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Wastewater Technology Fact Sheet
Ozone Disinfection

DESCRIPTION

Disinfection is considered to be the primary mechanism for the inactivation/destruction of pathogenic organisms to prevent the spread of waterborne diseases to downstream users and the environment. It is important that wastewater be adequately treated prior to disinfection in order for any disinfectant to be effective. Table 1 lists some common microorganisms found in domestic wastewater and the diseases associated with them.

Ozone is produced when oxygen (O_2) molecules are dissociated by an energy source into oxygen atoms and subsequently collide with an oxygen molecule to form an unstable gas, ozone (O_3), which is used to disinfect wastewater. Most wastewater treatment plants generate ozone by imposing a high voltage alternating current (6 to 20 kilovolts) across a dielectric discharge gap that contains an oxygen-bearing gas. Ozone is generated onsite because it is unstable and decomposes to elemental oxygen in a short amount of time after generation.

Ozone is a very strong oxidant and virucide. The mechanisms of disinfection using ozone include:

- Direct oxidation/destruction of the cell wall with leakage of cellular constituents outside of the cell.
- Reactions with radical by-products of ozone decomposition.
- Damage to the constituents of the nucleic acids (purines and pyrimidines).
- Breakage of carbon-nitrogen bonds leading to depolymerization.

TABLE 1 INFECTIOUS AGENTS POTENTIALLY PRESENT IN UNTREATED DOMESTIC WASTEWATER

Organism	Disease Caused
Bacteria	
Escherichia coli (enterotoxigenic)	Gastroenteritis
Leptospira (spp.)	Leptospirosis
Salmonella typhi	Typhoid fever
Salmonella (=2,100 serotypes)	Salmonellosis
Shigella (4 spp.)	Shigellosis (bacillary dysentery)
Vibrio cholerae	Cholera
Protozoa	
Balantidium coli	Balantidiasis
Cryptosporidium parvum	Cryptosporidiosis
Entamoeba histolytica	Amebiasis (amoebic dysentery)
Giardia lamblia	Giardiasis
Helminths	
Ascaris lumbricoides	Ascariasis
T. solium	Taeniasis
Trichuris trichiura	Trichuriasis
Viruses	
Enteroviruses (72 types, e.g., polio, echo, and coxsackie viruses)	Gastroenteritis, heart anomalies, meningitis
Hepatitis A virus	Infectious hepatitis
Norwalk agent	Gastroenteritis
Rotavirus	Gastroenteritis

Source: Adapted from Crites and Tchobanoglous, 1998.

When ozone decomposes in water, the free radicals hydrogen peroxy (HO_2) and hydroxyl (OH) that are formed have great oxidizing capacity and play an active role in the disinfection process. It is generally believed that the bacteria are destroyed because of protoplasmic oxidation resulting in cell wall disintegration (cell lysis).

The effectiveness of disinfection depends on the susceptibility of the target organisms, the contact time, and the concentration of the ozone. A line diagram of the ozonation process is shown in Figure 1. The components of an ozone disinfection system include feed-gas preparation, ozone generation, ozone contacting, and ozone destruction.

Air or pure oxygen is used as the feed-gas source and is passed to the ozone generator at a set flow rate. The energy source for production is generated by electrical discharge in a gas that contains oxygen. Ozone generators are typically classified by:

