Ozone Sanitation - A Sustainable and Efficacious Approach to Food Safety

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2017

ABSTRACT

Ozone's discovery and commercial use as a disinfectant can be traced back to the late 1800s. Early on, its primary function was sanitation and disinfection for potable water. The scientific community thoroughly studied and vetted the use of ozone for these specific applications, which led to the realization that ozone could benefit countless other industries as well. Throughout the rest of the 20th Century and now well into the 21st Century, research continues to show the benefits of using ozone for disinfection and sanitation purposes across a multitude of commercial industries.

INTRODUCTION

Since its discovery in the early 1800s, ozone has been proven to be an efficacious sanitizer, disinfectant and antimicrobial oxidizing agent. The disinfecting capability of 1 ppm (mg/L) of ozone dissolved in water (aqueous ozone) is equivalent to many times (10 to 4,000 times) the concentration of free available chlorine (Morris, 1975), depending on the pH, temperature and microorganism(s) to be destroyed. Ozone has been proven to be effective at oxidizing microorganisms such as viruses and bacteria because its method of oxidation prevents them from developing a tolerance to ozone.

In viruses, ozone oxidizes DNA and RNA which are ineffectively protected by a thin protein coat (von Sonntag & von Gunten, 2012). In bacteria, ozone rips electrons away from the disaccharides and amino acids that comprise the cell wall. This causes lysis or bursting of the wall, effectively destroying the organism. Figure 1 shows the steps leading to the destruction of bacteria in detail. Ozone begins its attack with the cell membrane (a), then continues its assault on glycoproteins, glycolipids, or certain amino acids along with sulfhydryl groups of some enzymes (b). Image (c) shows the initial damage to the membrane before break down of the cell wall becomes apparent (d). Complete perforation of the membrane (e) occurs just before the cell lysis or disintegration (f) (Rojas-Valencia, 2011).

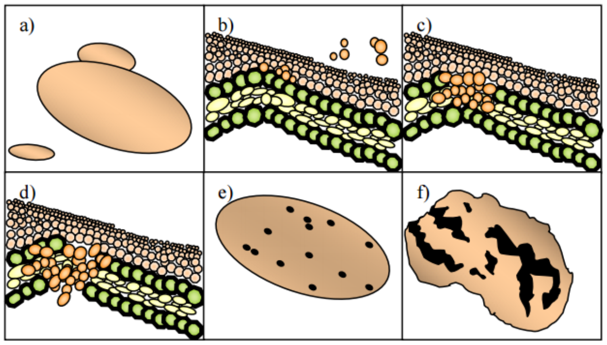


Figure 1. Bacteria lysis during ozone disinfection

Research has also shown ozone to be effective at oxidizing biofilms, pesticides, and pharmaceutical pollutants such as endocrine disruptors. However, it is important to note that partial oxidation of pesticides and endocrine disruptors can form ozonation byproducts that need to be further treated and removed from potable water with post filtration typically involving Advanced Oxidation Processes (AOP) in addition to utilizing bacteria, such as biologically activated carbon (BAC) filters.

OZONE BASICS

Ozone is a resonant molecule comprised of three oxygen atoms. The third atom is weakly bonded and electron deficient, causing the molecule to be unstable which consequently makes the ozone molecule an effective sanitizer, disinfectant, and oxidizer. Because of ozone's instability as a gas, it cannot be stored and must therefore be generated onsite near its point of use. It is produced via an ozone generator which utilizes a dry, oxygen-enriched feed gas and electricity. As the feed gas passes through the generator, the electrical energy (a plasma field) causes some of the oxygen (O_2) molecules to split, resulting in two singlet oxygen atoms (O^1). These singlet atoms (O^1) unite with other oxygen molecules (O_2) to produce ozone (O_3) (Figure 2).

