OZONICS INTERNATIONAL

200 East 33rd Street, # 26J New York, NY 10016-4831 Tel. 212-6790679 Fax 212-6798008

A PRIMER OF WATER, OZONE, and HEALTH: The challenge of aquapollution

Gerard Sunnen, M.D.

Introduction

There was a time, not so long ago, when the supply of clean water seemed limitless. In the last hundred years, industry, demographics, climactic changes, and pollution have changed this picture dramatically. Today, the quest for fresh water, devoiamand on our stressed environment.

This article introduces some notions about water in its relationship to health, and explores some principles of water purification as it may apply to potable water and to waters used for swimming, bathing, and water therapeutics, such as spas and hot tubs.

Touched upon are the processes of chlorination, ultraviolet application, and ozonation. Each has advantages and drawbacks. It seems that a cooperative marriage of these technologies could address the monumental task of cleansing the world's increasing stressed waters.

Aquapollution with microorganisms

An impressive spectrum of pathogenic organisms may be present in contaminated waters. Disinfection implies the destruction of all disease-producing organisms, while sterilization signifies the elimination of all organisms. Water purification, ideally needs to aim between the two. An abbreviated list of the numerous microorganism components of aquapollutants follow, attesting to the daunting task of properly disinfecting contaminated waters.

Bacteria. Bacterial species prone to contaminate waterworks belong to numerous families:

Enterobacteriaceae constitute a large group of bacteria whose natural habitat is the intestinal tract of humans and animals, namely: *Escherichia, Salmonella, Shigella, Klebsiella, Enterobacter, Serratia, Proteus, Morganella, Providencia* and *Yersinia*.

Escherichia coli commonly causes acute gastroenteritis and urinary tract infections. Bacterial toxins damage the intestinal mucosa producing hemorrhagic colitis. In severe cases, E. coli may invade other organs systems including blood, causing bacteremia and widespread dissemination. Bacterial invasion is more likely in hosts with weakened resistance (e.g., cancer, cirrhosis, diabetes, immunocompromise; or receiving steroids and antineoplastic drugs).

Salmonella species capable of infecting human hosts include *Salmonella thyphi* and *Salmonella parathyphi*. Thyphoid fever is transmitted by contaminated water more often than by food and causes significant worldwide mortality. Some individuals are chronic enteric carriers. The clinical syndrome includes fever, prostration, abdominal distress, and skin rash.

Shigella are slender thin bacterial rods responsible for Shigellosis (inflammatory dysentery), marked by fever, severe intestinal distress, and dehydration.

Streptococcus species are spherical cocci arranged in necklaces. These toxin-producing facultative anaerobes cause virulent pharyngitis, tonsillitis, scarlet fever, pneumonia, rheumatic fever, glomerulonephritis, endocarditis, and septic arthritis.

Staphylococcus species freely live on human skin and the mucous linings of the nasopharyngeal passages. They can readily invade tissues through their aggressive growth rate and the production of toxins. Clinical manifestations may include abscess, vascular thrombosis, osteomyelitis, pneumonia, endocarditis, and meningitis.

Pseudomonas aeruginosa is a motile moisture-tropic bacillus responsible for many hospital infections. Pseudomonas has been implicated in the colonization of skin ulcers, sinusitis, pneumonia, otitis, and conjunctivitis. It readily infects wounds, compli-

cating their resolution.

Legionella pneumophilia are small, slow-growing intracellular organisms fond of warm moist environments. Once in the lungs, *Legionella* causes an acute, febrile, potentially fatal respiratory illness, Legionnaire's disease. Over twenty species of Legionella are capable of causing human pathology.

Chlamydia constitute a large group of intracellular organisms resembling Gram-negative bacteria and containing large amounts of lipids. Since they cannot synthesize ATP, however, they are obligate parasites. *Chlamydia trachomatis* causes swimming pool conjunctivitis.

