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TECHNOLOGIES

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The following report was written by Warren Wood from Ozone Solutions Inc

HISTORY AND GENERAL STATEMENT

The first ozone installation was made by Siemens Company (Germany) in 1857. (Ref 151, p 17) Complex molecules can be broken down by the powerful oxidation effect of ozone. Ozone can react with compounds which cannot be broken down by biological agents (bacteria) or otherwise integrated into the biological process for further processing.

EFFECTS ON BACTERIA AND VIRUSES

Effects on bacterial aerosols

Aerosols were produced by spraying bacterial suspensions at 20 lb/sq. in pressure and concentrations of bacteria were in the range of 50-500 viable organisms per liter of air. The killing effect of ozone was determined by comparing the curves for decay with, and without, ozone. Ozone concentrations ranged from 2.0 PPM (parts per million) down to 0.023 PPM. Tests were performed on three organisms; Streptococcus salivarius, Streptococcus 'C' and Staphylococcus albus. The role of humidity in the action of ozone, particularly when the gas is at low concentration, was apparent. At humidities less than 45%, ozone, even in high concentrations, exerts no appreciable disinfecting action on bacteria. For humidities above 50%, however, ozone reduced the bacteria count. In fact, ozone as low as (0.025 PPM showed definite bactericidal action at 60 to 80% humidity.

Bacteria that have settled on surface

Bacteria on surfaces constitute a potential infection danger as a source of infection through redispersal in the air or contact with skin or clothes. Tests were made to determine whether ozone has any disinfecting action on deposited bacteria. Bacteria were sprayed on various surfaces: agar in Petri dishes; Whatman filter paper; sterile glass Petri dishes and wool cloth. These were placed in known conditions of humidity (range 60-85%), temperature and ozone concentration. After being exposed, the bacteria were counted and compared with surfaces having bacteria not exposed to ozone. Ozone in a concentration of 0.02 PPM in a moderately humid atmosphere exercises a very definite killing effect against bacteria on surfaces, but below this level it has little effect.

The kill depends on (a) the "depth" and type of surface; so moist agar, Whatman #1 filter paper and wool cloth are more favorable to survival than glass or #50 Whatman paper; (b) resistance to ozone of different types of bacteria: Staphylococcus albus resistance is greater than Streptococcus Salivarius, which in turn is greater than B.prodigiosus.

Discussion

Ozone, in concentrations up to 0.04 PPM in humid atmospheres exerts a disinfecting action on certain bacteria; streptococcus salivarius, Streptococcus 'C', Staphylococcus albus and B. prodigiosus. Tests on E. coli with up to 1 to 2 PPM in relatively dry air failed to destroy any organisms. This confirms ozone is a poor disinfectant at low humidities. However, at humidities above 60% tests confirmed pathogens can be destroyed by minute amounts of ozone. (Ref 158) Increasing the moisture content of the environment favorably influences germicidal effect. This is brought about by swelling of microbes making them more susceptible to destruction. (Ref. 1)

ODOR CONTROL

Ozone is unmatched as a deodorizer. Ozone has a strong characteristic odor even at very low concentrations. Its effect on the olfactory membrane makes it difficult or impossible to detect other odors when ozone is present. In low concentrations (0.01-0.02 PPM), ozone acts is a masking agent on most odors. Tests have demonstrated that room odors were undetectable even when ozone concentrations were less than 0.01 PPM. (Ref 158)

Some very delicate odors are destroyed even at these low concentrations. However, to totally eliminate "heavy" odors higher concentrations of ozone are required to react with gases in the air and odors trapped in materials. Time to deodorize is determined by the quantity of the substance producing odor and the quantity of ozone available to react with it. (Ref 152, 172)

Ozone at a concentration of 0.1 PPM will destroy microorganisms and eliminate most odors within 48 hours. (Ref 1)

Odoriferous substances are susceptible to oxidation, but the addition or oxygen to a substance (oxidation) dues not always render it safe. For example, oxidation of allyl alcohol yields aldehyde acrolein, a very deadly gas. Safety considerations apply only to definite industrial odors and do not include animal wastes or putrefactive gases of animal or vegetable tissue. Putrefaction produces highly odorous substances such as amino, aromatic and fatty acids, indole, skatole, cresol. said also the alkaloid-like ptomaines, such as tetramethylene-diamine and pentamethylene-diamene, etc. The effect of ozone on these substances is that of combustion; i.e., the find products of the hydrocarbons being CO_2 and water and those containing nitrogen, nitrogen pentoxide.

