Hypochlorous Acid

Handling

Identification of Petitioned Substance

Chemical Names: Hypochlorous acid, hypochloric(I) acid, chloranol, hydroxidochlorine

Other Name: Hydrogen hypochlorite, Chlorine hydroxide

Trade Names: Bleach, Sodium hypochlorite, Calcium hypochlorite, Sterilox, hypochlorite, NVC-10

CAS Numbers: 7790-92-3

Other Codes: European Community Number-22757, IUPAC-Hypochlorous acid

List other codes: PubChem CID 24341

InChI Key: QWPPOHNGKGFGJK-UHFFFAOYSA-N

UNII: 712K4CDC10

Summary of Petitioned Use

A petition has been received from a stakeholder requesting that hypochlorous acid (also referred to as electrolyzed water (EW)) be added to the list of synthetic substances allowed for use in organic production and handling (7 CFR §§ 205.600-606). Specifically, the petition concerns the formation of hypochlorous acid at the anode of an electrolysis apparatus designed for its production from a brine solution. This active ingredient is aqueous hypochlorous acid which acts as an oxidizing agent. The petitioner plans use hypochlorous acid as a sanitizer and antimicrobial agent for the production and handling of organic products. The petition also requests to resolve a difference in interpretation of allowed substances for chlorine materials on the National List of Allowed and Prohibited Substances that contain the active ingredient hypochlorous acid (NOP-PM 14-3 Electrolyzed water).

The NOP has issued NOP 5026 "Guidance, the use of Chlorine Materials in Organic Production and Handling." This guidance document clarifies the use of chlorine materials in organic production and handling to align the National List with the November, 1995 NOSB recommendation on chlorine materials which read:

> "Allowed for disinfecting and sanitizing food contact surfaces. Residual chlorine levels for wash water in direct crop or food contact and in flush water from cleaning irrigation systems that is applied to crops or fields cannot exceed the maximum residual disinfectant limit under the Safe Drinking Water Act (currently 4 ppm expressed as Cl_2)."

The recent policy memo, NOP PM-14-3, clarifies which synthetic chlorine compounds specified in the National List are allowed for use in organic production and handling. Although hypochlorous acid is an intermediate product produced when hypochlorite salts or chlorine are dissolved in water, purified or generated hypochlorous acid is not specifically included on the National List.

Characterization of Petitioned Substance

Composition of the Substance:

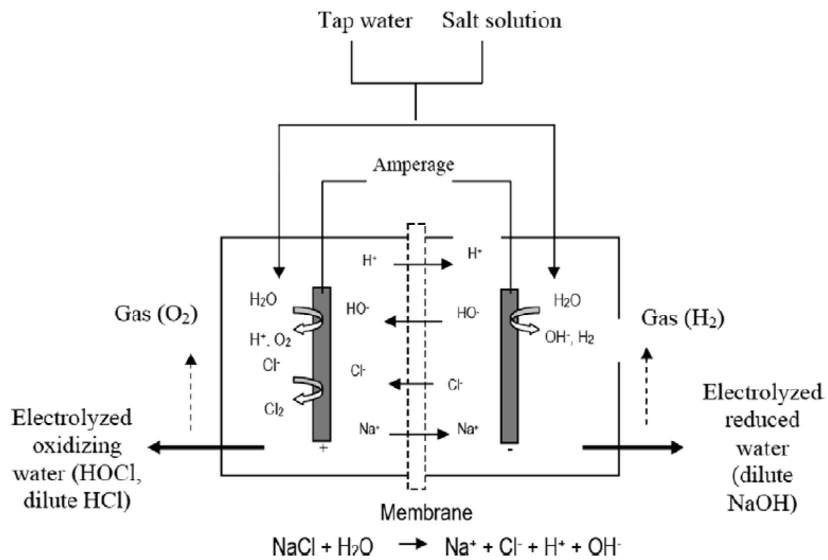
Hypochlorous acid (also referred to as electrolyzed water, EW) is an oxyacid of chlorine (with formula HClO) containing monovalent chlorine that acts as an oxidizing or reducing agent (NCBI, 2015; Su et al., 2007). It is a weak acid and highly unstable and can only exist in solution. The molecules are electron–accepting in oxidation-reduction reactions in which electrons are transferred from one molecule to another (NCBI, 2015).

Electrolyzed water ("electrolyzed water", EOW, ECA, electrolyzed oxidizing water, electro-activated water or electro-chemically activated water solution) is produced by the electrolysis of water-sodium chloride solution. The electrolysis of such salt solutions produces hypochlorous acid, hypochlorite, and free chlorine.

Source or Origin of the Substance:

As reported by Hricova et al., 2008 and Huang et al., 2009, EW is the product of the electrolysis of a dilute NaCl solution in an electrolysis cell, containing a semi-permeable membrane that physically separates the anode and cathode but permitting specific ions to pass through. The basic approach for producing EW is shown in Figure 1. The voltage between the electrodes is generally set at 9 to 10 volts (Al-Haq et al., 2005). During electrolysis, sodium chloride (NaCl) dissolved in deionized water (brine) dissociates into negatively charged chloride (Cl^-) and positively charged sodium (Na^+). At the same time, hydroxide (OH^-) and hydrogen (H^+) ions are formed. Negatively charged ions $Cl^-$and OH^- move to the anode to lose electrons and form oxygen gas (O_2), chlorine gas (Cl_2), hypochlorite ion (OCl^-), hypochlorous acid (HOCl) and hydrochloric acid.

Fig. 1 Schematic of hypochlorous acid generator action



(*from* Huang et al., 2009)

Positively charged ions such as H^+ and Na^+ move to the cathode to form hydrogen gas (H_2) and sodium hydroxide (NaOH). The solution separates into an acidic solution on the anode side of the membrane, with a pH of 2 to 6.0, an oxidation-reduction potential (ORP) of ≥1,000 mV, and a chlorine content of 10 to 90 ppm, and a basic solution on the cathode side of the membrane, with a pH of 7.5 to 13 and an ORP of ~-800 to -900 mV. The solution from the anode is called acidic electrolyzed water (EW), and the cathodic solution is known as basic EW. Neutral EW, with a pH of 6 to 7.5 and an ORP of 750 mV, is produced by mixing the anodic solution with OH^- ions or by using a single-cell chamber.

Basic chemical reactions at the anode (positive pole) and at the cathode (negative pole) are provided in Table 1. The solution from the anode is called acidic electrolyzed water, acid oxidizing water, or electrolyzed oxidizing water, and the cathodic solution is known as basic electrolyzed water, alkaline electrolyzed water, or electrolyzed reducing water. As reported by Al-Haq et al., 2005, there are a number of EW-producing instruments available in the marketplace. They can be divided into those that contain a membrane and produce acidic EW and basic EW (two-cell chamber) and those that do not contain a membrane and therefore produce neutral EW (single-cell chamber).

Table 1 Formula Representation of Hypochlorous Acid Production*	
Anode (positive pole):	$2H_2O \rightarrow 4H^{+}+O_2\uparrow+4e^{-}$
	$2NaCl \rightarrow Cl_2 + 2e^{-}+2Na^{+}$
	$Cl+H_2O \rightarrow HCl+HOCl$
Cathode (negative pole):	$2H_2O+ 2e^{-} \rightarrow 2OH^{-}+H_2\uparrow$
	$2NaCl +2OH^{-} \rightarrow 2NaOH+Cl^{-}$
*H-hydrogen, O-oxygen, Na-sodium, Cl-chlorine, e-transfer electron	

Properties of the Substance:

The physical properties and chemical composition (Table 2) of hypochlorous acid (EW) will vary depending on the concentration of NaCl solution, amperage level, time of electrolysis, temperature and pH (Wiant, C., 2013, Eryilmaz et al., 2013, Al-Haq et al., 2005). These properties impact the antimicrobial/sanitizing effects of hypochlorous acid (EW). Sanitizing means reducing the microorganisms of public health importance to levels considered safe, without adversely affecting either the quality of the product or its safety (Pfuntner, 2011).

Table 2. Chemical and Physical Properties of Hypochlorous acid (NCBI, 2015)	
Chemical formula	HOCl
Molar mass	52.46 g/mol
Appearance	colorless aqueous solution
Solubility in water	soluble
Number of H^+ bond acceptors	1
Number of H^+ bond donors	1
Density	1.4±0.1 g/cm^3
Dissociation constant (pKa)	7.53

The effectiveness of hypochlorous acid as an active sanitizing agent is determined in large part by the pH, a measure of the acidity or hydrogen ion concentration of the solution. Hypochlorous acid exists interchangeably with other chlorine species, including chlorine, hydrogen chloride (aqueous and gaseous) and hypochlorite. This is supported by the equilibrium chemistry of active chlorine. In a controlled pH environment, hypochlorous acid will exist as the dominant chlorine species under pH conditions ranging from 2 to 7.5 (Figure 2).

Specific Uses of the Substance:

Electrolyzed water (EW) is produced by electrolysis of a dilute water-sodium chloride solution flowing through specialized equipment designed to separate alkaline and acidic products (Fig. 1). This electrolytic process facilitates the conversion of chloride ions and water molecules into chlorine oxidants (chlorine gas, hypochlorous acid, and hypochlorite ion) within the anode chamber and sodium hydroxide in the cathode chamber of the production equipment. At an acidic to neutral pH, the predominant chemical species is hypochlorous acid (HOCl) with a high oxidation reduction potential (ORP) of ≥1,000 mV (Guentzel et al., 2008).

EW has received recent attention as an alternative to other chlorine disinfectants and sanitizers. A number of studies have demonstrated the strong antibacterial activity of EW water against foodborne pathogens on raw agricultural products and food contact surfaces. Applications of EW as a disinfectant for reducing microbial contamination have been reported for fresh fruits and vegetables, poultry carcasses, shell eggs, cutting boards, and food processing surfaces. Some advantages of using EW water are: 1) EW is as effective as any chlorine treatment, 2) it is not necessary to handle potentially dangerous chemicals, e.g. chlorine gas, chlorine dioxide, bleach, 3) the apparatus to produce EW is relative inexpensive and easy to operate, 4) because only water and sodium chloride are used EW production is environmentally friendly and 5) the properties of the EW can be controlled at the preparation site (Su et al., 2007).