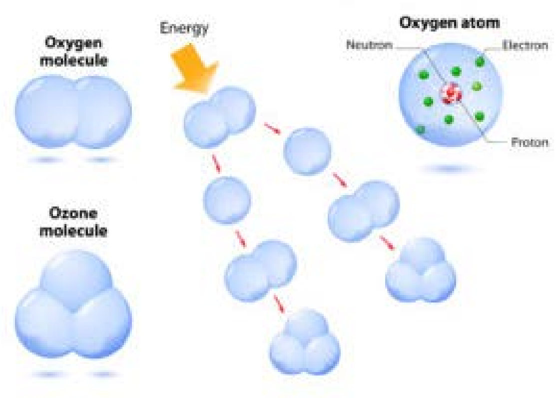


Figure 2. Formation of Ozone

When ozone gas is dissolved in water, its half-life can range from seconds to hours, depending upon the pH, temperature, level and type of contaminants in the water. Ozone oxidation of dissolved organic contaminants typically results in the formation of oxygen, carbon dioxide and smaller, more biodegradable molecular fragments.

OZONE OXIDATION STRENGTH COMPARISON

Chlorine-based chemicals have long been considered the industry standard for sanitation and disinfection purposes. However, since the 1970s, it has become evident that chlorination of certain waters can form disinfection by-products (DBP) that are carcinogenic. Because of that and the greater oxidative power of ozone, it has become more widely accepted as an alternative sanitizer and disinfectant in the food industry. Ozone's antimicrobial efficacy, as measured in electron volts, is superior to commercial sanitation products commonly used in today's modern food facilities (Figure 3). No other sanitation or disinfection chemical is stronger or more efficacious than ozone in terms of its oxidative power.

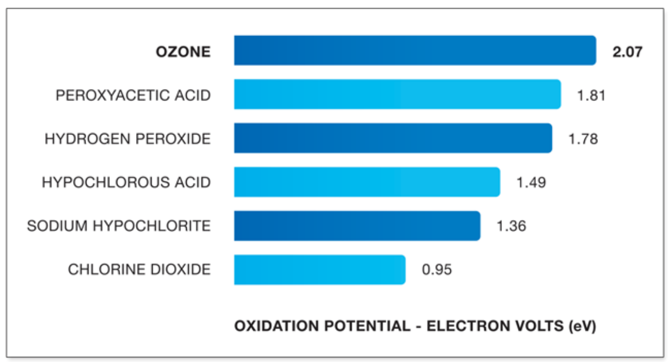


Figure 3. Oxidation Comparison

The Ct value term, based on models developed by Chick and Watson (Langlais, et al 1991), is used to indicate the level of ozone disinfection for specific microorganisms. The units for Ct are concentration (mg/L) multiplied by time (minutes) and is based on the empirical testing of the ozonation of various microorganisms under specific temperature and water quality conditions. The level of lethality is based on a logarithmic scale, where 1 log is equivalent to 90% kill, 2 logs is 99%, 3 logs is 99.9%, etc.

OZONE EFFICACY AND COMPARISONS TO CHLORINE-BASED CHEMICALS

Ozone has been widely studied over the past century for its disinfection efficacy and its superior strength to commonly used chlorine-based chemicals.

Table 1. Values of Specific Coefficients of Lethality for the Main Disinfectants (L/mg/min)

Disinfectant	Enterobacteria	Viruses	Bacterial Spores	Amoebic Cysts
O_3 (Ozone)	500	5	2	0.5
HOCl (Hypochlorous acid)	20	1 & up	0.05	0.05
OCl^- (Hypochlorite ion)	0.2	< 0.02	< 0.0005	0.0005
NH_2Cl (Chloramine)	0.1	0.005	0.001	0.02

Source: Morris (1975)

Table 2. Ct values (mg-min/L) for 99% Inactivation of Microorganisms with Disinfectants at 5°C.

Microorganism	Disinfectant			
	Free Chlorine (pH 6 to 7)	Preformed Chloramine (pH 8 to 9)	Chloride Dioxide (pH 6 to 7)	Ozone (pH 6 to 7)
E. coli	0.034-0.05	95-180	0.4-0.75	0.02
Polio 1	1.1-2.5	770-3740	0.2-6.7	0.1-0.2
Rotavirus	0.01-0.05	3810-6480	0.2-2.1	0.006-0.06
Phage f2	0.08-0.18	--	--	--
G. lamblia cysts	47->150	--	--	0.5-0.6
G. muris cysts	30-630	1400	7.2-18.5	1.8-2.0

Source: Hoff (1987)

Table 3. U.S. EPA Ct values (mg- min/L) for 3 log Inactivation of *Giardia* Cysts (99.9%) with Ozone at Different Temperatures with pH values from 6 to 9