Mycobacteria are thin straight aerobic rods, noted to be more resistant to chemical agents than other bacteria due to the fortified composition of their cell walls. The most recognized *Mycobacterium* disease is tuberculosis, transmitted by infective droplets. Many species, however, are present in water and cause disease. *Mycobacterium mirinum, M. ulcerans, and M. kansasii* are found in swimming pools and cause superficial granulomatous ulcerating conditions.

Vibrio cholerae infection, caused by a short, comma-shaped, toxin-wielding aerobic bacterial rod, is prevalent worldwide. *Vibrio* provokes the fulminant hypersecretion of fluids and electrolytes in the intestinal tract, potentially leading to fatal electrolyte dysequilibrium.

Viruses are intracellular parasites that require the energy of a host cell in order to replicate. Numerous viral families inhabit contaminated waters.

Viruses identified in impure waters tend to belong to the group of non-enveloped or naked viruses. This is logical because the envelopes of viruses are designed for life in the delicately balanced milieu of their mammalian hosts. On the other hand, naked viruses are protected by robust protein nucleocapsids that make them resistant to challenging environmental conditions.

Enteroviruses constitute a large family comprised of polioviruses, coxsackieviruses and echoviruses. Poliovirus enters the mouth, multiplies in the small intestine and the reticulo-endothelial systems, eventually invading the nervous system. It is responsible for minor poliomyelitis, marked by recovery, and major poliomyelitis, associated with paralysis. Coxsackievirus is associated with Herpangina, Hand-foot-and-mouth disease, epidemic pleurodynia, and aseptic meningitis. Echoviruses produce colds and aseptic meningitis.

Hepatitis A, another enterovirus found in contaminated waters, is transmitted intestinally and causes acute hepatitis, marked by nausea, vomiting, headache, chills and abdominal pain.

Rotaviruses, seen under the electron microscope, appear as round spheres with symmetrical stipples giving them the appearance of a wheel (*Rota*: wheel). Rotaviruses are a major cause of gastroenteritis, especially in children.

Caliciviridae whose spherical viral particles show 32 surface depressions (*calyx*: cup) and the closely related *Astroviridae* (*Astro*: star) are commonly found in polluted waters. Gastroenteritis (Norwalk) and hepatitis E are the main clinical manifestations of these families.

Adenoviruses (*Adeno*: adenoid tissue) often inhabit swimming pools, and multiply in the conjunctiva, the pharynx, and the small intestine. Pharyngitis, pneumonia, acute pharyngo-conjunctival fever, and epidemic keratoconjunctivitis in children and adults are its clinical manifestations.

Fungi. About one hundred among the thousands of species of molds and yeasts produce disease in humans. Many exist in unclean water systems. Fungal families capable of producing human disease include:
Dermatophytoses are fungi causing infections of the skin, hair, and nails. Among them: *Epidermophyton, Trichophyton* (Tinea pedis or Athlete's foot; Tinea unguium) and *Microsporum. Candida albicans,* a yeast, causes erythematous itchy skin patches, often where skin meets mucous membranes or in areas of moisture, as in skin folds. *Candida* is implicated in paronychia, a painful inflammation of the nail bed. *Pityrosporum orbiculare* causes Tinea versicolor, a hypopigmented skin condition with cosmetic implications. Cryptococcus presents as ulcerated pustular and nodular skin lesions, and in immunocompromised individuals

OZONICS INTERNATIONAL
200 East 33rd Street, # 26J New York, NY 10016-4831 Tel. 212-6790679 Fax 212-6798008

may involve the lungs and the meninges.

Protozoans commonly found in water include *Giardia lambia*, *Cryptosporidium*, and free-living amoeba (*Acanthamoeba, Negleria*). Because protozoan oocysts have thick shells, their inactivation requires higher chlorine, ultraviolet, or ozone concentration and contact time than are needed for bacterial or viral inactivation.

Giardia causes water-vectored epidemics. Trophozoites freely live in contaminated waters. Once ingested, they attach to the small intestine mucosa, multiply, and are excreted. Symptoms include nausea, abdominal cramps, intestinal distress, headache, fever, chills, and malaise. Some individuals can remain asymptomatic carriers.

