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(Review Article)

Ozonation, a novel bio-preservation technique for food processing in food industries

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Abstract

Application of ozone as a replacement to traditional sanitizers requires thorough understanding of its benefits and limitations; in some food a lesser log reduction rate is observable virtually less than the required 5log reduction rate. Ozone's ability to destroy microorganisms is through the oxidation of some important cellular components, specifically the bacterial cell surface being the major target, ozone does not significantly affect the nutrients contents or sensory qualities in food; it has lesser effect on increasing temperature of food during processing, ozonation is an effective technology in extending the shelf-life of fruit and vegetables, rinsing or dipping vegetables in water saturated with ozone is a positive method. Onions treated with ozone during storage was positive, mold and bacterial populations was greatly decreased and no any sign of change in chemical composition and sensory quality of the product. Ozone has great advantage in the food industry; it is sufficiently soluble and stable in water with high antimicrobial activity, no need for storage of hazardous substances when used it, has low running cost with no residual problems after treatment and it autodecomposes and its stable end-product is oxygen so the by product is virtually oxygen. However, ozone's limitation is still a threat in the food industry, it has the ability to desolubilize or decompose, or react with food constituents and targeted microorganisms. The reaction and the degradation of ozone diminish the residuals of this sanitizer during processing and subsequently lack of residuals could limit the ability of the processor's for in-line testing of effectiveness. This paper reviewed the different application of ozone in the food industry.

Keywords: Ozonation, preservation, food, bio-techniques

1. Introduction

The presence of microorganisms in food products such as vegetables, meats juices, fruits, and other related food substances is a challenge to the safety of foods. The immeasurable need of processed foods that is free from chemical preservatives and pathogens has greatly increased the demand for new food preservation techniques (1). The major aim is to make available food products with suitable nutritional, physicochemical and organoleptic alterations (2). For any food there is potential for it spoilage which can occur at any point between the acquisition of materials and the eventual consumption of a food product. From processing, packaging, distributing, marketing, transportation, storage and final use by the consumer. The challenge is how to ensure that foods are protected against food spoiling microorganisms and thereby increasing the shelf-life of the food. Different preservation techniques have been used and most of them act by preventing or inhibiting microbial growth (e.g., acidifying, drying, fermenting, curing, vacuum packing conserving, freezing, chilling, modified atmosphere packing, and adding preservatives). Their limitations necessitated the need for a novel preservation technique that will provide wide efficacy capable of preventing or reducing microbial or physical degradation of food and at the same time maintain nutritional and sensory quality.

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Modern technologies including UV irradiation, magnetic technology, high hydrostatic pressure, ultrasound, pulsed electricity, high intensity pulsed light and ozone (1). They contribute in preserving the antioxidants status, the ascorbic acid content, the storage stability and food safety. Considering that ozone is highly reactive, non-penetrable and can subsequently decompose to non-toxic oxygen leaving a non-residual feature in food after treatment makes it a suitable technology. Ozone in food and feed has been noted to offer negligible loss nutrients or sensory qualities in food; it does not raise the temperature of the food during processing (1). It is use in disinfection of water, meat treatments, fish, vegetables, fruits, swimming pools, waste water treatment and some dry food such as Maize and grain. This study is to critically evaluate the advantages and limitations of ozone application technology.

Ozonation is simply a chemical technology in food processing that requires exposing food or an intermediate product to ozone (3).

2. Ozone generation

Ozone is a strong antimicrobial agent with a wide-spectrum status because it work against microorganisms such as bacteria, protozoa, fungi, viruses, as well as bacterial and fungal spores found in fruits and vegetables. It is generated by means of splitting a diatomic molecule (O_2) of oxygen to form significantly free radical oxygen which in turn form a reaction with another diatomic oxygen molecule and subsequently form a triatomic (O_3) molecule called Ozone (3).