In addition to its microbiocidal action on actively growing bacteria, EW water is known to kill bacterial spores by damaging their inner membrane rendering them unable to germinate. However, spore killing by hypochlorous acid differs from the action of chlorine dioxide, where the killing action resembles hydrogen peroxide (Young and Setlow, 2003).

In their review of the scientific literature, Keskinen et al., 2009 reported that sanitizing washes are the most practical means of decontaminating raw produce. In commercial value added produce operations, solutions that contained chlorine compounds (with concentrations varying from 50-200 ppm) and with contact times of 2 minutes or greater showed a decrease in the bacterial load by from <1 log colony forming units (CFU)/gram (g) to 3.15 log CFU/g.

At a pH of 6.0-7.5 (neutral), EW (ORP=750 mV) contains primarily hypochlorous acid, hypochlorite ion and trace amounts of chlorine. The effectiveness of neutral EW as a sanitizer has been demonstrated for reducing *Escherichia coli* O157:H7, *Salmonella enteritidis* and *Listeria monocytogenes* biofilms on the surface of tomato (Deza et al., 2003) and also on plastic and wooden cutting boards (Deza et al., 2007).

EW has been reported to have strong bactericidal effects on many pathogenic bacteria, such as Escherichia coli O157:H7, *Listeria monocytogenes*, and Salmonella species (Kim et al., 2000). Suppression of fruit rot in pears caused by the fungus *Botryosphaeria berengeriana* was observed after dipping fruit in an EW water solution for as little as 10 minutes (Al-Haq et al., 2002).

EW quickly kills a variety of fungi and shows promise as a broad-spectrum contact fungicide for control of foliar diseases of greenhouse-grown ornamentals. One requirement for use in the greenhouse is that EW will not cause excessive phytotoxic symptoms on a wide variety of species. EW causes slight damage to some plant species but, in general, appears to be safe to use as a foliar spray on a wide variety of bedding plants grown under greenhouse conditions. Such applications may be useful in reducing bacterial contamination resulting from insect scale and known arthropod plant disease vectors (Buck et al., 2003).

The practice of spraying or washing of eggshells with electrolyzed water has been found to both reduce broiler mortality and microbial contaminations of shell eggs (Fasenko et al., 2009; Achiwa and Nishio, 2002). Discoloration was not observed with the use of electrolyzed water.

The problem of corrosion to processing equipment or hand irritation is a lesser concern when using neutral EW. Stainless steel is very resistant to chlorine products. The solution is stable and chlorine loss is significantly reduced at pH 6–8 (Ayebah et al., 2005 and Len et al., 2002).

Chlorine compounds are widely used sanitizers. In some cases, there is a potential for chlorine compounds used in sanitation to react with organic material (humic acid) which can lead to the formation of potentially carcinogenic and teratogenic trihalomethanes and haloacetic acids. A concern by the produce industry for the potential regulatory constraints on using chlorine in its present form has increased efforts to identify and evaluate alternative sanitizing agents (Stevens, 1982). Although, most of the concern in this area refers to the use of chlorine gas in the sanitation of drinking water, it is generally accepted that carcinogenic and teratogenic trihalomethanes and haloacetic acids are not formed by the action of hypochlorous acid in neutral and near-neutral solutions (Satyawli et al., 2007).

The use of chlorine products that form hypochlorous acid in solution at very low pH has limited potential for long-term applications. At this pH <4.0, dissolved chlorine gas can be rapidly lost due to volatilization, decreasing the biocidal effectiveness of the solution over time, but creating human health and safety issues. The high acidity of the solution may adversely affect food processing equipment and medical instruments surfaces by causing corrosion (Fisher, 2009).

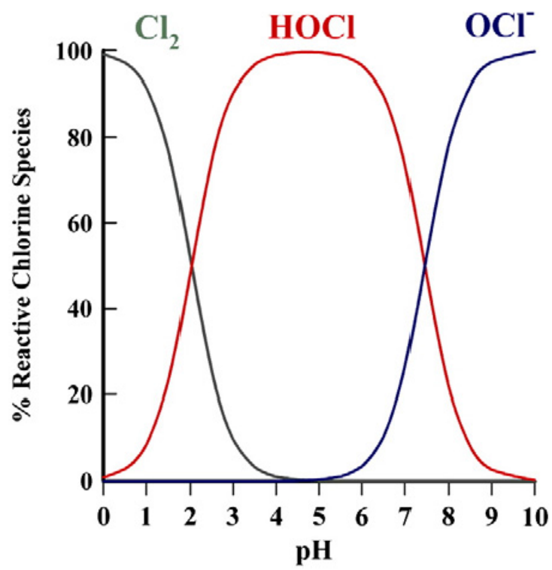


Fig. 2 The pH profile for reactive chlorine species

The relative concentrations of molecular chlorine (Cl_2; green), hypochlorous acid (HOCl; red) and hypochorite (−OCl; blue) were calculated at 140 mM chloride using K = 1.3 × 10−3 M2 for reaction 1 and a pKa of 7.44 for the reaction $HOCl \rightarrow {}^{-}OCl + H^{+}$ (Kettle et al., 2014)

Approved Legal Uses of the Substance:

The Environmental Protection Agency (EPA, 2014) registers all sanitizers and disinfectants as pesticides. However, onsite EW devices (generators) that use sodium chloride and water to produce antimicrobial substances are not required to be registered as a pesticide. The manufacturer of the device must provide documentation that the device complies with 40 CFR 152.500 and the manufacturing establishment's registration number should be on the device.

Hypochlorous acid can be used as an ingredient in an antimicrobial pesticide formulation and may be applied to dairy processing equipment, and food-processing equipment and utensils. Hypochlorous acid is listed in 40 CFR §180.940, Tolerance exemptions for active and inert ingredients for use in antimicrobial formulations (food-contact surface sanitizing solutions):

> Pesticide Chemical: Hypochlorous acid
> CAS No.: 7790-92-3
> Limits: When ready for use, the end-use concentration of all hypochlorous acid chemicals in the solution is not to exceed 200 ppm determined as total available chlorine.

40 CFR 180.1054 provides an exemption from the requirement of a tolerance for calcium hypochlorite:

> (a) Calcium hypochlorite is exempted from the requirement of a tolerance when used pre-harvest or postharvest in solution on all raw agricultural commodities.
>
> (b) Calcium hypochlorite is exempted from the requirement of a tolerance in or on grape when used as a fumigant postharvest by means of a chlorine generator pad.

The Food and Drug Administration (FDA) regulations (21 CFR Part 178) permit the use of sanitizing solutions containing sodium hypochlorite on food processing equipment and food contact surfaces. The active ingredients in these solutions are the chlorine oxidants hypochlorous acid, hypochlorite ion and free chlorine:

> The following provisions must be followed:
>
> 1) Equipment or articles sanitized with the solution must be allowed to drain adequately before contact with food.
> 2) Solutions used for sanitizing equipment shall not exceed 200 parts per million (ppm) of available chlorine.

In addition to sanitizing food contact surfaces, cleaning solutions containing the active ingredient hypochlorous acid may be used for sanitizing raw fruits and vegetables during the washing or peeling process. The federal regulations that apply differ slightly from those for sanitizing solutions.

The regulations (21 CFR §173.315 - Chemicals used in washing or to assist in the peeling of fruits and vegetables) specify two conditions for the permitted use of hypochlorite solutions in washing produce:

1) The concentration of sanitizer in the wash water must not exceed 200 ppm hypochlorite.
2) The produce must be rinsed with potable water following the chlorine treatment.
3) Contact times of one minute or greater are typically sufficient to achieve a thorough kill.
4) Any chlorine ingredient that is used for making a sanitizing solution, whether for equipment or raw produce, must be of sufficient purity to be categorized as a food grade substance.

FDA's Food Code (FDA, 2013) states that chemical sanitizers, including chemical sanitizing solutions generated on-site, and other chemical antimicrobials applied to food contact surfaces shall (chapter 7-204.11 of the Food Code):

(A) Meet the requirements specified in 40 CFR 180.940 tolerance exemptions for active and inert ingredients for use in antimicrobial formulations (Food-contact surface sanitizing solutions) or

(B) Meet the requirements as specified in 40 CFR §180.2020 pesticide chemicals not requiring a tolerance or exemption from tolerance-non-food determinations.

The criteria for chemicals for washing, treatment, storage and processing fruits and vegetable are stated in chapter 7-204.12 of the Food Code:

(A) Chemicals*, including those generated on-site, used to wash or peel raw, whole fruits and vegetables shall:

(2) Be generally recognized as safe (GRAS) for this intended use, or

(3) Be the subject of an effective food contact notification for this intended use (only effective for the manufacturer or supplier identified in the notification), and

(4) Meet the requirements in 40 CFR 156, Labeling Requirements for Pesticide and Devices.

*Neither Hypochlorous acid nor EW is mentioned by name.

The USDA's Food Safety and Inspection Service Directive 7120.1 "Safe and Suitable Ingredients Used in the Production of Meat and Poultry Products", has approved the use of electrolytically generated hypochlorous acid as a food additive for use on meat and poultry products. It is allowed for use on red meat carcasses down to a quarter of a carcass, whole or eviscerated poultry carcasses, in water used in meat and poultry processing, in poultry chiller water, for reprocessing contaminated poultry carcasses, on giblets and salvaged parts, and on beef primal cuts of beef. Depending on the product sanitized from 5 to 50 ppm free available chlorine can be used.

USDA's "Regulations Governing the Voluntary Grading of Shell Eggs" explains the minimum facility and operating requirements for shell egg grading and packing plants regarding shell egg cleaning operations. This includes specific temperature requirements for washing and rinsing eggs as well as the chlorine sanitizer that will be used (USDA, 2008).