Cryptosporidium protozoans replicate intracellularly in the mucosal cells of the small intestine. Oocysts are shed intestinally. Often absorbed through contaminated waters, oocysts, after an incubation period of a week or so, produce an acute illness with abdominal distress, fever, and malaise. This gastroenteritis may be especially disabling to immunocompromised hosts.

Entamoeba histolytica infection yields amoebic dysentery. *Balantidiumcoli* infection causes Balantidiasis with marked intestinal distress. Other pathogenic protozoans include *Isosporium, Cyclosporium*, and *Microsporium*, the latter frequently implicated in AIDS-related gastrointestinal disturbances.

Helminths are parasitic worms**.** Among helminthes residing in contaminated waters capable of producing human disease are *Ascaris lumbricoides, T. solium, and Tricuris trichuria.*

Aquapollution with particulate matter: Filtering and flocculation

Water often contains suspended coarse particulate matter. Sieves filter this unsettled pollutants in a first step in the water purification process. A procedure of flocculation and finer filtration removes finer particles in colloidal suspension.

Flocculating agents may include chemicals such as polyaluminum chloride and aluminum hydroxide. Ozone itself is an excellent flocculating agent. Once fine particles are aggregated appropriate filters can remove them.

Aquapollution with chemicals: The challenge of oxidation

Today, organic complex molecules are ubiquitous in the environment. Industry generates thousands of such molecules that all too readily make their way into aquifers. Oxidation, the process of giving a molecule an oxygen atom in exchange for its electrons, is the most effective method of neutralizing the toxicity of organic molecules and inorganic elements.

Ozone is a powerful oxidant, surpassed in this regard only by fluorine. Shonbein, in 1855, discovered that it reacted with ethelene. Exposing ozone to organic molecules containing double or triple chemical bonds yields many complex and as yet incompletely configured ephemeral transitional compounds (e.g., zwitterions, molozonides, cyclic ozonides), which may be hydrolyzed, oxidized, reduced or thermally decomposed to a variety of substances, chiefly aldehydes, ketones, acids and alcohols. Ozone reacts with saturated and unsaturated hydrocarbons, amines, sulfhydryl groups and aromatic compounds.

Oxidized by ozone's chemical action are phenols, tetrahydryl lead, oils, soaps, chlorinated alkanes and alkenes, tetrachloroethelene, pesticides, cyanide, iron, manganese, and taste and odor compounds. This pan-oxidizing property makes ozone a remarkable purifying agent for potable and bathing waters.

Chlorination: Chlorine and chlorine dioxide

Chlorine and chlorine dioxide are highly effective in inactivating a broad spectrum of bacteria, viruses, fungi, and protozoans. Historically, chlorine has been a godsend to public health, saving millions of lives since its inception as a water disinfectant.

When chlorine was initially applied to waters, the presence of organic compounds was minimal. Organic compounds, however, have proliferated dramatically in the last few decades. The addition of chlorine to waters containing organic compounds such as ammonia and bromine creates new compounds. The most extensively studied are the trihalomethanes, or THMs, comprised of a carbon atom connected to one hydrogen, and three halogen atoms. Chlorinated drinking and bathing waters contain measurable levels of four THMs, namely chloroform, chlorodibromomethane, bromodichlomethane, and bromoform. The

OZONICS INTERNATIONAL
200 East 33rd Street, # 26J New York, NY 10016-4831 Tel. 212-6790679 Fax 212-6798008

total allowable THM level in potable and bathing waters is subject to controversy, and standards vary around the world.

The presence of organic halogen compounds such as THMs is usually neither detected by odor nor by bodily reactions such as skin irritation. Rather, the importance of these compounds lies in their capacity to challenge the sensitive mucosal surfaces found in nasal passages and pulmonary linings. Present in the water, they readily evaporate to the water surface where they are breathed by swimmers. One of the possible resulting syndromes is hypersensitivity pneumonitis, characterized by cough, chest tightening and shortness of breath (McGregor 1993). THM's, in addition, are implicated in mutagenicity.