Whenever a high tension and low tension electrodes are divided by a corona dielectric medium and a narrow discharge gap they lead to formation of some part of the corona equipment and increase the process. An electron with sufficient kinetic energy (6-7eV) helps to dissociate the oxygen molecule with a particular amount of collision leading to formation of ozone from each oxygen atom. 1-3% of ozone can be raised when air molecules pass through the generator, however with pure oxygen, up to 6% ozone is obtainable (4).

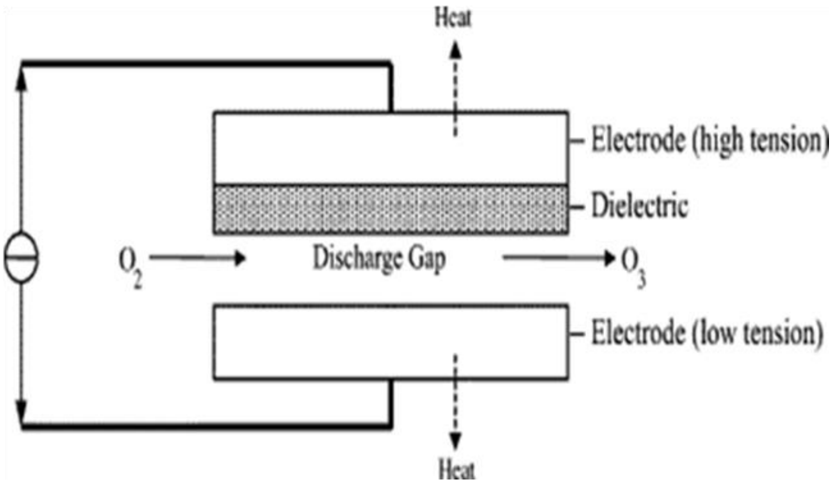

Figure 1 Sketched diagram of ozone generation by corona discharge method (4).

3. Antimicrobial effect of Ozone

Ozone has the ability to act on various organisms that includes Gram-positive and Gram-negative bacteria and their spores as well as vegetative cells (5). Ozone have been involved with antimicrobial activity in Gram-positive bacteria such as; *Listeria monocytogenes, Staphylococcus aureus, Bacillus cereus, Enterococcus faecalis* and Gram- negative like *Pseudomonas aeruginosa, Yersinia enterocolitica yeasts, Candida albicans* and *Zygosaccharomyces bacilli* and spores of and spores of *Aspergillus niger* (5,6). It is highly effective against protozoa, bacteria, viruses, fungi and even bacterial fungal spores (6, 7, 1). It has the ability to degrade mycotoxins largely produced by fungi through the process of oxidation of most unsaturated chemical bonds in the cell surface (8).

4. Microbial Inactivation

Ozone's ability to destroy microorganisms is through the oxidation of some important cellular components, specifically the bacterial cell surface being the major target [11]. It does this through two different mechanisms; the first is the oxidative process of sulfhydryl groups and amino acids of the enzymes, the peptides and proteins whereas the second mechanism is the oxidative process of polyunsaturated fatty acids to peroxides (5). It can destroy various microorganisms by the progressive oxidation of important cellular components [17]. It act directly against unsaturated lipids around the microbial cell envelope and subsequently causing a significant leakage of cell contents which leads to microbial lysis.

Table 1 Effect of different ozone treatment on food.