Action of the Substance:

This solution is generated by the electrolysis of a diluted water-sodium chloride solution passing through on electrolysis chamber. This electrolytic process facilitates the conversion of chloride ions and water molecules into chlorine oxidants (chlorine gas, hypochlorous acid, and hypochlorite ion) within the anode chamber. At an acidic to neutral pH, the predominant chemical species is hypochlorous acid (HOCl) with a high oxidation reduction potential (ORP) of ≥1,000 mV (Guentzel et al., 2008). The effectiveness of hypochlorous acid as an active sanitizing agent is determined in large part by the pH. Hypochlorous acid exists interchangeably with other chlorine species, including chlorine, hydrogen chloride (aqueous and gaseous) and hypochlorite (Fig 2). The pH is believed to reduce bacterial growth and make the bacterial cells more sensitive to active chlorine. Active chlorine compounds can destroy the membranes of microorganisms, but other modes of chlorine action (e.g., decarboxylation of amino acids, reactions with nucleic acids, and unbalanced metabolism after the destruction of key enzymes) have been reported as well (Huang et al., 2008; Hricova et al., 2008; Guentzel et al., 2008; Young and Setlow, 2003).

In Huang's et al., 2008 review of the scientific literature, the authors suggested that hypochlorous acid penetrates cell membranes and produces hydroxyl radicals, which exert their antimicrobial activity through the oxidation of key metabolic systems. Hricova et al., 2008 reported that researchers suggested that the high ORP is the determining factor for the antimicrobial activity of acidic EW. The ORP of a solution is an indicator of its ability to oxidize or reduce, with higher ORP values corresponding to greater oxidizing strength. The high ORP and low pH of acidic EW seems to act synergistically with hypochlorous acid to inactivate microorganisms.

Combinations of the Substance:

Dilute mixtures of chlorine based compounds and water are very common and cost effective for use in methods for sanitizing equipment in food processing operations. Chlorine materials on the National Organic Program's (NOP) National List of Allowed and Prohibited Substances have been approved for a variety of uses as an algicide, disinfectant, sanitizer and others. Chlorine based methods are commonly used for equipment cleaning.

The chlorine containing substances are:

- Calcium hypochlorite, 7 CFR § 205.601(a)(2)(i), 205.603(a)(7)(i), and 205.605(b);
- Chlorine dioxide, 7 CFR § 205.601(a)(2)(ii), 205.603(a)(7)(ii), and 205.605(b);
- Sodium hypochlorite, 7 CFR §205.601(a)(2)(iii), 205.603(a)(7)(iii), and 205.605(b); and
- Acidified sodium chlorite, 7 CFR§ 205.605(b).

When water is added to these chlorine compounds the resulting reaction produces hypochlorous acid, hypochlorite ion and chlorine (Fig 2). At a pH of 6.5, 95% of the chlorine is in the hypochlorous acid form; maintaining the water pH at this range provides the greatest sanitizing effect. In a processing plant environment, sanitizers are used in the presence of organic matter, such as debris, soils and microorganisms present, all of which reduce the sanitizer efficacy. The solutions need to be monitored and refreshed to maintain desired bactericidal activity. Also, NOP regulations restrict the residual chlorine levels in the water at the discharge or effluent point to the maximum residual disinfectant limit under the Safe Drinking Water Act, (40 CFR Part 142) currently established by the Environmental Protection Agency (EPA) at 4 mg/L (ppm) for chlorine (NOP 5026-The use of Chlorine Materials in Organic Production and Handling).

Status

Historic Use:

In their review of the scientific literature, Hricova et al., 2008 reported that EW was originally developed in Russia, where it has been used for water decontamination, water regeneration, and disinfection in medical institutions. Since the 1980s, EW also has been used in Japan. One of the first applications of EW was the sterilization of medical instruments in hospitals. In the late 1990s, food safety concerns regarding foodborne pathogens found raw produce have caused researchers to look at and evaluate alternative sanitizers such as EW. With recent improvements in technology and the availability of better equipment, EW has gained popularity as an effective and environmentally friendly sanitizer for the food industry.

Acidic EW is generally recognized as safe and reported effective against pathogens on produce. It has been shown to be an economically favorable alternative to chlorinated water. Other advantages include: (1) EW is produced on site by the electrolysis of sodium chloride solution with the help of an electrolysis flow generator, and 2) there is no need for handling or storage of potentially dangerous chlorine materials in liquid or solid form (Stopforth et al., 2008).

Organic Foods Production Act, USDA Final Rule:

Known as electrolyzed water, hypochlorous acid is a synthetic substance not found on the National List of Allowed and Prohibited Substances (§7 CFR 205.600-606) for production and handling of organic products. This solution is generated by the electrolysis of a diluted water-sodium chloride solution passing through on electrolysis chamber (Fig 1). This electrolytic process facilitates the conversion of chloride ions and water molecules into chlorine oxidants (chlorine gas, hypochlorous acid, and hypochlorite ion). When used in accordance with good agricultural practice, electrolyzed water can be used as an effective and environmentally friendly sanitizing solution.

International

- Canada - Canadian General Standards Board Permitted Substances List – CAN/CGSB-32.311-2006 Amended June 2011

http://www.tpsgc-pwgsc.gc.ca/ongc-cgsb/programme-program/normes-standards/internet/bio-org/permises-permitted-eng.html

Neither Hypochlorous acid (Sanitizer) nor Electrolyzed water is on the permitted substance list for processing and handling of organic food.

- CODEX Alimentarius Commission, Guidelines for the Production, Processing, Labelling and Marketing of Organically Produced Foods (GL 32-1999)

Neither Hypochlorous acid (Sanitizer) nor Electrolyzed water is on the permitted substance list for processing and handling of organic food.

- European Economic Community (EEC) Council Regulation, EC No. 834/2007 and 889/2008

Neither Hypochlorous acid (Sanitizer) nor Electrolyzed water is on the permitted substance list for processing and handling of organic food.

- Japan Agricultural Standard (JAS) for Organic Production—

Japanese Agricultural Standard for Organic Processed Foods (Notification No. 1606 of the Ministry of Agriculture, Forestry and Fisheries of October 27, 2005).

Foods additive list for processing and handling of organic food.

Hypochlorous acid water- Limited to be used for processed foods of plant origin (limited to those made by electrolysis of saltwater), animal intestine as disinfection, or egg as cleansing

- The International Federation of Organic Agriculture Movements (IFOAM)

http://www.organic-standards.Info/en/documents

Organic processing restricts disinfecting and sanitizing substances that may come in contact with organic products to water and substances that are on (a) list(s) referenced by the standard. Such lists are based on lists and/or criteria in international organic standards. In cases where these substances are ineffective and others must be used, organic processing ensures that these other substances do not come into contact with any organic products.

Neither Hypochlorous acid (Sanitizer) nor Electrolyzed water is on the permitted substance list for processing and handling of organic food.

Evaluation Questions for Substances to be used in Organic Handling

Evaluation Question #1: Describe the most prevalent processes used to manufacture or formulate the petitioned substance. Further, describe any chemical change that may occur during manufacture or formulation of the petitioned substance when this substance is extracted from naturally occurring plant, animal, or mineral sources (7 U.S.C. § 6502 (21)).

Chlorine gas dissolves in water to form a mixture of hypochlorous acid (HOCl) and hydrochloric acid (HCl). In aqueous solution, hypochlorous acid partially dissociates to form hypochlorite ions (OCl^-). An ion is an atom or molecule with an unequal number of protons and electrons giving the atom or molecule a net positive or negative electrical charge. Chloric acid ($HClO_3$) also forms from hypochlorous acid, but rapidly dissociates to chlorite ions (ClO_3^-). Salt formation (neutralization of an acid and a base) stabilizes ions and acids. Salts of hypochlorous acid are called hypochlorites. Salts of chlorous acid are called chlorites.

Sodium hypochlorite and calcium hypochlorite are hypochlorous acid salts approved for use as algicides, disinfectants and sanitizers in organic production and handling. However, for pre-harvest use (food sanitation) and uses where food may contact a disinfected or sanitized surface the total combined concentration of hypochlorous acid and hypochlorite ions permitted for organic production and handling may not exceed 4 ppm (NOP 5026 "Guidance, the use of Chlorine Materials in Organic Production and Handling."). Both calcium and sodium hypochlorite may be used in the treatment of seeds for organic edible sprout production at the level indicated on an environmental protection agency approved label for this application, which is generally 20,000 ppm (§205.601(a)(2)(i and iii), §205.603(a)(7)(i and iii), (§205.605(b)). Two other chlorine containing compounds, acidified sodium chlorite and chlorine dioxide are also approved for disinfection and sanitation purposes in organic food production and handling. Hypochlorous acid has not been reviewed by the NOSB for use in organic production and handling (NOP, 2014).

Sodium chloride (Salt—table salt) is an abundant mineral. Salt comes from mines or is processed from ocean or mineral rich spring water. Salt (NaCl) occurs naturally in foods. In moderate amounts it is necessary to support the metabolisms of all living organisms. When sodium chloride is dissolved in water, it chemically separates into positively charged sodium ions (Na^+) and negatively charged chloride ions (Cl^-). The separation is particularly easy because water has a very high dielectric constant. The hydration numbers for Na^+ and Cl^- respectively are 3 and 2. The hydration number of an ion is the number of water molecules that have lost their translational freedom because of their association with the ion. With a direct electric current imposed on the brine solution, positive ions migrate toward the negative pole (commonly called the cathode—cathodic pole) of a power source and negative ions migrate toward the positive pole (commonly called the anode—anodic pole). This process is called electrolysis. Electrolysis is simply a chemical method using electric current to drive an otherwise non-spontaneous reaction. Electrolysis produces much higher concentrations of hypochlorite ions (hypochlorous acid) in the solution.