Inactivation	Temperature °C (°F)					
	0.5 (33)	5 (41)	10 (50)	15 (59)	20 (68)	25 (77)
1.0 log	0.97	0.63	0.48	0.32	0.24	0.16
1.5 log	1.5	0.95	0.72	0.48	0.36	0.24
2.0 log	1.9	1.3	0.95	0.63	0.48	0.32
2.5 log	2.4	1.6	1.2	0.79	0.60	0.40
3.0 log	2.9	1.9	1.4	0.95	0.72	0.46

Source: U.S. EPA (1989a)

OZONE APPLICATIONS

Ozone has been documented to be significantly more effective than all the commonly-used sanitation chemicals available for commercial and industrial sanitation. It is unsurpassed for its antimicrobial efficacy, and is superior in terms of microbial log reduction. Also, given proper safety, material selection and environmental controls, it demonstrates no negative impacts on the facilities, products or employees. Ozone treatment is a uniquely safe and sustainable non-thermal sanitation process and is compatible with the proper processing materials (See Ozone Safety and Material Compatibility).

For application control, gaseous ozone is dissolved in water to create "ozone-enriched water" which is commonly referred to as *aqueous ozone*. Aqueous ozone can be utilized at several points of the process, depending on the commodity. The most common uses in the food industry are direct contact with the food product and/or surface sanitation and CIP/SIP. Since ozone is an approved food additive, it has the unique capability of providing sanitation to food and equipment simultaneously (i.e. food product on a conveyor belt). Ozone creates no organoleptic changes in food products (through direct or indirect contact), as traditional chemicals can and do. Ozone helps to remove residual pesticides and microorganisms such as *E. coli, Listeria monocytogenes, Salmonella choleraesuis, Campylobacter jejuni and Bacillus subtilis, etc.* from food products.

Direct product and surface application typically consists of a low-pressure spray using fixed spray bars, drench, shower or rain-type applicators (such as the Ozone Rain Pan), or with hand-held sprayers. It can also be added to flume water which can be recirculated if the process is moderately clean, or sent to the drain. Additional uses have also included sanitizing bottles or product water prior to flavor additives. In some facilities, gaseous ozone is used in controlled atmosphere (CA) environments for microorganism control, ripening delay and spoilage reduction resulting in increased shelf-life of the product. These processes can all be performed simultaneously with a centralized ozone system.

Aqueous ozone systems are typically controlled by a dissolved ozone monitor/controller which provides automatic dose control proportional to the water flow. Depending upon the application, the ozone concentration is commonly regulated to between 1.5 – 5.0 mg/L. Most applications use cold water (<75°F) sprayed at a low pressure (10 psi or less), allowing for gentle flooding of surfaces without causing pressurized over-spray that can inadvertently spread microorganisms to other areas of the facility and/or result in excessive off-gassing of ozone into the plant environment.

Ozone-enriched water can sanitize both food contact and non-food contact surfaces, as well as any other wettable area with sanitation needs. The use of ozone can reduce levels of fat, oil and grease on surfaces, as well as break down bacterial biofilm build-up, molds and mildew (particularly in areas of high sugar products). With continued use, ozone will sanitize floor drains and rid the drains and plumbing of biofilm and other microorganisms that can migrate back into the processing area (especially *Listeria monocytogenes*) with the benefit of adding dissolved oxygen to the wastewater and no adverse effects on wastewater treatment systems.

Additional benefits of the regular use of aqueous ozone include elimination of greasy film on facility floors, pre-ozonation of Reverse Osmosis (RO) source water to prevent biofouling of the RO membranes, and keeping conveyor belts clean and free of buildup consisting of food debris, sugar, fat, grease, fungi, and biofilm that may contain human or food sourced pathogens.

OZONE SAFETY AND MATERIAL COMPATIBILITY

Aqueous ozone systems operated per Good Manufacturing Process (GMP) are safe for workers. The systems utilize ambient ozone monitors to alert those in the area if a catastrophic equipment failure happens and the ozone concentration exceeds safe exposure limits. These monitors will also cut off power to the ozone generator to prevent further ozone gas leaking before repairs can be made to the system. If so desired, remote alarms or notifications can be linked to the monitor in the immediate vicinity of the ozone generator to prevent others from entering the area until it is safe.