Passing water through granular activated charcoal (GAC) after chlorination may significantly decrease THM levels. This process, however, may considerably stress cost parameters.

At times, an ultraviolet or an ozone-based water purification system (or even a chlorination system) will fail, overwhelmed by bacterial growth. In such instances, it may require "shocking" by high chlorination in order to re-establish purity.

Because chlorinated water is toxic to fish and other biota, chlorine is removed from treatment plants before returning treated waters to the environment. Chlorination, in itself, does not enhance water's oxygen content.

Ultraviolet disinfection

Ultraviolet radiation (UV) is successful, at appropriate dosages, in inactivating bacteria, viruses, fungi, spores, and cysts. High particulate content in water mitigates against its efficacy.

In ultraviolet water disinfection technology, electromagnetic UV energy is generated by mercury arc lamps. Electrical discharges passed through mercury vapor produces UV energy capable of piercing through bacterial cell walls, viral envelopes and cyst capsules. With UV injury to their genetic matter, microorganisms are unable to replicate.

A solid advantage of UV water technology is that nefarious residues are not generated, thus leaving the environment unspoiled.

Disadvantages include (1) "photo reactivation," or "dark repair," a phenomenon where microorganisms, once UV exposure is ended, are able to reverse the genetic damage they have incurred, and (2) UV, in itself, does not enhance the oxygenation of waters.

Ozonation

Currently, in the United States, there are approximately 330 municipalities using ozone as their primary water disinfectant. Worldwide, the number exceeds 3000.

Ozone's physico-chemical and biochemical properties
The oxygen atom exists in nature in several forms: (1) As a free atomic particle (O), it is highly reactive and unstable (2) Oxygen (O2) its most common and stable form, is colorless as a gas and pale blue as a liquid (3) Ozone (O3), has a molecular weight of 48, a density one and a half times that of oxygen. It contains a large excess of energy in its molecule (O3 ? 3/2 O2 + 143 KJ/mole). It has a bond angle of 127?± 3? resonating among several hybrid forms, is distinctly blue as a gas and dark blue as a solid. Ozone forms the first layer separating the earth's biosphere and outer space, shielding life from the sun's virulent ultraviolet radiation (4) O4 is a very unstable, rare, nonmagnetic pale blue gas that readily breaks down into two molecules of oxygen.

Ozone action on pathogens

Bacteria fare poorly when exposed to ozone, a fact appreciated since the 19th century. Ozone is a strong germicide needing only micrograms per liter for measurable action. At a concentration of 1 mg per liter of water at 1?C, ozone rapidly inactivates coliform bacteria, staphylococcus aureus, and *Aeromonas hydrophilia* [Lohr 1984]. The inactivation rate of enteroviruses is more rapid than for *E coli*, takes place in relatively small concentrations of ozone, and is influenced by pH, temperature, and the presence of ambient organic compounds (Ivanova 1983).

OZONICS INTERNATIONAL

200 East 33rd Street, # 26J New York, NY 10016-4831 Tel. 212-6790679 Fax 212-6798008

Enterobacteriaceae form a large group of microorganism families whose natural habitat is the intestinal tract of humans and animals. Consequently, they are commonly found in contaminated waters. These Gram-negative organisms include: *Escherichia coli, Salmonella, Enterobacter, Shigella, Klebsiella, Serratia, and Proteus.* All are susceptible to ozone's inactivation potential. Other ozone-sensitive bacterial species include *Streptococci, Legionella pneumophila, Pseudomonas aeruginosa, Yersinia, Campylobacteri,* and *Mycobacteria*. Ozone destroys both aerobic, facultative, and importantly, anaerobic bacteria, which are mostly responsible for the devastating sequelae of complicated infections, as exemplified by gangrene.