The chlorine industry which produced over 72.8 million tons of chlorine in 2014 commonly uses the electrolytic properties of sodium chloride (NaCl) in solution (brine) to manufacture chlorine (European Commission, 2014). Brine electrolysis produces chlorine gas which both bubbles from the brine solution when the pH is low and dissolves in water rapidly forming hypochlorous acid when the pH is high. Inserting a semi-permeable membrane (perfluoracetate film) between the two electrodes of an electrolysis device permits further concentration of the products of this reaction. During membrane mediated electrolysis of brine at pH 4-7, hypochlorous acid (electrolyzed water) forms at the anode (negatively charged hypochlorite ions in aqueous solution) and sodium hydroxide forms at the cathode. Once concentrated hypochlorous acid and sodium hydroxide solutions may be removed from the electrolysis system for use and replaced by fresh brine (Fig 1).

Evaluation Question #2: Discuss whether the petitioned substance is formulated or manufactured by a chemical process, or created by naturally occurring biological processes (7 U.S.C. § 6502 (21)). Discuss whether the petitioned substance is derived from an agricultural source.

Hypochlorous acid as described for the petitioned use is a synthetic substance. The chemical process that is used to produce hypochlorous acid from brine is called electrolysis. Salt (Sodium chloride) and water used to make brine both occur naturally. Electrolysis is the use of direct electric current to drive a chemical reaction that would not otherwise occur naturally or spontaneously. A schematic apparatus for the production of electrolyzed water is provided (Fig 1). The formula based depiction of hypochlorous acid production that is demonstrated by this apparatus is provided in Table 1 (Huang et al., 2008).

Evaluation Question #3: If the substance is a synthetic substance, provide a list of nonsynthetic or natural source(s) of the petitioned substance (7 CFR § 205.600 (b) (1)).

There are no commercially available sources of natural hypochlorous acid. However, many animals have a set of phagocytic cells that are protective against invasion of pathogenic bacteria and employ various enzymatically mediated mechanisms including hypochlorous acid to accomplish bacterial killing (Nakayasu et al., 2005). An example of an enzymatically mediated adaptive immune response is the myeloperoxidase secreted by human neutrophils. Myeloperoxidase which appears to be conserved and present in other animal species uses hydrogen peroxide and chloride present during the adaptive immune response to produce hypochlorous acid. Hypochlorous acid binds to bacterial membranes, modifying their proteins, increasing their permeability and subsequently killing the bacteria (Prokopowicz et al., 2010). It has also been shown that purified human myeloperoxidase is effective *in vitro* in killing bacteria at neutral pH by catalyzing the production hypochlorous acid in the presence of hydrogen peroxide and chloride (Sips and Hamers, 1981).

It was first shown that synthetically produced hypochlorous acid contained in electrolyzed water with a free chlorine concentration of 10 to 80 ppm was effective in killing *Stapylococcus aureus*, *Escherichia coli* and *Salmonella spp.* on laboratory and kitchen surfaces (Shimizu and Hurusawa, 1992; Venkitanarayanan et al., 1999).

Evaluation Question #4: Specify whether the petitioned substance is categorized as generally recognized as safe (GRAS) when used according to FDA's good manufacturing practices (7 CFR § 205.600 (b)(5)). If not categorized as GRAS, describe the regulatory status.

Hypochlorous acid is not currently listed in 21 CFR 184, 184 or 186 as generally recognized as safe. However, only two entries for hypochlorous acid are listed in the US Food and Drug Administration's (FDA) inventory of effective food contact substance (FCS) notifications. This database lists effective premarket notifications in the United States for food contact substances database that have been demonstrated to be safe for their intended use. Under section 409(h)(2)(C) of the Federal Food, Drug, and Cosmetic Act (21 U.S.C. 348 (h)(2)(C)) a food contact substance notification (FCN) is only effective for the manufacturer or supplier identified in the notification. Persons who market a FCS based on an effective notification must be able to demonstrate that the notification is effective for their food contact substance. All persons who purchase a food contact substance manufactured or supplied by a manufacturer or supplier identified in an effective notification may rely on that notification to legally market or use the food contact substance for the use that is the subject of the notification, consistent with any limitations in that notification.

1) FCN No. 1176

    HSP USA, LLC (According to Section 409(h)(1)(C) of the Federal Food, Drug, and Cosmetic Act, food contact substance notifications (FCNs) are effective only for the listed manufacturer and its customers. Other manufacturers must submit their own FCN for the same food contact substance and intended use.)

    Food Contact Substance: Hypochlorous acid (CAS Reg. No. 7790-92-3)

    Notifier: HSP USA, LLC, Manufacturer: HSP USA, LLC

    Intended Use: For use as an antimicrobial agent in a solution for the re-hydrating of fresh fruits and vegetables including leafy green vegetables.

    Limitations/Specifications*: The concentration of available free chlorine will be limited to 60 ppm, and the food contact substance (FCS) will be replaced after use if the concentration falls below 25 ppm available free chlorine. Leafy greens or other uncut fruits and vegetables will be soaked in a 20 gallon solution of the FCS in five pound loads for a minimum of five minutes and a maximum of ten minutes. The FCS solution will drain off of the fresh produce for a minimum of ten minutes before the produce is used for display or prepared for consumption.

FDA Decision: Finding of No Significant Impact (FONSI)

Effective Date: Aug 15, 2012

2) FCN No. 1470

Sterilox Food Safety/Div. of PuriCore (According to Section 409(h)(1)(C) of the Federal Food, Drug, and Cosmetic Act, food contact substance notifications (FCNs) are effective only for the listed manufacturer and its customers. Other manufacturers must submit their own FCN for the same food contact substance and intended use.)

Food Contact Substance: Hypochlorous acid (CAS Reg. No. 7790-92-3) electrolytically generated in dilute solution.

REPLACES FCN 692

Notifier: Sterilox Food Safety/Div. of PuriCore, Manufacturer: Sterilox Food Safety/Div. of PuriCore

Intended Use: For use as an antimicrobial agent in solutions used to re-hydrate fresh and fresh-cut fruits and vegetables.

Limitations/Specifications*: On-site generation of the FCS solution will occur at least every 24 hours. The concentration of available free chlorine will not exceed 60 ppm, and the FCS solution will be replaced if the concentration falls below 25 ppm available free chlorine. Fresh and fresh-cut produce may be treated with the FCS solution by soaking for 90 seconds to 10 minutes or by spraying. After treatment, the produce will be allowed to drain for no less than 10 minutes before it is placed on display or prepared for consumption.

FDA Decision: Finding of No Significant Impact (FONSI)

Effective Date: Jan 1, 2015

The FDA Food Code describes the generation of hypochlorous acid (electrolyzed water, electro chemically activated water, elector activated water) through on-site technology and refers the user of these technologies to seek efficacy data from the equipment manufacturers, since the EPA does not require registration for this type of equipment (FDA, 2013).

Evaluation Question #5: Describe whether the primary technical function or purpose of the petitioned substance is a preservative. If so, provide a detailed description of its mechanism as a preservative (7 CFR § 205.600 (b)(4)).

The primary technical function of hypochlorous acid is disinfection of food and food contact surfaces used in the production and handling of food. A disinfectant is a chemical agent that helps eliminate undesirable microorganisms from inanimate environmental surfaces. It is similar to an antiseptic, except that antiseptics are used on living tissue. A sanitizer is a chemical or physical agent that reduces microorganism contamination levels on inanimate environmental surfaces (Martinez, 2009). Hypochlorous acid is also used for disinfecting foods such as meat, eggs or fresh produce preventing bacterial and fungal growth and extending shelf life. A biostatic agent inhibits the growth of microorganisms (Martinez, 2009). The desirable effect of disinfectants on the sensory properties of fresh-cut vegetables is preserving quality and slowing down deterioration. Hypochlorous acid at a concentration of 50 ppm did not significantly affect quality characteristics such as color and general appearance as well as visual quality of fresh-cut lettuce and carrots. However, when the concentration was increased to 240 ppm, it caused detrimental effects on fresh-cut lettuce resembling leaf burn despite showing a significantly higher reduction of E. coli O157:H7 (Gil et al., 2015). A study of California consumers' attitudes toward organically grown lettuce indicated that the most desirable quality attributes irrespective of production and handling methods are freshness, value, free of insects, and safe for workers (Wolf et al., 2002).

Evaluation Question #6: Describe whether the petitioned substance will be used primarily to recreate or improve flavors, colors, textures, or nutritive values lost in processing (except when required by law) and how the substance recreates or improves any of these food/feed characteristics (7 CFR § 205.600 (b)(4)).

Hypochlorous acid is not a flavoring agent, a colorant, a texturizer or a nutritional supplement. Its technical function is primarily as a disinfectant of food and food contact surfaces. It can be added to solutions used for washing or spraying food products to reduce microbial contamination consisting of bacteria and fungi that cause spoilage.

Evaluation Question #7: Describe any effect or potential effect on the nutritional quality of the food or feed when the petitioned substance is used (7 CFR § 205.600 (b)(3)).

Red radish seeds infected with *Listeria monocytogenes* responded differently to decontamination treatment with 20,000 ppm calcium hypochlorite, 50 and 100 ppm chlorinated water, acidic electrolyzed water (60-80 ppm hypochlorous acid), low-alkaline electrolyzed water (60-80 ppm hypochlorous acid), and ozonated water compared to distilled water treated control seeds. Treatments with 20,000 ppm calcium hypochlorite, acidic and low-alkaline electrolyzed water were more effective than treatments with chlorinated water and ozonated water. Immersion in 20,000 ppm calcium hypochlorite resulted in a 1000 fold microbial reduction, while treatments with acidic and low-alkaline electrolyzed water reduced aerobic plate count (APC) by 1000 fold and *L. monocytogenes* counts by 100 fold. After sprouting, APC and *L. monocytogenes* counts on seeds treated with 20,000 ppm calcium hypochlorite, acidic and low-alkaline electrolyzed water were significantly lower than the control. The germination rate ranged from 93.5% to 97.7% except for 20,000 ppm calcium hypochlorite (from 82.3% to 84.8%) after 48 hours (Kim et al., 2010).