Because ozone is a strong oxidizer, the use of compatible materials that can withstand prolonged exposure to ozone is important. Acceptable materials include the following:

- Stainless Steel (304, 316 and foil)
- Aluminum (all grades)
- Concrete, painted surfaces, wood
- Painted concrete
- Plastics: ECTFE, PTFE, PVC, PVDF, HDPE (Polyethylene)
- Gaskets: FPM (Viton), EPDM
- Rubber Modified Vinyl
- Glass

Natural rubber latex is not suitable for use with aqueous ozone and mild steel may experience surface rusting.

INDUSTRY AND REGULATORY ACCEPTANCE OF OZONE

The use of ozone has had wide commercial adoption and multiple approvals from government agencies, globally, for well over one hundred years. However, in the U.S., approvals didn't start showing up until the 1970s. Since then, all the pertinent U.S. government agencies have added ozone to their lists of approved antimicrobials for multiple applications in the food industry.

With increased interest in adopting more sustainable practices, increasing consumer demand for more organic and healthy food options, as well as much stricter food safety rules (i.e. FSMA, HAACP and HARPC), the use of ozone has accelerated the move away from multi-chemical based sanitation treatments. Other events, including water availability and cost, food recalls, foodborne illnesses, waste water concerns and the need to reduce operating costs, have advanced the use of ozone-based technology either as a replacement for, or an addition to traditional chemical-based and thermal-based sanitation treatments. Ozone is an FDA, USDA and USDA Organic approved antimicrobial food additive. It is an EPA approved antimicrobial oxidizer for potable water, surface sanitation and CIP/SIP.

Below is a summary of the current regulatory information on ozone use in the food industry by agency. Additional documentation further describing the regulations in detail can be found at the end of this document (Regulatory Documentation).

- **FDA** – Regulates and allows ozone contact with foods (F&V, seafood, shell eggs, bottled water)
- **USDA/FSIS** – Regulates and allows ozone contact with meat, poultry and egg products
- **USDA National Organic Program (NOP)** – Allows ozone for organic food contact
- **EPA/FIFRA** – Regulates ozone generators under their device program (sanitation and potable water)
- **OSHA** – Regulates ozone (for worker exposure) in workplace air

DETAILED REGULATORY DOCUMENTATION

FDA

21 § CFR 129.80 (3/15/1977; amended 4/4/2012)

Bottled water plant sanitizing of contact surfaces and any other critical area

0.1 ppm ozone-enriched water solution for at least five minutes (Ct value of 0.5 mg-min/L)

21 CFR §173.368 (6/26/2001)

FDA Secondary Direct Food Additives Permitted in Food for Human Consumption

Ozone may be safely used in the treatment, storage, and processing of foods, including meat and poultry

Ozone is used as an antimicrobial agent in accordance with current industry standards of good manufacturing practice

21 § CFR 178.1010 (b) (1, 3, 9, 30, 38) (3/16/1977)

“Category Three Certification”: <15 cfu per cm for Yeast, Mold, Bacteria; No rinse

§178.1010 (b): “The solutions consist of one of the following, to which may be added components generally recognized as safe (GRAS) and components which are permitted by prior sanction or approval.”

- (1) 200 ppm chlorine
- (3) 25 ppm iodine (iodophore)
- (9) 200 ppm quaternary ammonia compound
- (30) 400-600 ppm peroxide
- (38) 128-156 ppm peroxyacetic acid

Ozone is (GRAS) and listed under prior sanction (USEPA/FIFRA) Standard Dose 1-5 ppm Ozone

USDA/FSIS

November 27, 2001, the American Meat Institute filed a letter with USDA/FSIS requesting interpretation of the scope of the FDA rule allowing the use of ozone as an antimicrobial agent

USDA/FSIS determined that, “The use of ozone on raw and ready-to-eat meat and poultry products just prior to packaging is acceptable,” and that there are “no labeling issues in regard to treated product”

USDA/FSIS Directive 7120.1 (12/17/02) (Revised 3/3/16)

“The attachment below identifies the substances that have been accepted since January 2000 by FSIS as safe and suitable for use in the production of meat and poultry products”

(Attachment 1) Antimicrobial - Ozone

1. All Meat and Poultry Products
2. In accordance with current industry standards of good manufacturing practice
3. Reference 21 CFR § 173.368