The cell envelopes of bacteria are composed of intricate multilayers. Covering the bacterial cytoplasm to form the innermost layer of the envelope is the cytoplasmic membrane, made of phospholipids and proteins. Next, a polymeric layer built with giant peptidoglycan molecules provides bacteria with a stable architecture. In Gram-positive organisms, the pepticoglycan shell is thick and rigid. By contrast, Gram-negative bacteria possess a thin pepticoglycan lamella on which is superimposed an outer membrane made of lipoproteins and lipopolysaccharides. In acid-fast bacteria, such as *Mycobacterium*, up to one half of the capsule is formed of complex lipids and glycolipids. The high lipid content of the cell membranes of these ubiquitous bacteria may explain their sensitivity, and eventual demise, subsequent to ozone exposure.

The outermost bacterial layer is the polysaccharide capsule. In many bacterial species, the capsule, by way of its stickiness, enables adherence to host tissues. The capacity of Streptococcus mutans to accrete to tooth enamel, for example, is due to its capsular properties.

The most cited explanation for ozone's bactericidal effects centers on disruption of cell membrane integrity through oxidation of its phospholipids and lipoproteins. There is evidence for interaction with proteins as well (Mudd 1969). In one study exploring the effect of ozone on E. coli, evidence was also found for ozone's penetration through the cell membrane, reacting with cytoplasmic contents, and converting the closed circular plasmid DNA to open circular DNA, which would presumably diminish the efficiency of bacterial procreation (Ishizaki 1987). Capsular polysaccharides may be possible sites for ozone action.

Viruses are parasites at the genetic level, separated into families based on their structure, type of nucleic genome, and mode of replication. Many virions contain a phospholipid envelope with glycoprotein spikes, encasing a nucleocapsid containing nucleic acids (DNA or RNA) and structural proteins.

All viruses are susceptible to ozone's neutralizing action. Viruses, however, differ in their susceptibility to destruction by ozone. In one study, poliovirus resistance was 40 times that of coxsackievirus. Relative susceptibility in ascending order was found to be: poliovirus type 2, echovirus type 1, poliovirus type 1, coxsackievirus type B5, echovirus type 5, and coxsackievirus type A9. In pure water, at maximal solubility of ozone and room temperature, echovirus type 29 is inactivated in one minute, poliovirus type 1 in two, type 3 in three, and type 2 in seven minutes (Roy 1982). Analysis of viral components showed damage to polypeptide chains and envelope proteins that could result in attachment capability compromise, and breakage of the single-stranded RNA, producing replicating dysfunction. Other researchers [Riesser 1977], in similar experiments, concluded that in ozonation, it is the viral capsid that sustains damage.

Lipid-enveloped viruses are sensitive to treatment with ether, organic solvents, and ozone, indicating that disruption or loss of lipids results in impaired or destroyed infectivity. Viruses containing lipid envelopes include the Hepadnaviridae (Hepatitis B) Flaviviridae (Hepatitis C, West Nile virus, yellow fever); *Herpesviridae*, a large family grouping the Simplex, Varicella-Zoster, Cytomegalovirus, and Epstein-Barr viruses; the *Orthomyxoviridae* (Avian influenza); the *Paramyxoviridae* (mumps, measles); the *Coronaviridae* (SARS); the *Rhabdoviridae* (rabies); the Togaviridae (Rubella, encephalitis); the Bunyaviridae (Hantavirus); the Poxviridae (Smallpox); and the *Retroviridae* (HIV), among others. Indeed, once the virion's lipid envelope becomes fragmented, its DNA or RNA core cannot survive.

Non-enveloped (naked) viral families susceptible to ozone neutralization include: The *Adenoviridae* (respiratory infection, cystitis, conjunctivitis; the *Picornaviridae* (Polio, Hepatitis A, colds); the *Papillomaviridae* (genital warts) *Caliciviridae* (hepatitis E); the *Astroviridae* and the *Reoviridae.* (Gastroenteritis).

Naked viruses have a protein outer layer made of protein surrounding their nucleic acid core, the capsid. Ozone has well-documented action on proteins. The formation of protein peroxides disrupts capsid integrity. Without a capsid, the virion cannot survive (Riesser 1977).

