Application of Ozone in Food Processing Operations

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Abstract

The potential utility of ozone in food processing lies in the fact that ozone is a 52% stronger oxidant than chlorine. The widespread use of chlorine by the US food industry is under scrutiny and the acceptance of chlorine as the primary sanitizing agent for food process operations is being reconsidered by many processors and regulators. By US law, ozone is classified as a food additive thus its use in or on food is regulated. This classification disallows for ozone's use as a direct contact food sanitizing agent. However, quite recently the US Food and Drug Administration (FDA) has been petitioned for the acceptance of ozone as a Generally Recognized As Safe (GRAS) substance. Prior to the regulatory acceptance of ozone as a direct contact food sanitizer, water containing an ozone residual can not be applied to food. This is not to imply that ozone has no other useful agricultural applications. Numerous agricultural applications exist aside from the use of ozone as a sanitizing agent for commodities or produce. The focus of this work is to determine the efficacy of ozone as a chlorine replacement in the sanitation of whole, fresh fruits and vegetables. A 200 gallon flume wash test system was constructed in the fruit and vegetables pilot plant of the Food Science and Nutrition Department, California Polytechnic State University, San Luis Obispo. Research studies, using ozone in pure water as a direct contact sanitizing agent have been conducted on several agricultural commodities and the results are promising. In the washing of broccoli with water containing up to I ppm dissolved ozone, the contact time (CT) necessary for a one log-fold reduction in aerobic plate count microorganisms was 6.0 minutes. Ozone is an effective germicide and many studies over the years have demonstrated greater lethality rates, however, contact times may be too excessive for some fast-paced industrial operations. Relationships between lethality rate and higher ozone concentrations, or combining ozone with other germicidal processes or pro-oxidants have not yet been conducted. Regard less, the utilization of ozone by the food processing industries will continue to grow, especially in light of the fact that ozone is gaining industry acceptance and limitations are being imposed on the use of chlorine and other chemical sanitizing agents. Ozone does not leave a chemical residual and for some industrial sanitizing operations this may be seen as a disadvantage. But, when it comes to our food supply, no residual, and fewer residual by-products is a distinct advantage.

INTRODUCTION

Numerous studies over the years have shown that ozone can act as an effective sanitizing or germicidal agent. Ozone has mainly been used reduce the organic load and disinfect water supplies, mostly in Western Europe (Diaper, 1975; Kinman, 1972). As of the 1980's the state of California, and the US in general, are beginning to take advantage of ozone for potable water treatment as evident by the Sylmar facility (Glaze, 1986) and other large water treatment facilities. Quite recently, the city of San Luis Obispo and many other municipalities are using ozone for water treatment and swimming pool sanitation. A large food processing facility may have the same water requirements as a community of five to fifteen thousand people.

The potential utility of ozone to the food industry lies in the fact that ozone is a 52% stronger oxidant than chlorine and acts over a wider spectrum of microorganisms than does chlorine and all other common disinfectants (Katz, 1986). Next to fluorine, ozone is known as the most powerful oxidizing agent readily available to humans. Ozone is effective at killing microorganisms through oxidation of their cell membranes, and most of the pathogenic foodborne microbes are quite susceptible to this oxidizing effect. During food processing operations, surface disinfection of the raw or partially-processed commodities is very important. It is believed that approximately 30% of fresh produce is lost by microbial spoilage from the time of harvest, through handling, storage processing, and to consumers home up to the time of consumption (Beuchat, 1991). The presence of pathogenic microorganisms is of paramount concern to the food processor, and ultimately the consumer. According to the US General Accounting Office (GAO) testimony (Robinson, 1996), the Center for Disease Control and Prevention (CDC) has targeted four bacterial pathogens most commonly identified with outbreaks of foodborne illness: *Escherichia coli* 0157:H7, *Salmonella enteriditis*, *Listeria monocytogenes*, and *Campylobacter jejuni*. At least 30 pathogens are associated with foodbome illness, but these four are most common with the greatest economic impact. CDC tracks cases of illness caused by *Shigelia spp*., but not *L. monocytogenes*, so *Shigella* is of major concern medically, if not as much so economically. Two recent US Department of Agriculture (USDA) estimates place some of the costs associated with foodborne illness in the $5.5 billion to $22 billion per year range. Other estimates also place *Staphylococcus aureus* among foodborne pathogens leading to high medical costs and productivity losses (Aldrich, 1994).

