next improvements of peroxidation method.

7. Iron: Greenest Chemical Used for Treating Water

Iron is one of the earth's most abundant resources, making up at least five percent of the earth's crust [106]. When rainfall seeps through the soil, the iron in the earth's surface dissolves, causing it to go into almost every natural water supply, including well water. Even if iron exists in water, it is rarely observed at levels bigger than 10 mg/L. Besides, iron is not viewed as toxic to health as it is vital for good health because it transports oxygen in the blood. The current recommended limit for iron in water, 0.3 mg/L, is founded on taste and appearance rather than on any detrimental health impact [78, 107].

8. Conclusions

The main points drawn from this work may be given as:

1. Potassium ferrate(VI) was observed to be more active than sodium hypochlorite in demobilizing *E. coli* spiked in tap water [39]. To attain the identical *E. coli* disinfection performance, smaller injection and residence period were needed, the efficiency was less touched by solution pHs, and the killing percentage of the ferrate(VI) was faster than that of sodium hypochlorite. In addition, potassium ferrate was discovered to be efficient in oxidizing sulfamethoxazole, a largely used antibacterial drug [108]. Its elimination was observed to fit a first-order kinetic with a half-life of 2 min at pH 7 employing more Fe(VI) concentration (10 mM) than the sulfamethoxazole in water [105].
2. Preoxidation to ameliorate coagulation would begin to be more and more common in the potable water industry if the source waters carry out an elevated amount of organic matter, algae cells, or other contaminants. Nevertheless, to bypass the likely issues provoked by injecting preoxidation chemicals (such as ferrate, even if it is viewed as green chemical), it is needful to assess the features of source water and to evaluate their effects on preoxidation stage. Moreover, investigations concentrating on the safety of implementing preoxidation method in potable water treatment must be also performed [104, 109, 110].
3. From an investigation [103], jar test findings proved that liquid ferrate coagulant gives better pretreatment than traditional ferric chloride for seawater with elevated organic content usually observed throughout algal blooms. Elevated percentages for liquid ferrate were obtained during the in-situ wet oxidation method that may comparatively readily be adjusted to classical techniques employing ferric chloride as a coagulant. Employing liquid ferrate for the coagulation and flocculation pretreatment was discovered to be more efficient in eliminating organic carbon in seawater below algal bloom circumstances, and as furnished a complementary biocidal impact via performant demobilization of microbes in the feedwater. Consequently, liquid ferrate is viewed as an outstanding choice for coagulation/flocculation pretreatment in SWRO methods, particularly during algal bloom conditions.
4. As the greenest chemical used in water treatment, ferrate merits more interests in terms of laboratory research and large-scale application. However, technical problems related to preoxidation effects on coagulation efficiency and DBPs problems remain to be firstly taken into account beside to its industrial preparation.

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