Fungi families inhibited and destroyed by exposure to ozone include Candida, Aspergilus, Histoplasma, Actinomycoses, and

OZONICS INTERNATIONAL
200 East 33rd Street, # 26J New York, NY 10016-4831 Tel. 212-6790679 Fax 212-6798008

Cryptococcus. The multilayered cell walls of fungi are composed of approximately 80% carbohydrates and 20% proteins and glycoproteins. The presence of many disulfide bonds has been noted, making this a possible site for oxidative inactivation by ozone. Ozone has the capacity to diffuse through the fungal wall into the organismic cytoplasm, thus disrupting vital cellular function.

Protozoan organisms disrupted by ozone include *Giardia, Cryptosporidium*, and free-living amoebas, namely *Acanthamoeba, Hartmonella*, and *Negleria*. Spores of *Bacillus cereus and Bacillus megaterium* were susceptible to ozone exposure at 5 minutes (Broadwater 1973). Several authors have demonstrated ozone's capacity to penetrate through the walls of *Giardia* cysts causing structural damage, and their demise (Widmer 2002, Wickramanayake 1984, Finch 1993).

Conclusion

Today, pure water is increasingly synonymous with health. Pure water implies water devoid of all organisms, free from particulate matter and, most importantly, maximally enriched with oxygen. Indeed, pure water that is also oxygenated, whether used for drinking, or for bathing, is a key ingredient for optimal well-being.

An overview of pathogens commonly found in contaminated waters serves to illustrate the complexities facing water purification technologies.

Briefly described are the essential steps in water purification: filtration, flocculation, and oxidation, and some of the advantages and drawbacks of chlorination, ultraviolet purification, and ozonation.

While it is true that chlorine is effective against a wide spectrum of microorganisms, several disadvantages present themselves with its use that mitigate against its sole inclusion in a state-of-the-art facility. Chlorinated bathing waters tend to: (1) Induce the yellowish coloration of hair (2) Produce skin irritation (3) Induce allergic and other responses such as hypersensitivity pneumonitis. Furthermore, it is increasingly recognized that the interaction of chlorine with organic molecules already present in the water yields halogenated by-products, such as trihalomethanes, which are associated with (a) Irritation of the eyes, the nasal mucosa, and the lungs, and (b) Mutagenic effects.

Chlorination, however, may be the only agent able to come to the rescue of water systems overrun with pathogens. In the technique of "shocking," for example, a body of water may be brought back to its just equilibrium.

Technology using ozonation/oxygenation of waters for pools, spas, and hot tubs has, in recent years, shown special advantageous features over other technologies.

Ozonation/oxygenation of bathing waters: (1) Provides swimming pools with a pristine fresh feel devoid of odors (2) Imparts water with a natural blue tint (3) Is effective in inactivating bacteria, viruses, and fungi, and even microorganisms prone to replication in the warm waters of spas and hot tubs such as *Pseudomonas aeruginosa* (4) Does not generate trihalomethanes, and (5) Oxygenates water.

Because ozone has more than twice the oxidizing power of chlorine but reacts thousands of times faster, ozonation of water provides, in addition to its broad spectrum of antibacterial, antiviral, antifungal, sporocidal, and antiprotozoan action, superior elimination of organic, inorganic matter, and complex industrial molecules. Additionally, the ozone in water elegantly reverts to oxygen, leaving no chemical residues and respecting the environment.

Not surprisingly, bathing in ozonated waters is consistently reported to induce an enlivening feeling of well-being.

Chlorination, ultraviolet application, and ozonation, each have their advantages and their drawbacks. It seems that a cooperative marriage of these technologies could address the monumental task of cleansing the world's increasing stressed waters.