Most of the microorganisms associated with fruits and vegetables are harmless to humans. This includes the lactic acid bacteria, coryneforms, pseudomonads, xanthomonads, micrococci, many fungi and coliforms. These microorganisms do play an important role in the spoilage of food and dictate the shelf-life of the fresh fruit and vegetables. Most healthy raw produce will have on them anywhere from a few thousand to millions of microorganisms per gram. The presence of many of these microorganisms is a concern for causing product spoilage and normal washing procedures may reduce the indigenous microbial load on the surface by up to 99%. With an initial microflora of one to ten thousand microbes per gram, spoilage can occur within ten to fourteen days at a storage temperature of 40^0F. The lower the initial microbial load, the longer the expected shelf-life of the produce. Ozone is a very effective germicide; viruses, bacteria, yeast, mold, spores, and aemebocytes are all killed with enough exposure (Restaino et al, 1995; Finch and Fairbairn, 1991; Korich et al, 1990; Larson 1988).

This germicidal effect is not the only advantage ozone may have for a food processor. Ozone has a variety of uses related to agriculture and food processing. For the most part, such uses are unrecognized and the utility of ozone to the US food industry goes largely untapped. The agricultural applications of ozone would include: Treatment of process wash waters prior to and during use (increasing water re-use); treatment of discharge waters (reducing BOD and surcharges for water discharge); production of sanitary packing ice (of value to seafood products); aquaculture water maintenance; maintenance of drip irrigation lines; pond water maintenance; treatment of irrigation water prior to use; soil fumigation; washing of peels; sanitation of coolers and storerooms; container or packaging material sanitation; and, spray washing or other wash processes. Certainly, other agricultural applications exist and this is increasingly being recognized (Giacchetti, 1997).

It is believed there are no lingering chemical residuals in ozone-treated water, since it dissipates rapidly into oxygen, and this may be true in a pure system. In the processing of our food, water used for the washing, cooling and transport of fruit and vegetables accumulates a high organic load. Research performed by Environmental Protection Agency (EPA) scientists (Richardson et al., 1996) demonstrated that ozone is far more benign in the generation of toxic by-products when compared to the common sanitizing agents chlorine and chlorine dioxide. Recently, the USDA has granted approval for the use of ozone in recycling poultry chill-water, after more than a decade of research to support such use (Sheldon and Brown, 1986). This was a great leap forward for the use of ozone in food processing. At the time this abstract was first submitted to IOA, ozone was not accepted as a direct-contact food sanitizing or germicidal agent. Since that time a petition was submitted to the FDA requesting that ozone be granted GRAS status (Graham, 1997). This level of acceptance would allow for the widespread use of ozone in food processing operations and not put restrictions on the contact of ozone with foods.

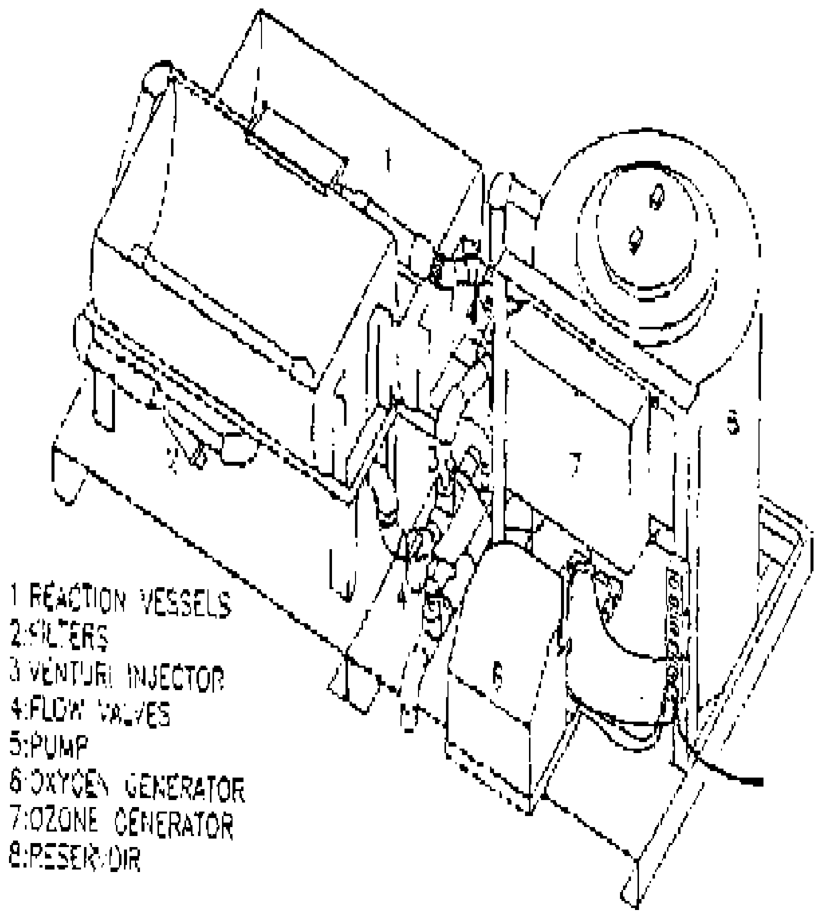
The broad objective of this research is to support the approval of ozone as a food sanitizing agent and educate the food processing industry as to its potential for utilization. Ozone will not be the cure-all for the prevention of foodborne illness, nevertheless, there are numerous circumstances and processes where ozone may prove to be superior to the germicides now in common use.