Where putrefaction occurs - the air from sewers, etc. - while highly odoriferous, contains but traces of these substances. The odors are easily and completely destroyed by ozone. Ozone has been used in San Francisco to deodorize a sewage pumping station when the pump screens had to be cleaned. A rat died in a wall of an office building and the odor penetrated several offices. The application of ozone completely destroyed the odor. (Ref 153)

Single atoms of oxygen from the decomposition of ozone immediately oxidize odors. The lower the temperature and the larger the odor molecules, the weaker the oxidizing effect. Humidity lists no effect on this process, but does accelerate destruction of bacteria, viruses and fungi that may contribute to odor. (Ref 1)

THE SMELL OF OZONE

Ozone at low concentrations (0.01-0.04 PPM) leaves a fresh and pleasant smell to a room. Higher concentrations exhibit an “electrical” odor. This is typically smelled after a strong lighting or rainstorm.

STERILIZING

Ozone at ambient temperatures is the only substance which can be used as a total sterilizing agent and a substitute for high temperature. (Ref 1) Pyrogens, byproducts of microbial growth that are toxic to humans, are not eliminated after normal autoclaving or dry heat sterilization. Pyrogens adhere firmly to surfaces of containers and are removed only after heating at very high temperatures for extended periods of time. Because pyrogenic material is a lipopolysaccharide, the unsaturated double bonds are easily oxidized by ozone. (Ref 34, 40) Therefore, ozone has a distinct advantage over other depyrogenation methods. (Ref 24)

USE IN AIR CONDITIONING

Molds in ducts, filters and other parts of ventilating equipment, in basements and other damp places produce objectionable odors. In low concentrations ozone masks odors, giving a freshness to the air normally absent in recirculated air. Also with time and the right humidity conditions, ozone destroys bacteria and mold. Where possible, ozone should be introduced in sufficient quantity to mix with all the air when the building is unoccupied. With recirculation, this will build up a concentration sufficient not only to deodorize the air but thoroughly disinfect and sterilize the entire building and HVAC equipment. This will result in the reduction of molds, bacteria and decomposing organic material in the duct work and parts of the equipment that are inaccessible. This work should be completed and the ozone reduced to acceptable levels before the building is occupied again.

<u>Effect of ozone on Escherichia coli and Staphylococcus aureus</u> - W.J. Kowalski. Penn State University

Controlled levels of ozone are used in Europe in air conditioning systems to deodorize and freshen air in theaters, shopping malls, offices, etc. Demand for make-up air is reduced as the recycle system furnishes air of sufficient purity. Body odors, cigarette smoke mid various unpleasant smells are removed. These gases are mostly hydrocarbons, together with hydrogen sulfide and are rapidly destroyed by ozone. (Ref 1)

Our body automatically controls respiration. When air contains even minute and practically imperceptible quantities of disagreeable odors we involuntarily shorten out breathing. Even though rate of respiration may increase under such conditions, the total volume of oxygen taken into our lungs is reduced. This results in a mild form of autointoxication as wastes increase in the blood, and we feel lethargic and tired. (Ref 153) In 1919, the first ozone machine was installed in the air duct of the O'Fallon School (St. Louis). The effects were so positive that Ozonators were installed in thirteen old schools and three new ones. Teachers and administrators noted an improvement in the health of the children and a reduction in the number of colds.

The St. Louis Hygiene Department kept a record or all absences on account of illness, the nature of the disease and time lost. Two tests were conducted, one in the morning without ozone and one in the afternoon with ozone. Physicians from the Hygiene Department exposed agar dishes and delivered them to the City Bacteriologist for incubation and count. The afternoon test with ozone averaged half the bacteria count of the morning test when no ozone was used. Another test was conducted with 65% recirculated air. Recirculated air with ozone gave 36 percent less bacteria than 100% fresh air without ozone. Odors were entirely absent in the recirculated air test.

EFFECTS ON BACTERIA AND VIRUSES

Bacteria are microscopically small, single-cell creatures having a primitive structure. They take up foodstuffs and release metabolic products, and multiply by division. The bacteria body is sealed by a relatively solid-cell membrane. Their vital processes are controlled by a complex enzymatic system. Ozone interferes with the metabolism of bacterium-cells, most likely through inhibiting and blocking the operation of the enzymatic control system. A sufficient amount of ozone breaks through the cell membrane, and this leads to the destruction of the bacteria. (Ref 5,24)

Viruses are small, independent particles, built of crystals and macromolecules, Unlike bacteria, they multiply only within the host cell. They transform protein of the host cell into proteins of their own. Ozone destroys viruses by diffusing through the protein coat into the nucleic acid core, resulting in damage of the viral RNA. At higher concentrations, ozone destroys the capsid, or exterior protein shell by oxidation so DNA (deoxyribonucleic acid) or RNA (ribonucleic acid) structures of the microorganism are affected. In fact, DNA and RNA breakdown products could be identified in this case. (Ref. 24)

EFFECTS ON SPECIFIC BACTERIA, VIRUSES AND MOLDS

Aspergillus Niger (Black Mount). Destroyed by 1.5 to 2 mg/I.