References

Ackey D, Walton TE. Liquid-phase study of ozone inactivation of Venezuelan Equine Encephalomyelitis virus. Appl Environ Microbiol 1985; 50: 882-886
Armstrong. Infectious Diseases, First Ed. Mosby, Philadelphia, 2000
Beltran FJ. Ozone Reaction Kinetics for Water and Wastewater Systems. CRC Press, 2003
Bocci V. Oxygen-Ozone Therapy: A Critical Review. Kluwer Academic Press, Dordrecht, The Netherlands, 2002

OZONICS INTERNATIONAL
200 East 33rd Street, # 26J New York, NY 10016-4831 Tel. 212-6790679 Fax 212-6798008

Bocci V. Biological and clinical effects of ozone. Br J Biomed Sci. 01 Jan 1999; 56(4): 270-279
Bolton DC, Zee YC, Osebold JW. The biological effects of ozone on representative members of five groups of animal viruses. Environmental Research 1982; 27:476-484
Broadwater WT, Hoehn RC, King PH. Sensitivity of three selected bacterial species to ozone. Applied Microbiology 1973 Sept; 26(3): 391-393
Cardile V, et al. Effects of ozone on some biological activities of cells in vitro. Cell Biology and Toxicology 1995 Feb; 11(1): 11-21
Carpendale MT, Freeberg JK. Ozone inactivates HIV at noncytotoxic concentrations. Antiviral Research 1991; 16:281-292
Domingue EL, Tyndall RL, Mayberry WR, Pancorbo OC. Effects of three oxidizing biocides on *Legionella pneumonia* Serogroup I. Applied and Environmental Microbiology 1988 Mar; 54(3): 741-747
Dyas A, Boughton B, Das B. Ozone killing action against bacterial and fungal species. Journal of Clinical Pathology 1983; 36(10): 1102-1104
Edelstein PH, Whittaker RE, Kreiling RL, Howell CL. Efficacy of ozone in eradication of *Legionella pneumonia* from hospital plumbing fixtures. Applied and Environmental Microbiology 1982 Dec; 44(6): 1330-1334
Eichelsdörfer D. Application of ozone for treatment of swimming pool water in the Federal Republic of Germany. Eighth Ozone World Congress, Zurich, Switzerland, Sept 1987
Evans AS, Kaslow RA (Eds). Viral infections of humans: Epidemiology and control. Plenum, New York, 1997
Farooq S, Akhlaque S. Comparative response of mixed cultures and virus to ozonation. Water Research 1983; 17:809
Finch GR. Ozone Disinfection of Giardia and Cryptosporidium. Am Water Works Association, 1994
Finch GR, Black EK, Labatiuk CW et al. Comparison of Giardia lamblia and Giardia muris cyst inactivation by ozone. Applied and Environmental Microbiology 1993; 59: 3674-3680
Harakeh M, Butler MJ. Factors influencing the ozone inactivation of enteric viruses in effluent. Ozone: Science and Engineering 1985; 6:235-243
Hurst CJ. Viral Ecology. Academic Press, New York, 2000
Katzenelson E, Biedermann N. Disinfection of viruses in sewage by ozone. Water Research (Pergamon Press) 1976; 10:629-631
Khadre Y. Sporicidal action of ozone and hydrogen peroxide: A comparative study. Int J Food Microbiol 2001 Dec 30; 71(2-3): 131-138
Knipe DM, Howley PM. Fundamental Virology, Fourth Edition. Lippincott Williams & Wilkins, Philadelphia, 2001
Komanapalli I, Lau B. Inactivation of *bacteriophage l, Escherichia coli and Candida albicans* by ozone. Appl Microbiol Biotechnol 1998; 49:766-769
Langlais B, Perrine D. Action of ozone on trophozoites and free amoeba cysts, whether pathogenic or not. Ozone: Science and Engineering 1986; 8:187-198
Leland DS. Clinical Virology. Saunders, Philadelphia, 1996
Liou C, Wang J, Ooi H. Effect of ozone treatment on Eimeria Colchici oocysts. J Parasitology 2002; 88(1): 159-162
Marhell EK, Voge M, John DT. Medical Parasitology. Saunders, Philadelphia, 1986
Max J. Antibodies kill by producing ozone. Science 15 Nov 2002; 298: 1319
McGregor R. Case study: Ozone-based water treatment for high quality air and water in a municipal swimming center. Proceedings, Eleventh Ozone World Congress, San Francisco, 1993
Menzel DB. Ozone: an overview of its toxicity in man and animals. J Toxicol Environ Health 1984; 13:183-204
Mercado-Burgos N, Hoehn R, Holliman R. Effects of halogens and ozone on *Schistosoma* ova. J of Water Pollution Control Federation 1975; 47: 2411-2419
Murray PR (Ed). Manual of Clinical Microbiology. ASM Press, Washington, DC, 1995
Olinescu R, Smith TL. Free Radicals in Medicine. Nova Science Publishers, Inc. Huntington, New York, 2002
Rakness K. Ozone in Drinking Water Treatment: Process Design, Operation, and Optimization. Am Water Works, 2005
Razumovskii SD, Zaikov GE. Ozone and its reactions with organic compounds. Elsevier, Amsterdam, 1984
Rice RG. Evolution of drinking water treatment with ozone. In: Proceedings of the International Ozone Symposium, Oct 21 and 22, 1999, Basel, Switzerland
Rice RG. Century 21 – Pregnant with ozone. Ozone Science and Engineering 2002; 24: 1-15
Roy D, Engelbrecht RS, Chian ES. Comparative inactivation of six enteroviruses by ozone. J Am Water Works Assoc 1982; 74:660-664
Roy D, Wong PK, Engelbrecht RS, Chian ES. Mechanism of enteroviral inactivation by ozone. Applied Environmental Microbiology 1981; 41:718-723
Ryan KJ (Ed). Medical Microbiology. Appleton & Lange, Norwalk, Connecticut, 1994
Sobsey MD. Inactivation of health-related microorganisms in water by disinfection processes. Water ScienceTechnology 1989; 21(3): 179-195
Sunnen G. Ozone in medicine: Overview and future directions. Journal of Advancement in Medicine 1988; 1(3): 159-174
Sunnen G. Possible mechanisms of viral inactivation by ozone. Townsend Letter for Doctors 1994 Ap: 336