Materials and Methods

For most tests, the commodities were obtained directly from commercial packing houses. In some cases the commodities were personally collected right from the transport gondola or bin at the processing facility. In a few cases during initial germicidal efficacy tests, the commodities were purchased from a local grocery store and in a few instances, the commodities were collected from the Cal Poly farm. In all, broccoli, broccoflower (a broccoli and cauliflower hybrid), carrots, onions, and tomatoes have been tested. Tomatoes were of the variety called "Jackie". These tomatoes are harvested green and immature subsequently undergoing accelerated ripening and distribution to fresh market. In other words, all commodities are fresh-market produce not intended for further processing. Approximately 30 to 60 lbs of produce was utilized per experiment, depending on the number of analyses to be performed.

Approximately 3 kg (7 lbs) of the test commodity is placed in a pre-sanitized polypropylene mesh bag and washed in the flume for 3 minutes with no ozone. Another sample was collected as a negative control (raw; no water or ozone) and after laboratory preparation of these control samples the water in the 200 gal test system was charged with ozone to a level of 0.75 to 1.0 ppm (mg/L). Samples were then treated in the water flume for 1, 3 and 10 minutes. Ozone concentration was monitored indirectly using an ORP probe and periodically the ozone concentration in the flume water was determined using the Indigo Method (AccuVac Ampoules; HACH Corp.). Microbiological analyses were performed immediately after the wash treatments in the on-site laboratory.

Microbiological examinations included both aerobic count plates and coliform count plates. American Public Health Association (Speck, 1976) and FDA procedures (FDA/BAM, 1995) were followed for all tests and 3M Petrifilm was used as the plating medium. Methods for the handling and enumeration of plates were according to the manufacturer's specifications.



The ozone test system was constructed to mimic the turbulence found in an industrial flume wash for fruit or vegetables (see Figure 1; Fiori, 1994). The system has a 125 gallon reservoir with a one horsepower centrifugal pump capable of moving 40 gallons per minute over the 12 by 1 inch weir. Commodities are immersed in the lower of the two reactor vessels where turbulence is at its greatest. The air preparation system utilizes pressure swing adsorption technology and produces approximately 70% pure 0_2 as a feed gas to the ozone generator. The ozone generator (Model P-2000, ClearWater Tech) utilizes coronal discharge technology. The unit is capable of producing a maximum of 15.4 grams of ozone per hour. A portion of the water flow from the reservoir or reactor vessel is deviated from its course to the pump and is routed to flow through the Mazzie injector. Water flow creates negative pressure and this draws the ozone and air mixture into the injector. The reservoir allows for longer contact time between the ozone gas and the water, increasing the transfer of the ozone to the bulk of the water.

Results and Discussion

The results of washing experiments depicted in Figure 2 below demonstrate CT Values of 9.6 minutes per log-fold reduction in aerobic microbial load for carrots, 7.5 minutes per log-fold reduction for broccoflower, and 6.0 minutes per log-fold reduction for broccoli. For all CT Values, the ozone concentration is standardized at 1 ppm. Six minutes may be too long for a fast-paced industrial wash process. Consequently, the flume water may require an ozone concentration of up to 2 ppm, thus reducing the time factor in half for an equivalent microbial kill. As evident from the data, every commodity is unique and will require a specific treatment to achieve a reasonable reduction in indigenous microbial load. There are numerous variables involved in the washing of produce. Ozone concentration and organic load were controlled in these experiments, as was the time of exposure. Other than those factors, variables evident in a flume wash system might include; the temperature of the water, the hardness and general chemistry of the water, flow rate in the flume and the contact system, surface area of the commodity, non-target demand substances, types and load of microorganisms present on the commodity, and other variables. Industrial wash systems may also employ surfactants and calcium salts which may or may not have an effect on the CT Values achieved.