Bacillus Bacteria. Destroyed by 0.2 m/I within 30 seconds (Ref. 26, 27, 33)

Bacillus Anthracis. Causes anthrax in sheep, cattle and pigs. Also a human pathogen. Ozone susceptible.

Candida Bacteria. Ozone susceptible. (Ref 24)

Clostridium Bacteria. Ozone susceptible. (Ref 24)

Clostridium Botulinum Spores. Its toxin paralyses the central nerve system, being a poison multiplying in food and meals. 0.4 to 0.5 mg/l threshold value.

Coxsackie Virus. Destroyed to zero level in less than 30 seconds by 0.1 to 0.8 mg/l (Ref 30, 31, 34, 36, 37, 38)

Diphtheria Pathogen. Destroyed by 1.5 to 2 mg/l.

Eberth Bacillus (Typhus abdomanalis). Spreads typically by aqueous infection and causes typhoid. Destroyed by 1.5 to 2 mg/l.

Echo Virus 29: The virus most sensitive to ozone. After a contact time of 1 minute at 1 mg/l of ozone, 99.999% killed. (Ref 151, p. 17)

Escherichia Coli Bacteria (from feces) Destroyed by 0.2 mg/l within 30 seconds. (Ref 26, 27, 33)

Encephalomyocarditis Virus. Destroyed to zero level in less than 30 seconds with 0.1 to 0.8 mg/l. (Ref 30, 31, 34, 36, 37, 38)

Endamoebic Cysts Bacteria. Ozone susceptible. (Ref 24)

Enterovirus Virus. Destroyed to zero level in less than 30 seconds with 0.1 to 0.8 mg/l. (Ref 30, 31, 34, 36, 37, 38)

GDVII Virus. Destroyed to zero level in less than 30 seconds with 0.1 to 0.8 mg/l. (Ref 30, 31, 34, 36, 37, 38)

Herpes Virus. Destroyed to zero level in less than 30 seconds wit 0.1 to 0.8 mg/l. (Ref 30, 31, 34, 36, 37, 38)

Influenza Virus. 0.4 to 0.5 mg/l threshold value.

Klebs-Loffler Bacillus. Destroyed by 1.5 to 2 mg/l.

Luminescent Basidiomycetes (species having no melanin pigment). Destroyed in10 minutes at 100 PPM.

Penicillium Bacteria. Ozone susceptible. (Ref 24)

Poliomyelitis Virus. 99.99% kill with 0.3 to 0.4 mg/l in 3-4 minutes.

Proteus Bacteria. Very susceptible. (Ref 24)

Pseudomonas Bacteria. Very susceptible. (Ref 24)

Rhabdovirus virus. Destroyed to zero level in less than 30 seconds with 0.1 to 0.8 mg/l. (Ref 30, 31, 34, 36, 37, 38)

Salmonella Bacteria. Very susceptible. (Ref 24)

Schistosoma Bacteria. Very susceptible. (Ref 24)

Staphylococci. Destroyed by 1.5 to 2.0 mg/l.

Stomatitis Virus. Destroyed to zero level in less than 30 seconds with 0.1 to 0.8 mg/l. (Ref 30, 31, 34, 36, 37, 38)

Streptococcus Bacteria. Destroyed by 0.2 mg/l within 30 seconds. (Ref 26, 27, 33)

Vesicular Virus. Destroyed to zero level in less than 30 seconds with 0.1 to 0.8 mg/l. (Ref 30, 31, 34, 36, 37, 38)

Virbrio Cholera Bacteria. Very susceptible. (Ref 24)

Vicia Faba progeny. Ozone causes chromosome aberration and its effect is twice that observed by the action of X-rays.

The effect of ozone below a certain critical concentration value is small or zero. Above this level all pathogens are eventually destroyed. This effect is called all-or-none response and the critical level the "threshold value". (Ref 24,25,27,28,29,52)

There is a two-step process of inactivation or viruses. Period one lasts less than 10 seconds, during which time a kill rate of about 99% is achieved. Period two runs for several minutes to complete destruction. This phenomenon is independent of changes in ozone concentration between 0.07 and 2.5 mg/l. (Ref 1)

HEALTH AND MEDICINE

"EXPOSURE TO OZONE REDUCES INFLUENZA DISEASE SEVERITY AND ALTERS DISTRIBUTION OF INFLUENZA VIRAL ANTIGENS IN MURINE LUNGS."