Naturally contaminated shelled peanuts with aflatoxin B1 levels greater than 34.8 parts per billion (ppb) treated with hypochlorous acid at pH 3.0 showed a significant reduction in aflatoxin level after treatment (>5 ppb): an 85% decrease. Aflatoxin B1 is a powerful toxin produced by *Aspergillus spp*. mold. It is known to contaminate peanuts and is potentially carcinogenic. Protein, lipid and carbohydrate levels did not significantly leading to the conclusions that treatment with hypochlorous acid reduced aflatoxin B1 levels but did not affect peanut nutrition (Zhang et al., 2012).

Drying is traditionally used to preserve fish. However, bacteria present during the drying process can affect both nutrition and organoleptic properties of the dried products. Drying carp filets with thymol and carvacrol (oil of oregano) after treatment with electrolyzed water significantly reduced fat oxidation, protein degradation and improved the overall organoleptic and flavor profile of the product when compared to no treatment. This process had a greater antimicrobial and antioxidant effect than other treatments, and resulted in good preservation of carp fillets during the drying process. (Mahmoud et al., 2006). However, National Organic Program regulations do not currently allow for the certification of fish (7 CFR Part 205).

The pesticides acephate, omethoate and dimethyl dichlorovinyl phosphate are commonly used as broad-spectrum insecticides in pest control for conventional agriculture and high-residual levels are frequently detected in vegetables. The use of these pesticides is prohibited in organic production and handling. Electrolyzed water (70 ppm chlorine) can effectively reduce the concentration of acephate, omethoate and dimethyl dichlorovinyl phosphate residues on fresh spinach, cabbage and leek more effectively than tap water alone. Reduction ranged from 46% to 74%. It may be possible to mask the use of some pesticides in organic production with the use of electrolyzed water. In addition, electrolyzed water did not affect the contents of ascorbic acid (vitamin C) suggesting that using electrolyzed water to wash vegetables would not result in loss of nutrition (Hao et al., 2011).

Evaluation Question #8: List any reported residues of heavy metals or other contaminants in excess of FDA tolerances that are present or have been reported in the petitioned substance (7 CFR § 205.600 (b)(5)).

It is well known that chlorine rapidly hydrolyzes to near completion in water forming hypochlorous acid (HOCl), hypochlorite (OCl-) and Cl_2. The relative concentration of these species is pH dependent. At pH 6-7, hypochlorous acid is the dominant species at 90%. At pH 8, hypochlorite is the major species. Since it is produced at pH 6-7 and concentrated by membrane mediate electrolysis of brine, electrolyzed water contains mostly hydrochlorous acid at concentrations 60-80 ppm (Fukayama et al., 1986). Furthermore, of the three aqueous species, hypochlorous acid is the primary bactericidal agent in aqueous chlorine, possessing approximately 80% of the germicidal potency of hypochlorite (White, 1972). Thus, higher level total chlorine requirements for the use of sodium or calcium hypochlorite in disinfection or sanitation may not be applicable to the use of hypochlorous acid since its germicidal capacity is greater at a lower total chlorine concentration.

Hypochlorous acid at low pH and high concentration is unstable and decomposes to halogenated chemical species: chlorine, chlorite, chlorate and trihalomethanes (THMs) including: bromodichloromethane, dibromochloromethane and bromoform) and oxygen (EPA, 2014).

Hypochlorous acid is electrophilic and can react with organic compounds such as those present in agricultural commodities and products. Chlorine in hypochlorous acid is likely to combine with an electron pair in ammonia, amines, phenols and other aromatics present in organic substrates. Substrates can include carbohydrates, lipids and proteins. Radiolabeled chlorine was followed in during an immersion process for shrimp in 150 ppm hypochlorous acid. It was found that 1.5% (2.25 ppm) of the labeled chlorine was found in the edible portion of the shrimp. Chlorine from hypochlorous acid, usually at concentrations at or above 200 ppm has been found to bind to lipid, proteins and carbohydrates of immersed meat, poultry and fish although at low levels. At higher chlorine treatment levels (>200 ppm) there is potential for the formation of chloroform at very low levels in meat products (Fukayama et al., 1986).

Contaminants listed in the US Food and Drug Administration's Guidance for Industry: Action Levels for Poisonous or Deleterious Substances in Human Food and Animal Feed are unlikely to be found in hypochlorous acid since it is the electrolysis product of two generally recognized as safe materials, salt and water.

Evaluation Question #9: Discuss and summarize findings on whether the manufacture and use of the petitioned substance may be harmful to the environment or biodiversity (7 U.S.C. § 6517 (c) (1) (A) (i) and 7 U.S.C. § 6517 (c) (2) (A) (i)).

Chlorine is widely used to disinfect drinking water and wastewater prior to discharge, and when used appropriately, its role in preventing the spread of waterborne infectious diseases is well established. Low levels of residual chlorine, however, can be harmful to aquatic life if drinking water or heavily chlorinated waste-water is discharged into the environment. Australian cladocerans are small crustaceans similar to North American daphnia. They are particularly sensitive to chlorine in their environment. At pH 7.5-8.3 where a high proportion of aqueous chlorine is expected to be hypochlorite, the lowest concentration of total chlorine in a one hour exposure to have an effect on them was 0.28 ppm. The eastern king prawn is endemic to

Australia coastal waters. In similar chlorine toxicity studies on these crustaceans in saltwater the lowest effective concentration was 0.12 ppm (Manning et al., 1996). Although hypochlorous acid would be more reactive for crustaceans at pH below 7.0, the molecular form of aqueous chlorine in their native condition is hypochlorite.

Chlorine gas was first registered in the US in 1948, as a disinfectant for swimming pool, drinking water, cooling towers and sewage systems. In 1991, it was declared exempt from the requirement for a tolerance except for use on raw agricultural commodities because measurable residues were not expected. Hypochlorous acid, one of the two chlorine hydrolysis products is an oxidizing agent having a sanitizing effect on organic and inorganic contaminants. When treated effluent is released into receiving waters, free residual chlorine dissipates rapidly with a half-life of 1.3 to 5 hours. The ultimate fate of chlorine containing effluent is site specific and depends on factors such as the chemical constituents of their receiving waters, their temperature, the dilution ratio and the intensity of sunlight (EPA, 1999).

In studies with lithium chloride, which forms hypochlorous acid in aqueous solutions at $pH < 7.0$, toxicity to birds was minimal on a sub-acute dietary basis. However, hypochlorous acid was found to be very toxic to fish and freshwater invertebrates. Levels of concern were 0.009 ppm for aquatic invertebrates, 0.023 ppm for freshwater fish and 0.013 ppm for estuarine organisms. Levels for endangered species were 0.00085 ppm for aquatic invertebrates, 0.0023 ppm for freshwater fish and 0.0013 for estuarine invertebrates (EPA, 1999).

Diluted aqueous solution of hypochlorous acid decomposes very slowly in the dark but more rapidly in the presence of light, particularly rapidly in full sun light, by producing hydrogen chloride and oxygen. Some chlorine and chloric acid may also develop. Chlorine released into the environment is distributed into water and preferably air. In water and in atmosphere chlorine/hypochlorite undergoes photolysis with an estimated half-life of 1-4 hours, depending on the time of the day. In natural water, in the presence of organic or inorganic compounds, the free available chlorine immediately reacts forming various chlorinated by-products e.g. chloramines and chloromethanes which are mainly distributed to the hydrosphere, but are also able to transfer to some extent to the atmosphere depending on their intrinsic properties. A potential for bioaccumulation or bioconcentration of active chlorine species can be disregarded, because of their water solubility and their high reactivity.

<u>Evaluation Question #10:</u> Describe and summarize any reported effects upon human health from use of the petitioned substance (7 U.S.C. § 6517 (c) (1) (A) (i), 7 U.S.C. § 6517 (c) (2) (A) (i)) and 7 U.S.C. § 6518 (m) (4)).

In general, hypochlorous acid at pH 6.5-7.5 is safer to use than other chlorine containing disinfectants. The concentration of chlorine present in electrolyzed water is usually over ten thousand times less than household bleach. There is also the advantage of its production on site, alleviating the need to transport dangerous material. Chlorine in the form of hypochlorous acid is one of the most effective disinfectant and sanitizer for reduction and removal of foodborne pathogens.

Chlorine bleach, or hypochlorous acid, is the most reactive two-electron oxidant produced in appreciable amounts in our bodies. It is very toxic and oxidizes cell membranes. Neutrophils are the main source of hypochlorous acid. The human innate immune system uses hypochlorous acid to fight infection but also directs it against host tissue in inflammatory diseases (Kettle et al., 2013). Hungarian obstetrician Dr Ignaz Phillip Semmelweis (July 1, 1818–August 13, 1865) is attributed with recognizing the cause of puerperal sepsis (child bed fever) and introducing chlorine handwashing for the first time to prevent this disease. The medical term used to describe the chlorine hand microbicide developed by Semmelweis was *chlorina liquida* (Noakes et al., 2007). It was hypochlorous acid. Hypochlorous acid is reactive with a wide variety of organic substances including proteins, carbohydrates and lipid (Deborde and Gunten, 2008).