Every food processing facility is unique and many of these facilities will be able to adapt or retrofit their system to the use of ozone, removing the chlorine which is now in widespread use. If a system is to be retrofitted, an evaluation must first be performed to be sure that safety issues are all addressed and that there are compatible materials used in the construction of the wash water system. In many cases, it may be advantageous to add a contact reservoir and some type of filtration apparatus to improve on ozone dissolution and contact, and keep the level of non-target demand substances to a minimum. Some produce enters the processing facility with a high organic load (carried in from harvest) and multiple stage wash systems may be the only way to achieve a kill of the microbes with the available ozone in a reasonable period of time. In some systems, such as for tomatoes, the initial wash is at a temperature of 105^{O}F. The high temperature combined with high organic load makes ozonation of the first wash tank difficult.

Figure 3 shows the reduction in microbial load as a factor of time of exposure. Data presented is an average of three experiments and error bars represent one standard deviation from the mean. Treatments given to the tomatoes are represented along the x-axis (not to scale). Raw tomatoes are untreated; N3 are washed for three minutes in water with no ozone; 1M, 3M, and l0M represent the time of exposure to wash water containing ozone at a concentration of approximately 1 ppm. The experimental system, in the case of this commodity, may not accurately reflect practices in industry since the fresh-market tomato industry typically uses a multi-stage wash system with the first stage having heated water, as mentioned above. Regardless, it is no surprise that ozone is able to have a germicidal effect on the indigenous microflora of fresh tomatoes. One factor not mentioned thus far would be the contribution ozone would have in reducing cross-contamination of the commodity from one load to the next as they pass through the wash system. By maintaining a reduced microbial load in the wash water, one load of produce, which may have a pathogenic microorganism like *E. coli* or spoilage microorganisms not found on other loads, will not contaminate all the produce passing through the wash system in a given period of time. Thus, water maintenance is a major concern to the food processor and should be reason enough to use ozone as a sanitizing agent for their wash water systems.