USDA NATIONAL ORGANIC PROGRAM (NOP) ALLOWED SUBSTANCES

Ozone is listed in the NOP Final Rule **(§ 205.605 (b) (20)** pg. 437 - Nonagricultural (non-organic) substances allowed as ingredients in or on processed products labeled as "organic" or "made with organic (specified ingredients or food group(s))"

(b) Synthetics allowed: (20) ozone

Food Safety and Inspection Service New Technology Information Table Last Updates January 25, 2017

http://www.fsis.usda.gov/wps/portal/fsis/topics/regulatory-compliance/new-technologies/new-technology-information-table

Listed technology: Ozone

FSIS Compliance Guideline: Controlling *Listeria monocytogenes* in Post-lethality Exposed Ready-to-Eat Meat and Poultry Products - January 2014

A. Post-lethality Treatments and Antimicrobial Agents

Buege, D.R., Ingham, S.C. and J.A. Losinski (University of Wisconsin-Madison), "Evaluation of Del Ozone's Delzone® Sanitation System as a Post-Lethality Treatment to Control *Listeria monocytogenes* Contamination on Ready-To-Eat Meat Products", Confidential Report to Del Ozone, April 16, 2004.

I. Use of Antimicrobial Ingredients including Bacteriophages, Lactates, Acetates, Diacetates, and Ozone

Ozone is an antimicrobial gas usually applied in an aqueous solution to products, food contact surfaces as a continuous spray (e.g., belts, moving tables), and nonfood contact environmental surfaces. Currently, the use of ozone is permitted by FDA and FSIS (21 CFR 173.368, FSIS Directive 7120.1) for use with all meat and poultry products, including RTE meat and poultry products.

Buege et al., (2004) showed 1.0 to 2.4 log reductions (average 1.5) of *Lm* when 0.6 ppm ozone for 30 seconds was applied to ham, salami, meatloaf, natural casing wieners, and skinless wieners.

FSIS USDA Training - Process Category Introduction 3/25/2015 Inspection

Poultry Slaughter – Antimicrobial Interventions

Raw Product – Intact Processing Category

Common Controls - Biological

In addition to the controls that may have already been used during the slaughter process, establishments commonly utilize additional antimicrobial interventions for pathogens of concern.

On August 21, 2014, FSIS published the Modernization of Poultry Slaughter Inspection final rule. FSIS Notice 50-14 addresses how IPP are to verify compliance with approved online and offline reprocessing antimicrobial intervention systems. *Establishments that slaughter poultry other than ratites are allowed to use these approved systems to clean carcasses accidentally contaminated with digestive tract contents **(9 CFR 381.91)**. A list of approved systems is included as an attachment to this notice.*

Ozone

Ozone may be used in contact with food as a gas or liquid as an antimicrobial in meat and poultry products, including ground meats.

EPA/FIFRA OFFICE OF PESTICIDE PROGRAMS (OPP) DISINFECTANT TECHNICAL SCIENCE SECTION (DIS/TSS)

EPA regulates ozone as a pesticide- producing device

Ozone generators must be registered by the EPA under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)

Each Ozone Generator Manufacturer has a unique EPA registered establishment number as a pesticide-producing device

For no-rinse surface sanitation compliance the USEPA/FIFRA Office of Pesticide Programs (OPP) Disinfectant Technical Science Section (DIS/TSS) requires:

1. Antimicrobial efficacy data determined by AOAC International methods
2. Toxicological profiles
3. Environmental impact information
4. Specific label information and directions for use

Ozone Generators are recognized by the EPA as antimicrobial producing devices per EPA documentation published in 1976, with an EPA Establishment Number necessary for compliance.