Neutrophils are highly specialized for their primary function, the phagocytosis and destruction of microorganisms. Microorganisms in blood or tissue are coated with opsonins (generally complement and/or antibody). The coated microorganisms bind to specific receptors on the surface of the neutrophils, phagocytized incorporating the microorganism into an intracellular vesicle (phagocytosis). Hydrogen peroxide is first secreted from membrane bound respiratory enzymes and floods the vesicle. A neutrophil enzyme, myeloperoxidase (MPO) is also released into the vesicle with the hydrogen peroxide (H_2O_2), as well as a halide, particularly chloride. The primary product of the MPO-H_2O_2-chloride system is hypochlorous acid. Subsequent formation of chlorine, chloramines, hydroxyl radicals, singlet oxygen, and ozone has also been proposed. These same toxic agents can be released to the outside of the cell, where they may attack normal tissue and thus contribute to the pathogenesis of disease, e.g. atherosclerosis, renal injury, carcinogenesis, lung injury, multiple sclerosis, cystic fibrosis, Alzheimer's disease, brain infarction and Parkinson's disease. The MPO system, *vis â vis* hypochlorous acid plays an important role in the microbiocidal activity of phagocytes including monocytes and neutrophils (Sips and Hamers, 1981; Klebanoff, 2005). Antigens are label by the action of hypochlorous acid, making them better substrates for immune presentation and ultimately for the production of antibodies in the antibody mediated immune response (Prokopowicz et al., 2012).

Although the ingestion of chlorine gas is unlikely, solutions of chlorine may pose hazard by this route of exposure (OECD, 2003). Poisoning incidents involving accidental ingestion of household bleach, chlorine has caused a burning sensation in the mouth and throat, irritation to the digestive tract and stomach, and vomiting. Exposure to chlorine gas causes effects ranging from bronchitis, asthma and swelling of the lungs, to headaches, heart disease and meningitis. Acute exposure causes more severe respiratory and lung effects, and can result in fatalities. (EPA, 1999). Available chlorine is readily absorbed via oral route and distributed into plasma, bone marrow, testis, skin, kidney and lung. Only ca. 50% is excreted mainly with the urine followed by excretion with feces. HOCl is not enzymatically metabolized and its (bio) transformation readily occurs through direct reactions with organic compounds or with other chemicals present in the cellular environment, leading to the formation of chlorinated organic compounds possessing their own inherent toxicity (OECD, 2003). More often, however, the effects are not permanent; complete and rapid recovery generally occurs with treatment (EPA, 1999).

Chlorine disinfectants have been shown to cause occupational dermatitis or irritation of the skin. People who are asthmatic or allergic to chlorine may be at high risk for adverse reactions after inhaling or ingesting chlorine, for example, after drinking treated water (EPA, 1999). No information is available on any potential systemic toxicity that can be caused by dermal route as no dermal acute toxicity studies are available for both chlorine or hypochlorite salts solutions. It can be expected to be low considering the low acute systemic toxicity by the oral route (OECD, 2003).

Pursuant to 40 CFR §180.1095, Chlorine gas is exempt from the requirement of a tolerance when used pre- or postharvest on all raw agricultural commodities. Use of chlorine in food processing water systems to prevent decay of raw agricultural commodities may result in residues on treated produce; however, finite residues or residues above naturally occurring background levels are not expected. Similarly, if livestock ingest chlorine treated water, finite residues or residues above background levels are not expected to occur in meat, milk or eggs. Chlorine gas used as a food contact surface sanitizer on food, meat or poultry processing premises and equipment is under FDA's regulatory purview. EPA regulates contaminants in drinking water under the Safe Drinking Water Act (SDWA). The Office of Drinking Water has established a

Maximum Residual Disinfectant Level (MRDL) of 4 mg/L for chlorine. An MRDL is an enforceable Federal Standard (EPA, 1999).

Risk to the public is not anticipated from consuming food or water treated with chlorine. Although residues may remain on fruits and vegetables as a result of their treatment with chlorine solution, these residues are exempt from tolerance requirements and are not believed to pose risks. Residues above background levels are not expected in meat, milk or eggs as a result of chlorine use in drinking water. Use of chlorine to sanitize food contact surfaces and food processing equipment presumably does not result in residue of concern in foods (this use is under FDA's jurisdiction). EPA's Office of Drinking Water regulates chlorine in drinking water supplies under the SDWA (EPA, 1999).

Table 3. Disinfection methods with their advantages and disadvantages

Treatment	Advantages	Disadvantages
Sodium hypochlorite Calcium hypochlorite Chlorine dioxide Acidified Sodium Chlorite	Chlorine based disinfectants, very effective at killing most microorganisms including spores. Liquids best used at pH 6.5-7.5.	After use concentration must be less than 4 ppm. Can damage products at high concentrations. Issues with humic acids.
Ozone	Effective disinfectant kills rapidly.	Must be produced on site, harmful to humans. Not approved for organic production and handling.
Irradiation	Very effective disinfectant.	May affect sensory qualities of products, harmful to humans. Ionizing radiation is not permitted in organic production.
Hydrogen Peroxide (H_2O_2)	Potential as disinfectant.	Affects sensory qualities of some products, harmful to humans and not applicable to all products.
Organic Acids	Effective alone or in combination with other sanitizers, simple products such as lemon juice, or vinegar may be used.	Not useful for all products, may have adverse effects on sensory qualities, may lead to loss of germination percentage when used on seeds.
Essential Oils	Most effective for gram positive bacteria.	Gram negative bacteria are more resistant, adverse sensory effects.
High Temperatures	Successful disinfection method.	Not applicable to all products consumed raw.
Biocontrol and non-thermal process	Not well tested in fruit and vegetable products.	High cost, not enough research.

Cooper et al., 2007

A no-observed-adverse-effect level (NOAEL) of 950 ppm available chlorine (59.5 milligram (mg)/kilogram (kg) body weight (bw)/day) can be derived from a 13-week rat study with sodium hypochlorite in drinking water. A NOAEL of 14 mg/kg bw/day for rats and a NOAEL of 22.5 mg/kg bw/day for mice can be derived from a two year study with sodium hypochlorite in drinking water. No evidence of treatment related carcinogenicity was observed in mice and rats exposed by inhalation to chlorine and orally to sodium hypochlorite, but some equivocal results were reported for female rats by oral route. For human cancer no association between chlorine exposure and tumor incidence was observed (OECD, 2003).

Evaluation Question #11: Describe any alternative practices that would make the use of the petitioned substance unnecessary (7 U.S.C. § 6518 (m) (6)).

Chlorine in different forms has been traditionally preferred for disinfection. There are a few alternatives such as ozone or other gas treatments, UV irradiation, different organic acids, essential oils and mild heating (Cooper et al., 2007). Heat is a reliable method eliminating contamination for some products, e.g. after washing the article can be dried at 80^{o}C or higher for 2 hours or more to remove contamination. Microwave treatment or infrared radiation can also be used to heat the material. Ultraviolet light produces a maximum bactericidal effect at 240-280 nm. It is useful for non-porous surface, but has limited use for porous surfaces and is potentially destructive to produce, meat or fish. Pasteurization kills microorganisms, but does not kill bacterial spores (CDC, 2008). Water can be pasteurized prior to use in crisping greens. Some advantages and disadvantages are provided in Table 3. A handler is prohibited from using ionizing radiation in or on agricultural products intended to be sold as "organic." Ionizing radiation cannot be used in or on any ingredients labeled "organic" (7 CFR 205.105; 21 CFR 179.26). Radiation sources such as radiofrequency (microwave) used for heating food (21 CFR 179.30) and ultraviolet for food processing and treatment (21 CFR 179.39) are not ionizing radiation per the US Food and Drug administration definition (21 CFR 176.26).

The safe drinking water act requires that drinking water depending on its source meets specific criteria determining the need for a combination of filtration and treatment with chlorine to remove pathogenic organisms. Chlorine is described in the Safe Drinking Water act as an alternative to filtration. Water can also be filtered through a 0.22 micron or less filter to remove bacteria (CDC, 2008).

Evaluation Question #12: Describe all natural (non-synthetic) substances or products which may be used in place of a petitioned substance (7 U.S.C. § 6517 (c) (1) (A) (ii)). Provide a list of allowed substances that may be used in place of the petitioned substance (7 U.S.C. § 6518 (m) (6)).

Isopropanol (CAS No. 67-63-0) and ethanol (CAS No. 64-17-5) are aliphatic alcohols both permitted substances in organic crop and livestock production. Respectively, as synthetic substances allowed for use as algicides, disinfectants, and sanitizers §205.601(a)(1)(ii) and §205.601(a)(1)(i) in organic crop production and §205.603(a)(1)(ii) and §205.603(a)(1)(i) as in organic livestock production (USDA, 2014a; 2014b). Organically produced ethanol is marketed and available commercially for organic handling. Isopropanol is only available in synthetic form and is not allowed in organic handling. Isopropanol is a high production volume chemical used in many industrial and consumer products as a disinfectant. It does not persist in the environment and has been well characterized in mammalian/human toxicological studies (OECD, 1997).

Sodium and calcium hypochlorite, better known as bleach, are widely used compounds whose chemical and toxicological properties are extensively documented in published literature. These chemicals were first registered for use as pesticides in 1957. Sodium and calcium hypochlorite are chlorinated inorganic disinfectants used to control bacteria, fungi, and slime-forming algae that can cause diseases in people and animals (EPA, 1991, 1992; USDA, 2006a, Ricke et al., 2012). These disinfectants also are used in cleaning irrigation, drinking water, and other water and wastewater systems.

Chlorine dioxide is an antimicrobial disinfectant and pesticide used to control harmful microorganisms including bacteria, viruses, and fungi on inanimate objects and surfaces primarily in indoor environments. It is used as a food disinfectant (e.g., for fruit, vegetables, meat, and poultry), for disinfecting food processing equipment, and treating medical wastes, (EPA, 2003; USDA, 2006a).

Copper sulfate is used as a fungicide and algicide for organic production (USDA, 2011; 2015a). Ethanol is used for disinfection of production tools and surfaces, plant regulation (ripening) and topical disinfection (USDA, 2014b). Hydrogen peroxide is used as an algicide and fungicide in greenhouses and horticultural settings, applied to greenhouse structures and surfaces as well as greenhouse seeds, soils and plants (USDA, 2015b). Ozone gas has been for the treatment of drinking water, as a disinfectant and sanitizer (USDA, 1995; 2002). Peracetic acid is used in food processing and handling is as a sanitizer for food contact surfaces and as a disinfectant for fruits, vegetables, meat, and eggs (USDA, 2000). Phosphoric acid is used in food processing and handling is as a sanitizer for food contact surfaces and as a disinfectant (USDA, 2003). Soaps are used as algicides and demossers in organic crop production (USDA, 2015c).

