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 used 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 (O2) of oxygen to form significantly free radical oxygen which in turn form a reaction with another diatomic oxygen molecule and subsequently form a triatomic (O3) 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](image.png) 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* (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| Ozone gas by Bubble column reactor     | Escherichia coli O157:H7 | 5.0           |                                    | (10)   |
| Apple cider| Ozone by Pumping                       | Escherichia coli ATCC 25922 and NCTC 12900 | 5.0           |                                    | (11)   |
| Orange juice| Ozone by Pumping                       | Escherichia coli O157:H7 Salmonella | 0.4 1.8       | Ascorbic acid (decreases) Significant difference in colour | (9)    |
| Orange juice| Ozone by Pumping                       | Escherichia coli ATCC 25922 and NCTC 12900 | 5.0           |                                    | (12)   |
| Orange juice| Ozone gas by Pumping                   | Yeast (S. cerevisiae) decreases |                |                                    | (13)   |
| Orange juice| Ozone by Pumping                       | 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 sparged into juice               | Patulin (mycotoxin) (decreases) |                |                                    | (15)   |
| Orange juice| Ozone gas By bubble column reactor     | Patulin (mycotoxin) (decreases) |                | Colour (decreases), cloud value (No change), pH (No change), Ascorbic acid (decreases) | (16)   |
| Tomato juice| Ozone gas By bubble column reactor     |                       |                | Colour (decreases), cloud value (No change), pH (No change), Ascorbic acid (decreases) | (17)   |
| Food Item          | Treatment                          | Changes                                                                 | References |
|-------------------|------------------------------------|-------------------------------------------------------------------------|------------|
| 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)                                  | (19)       |
|                   |                                     | Sediments (decreases)                                                   |            |
| Apple cider       | Escherichia coli O157:H7           |                                                                         | (10)       |
| Meat              | Ozonation                           | Escherichia coli Califorms S. trpimurium Aerobic plate count            | (20)       |
|                   |                                    | Change in colour, lipid stability aroma and flavor. No change of odour   |            |
| Lettuce           | Ozonated water                      | Shigella sonnei                                                         | (21)       |
| Tomatoes          |                                    | Mesophilic bacteria psychrotrophic bacteria yeasts moulds                | (22)       |
|                   |                                    | Appearance (no change), taste (no change), aroma (decreases) and overall quality (no change), texture (increases), Ascorbic acid (increases), glucose (increases), fructose (increases) |            |
| Strawberry        | Ozonated air                        | Fungal decay (delayed)                                                  | (23)       |
|                   |                                    | Sucrose (decreases), glucose (increases), fructose (increases), vitamin C (increases); aroma quality (increases) |            |
| Strawberry        | Continuous gaseous ozone            | Escherichia coli O157:H7 Salmonella enterica                           | (22)       |
|                   | Pressurised gaseous ozone           |                                                                         |            |
| Raspberry         | Continuous gaseous ozone            | Escherichia coli O157:H7 Salmonella enterica                           | (22)       |
|                   | Pressurised gaseous ozone           |                                                                         |            |
| Item                  | Treatment       | Pathogen(s)                                      | Log Reduction | Effect on Parameters                                                                 |
|-----------------------|-----------------|--------------------------------------------------|---------------|--------------------------------------------------------------------------------------|
| Lettuce               | Ozonated water  | Polyphenol oxidase decreases                     |               | Antioxidants (no change), vitamin C (decreases), visual appearance (no change)        |
| Strawberry            | Aqueous ozone   | *Escherichia coli* O157:H7 *Salmonella enterica* | 2.90          | vitamin C (decreases)                                                                |
| Raspberry             | Aqueous ozone   | *Escherichia coli* O157:H7 *Salmonella enterica* | 5.6           | Colour (no change)                                                                   |
| Blueberries           | Aqueous ozone   | *Escherichia coli* O157:H7 *Salmonella enterica* | 3.0           | Colour (no change)                                                                   |
| Watermelon            | Ozone gas in cold water | aerobic plate count; | 1-1.5       | Colour and overall quality decreases                                                  |
| Celery                | Ozonated water  | Total number of bacteria  | 1.15          | No change in sugar and colour (no change)                                             |
| Green pepper          | Gaseous Ozone   | *Escherichia coli* O157:H7                      | 5             |                                                                                       |
| Fresh-cut potato strips |                | coliforms and anaerobic bacteria decreases drastically |               | Shelf life and non-enzymatic browning increases                                        |
| 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) |

### 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 digitatum* and *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) |
| *Penicilliumspp.* | 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 nidulans and 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) |
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 its 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, its 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 consent 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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