VALIDATION STUDIES

NSF International Toxicology Labs Test Results ca 2000-2001

Ozone systems with an aqueous ozone output of 1.5-2.0 ppm dissolved ozone tested for antimicrobial efficacy

Antimicrobial Efficacy Protocols

DIS/TSS-1 (AOAC Official Method 961.02, Germicidal Spray Products as Disinfectants, for both broad-spectrum and hospital/medical environment efficacy claims) was chosen by the Microbiology and Toxicology Groups at NSF as the best testing protocol efficacy testing of aqueous ozone sanitizing on hard surfaces

NSF also chose DIS/TSS-4 (AOAC Method 960.09 Germicidal and Detergent Sanitizing Action of Disinfectants) for additional efficacy testing

NSF conducted studies according to EPA-established AOAC Official Methods 961.02 & 960.09, Germicidal Spray Products as Disinfectants, and Germicidal & Detergent Sanitizing Action of Disinfectants test procedures (Aqueous ozone 1.5-2.0 mg/L) (Note: log reductions are mandated by the AOAC Method)

AOAC 961.02 Results (AOAC Method 961.02 requires a minimum log 6 reduction)

Salmonella choleraesuis	6 log reduction (99.9999%)	180 seconds
Staphylococcus aureus	6 log reduction (99.9999%)	600 seconds
Pseudomonas aeruginosa	6 log reduction (99.9999%)	300 seconds
Trichophyton mentagrophytes	6 log reduction (99.9999%)	30 seconds

Additional evaluations as per AOAC 961.02 Results (AOAC 961.02 Additional evaluations require a minimum log 4 reduction)

Campylobacter jejuni	4 log reduction (99.99%)	180 seconds
Aspergillus flavus	4 log reduction (99.99%)	300 seconds
Brettanomyces bruxellensis	4 log reduction (99.99%)	180 seconds
Listeria monocytogenes	4 log reduction (99.99%)	180 seconds

AOAC 960.09 Results (AOAC Method 960.09 requires a minimum log 5 reduction)

Escherichia coli	5 log reduction (99.999%)	30 seconds

Robert Donofrio, et al, IWA Publishing 2013 Journal of Water and Health | 11.2 | 2013

Antimicrobial Validation for *Cryptosporidium parvum* Reduction by NSF International – Low Dose Ozone (CT 0.74)

Pass compliance requires a 3 log (99.9%) reduction of *Cryptosporidium parvum*

Actual Microbial Reductions in 30 Seconds (Actual Ozone Ct value was 0.76)

Cryptosporidium parvum	3.0 log (>99.9%)

NSF International Validation Study

M.A. Khadre, A.E. Yousef, International Journal of Food Microbiology 71 (2001) 131–138

Bacillus subtilis

"It is evident that ozone is superior to hydrogen peroxide in killing bacterial spores. Hydrogen peroxide at ~10,000-fold higher concentration was less effective than ozone against *Bacillus* spores. The comparatively low concentration needed to eliminate large populations of spores at ambient temperature in short time periods makes ozone best suited for industrial settings."

M.A. Khadre, A.E. Yousef, International Journal of Food Microbiology 66 (2001) 1247

B. cereus

Aqueous Ozone 0.12 mg/L @ 5 minutes (Ct 0.6) @ 28°C = > 2 log reduction

M.A. Khadre, A.E. Yousef, International Journal of Food Microbiology 71 (2001) 131

B. cereus

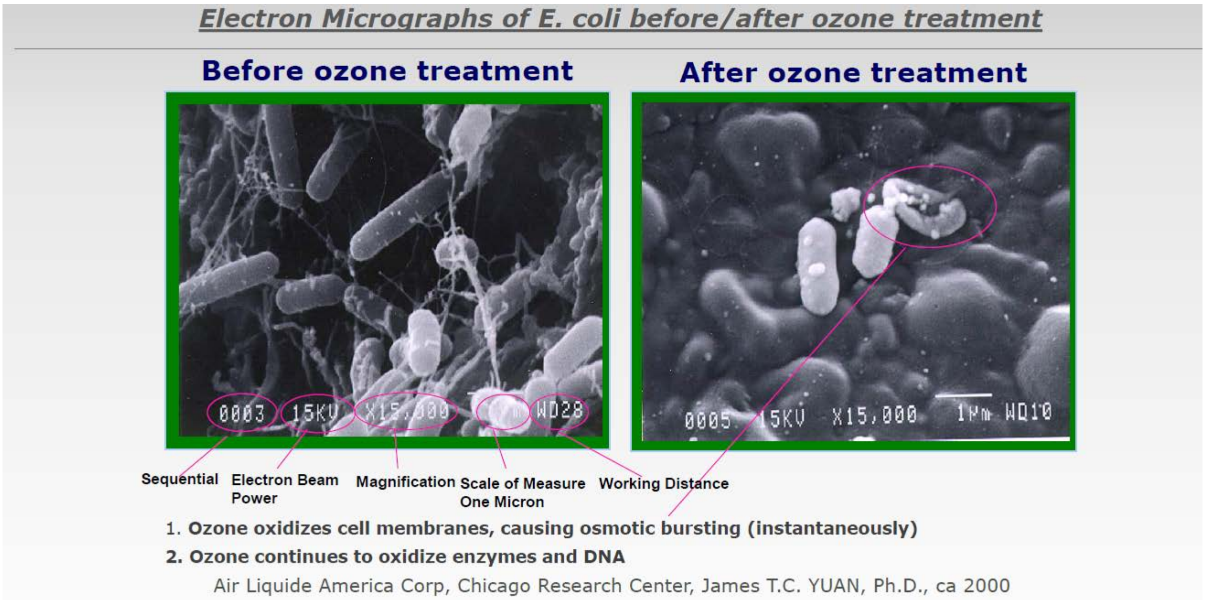
Aqueous Ozone 11.0 mg/L @ 1 minutes (Ct 11.0) @ 22°C = > 6 log reduction