This study was undertaken to assess the effects of exposure to ozone on the course of influenza virus infection. Mice were exposed to ozone or filtered air, or both, with aerosolized infection by influenza virus. It was found that animals exposed to ozone during infection showed a reduced severity of disease measured by decreased mortality and delayed time of death. (Ref 156)

Ammonia, and to some degree hydrogen sulfide, affect pig performance directly (by altering metabolic reactions) and indirectly (by influencing pig health). Atmospheric ammonia was particularly damaging to young pigs infected with Ascaris suum. (Ref 173, 174, 175) Ozone reduces harmful ammonia said hydrogen sulfide. Ozone converts ammonia (NH_3) to harmless nitrogen and water vapor. Hydrogen sulfide (H_2S) is broken down into water and sulphur dioxide, also a powerful disinfectant.

OXIDATION POTENTIAL

Ozone owes its excellent bactericidal, viricide, and sporicidal activities to its powerful oxidizing properties. Ozone has an oxidation potential of +2.07 volts as compared to HOCL (the active form of Chlorine in aqueous solution) which is +1.49 volts. It is reported to be 3000 times as germicidal as chlorine. It retains this strong oxidizing capability in aqueous solution, a property crucial for water disinfection and sterilization, as well as in high humidity air applications. (Ref. 24) See Oxidation Potential Chart.

HALF LIFE

As soon as ozone is formed, it starts to decay to oxygen. The half life is 2.5 to 7 minutes in most applications, depending on the ambient conditions. In cool, sterile environments the half life can extend to 60 minutes. Higher temperatures lead to shorter half life.

OZONE COMPARED TO OTHER GASEOUS DISINFECTANTS

Gaseous disinfectants in common use are sulphur dioxide, formaldehyde, and in certain applications, hydrocyanic acid. It has been clearly demonstrated that ozone in equivalent concentrations exerts a much stronger bactericidal effect than any of the foregoing disinfectants. To obtain the same bactericidal effect concentration of 160 times the amount is required for sulphur dioxide, 37 times the amount for formaldehyde, and 1.7 times the amount for hydrocyanic acid gas. (Ref. 152)

SOME SPECIFIC COMPOUNDS OXIDIZED BY OZONE

Ammonia, Phenolics, Detergents, Fulvic Acid, Tannic Acids (plant-originated acids), Sulfides

Cyanides, Spores of Molds (very effective), Amoebae (very effective), 2.4D, Arsenic

Chlorine and its derivatives, DDT, Dioxins

Cigarette smoke: A puff of cigarette smoke contains 4 billion particles and more than 1500 compounds, ranging from light, reactive gases (deadly carbon monoxide is one), suspended chemical particulates and tars. Ozone destroys most of these products and even “burns” the lighter tars in the air and converts them to harmless carbon.

Haloforms. Strongly reduced by ozone. Large amounts of Aldehydes and Keytones are produced as a byproduct. With a reaction time of 10 to 1440 minutes, the concentration of Aldehydes will be 8.5 times larger at a dosage of 1 mg/l and 30.6 times larger at a dosage of 5 mg/l. (Ref 12)

Perchlorate Biphenyls. With simultaneous ultraviolet irradiation it is even possible to subject PCBs, the successors of DDT, to oxidative decomposition. (Ref 151 p.15)

Phenol. (Ref 12)

Trihalomethanes (toxic product of chlorine, algae reaction)

Trichlorophenol. 1.0 mg/l reduces 500 microgram Trichlorophenol and 5.0 mg/l reduces 2500 microgram Trichlorophenol. (Ref 12)

USE IN PRODUCT STORAGE

Ozone has been used in food preservation since 1909. Storage places, warehouses and refrigerated lockers can be disinfected. High humidity in the environment favorably influences germicidal effect. Ozone decomposition is accelerated due to high moisture content, the walls of the storage room, the packaging materials, the absorption effect of the stored goods, and also the oxidation reactions taking place. The ozone generator must have sufficient capacity to maintain ozone at the required level. A strong air movement is required to assure optimum distribution of ozone. The storage space need not be air tight as long as the capacity of the ozone generator is sufficient to replenish the ozone lost through air exchange. (Ref 1)

The prerequisite in the control of microorganisms is the maintenance of clean environment. The microbial population of the product and the storage environment determine the storage life of the product. When a food product is exposed to contamination during preparation, handling or storage, large numbers of microorganisms are introduced into the product. In food, microorganism find a favorable habitat for growth and each new generation of bacteria means a doubling of the population. The result is a breakdown of the food product evidenced by objectionable physical appearance, taste and odor.