Sodium carbonate peroxyhydrate is used applications where the use of liquid hydrogen peroxide is impractical. Sodium carbonate peroxyhydrate provides the same oxidative/reductive action of hydrogen peroxide in a solid form making it an easy to use source of hydrogen peroxide for environmental control. Hydrogen peroxide acts as both a chemical oxidant and reducing agent, as a supplier of molecular oxygen (USDA, 2014c).

<u>Evaluation Information #13:</u> Provide a list of organic agricultural products that could be alternatives for the petitioned substance (7 CFR § 205.600 (b) (1)).

Sodium chloride can be used to disinfect surfaces and water at concentrations greater than 10% (Somani et al., 2011). The antimicrobial efficacy of citric acid has been documented against foodborne microorganisms in fluid medium (Ricke et al., 2012). Organic Acids (e.g., acetic acids, ascorbic acid, citric acid, lactic acid, lactates, tartaric acid, malic acid and vinegar) and essential oils have been used as disinfectants (Table 3) with varying amounts off success (Cooper, 2007; Ricke et al., 2012).

Nisin and the bateriocins are bacterial polypeptides produced by the bacterium, *Streptomyces lactis* with antimicrobial properties (Ricke et al., 2012). Although they can be naturally produced, many are produced via recombinant technology. They are prohibited from use in organic production and handling. Nisin was reviewed by the NOSB in 1995 (USDA, 1995).

Egg white lysozyme has also been used as an antimicrobial (Ricke, 2012). Biopreservation with protective bacterial cultures known as spoilers can also be used (Ricke, 2012). Water can be used to rinse surfaces and food. Hot water, near $100^{\circ}C$ will reduce microbial contamination.

References

Abadias, M., Usall, J., Oliveira, M., Alegre, I. and Viñas I. (2008) Efficacy of neutral electrolyzed water (NEW) for reducing microbial contamination on minimally-processed vegetables, International Journal of Food Microbiology, 123, pp. 151-158.

Achiwa, N. and Nishio, T. (2003) The use of electrolyzed water for sanitation control of eggshells and GP Center, Food Sci. Technol. Res., 9:1, pp. 100-103.

Al-Haq, M. M., Sugiyama, L.J. and Isobe, S. (2005) Applications of electrolyzed water in agriculture and food industries, Food Sci. Technol. Res. 11:2, pp.135–150.

Al-Haq, M., Seo, Y., Oshita, S. and Kawagoe, Y. (2002) Disinfection effects of electrolyzed oxidizing water on suppressing fruit rot of pear caused by *Botryosphaeria berengeriana*, Food Research International, 35, pp. 657–664.

Ayebah, B. and Hung, Y.-C. (2005) Electrolyzed water and its corrosiveness on various surface materials commonly found in food processing facilities, Journal of food process engineering, 28:3, pp. 247–264.

Boyette, M. D., Ritchie, D. F., Carballo, S. J., Blankenship, S. M., & Sanders, D. C. (1993). Chlorination and postharvest disease control, Horticultural Technology, 3 ,, pp. 395–400.

Buck, J.W., van Iersel, M.W., Oetting, R.D., and Hung, Y-C. (2003) Evaluation of acidic electrolyzed water for phytotoxic symptoms on foliage and flowers of bedding plants, Crop Protection, 22, pp. 73–77

Centers for Disease Control—CDC (2008) Guideline for Disinfection and Sterilization in Healthcare Facilities, 2008, US Department of Health and Human Services

Cooper, J., Leifert and Niggli, U. (2007) Handbook of Organic Food Safety and Quality, Elsevier

Deborde, M. and von Gunten, U. (2008) Reactions of chlorine with inorganic and organic compounds during water treatment—Kinetics and mechanisms: A critical review, Water Research, 42, pp. 13–51.

Deza, M.A., Araujo, M. and Garrido, M.J. (2003) Inactivation of *Escherichia coli* O157:H7, *Salmonella enteritidis* and *Listeria monocytogenes* on the surface of tomatoes by neutral electrolyzed water, Letters of Applied Microbiology, 37, pp. 482–487.

Deza, M.A., Araujo, M. and Garrido, M.J. (2007) Efficacy of neutral electrolyzed water to inactivate *Escherichia coli*, *Listeria monocytogenes*, *Pseudomonas aeruginosa* and Staphylococcus aureus on plastic and wooden kitchen cutting boards, Journal of Food Protection, 70:1, pp. 102–108.

Eryilmaz, M. and Palabiyik, I.M., (2013) Hypochlorous acid-analytical methods and antimicrobial activity, Tropical J. Pharmaceutical Research, 12:1, pp. 123-126.

European Community (2014) A study on composition and drivers of energy pricesand costs in energy intensive industries: the case of the chemical industry – chlorine, Framework contract no entr/2008/006 lot 4 for the procurement of studies and other supporting services on commission impact assessments and evaluation, Center for European Policy Studies.

Fasenko, G.M., O'Dea Christopher, E.E. and McMullenm L.M. (2009) Spraying hatching eggs with electrolyzed oxidizing water reduces eggshell microbial load without compromising broiler production parameters, Poultry Science, 88, pp. 1121–1127.

Fisher, P. (2009) Water treatments for pathogens and algae, Water Treatment for Pathogens and Algae is a compilation of articles originally published as a twelve-part series in GMPro Magazine in 2008-2009.

Fukayama, M.Y., Tan, H., Wheeler, W.B. and Wei, C-I. (1986) Reactions of Aqueous Chlorine and Chlorine Dioxide with Model Food Compounds, Environmental Health Perspectives, 69, pp. 267-274. Environmental Health Perspectives, Vol. 69, pp. 267-274, 1986.

Gil, MI., Gomez-Lopez, V.M., Hung, Y-C. and Allende, Ana (2015) Potential of Electrolyzed Water as an Alternative Disinfectant Agent in the Fresh-Cut Industry, Food Bioprocess Technol., 8, pp. 1336–1348.

Guentzel, J.L., Lam, K.L., Callan, M.A., Emmons, S.A. and Dunham, V.L. (2008) Reduction of bacteria on spinach, lettuce, and surfaces in food service areas using neutral electrolyzed oxidizing water, Food Microbiology, 25, pp. 36–41.

Hati, S., Mandal, S., Minz, P., Vij, S., Khetra, Y., Singh, B. and Yadav, D. (2012) Electrolyzed oxidized water (EOW): Non-thermal approach for decontamination of food borne microorganisms in food industry, Food and Nutrition Sciences, 3:6, pp. 760-768.

Hricova, D., Stephan, R. and Zweifel. C. (2008) Electrolyzed water and its application in the food industry, Journal of Food Protection, 71:9, pp. 1934–1947.

Huang, Y., Hung, Y., Hsu, S., Huang, Y., and Hwang, D. (2008) Application of electrolyzed water in the food industry, Food Control, 19, pp. 329-345.

Jun, S-Y., Kim, Y-H., Sung, J-M., Jeong, J-W., Moon, K-D., Kwon, J-H. and Lee, Y-K. (2010) Effects of Seed Decontamination Treatments on Germination of Red Radish Seeds during Presoaking, J Korean Soc Food Sci Nutr, 39:10, pp. 1528-1534.

Keskinen, L.A., Burke, A. and Annous, B.A. (2009) Efficacy of chlorine, acidic electrolyzed water and aqueous chlorine dioxide solutions to decontaminate Escherichia coli O157:H7 from lettuce leaves, International Journal of Food Microbiology, 132:2-3, pp. 134-140.

Kettle, A.J., Albrett, A.M., Chapman, A.L., Dickerhof, N., Forbes, L.V., Khalilova, I. and Turner, R. (2014) Measuring chlorine bleach in biology and medicine, Biochimica et Biophysica Acta, 1840, pp. 781–793

Kim, C., Hung, Y-C. and Brackett, R.E. (2000) Efficacy of electrolyzed oxidizing (EO) and chemically modified water on different types of foodborne pathogens, International Journal of Food Microbiology, 61, pp. 199–207.

Klebanff, S. (2005) Myeloperoxidase: friend and foe, Journal of Leukocyte Biology, 77, pp. 598-625.

Len, S.-V., Hung, Y.-C., Chung, D., Anderson, J.L., Erickson, M.C., Morita, K. (2002) Effects of storage conditions and pH on chlorine loss in electrolyzed oxidizing (EO) water, J of Agriculture and Food Chemistry, 50, pp. 209–212.

Mahmoud, B.S.M., Yamazaki, K., Miyashita, K., Kawai, Y., Shin, I-S., and Suzuki, T. (2006) Preservative effect of combined treatment with electrolyzed NaCl solutions and essential oil compounds on carp fillets during convectional air-drying, International Journal of Food Microbiology, 106, pp. 331 – 337.

Manning, T.M., Wilson, S.P. and Chapman, J.C. (1996) Toxicity of Chlorine and Other Chlorinated Compounds to Some Australian Aquatic Organisms, Bull. Environ. Contam. Toxicol., 56, pp. 971-976

Martinez, J.E. (2009) The rotation of disinfectants principle: true or false, Pharmaceutical Technology, 33:2, pp. 58-71.

McGlynn, W. (2013) Guidelines for the Use of Chlorine Bleach as a Sanitizer in Food Processing Operations, Food and Agricultural Products Research and Technology Center, Oklahoma State University, FAPC-116.

Nakayasu, C., Somamoto, T., Hasegawa, S., Yoshitomi, T. and Okanoto, N. (2005) Differential spontaneous killing of human and murine tumour cells by leucocyte subpopulations from peripheral blood leucocytes, Fish & Shellfish Immunology, 19, pp. 115-126.