Food	Application form	Microbial population	Log-Reduction	Quality and nutritional Attributes	Source
Apple cider	Ozone gas by pumping	*Salmonella*	1.0		(9)
Apple cider		*Escherichia coli*O157:H7	5.0		(10)
Apple cider	Ozone by Bubble column reactor	*Escherichia coli*ATCC 25922 and NCTC 12900	5.0		(11)
Orange juice	Ozone by pumping	*Escherichia coli* O157:H7 *Salmonella*	0.4 1.8		(9)
Orange juice	Ozone by Bubble column reactor	*Escherichia coli*ATCC 25922 and NCTC 12900	5.0		(12)
Orange juice	Ozone gas by pumping	Yeast *(S. cerevisiae)* decreases		Ascorbic acid (decreases) Significant diference in colour	(13)
Orange juice	Ozone by Bubble column reactor	*Listeria monocytogenes Listeria innocua*	5.0		(13)
Apple cider	Ozone gas bubbled into juice	Patulin (mycotoxin) (decreases)		Sediment increases and colour remain the same	(14)
Apple juice	Ozone gas sparged into juice	Patulin (mycotoxin) (decreases)			(15)
Orange juice	Ozone gas By bubble column reactor)			Colour (decreases), cloud value (No change), pH(no change), Ascorbic acid (decreases)	(16)
Tomato juice				Colour (decreases), cloud value (No change), pH(no change), Ascorbic acid (decreases)	(17)

Strawberry Juice	Ozone gas By bubble column reactor			Colour (decreases), pH(no change), Ascorbic acid (decreases), anthocyanins (decreases)	(17)
Blackberry Juice				Colour (no change) pH(no change), ascorbic acid (decreases), anthocyanins (no change)	(18)
Apple cider	Ozone gas by pumping	Moulds (decreases); yeast (decreases)		Sediments(decreases)	(19)
Apple cider		*Escherichia coli*O157:H7	5.0		(10)
Meat	Ozonation	*Escherichia coli* *Califorms* *S.trphimurium* Aerobic plate count	6.51 5.89 5.70 7.20	Change in colour, lipid stability aroma and flavor. No change of odour	(20)
Lettuce	Ozonated water	*Shigella sonnei*	1.8		(21)
Tomatoes		Mesophilic bacteria psychrotrophic bacteria yeasts moulds	1.07 1.27 0.5 0.5	Appearance (no change), taste (no change), aroma (decreases) and overall quality (no change), texture (increases), Ascorbic acid (increases), glucose (increases), fructose (increases)	(22)
Strawberry	Ozonated air	Fungal decay (delayed)		Sucrose (decreases), glucose (increases), fructose (increases), vitamin C (increases); aroma quality (increases)	(23)
Strawberry	Continuous gaseous ozone Pressurised gaseous ozone	*Escherichia coli* O157:H7 Salmonella enterica	2.96 2.60		(22)
Raspberry	Continuous gaseous ozone Pressurised gaseous ozone	*Escherichia coli* O157:H7 Salmonella enterica	3.75 3.55		(22)

Lettuce	Ozonated water	Polyphynol oxidase decreases		Antioxidants (no change), vitamin C (decreases), visual appearance (no change)	(24)
Strawberry		*Escherichia coli*O157:H7 *Salmonella enterica*	2.90 3.3		(22)
Raspberry	Aqueous ozone	*Escherichia coli*O157:H7 *Salmonella enterica*	5.6 4.50		(22)
Blueberries	Aqueous ozone Gaseous ozone	*Escherichia coli*O157:H7 *Salmonella enterica*	3.0 2.2	Colour (no change)	(22)
Water melon	Ozone gas in cold water	aerobic plate count;	1-1.5	Colour and overall quality decreases	(25)
Celery	Ozonated water	Total number of bacteria polyphynol oxidase decreases	1.15	No change in sugar and colour (no change)	(26)
Green pepper	Gaseous Ozone	*Escherichia*. *coli*O157:H7	5		(27)
Fresh-cut potato strips		coliforms and anaerobic bacteria decreases drastically		Shelf life and non-enzymatic browning increseses	(25)
Pistachio (Pistachio veral		*Escherichia. coli(*decrease*) and Bacillus cereus*(decreases)		pH (No change), and peroxide values (No change), colour (No change), fatty acid composition (No change)	(15)

5. Ozone on fungi

Basically fewer studies on the effect of ozone on filamentous fungi inactivation has been done but most of the problems relating to food decay at postharvest level are associated with fungi most of which are *Aspergillus, Penicillium* and *Fusarium* species (37). Most of the applications of ozone against fungi have to do with using gaseous ozone directly and evaluate the germination, sporulation, or growth of *Aspergillus, Penicillium and Fusarium species*. The table below shows a summary of ozone treatment against fungi.