Quote per Dr. Ahmed Yousef, February 2009

"Regarding International Journal of Food Microbiology 66 (2001) 1247 and 71 (2001) 131, both studies provide statistical comparison only; therefore, the ozone was not optimized, it is very likely that ozone is more cost- efficient at lower quantities, and should be re-evaluated for optimum CT value and efficacy for *Bacillus*."

James T.C. Yuan Ph.D., Air Liquide America Corp, Chicago Research Center, ca 2000

Industry Apple Surface Study *E. coli* (Ct 1.0)



Stephanie L. Rogers, et al, Journal of Food Protection, Vol. 67, No. 4, 2004, Pages 721–731

A Comparison of Different Chemical Sanitizers for Inactivating *Escherichia coli* O157:H7 and *Listeria monocytogenes* in Solution and on Apples, Lettuce, Strawberries, and Cantaloupe

Log reduction time (LRT): time (in seconds) required to reduce bacterial populations by log 1 at 21-23°C

Treatment	*E. coli* O157:H7	*L. monocytogenes*
Peracetic acid (80 ppm)	65 ± 0.21	70 ± 0.17
CTP (100 ppm chlorine)	31 ± 0.13	35 ± 0.32
CTP (200 ppm chlorine)	22 ± 0.19	27 ± 0.18
Chlorine dioxide (3 ppm)	24 ± 0.20	25 ±0.21
Chlorine dioxide (5 ppm)	18 ± 0.31	19 ± 0.24
Ozone (3 ppm)	16 ± 0.31	15 ± 0.26

Ozone (3 ppm) was extremely effective against *L. monocytogenes* and *E. coli* O157:H7 on produce. Kim et al. *(22)* also found 1.3 ppm ozone to be highly effective on fresh lettuce, with mesophilic bacteria decreasing > 4 log after a 5-min exposure. (22) Kim, J., A. E. Yousef, and G. W. Chism. 1999. Use of ozone to inactivate microorganisms on lettuce. *J. Food Safety* 19:17–34.

Aqueous model system studies. Peroxyacetic acid (80 ppm) had the highest LRT (65 and 70 s), while chlorine dioxide (5 ppm) and ozone (3 ppm), which were not significantly different from each other, had the lowest LRT (15 to 19 s), respectively, for *E. coli* O157:H7 and *L. monocytogenes*. LRT values for CTP (200 ppm chlorine) and chlorine dioxide (3 ppm) (22 to 27 s) were significantly higher than those for chlorine dioxide (5 ppm) and ozone (3 ppm) for both *E. coli* O157:H7 and *L. monocytogenes*.