There is no compound that can be applied to a dirty surface to destroy all microorganisms. To demonstrate, a good sanitizer was applied liberally to a ditty wail in a food handling plant. This wall had a bacterial population of 28,000,000 organisms on a two-inch square. Five minutes after treatment the wall still had a bacteria count of 11,000,000. Although the contamination had been reduced, the wall was still heavily contaminated A food product entering this storage room had a relatively low surface bacteria count, but in 48 hours the product had a count of 150,000 in a two-inch square. Air examination showed an extremely high bacteria count. Even though multiplication of bacteria might be slowed by low temperature, the product was acquiring high count that would reduce its shelf-life after it left the storage room. If kept for a longer period in storage, its storage life would be considerably shorter than if stored in a room relatively free of contamination. (Ref. 161)

FISH STORAGE

Freshly caught fish can be stored longer if washed in water containing ozone. If it is packed in ice made from water containing ozone. Freshness can be extended. (Ref 176)

CONTROL OF SURFACE MICROFLORA

In a refrigerated atmosphere with ozone, the growth of the surface microflora (pseudomonas families, spores, Salmonellae and staphylococci) is eliminated or retarded. (Ref. 1)

Forequarters of beef with relatively equal bacteria counts were tested, one in the ozone-treated refrigerator at a concentration of approximately 0.1 PPM of ozone and 60-deg F, and the other under similar conditions except for the lack of ozone. At the end of the test period, the ozone-treated beef had about the same count as at the start, but the untreated beef showed an increase of 600 percent. (Ref 161)

Ozone used in beef storage is most efficient if the meat surface has around 60% moisture content. (Ref 1)

Beef stored in a cooler under an ozone concentration of 0.04 PPM at 2-deg C, experiences 0.9 to 1.0 percent less shrinkage in three days and 17 percent less in 7 days. Trim loss is reduced by 2.6 to 5.5 percent. This is less shrinkage and trim loss than meat stored under identical conditions but without ozone usage. (Ref 2)

The storage life of beef a refrigerated state can be increased by 30 to 40 percent if the beef is kept in an atmosphere of 7.7 to 15 PPM. and the microbial saturation of its surface is not greater than 1000 bacteria per square cm. (Ref 1)

As a comparison based on 99.99% of bacterial concentration being killed and time taken: Ozone is

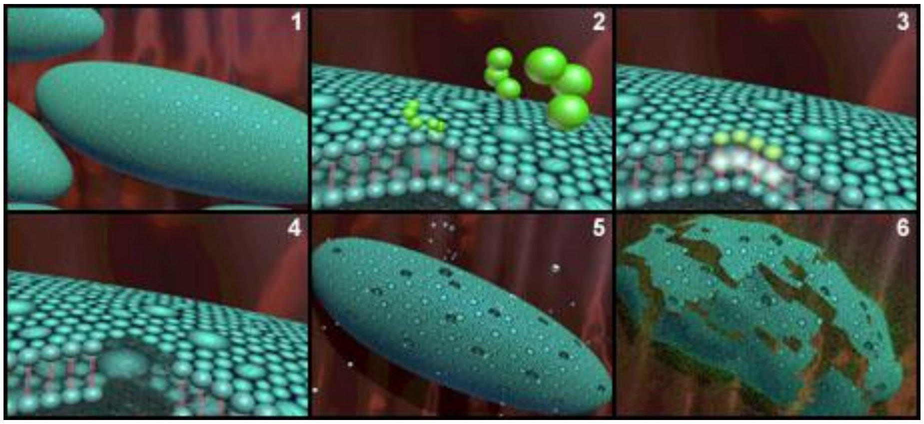
25 times of that of HOCl (Hypochlorous Acid)

2,500 times of that of OCl (Hypochlorite)

5,000 times of that of NH_2Cl (Chloramine).

Further more, ozone is at least 10 times stronger than chlorine as a disinfectant. Chlorine also results in the production of chloroform, carbon tetrachloride, chloromethane besides THMs. On the other hand, ozone does not even leave any trace of residual product upon its oxidative reaction.

Effect of Ozone on Bacteria



1 - Computer generated image of a bacteria cell

2 - Close-up of ozone molecule coming into contact with bacterial wall

3 - Ozone penetrating and creating hole in bacterial wall

4 - Close-up effect of ozone on cell wall

5 - Bacterial cell after a few ozone molecules come into contact

6 - Destruction of cell after ozone (cell lysing)