Table 2 Summary of result obtained in different experiment involving ozonation showing effectiveness against microorganism on different food.

Microorganism	Application form	Matrix	main effect of Ozone after experiment	Reference(s)
Aspergillus fumigatus	0.6–1.9 g/m 3of gaseous Ozone (continuously)	Cultivated media	Filamentous fungi are less sensitive than bacteria	(20)
Aspergillus parasiticus	0.1 g/m 3of gaseous Ozone (occasional fumigation)	Maize	63% Reduction in fungal counts after 3 days of application	(20)
Penicillium digitatumand Penicillium italicum	0.1–2 g/m 3of gaseous Ozone , at 4.5–10°C	Lemons and Oranges	Increase in radial growth of *P. Italicum*,decrease in radial growth of *P. digitatum*, a decrease of sporulation in both	(6)
Penicciliumspp.	Gaseous Ozone at different levels	Cheese	fungal counts reduction on cheese surface and in the ripening room and	(31)
Total mycoflora	Gaseous form of Ozone	Barley	Reduction in mycelia growth and spores germination	[3]
Total mycoflora	0.01–0.02 g/metre cube of gaseous Ozone for 3 and 4 hours	Dried figs	fungal counts reduction	(32)
Micromycetes Fusarium, Geotrichum, Myrothecium, Mucor, Alternaria, Verticillium, Penicillium & Aspergillus	1.4 g/m 3of gaseous Ozone	Wheat	fungal counts reduction	(33)
Aspergillus niger	Gaseous Ozone	Onion	Reduction in spore germination, change of colony color, change of uniformity of colony, and formation of sterile mycelia	(34)
Fusarium, Alternaria, Penicillium, and Aspergillus Species	3.85 g/m 3of gaseous Ozone , for 1, 1.5, and 3 minutes	Seeds of wheat and pea, barley,	Reduction of fungal counts	(29)
Aspergillus nidulansand A. ochraceus	0.4–0.6 g/m 3of gaseous Ozone	Cultivated media	Reduction of growth rates more pronounced at lower ozone levels;*A. nidulans* spores	(35)

	at 18 °C, for 10 minutes 0.0004 g/m 3of gaseous Ozone at 18 °C, for 12 days		is more sensitive than *A. ochraceus*	
Total mycoflora	0.002, 0.006, and 0.01 g/metre cube of gaseous Ozone for 1 hour	Date fruits	fungal counts reduction	(36)

6. Conclusion

Application of ozone as a replacement to traditional sanitizers requires thorough understanding of its benefits and limitations; in some food a lesser log reduction rate is observable virtually less than the required 5 log reduction rate. This to say it effectiveness depends largely on factors such as the quantity applied, residual ozone in the medium, pH, temperature, humidity, additives surfactants, sugars, etc as well as the quantity of organic matter surrounding the cells . eg bubbling of ozone in stored apples inoculated with *Escherichia. coli*O157:H7 tends to be more effective than dipping in ozonated water, bubbling and dipping resulted in 3.7 log and 2.6 log reduction respectively. Table 1 and 2 demonstrated the positive and some negative effect of ozone in the food industries where we see high log reduction in some application and virtually low in others (<5.00), change in nutritional and sensory qualities such as loss of aroma, colour, ascorbic acid content, lipid stability etc is also observed in some application, it is therefore wise to say ozone has wide benefits in the food industries but at the same time has its own limitation even though some of the negative result obtained may be due to environmental factors, method of application, specific food characteristics and experimental error, it negative effect on humans especially on respiratory system is also a threat.

Compliance with ethical standards

The authors complied with ethical clearance throughout the, publishers and authors concent were put in place before venturing into the research work.

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Disclosure of conflict of interest

The authors declare no conflicts of interest in the work, all constructive criticism have been taking into consideration and authors agreed accordingly.

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