National Center for Biotechnology Information—NCBI (2015) Hypochlorous Acid, PubChem Compound Database; CID=24341, https://pubchem.ncbi.nlm.nih.gov/compound/24341 (accessed Aug. 9, 2015).

Organization for Economic and Cooperative Development—OECD (1997) Isopropanol, Cooperative chemicals assessment meeting (SIAM) 6, 9-11 June 1997, Screening information dataset.

Organization for Economic and Cooperative Development—OECD (2003) Chlorine. CAS No. 7782-50-5, Cooperative chemicals assessment meeting (SIAM) 16, 27-30 May 2003, Screening information dataset.

Park, E.J., Alexander, E., Taylor, G.A., Costa, R. and Kang, D. H. (2009) The decontaminative effects of acidic electrolyzed water for *Escherichia coli* O157:H7, *Salmonella typhimurium*, and *Listeria monocytogenes* on green onions and tomatoes with differing organic demands, Food Microbiology, 26:4), pp. 386-390.

Pfuntner, A. (2011) Sanitizers and disinfectants: the chemicals of prevention, Food Safety Magazine, 17:4, pp. 16, 18-19, 77.

Prokopowicz, Z., Marcinkiewicz, J., Katz, D.R. and Chain, B.M. (2012) Neutrophil Myeloperoxidase: Soldier and Statesman, Arch. Immunol. Ther. Exp., 60, pp. 43–54.

Prokopowicz, Z.M., Arce, F., Biedron, R. Chiang, C.L.L., Cisek, M., Katz, D. R., Nowakowska, M., Zapotoczny, S. Marcinkiewicz, J. and Chain, B. (2010) Adaptive immunity cross-priming, and the induction of that facilitates antigen processing, hypochlorous acid: a natural adjuvant, J. Immunol., 184, pp. 824-835.

Ricke, S.C., van Loo, E.J., Johnson, M.G., and O'Bryan, C.A. (2012) Organic meat production and processing, John Wiley and Sons, Ames, Iowa

Satywali, Y., van de Wiele, T., Saveyn, H., van der Meeren, P. and Verstraete, W. (2007) Electrolytic reduction improves treatability of humic acids containing water streams, J. Chem Technol. Biotechnol., 82, pp. 730–737.

Shimizu, Y. and Hurusawa, T. (1992) Antiviral, antibacterial and antifungal actions of electrolyzed oxidizing water through electrolysis, Dental Journal, 37, 1055-1062.

Silva, E. (2008) Approved chemicals for use in organic postharvest systems, Adapted from: Silva, E. 2008. Approved chemicals for use in organic postharvest systems. In Wholesale success: a farmer's guide to selling, postharvest handling, and packing produce (Midwest edition). Available online at: http://www.familyfarmed.org/wholesale-success/ (verified 6 Dec 2011).

Sips, H. and Hamers, M.N. (1981) Mechanism of the bacterial action of myeloperoxidase: increased permeability of the Escherichia coli cell envelope, Infection and Immunity, 31:1, pp. 11-16.

Somani, S.B., Ingole, N.W. and Kulkarni, N.S. (2011) Disinfection of water by using sodium chloride (NaCl) and sodium hypochlorite (NaOCl), Journal of Engineering Research and Studies, 2:4, pp. 40-43.

Stevens, A.A. (1982) Reaction Products of Chlorine Dioxide, Environmental Health Perspectives, 46, pp. 101-110.

Su, Y-C., Liu, C. and Hung, Y-C. (2007) Electrolyzed Water: Principles and Applications, *in* New Biocides Development, the combined approach of chemistry and microbiology, Peter Zhu, *ed*., American Chemical Society , Washington, DC, pp. 309-321.

Suzuki, T., Itakura, J., Watanabe, M., Yuri Sato, M. O. and Yuko Yamaya, Y. (2002) Inactivation of Staphylococcal Enterotoxin-A with an Electrolyzed Anodic Solution, J. Agric. Food Chem., 2002, 50, pp. 230-234.

US Department of Agriculture—USDA (1995) Ozone Technical Report, Agricultural Marketing Service, National Organic Programs, Petitioned Substances

US Department of Agriculture—USDA (2000) Peracetic Acid Technical Report, Agricultural Marketing Service, National Organic Programs, Petitioned Substances

US Department of Agriculture—USDA (2002) Ozone Technical Report, Agricultural Marketing Service, National Organic Programs, Petitioned Substances

US Department of Agriculture—USDA (2003) Phosphoric Acid Technical Report, Agricultural Marketing Service, National Organic Programs, Petitioned Substances

US Department of Agriculture—USDA (2006a) Chlorine/Bleach Technical Report, Agricultural Marketing Service, National Organic Programs, Petitioned Substances

US Department of Agriculture—USDA (2006b) Copper Sulfate Technical Report, Agricultural Marketing Service, National Organic Programs, Petitioned Substances

US Department of Agriculture—USDA (2008) Regulations Governing the Voluntary Grading of Shell Eggs, Marketing and Regulatory Programs, Agricultural Marketing Service, Livestock, Poultry and Seed Programs, 7 CFR Part 56, Effective March 30, 2008.

US Department of Agriculture—USDA (2014a) Isopropanol Technical Report, Agricultural Marketing Service, National Organic Programs, Petitioned Substances

US Department of Agriculture—USDA (2014b) Ethanol Technical Report, Agricultural Marketing Service, National Organic Programs, Petitioned Substances

US Department of Agriculture—USDA (2014c) Sodium Carbonate Peroxyhydrate Technical Report, Agricultural Marketing Service, National Organic Programs, Petitioned Substances

US Department of Agriculture—USDA (2015a) Copper Sulfate Technical Report, Agricultural Marketing Service, National Organic Programs, Petitioned Substances

US Department of Agriculture—USDA (2015b) Hydrogen Peroxide Technical Report, Agricultural Marketing Service, National Organic Programs, Petitioned Substances

US Department of Agriculture—USDA (2015c) Nisin, Agricultural Marketing Service, National Organic Programs, Petitioned Substances

US Department of Agriculture—USDA (2015c) Soap Technical Report, Agricultural Marketing Service, National Organic Programs, Petitioned Substances

US Environmental Protection Agency—EPA (1991) Reregistration eligibility decision (R.E.D.) facts, Sodium and Calcium Hypochlorite Salts, Pesticides and toxic substances (7508W), EPA-783-F-91-108.

US Environmental Protection Agency—EPA (1992) Reregistration eligibility document (R.E.D.), Sodium and calcium hypochlorite salts, list A, case 0029, Office of pesticide programs, special review and reregistration division.

US Environmental Protection Agency—EPA (1998) National Primary Drinking Water Regulations: Disinfectants and Disinfection Byproducts, Federal Register, Vol. 63:241, pp. 69390-69476.

US Environmental Protection Agency—EPA (1999) Reregistration eligibility decision (R.E.D.) facts, chlorine gas, Prevention, pesticides and toxic substances (7508W), EPA-783-F-99-01.

US Environmental Protection Agency—EPA (2003) Reregistration Eligibility Decision (RED) for Chlorine Dioxide and Sodium Chlorite (Case 4023), Pesticides and toxic substances (7510W), EPA-738-R-06-007.

US Environmental Protection Agency—EPA (2014) Antimicrobial Pesticide Products

US Environmental Protection Agency—EPA (2014) Environmental Assessment for Food Contact Notification FCN 1470, http://www.fda.gov/Food/IngredientsPackagingLabeling/EnvironmentalDecisions/default.htm

US Environmental Protection Agency—EPA (2015) Safe Drinking Water Act

US Food and Drug Administration (2015) FDA Inventory of Effective Food Contact Substance (FCS) Notifications; Last updated 6/30/2015.

US Food and Drug Administration—FDA (2013) Code of Federal Regulations, 21CFR110.3—current good manufacturing practice in manufacturing, packing, or holding human food, definitions.

US Food and Drug Administration—FDA (2013) Food Code, US Public Health Service, US Department of Health and Human Services, College Park, MD 20740

Vandekinderen, I., van Camp, J., Meulenaer, B.D., Veramme, K. Bernaert, N., Denon, Q., Ragaert, P. and Devieghere, F. (2009) Moderate and High Doses of Sodium Hypochlorite, Neutral Electrolyzed Oxidizing Water, Peroxyacetic Acid, and Gaseous Chlorine Dioxide Did Not Affect the Nutritional and Sensory Qualities of Fresh-Cut Iceberg Lettuce (Lactuca sativa Var. capitata L.) after Washing, J. Agric. Food Chem. 2009, 57, 4195–4203.

Venkitanarayanan, K., Ezeike, G., Hung, Y. and Doyle, M. (1999) Inactivation of *Escherichia coli* O157:H7 and *Listeria monocytogenes* on plastic kitchen cutting boards by electrolyzed oxidizing water, Journal of Food Protection, 62: 8, pp. 857–860.

White, G. C. (1972) Handbook of Chlorination. Van Nostrand Reinhold Company, New York.

Wiant, C. (2013) The chlorine residual: A public health safeguard, Water Quality and Health Council.

Wolf, M.M, Johnson, B., Cochran, K., and Hamilton, L. (2002) Consumer attitudes toward organically grown lettuce, Journal of Food Distribution Research, 32:1, pp. 155-160.

Yang, H., Swem, B.L. and Li, Y. (2003) The Effect of pH on Inactivation of Pathogenic Bacteria on Fresh-cut Lettuce by Dipping Treatment with Electrolyzed Water. Journal of Food Science, 68, pp.1013–1017.

Young, S.B. and Setlow, P. (2003) Mechanisms of killing of *Bacillus subtilis* spores by hypochlorite and chlorine dioxide, Journal of Applied Microbiology 2003, pp. 54–67.

Zhang, Q., Xiong, K., Tatsumi, E. Li, L-t. and Liu, H-J. (2012) Elimination of aflatoxin B1 in peanuts by acidic electrolyzed oxidizing water, Food Control, 27, pp. 16-20.