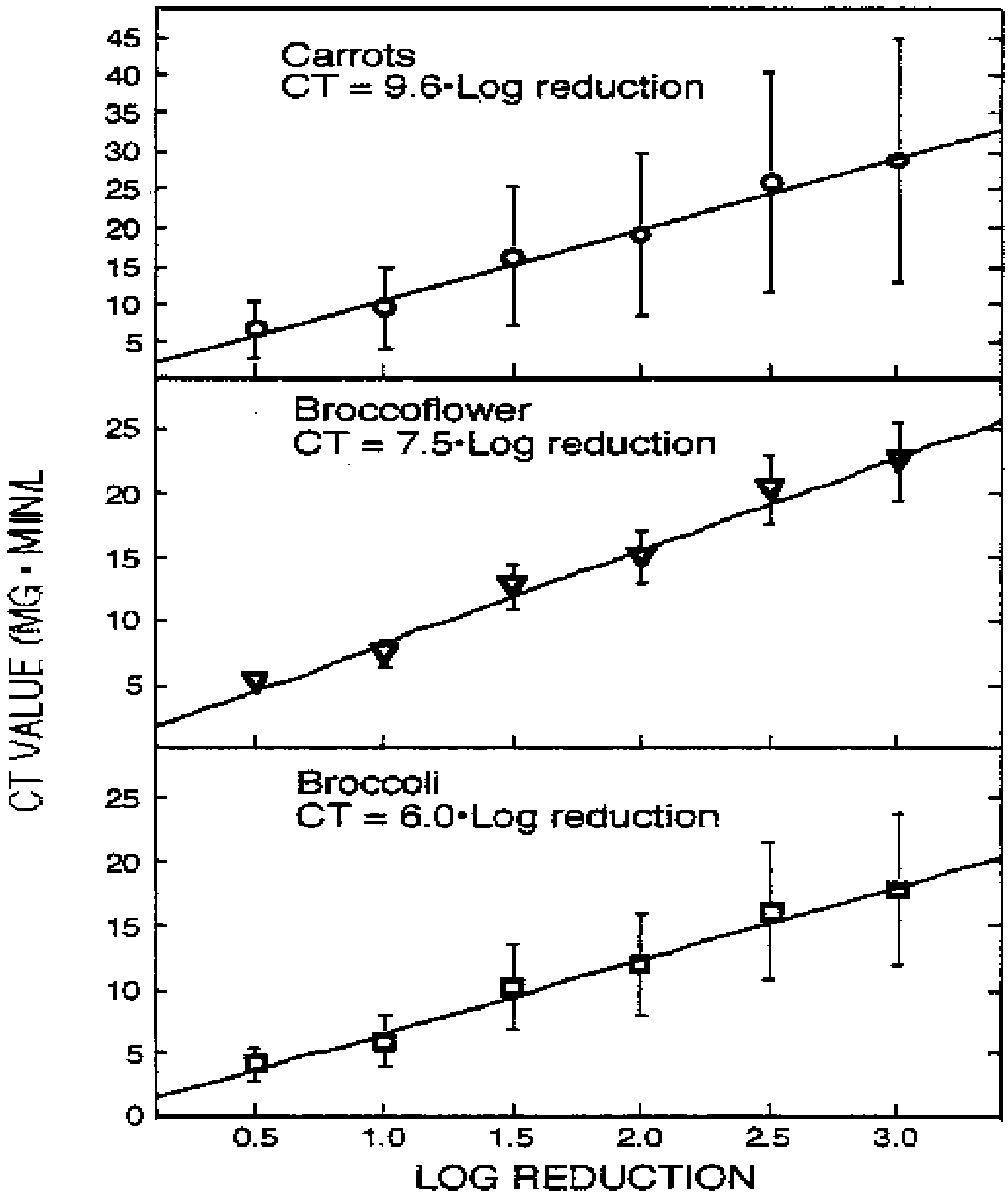


Figure 2: CT Values as time in minutes per log reduction for carrots, broccoflower, and broccoli. Values reported were determined by averaging of 5, 2, and 11 experiments respectively.