OZONICS INTERNATIONAL
200 East 33rd Street, # 26J New York, NY 10016-4831 Tel. 212-6790679 Fax 212-6798008

Thanomsub B. Effects of ozone treatment on cell growth and ultrastructural changes in bacteria. J Gen Appl Microbiol 01 Aug 2002; 48(4): 193-199
Thompson S, Jackson J, Suva-Castillo M, et al. Detection of infectious human adenoviruses in tertiary-treated and ultraviolet-disinfected water. Water Env Res 2003 Mar-Ap; 75(2): 163-170
Valentine GS, Foote CS, Greenberg A, Liebman JF (Eds). Active Oxygen in Biochemistry. Blackie Academic and Professional, London, 1995
Vaughn JM, Chen Y, Linburg K, Morales D. Inactivation of human and simian rotaviruses by ozone. Applied Environmental Microbiology 1987; 48:2218-2221
Vaughn JM, Chen YS, Novotny JF. Effects of ozone treatment on the infectivity of hepatitis A virus. Can J Microbiol 1990; 36:557-560
Viebahn R. The Use of Ozone in Medicine. Odrei Publishers, Iffezheim, 1999
Wells KH, Latino J, Gavalchin J, Poiesz BJ. Inactivation of human immunodeficiency virus Type 1 by ozone in vitro. Blood 1991 Oct; 78(7): 1882-1890
Wentworth P, McDunn JE, Wentworth AD, et al. Evidence for antibody-catalysed ozone formation in bacterial killing and inflammation. Science 13 Dec 2002; 298:2195-219
White DO, Fenner FJ. Medical Virology, Fourth edition. Academic Press, New York, 1994
Wickramanayake G, Rubin A, Sproul O. Inactivation of *Giardia lamblia* cysts with ozone. Applied and Environmental Microbiology 1984; 48:671-672
Widmer G, Clancy T, Ward H, et al. Structural and biochemical alterations in *Giardia lamblia* cysts exposed to ozone. J Parasitology 2002; 88(6): 1100-1106
Zhov P, Neeman J. Use of Chlorine dioxide and Ozone for Control of Disinfection By-products. Awwarf, 2005