Produce inoculation studies. Chlorine dioxide (5 ppm) and ozone (3 ppm) were not significantly different from each other and had the lowest LRT (22 to 96 s), while peroxyacetic acid had the highest LRT for *L. monocytogenes* on all produce types (79 to 131 s). CTP (200 ppm chlorine) and chlorine dioxide (3 ppm) were not significantly different from each other and had similar LRT values (30 to 100 s), regardless of produce type. CTP (100 ppm chlorine) was significantly different from all other treatments on whole apples, sliced apples, and whole lettuce, but LRT values (41 to 118 s) were significantly lower than those for peroxyacetic acid. LRT values (39 to 60 s) for shredded lettuce, strawberries, and cantaloupe treated with CTP (100 ppm chlorine) were not significantly different from those treated with CTP (200 ppm chlorine). Treatment of shredded lettuce with CTP (100 and 200 ppm chlorine), chlorine dioxide (3 and 5 ppm), and ozone (3 ppm) yielded LRT values that were not significantly different from each other (96 to 104 s).

In conclusion, the results of this study indicate that peracetic acid (80 ppm), CTP (100 and 200 ppm chlorine), chlorine dioxide (3 and 5 ppm), and ozone (3 ppm) effectively decreased the numbers of *E. coli* O157:H7 and *L. monocytogenes* on fresh produce. Chlorine dioxide (3 and 5 ppm) and ozone (3 ppm) were more effective against *E. coli* O157:H7 and *L. monocytogenes* compared with the other sanitizers.

Laszlo Varga, et al, International Journal of Dairy Technology, Vol 69 May 2016

Use of ozone in the dairy industry: A review

Summary

Ozone treatment is a cost-effective and eco-friendly food-processing technology. It has successfully been used for the removal of milk residues and biofilm-forming bacteria from stainless steel surfaces and in milk processing, including fluid milk, powdered milk products and cheese. Ozonation has been shown to prevent mould growth on cheese and inactivate airborne moulds in cheese ripening and storage facilities. Ozone treatment has also been found to be a promising method for reducing the concentrations of pollutants in dairy wastewaters

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K.L. Bialka And A. Demirci Journal of Food Science—Vol. 72, Nr. 9, 2007

Decontamination of *Escherichia coli* O157:H7 and *Salmonella enterica* on Blueberries Using Ozone and Pulsed UV-Light

The results of this study indicate that both ozone and pulsed UV-light have a potential to be used as a method of decontaminating blueberries. Maximum reductions after treatment with gaseous ozone were 3.0 and 2.2 log10 CFU/g of *Salmonella* and *E. coli* O157:H7, respectively. The maximum reductions achieved after treatment with aqueous ozone were 5.2 and 6.2 log10 CFU/g of *E. coli* O157:H7 and *Salmonella*, respectively. Furthermore, sensory analysis failed to detect a significant difference in the gaseous ozone, aqueous ozone or pulsed UV-light treated compared with untreated blueberries.

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ABOUT THE AUTHOR

Beth Hamil has over 32 years' professional experience in ozone system development, ozone applications, ozone consulting (including applications engineering), and project management, spanning a comprehensive range of commercial industries including, aquatics, food safety applications (commercial and food service), wineries, pharmaceutical and industrial uses. She is highly experienced and very adept with regulatory compliance responsibilities for the use of ozone, while staying up-to-date with emerging governmental compliance developments. Her ongoing focus continues to be developing parameters for ozone efficacy and worker/environmental safety for a broad range of applications. Visit www.bethhamilo3consulting.com for more information.

EDITORIAL CONTRIBUTIONS

Thoram Charanda serves as Director of Research & Development for Guardian Ozone. His 27+ years of experience began working with ozone treatment systems while overseeing the chemistry department of Life Support at The Living Seas in EPCOT. That experience with ozone systems led him to Guardian in 2008 when he started the R&D lab dedicated to ozone kinetics and oxidation chemistry along with the development of specialized process treatment schemes and new devices used to advance industrial and commercial ozone technology and applications.

Jessica Pedisich serves as the Research Chemist for Guardian Ozone. Her experience with ozone treatment systems began with a water chemistry internship at Walt Disney World. Her work there led her to the Guardian R&D Lab in 2011 where she has since taken on much of the lab-scale testing and daily operations.

Guardian Research & Development Laboratory (GRDL) was established in 2008 to address the specialized needs of highly complex ozone and advanced oxidation process (AOP) chemistry. The state of the art facility is equipped with multiple ozone generator systems, ozone injection systems, reactor vessels, and analytical equipment necessary to evaluate a wide range of water, wastewater, and gas-phase ozone applications. For more information on the lab and the services it provides, visit www.OzoneResearchLab.com.