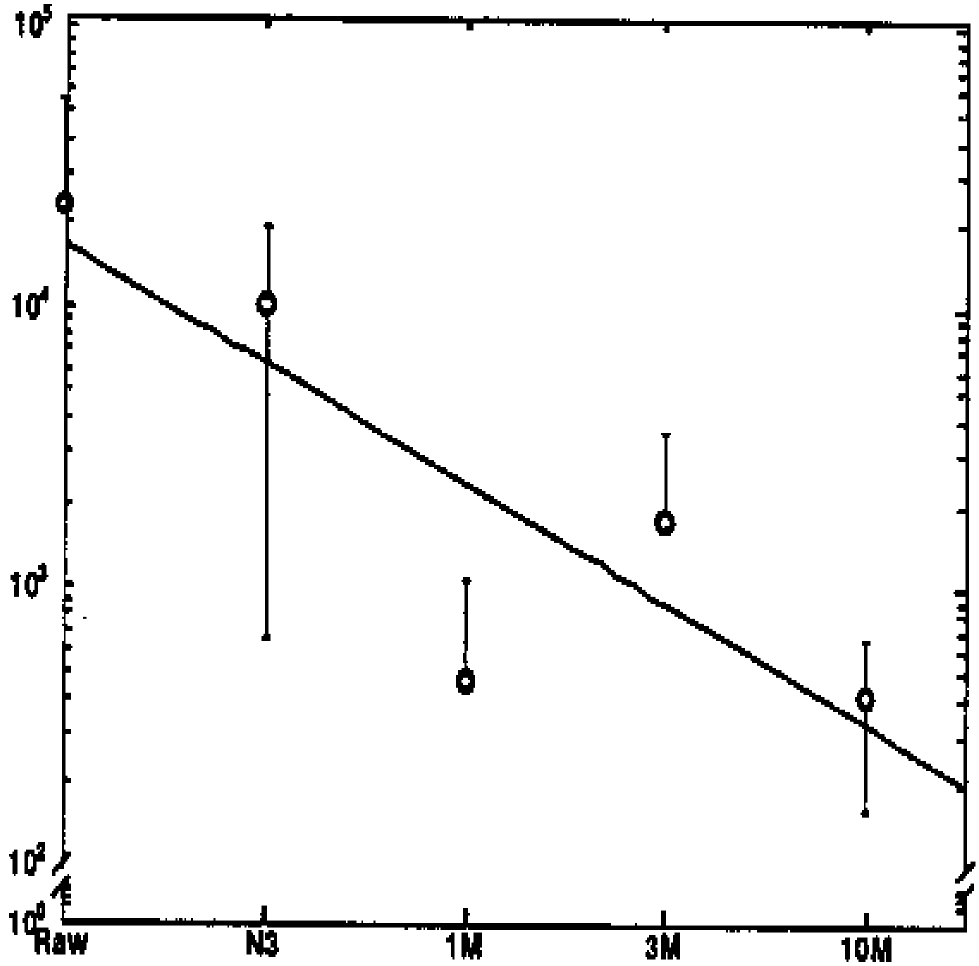


Figure 3: Germicidal effect of ozone on tomatoes. Raw fruit, wash with non-ozonated water (N3), one minute, three minute, and ten minute washes with water containing ozone at approximately 1 ppm (1M, 3M, 10M, respectively).

Conclusions

Every commodity is unique in both its physical chemistry and handling practices by the food industry. Most every food processing operation and facility is unique in the manner by which they wash their raw agricultural commodities prior to further processing or packing. Ozone is at minimum as effective as common sanitizing agents used in wash waters in the food industry. Very soon, ozone will gain widespread acceptance as a direct contact food sanitizing agent. And, for many raw whole agricultural commodities ozone will prove to be the chemical of choice for sanitary washing.

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References

Aldrich, L. 1994. Food safety policy: Balancing risk and costs. *In: Food Review*. USDA Economic Research Service, l7(2):1O-l 1.

Beuchat, L.R. 1991. Surface disinfection of raw produce. Dairy, Food and Environmental Sanitation 12(1):6-9.

Diaper, E.W.J. 1975. Disinfection of water and wastewater using ozone, p.21 1-231. *In : Disinfection of water and wastewater,* J.D. Johnson (Ed.), Ann Arbor Science Publ., Inc., Ann Arbor, MI.

Finch, G.R. and N. Fairbairn. 1991. Comparative inactivation of poliovirus type 3 and MS2 coliphage in demand-free phosphate buffer by using ozone. Appl. Environ. Microbiol. 57(1l):3 121-3126.

Fiori, S.R. 1994. M.S. Thesis, Cal Poly State University, Civil and Environmental Engineering Department.

Food and Drug Administration. 1995. Bacteriological Analytical Manual, 8th Edition. AOAC International publications, Gaithersgurg, MD.

Giacchetti, N. 1997. Ozone: Oh so effective. American Vegetable Grower 2:26-27, 36.

Glaze, W.H. 1986. Reaction products of ozone: A review. Environmental Health Perspectives. 69:151-157.

Graham, D. 1997. Use of ozone for food processing. Food Technology 51 (6):72-75.

Katz, D. 1986. Ozone Technology. Golf Course Management. April:28-36.

Kinman, R.N. 1972. Ozone in water disinfection, p.123-144. In: Ozone in water and wastewater treatment. F.L. Evans (Ed.), Ann Arbor Scientific Publishers, Inc., Ann Arbor, MI.

Korich, D.G., J.R, Mead, M.S. Madore, NA. Sinclair, and C.R. Sterling. 1990. Effects of ozone, chlorine dioxide, chlorine, and monochloramine on *Cryptosporidium parvum oocyst* viability. Appl. Environ. Microbiol. 56(5): 1423-1428.

Larson, R.A., (Ed.) 1988. Biohazards of Drinking Water Treatment. Lewis Publishers, Chelsea, MI.

Mitstuda, H., H. Ominami, and A. Yamamoto. 1990. Synergistic effect of ozone and carbon dioxide gasses for sterilizing food. Proc. Japan. Acad. 66(B):68-72.

Restaino, L., E.W. Frampton, J.B. Hemphill, and P. Palnikar. 1995. Efficacy of ozonated water against various food-related microorganisms. Appl. Environ. Microbiol. 61(9):3471-3475.

Richardson, S., A.D. Thruston, Jr., and T.W. Collette. 1996. Future use of chlorine, chlorine dioxide, and other chlorine alternatives. Abstracts of the Annual Meeting of the Institute of Food Technologists, p.140.

Robinson, R. A. 1996. Food safety: Reducing the threat of foodborne illnesses. Testimony before the Subcommittee on Human Resources and Intergovernmental Relations. GAOIT-RECD-96-185.

Speck, M. L. 1976. Compendium of Methods for the Microbiological Examination of Foods, American Public Health Association. Washington, D.C.