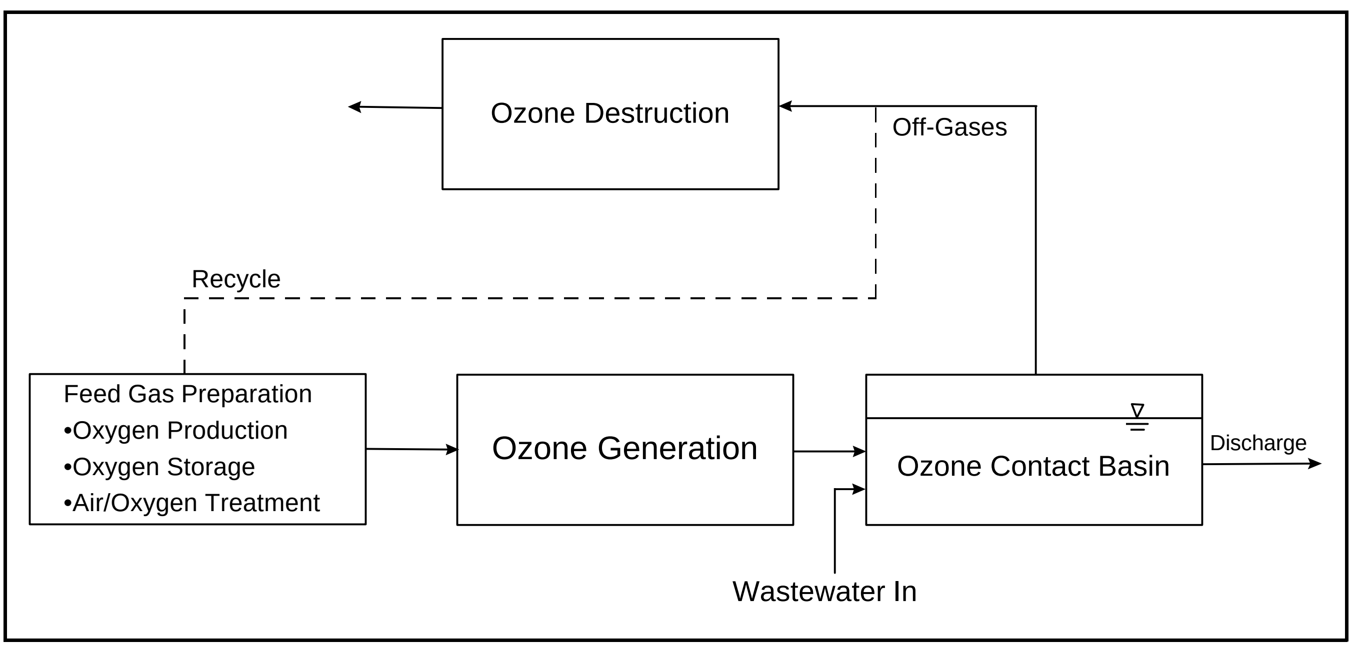
- The control mechanism (either a voltage or frequency unit).
- The cooling mechanism (either water, air, or water plus oil).
- The physical arrangement of the dielectrics (either vertical or horizontal).
- The name of the inventor.

However, generators manufactured by different companies have unique characteristics but also have some common configurations.

The electrical discharge method is the most common energy source used to produce ozone. Extremely dry air or pure oxygen is exposed to a controlled, uniform high-voltage discharge at a high or low frequency. The dew point of the feed gas must be -60°C (-76°F) or lower. The gas stream generated from air will contain about 0.5 to 3.0% ozone by weight, whereas pure oxygen will form approximately two to four times that concentration.

After generation, ozone is fed into a down-flow contact chamber containing the wastewater to be disinfected. The main purpose of the contactor is to transfer ozone from the gas bubble into the bulk liquid while providing sufficient contact time for disinfection. The commonly used contactor types diffused bubble (co-current and counter-current) are positive pressure injection, negative pressure (Venturi), mechanically agitated, and packed tower. Because ozone is consumed quickly, it must be contacted uniformly in a near plug flow contactor.

The off-gases from the contact chamber must be treated to destroy any remaining ozone before



Source: U.S. EPA, 1986.

FIGURE 1 OZONE PROCESS SCHEMATIC DIAGRAM

release into the atmosphere. Therefore, it is essential to maintain an optimal ozone dosage for better efficiency. When pure oxygen is used as the feed-gas, the off-gases from the contact chamber can be recycled to generate ozone or for reuse in the aeration tank. The ozone off-gases that are not used are sent to the ozone destruction unit or are recycled.

The key process control parameters are dose, mixing, and contact time. An ozone disinfection system strives for the maximum solubility of ozone in wastewater, as disinfection depends on the transfer of ozone to the wastewater. The amount of ozone that will dissolve in wastewater at a constant temperature is a function of the partial pressure of the gaseous ozone above the water or in the gas feed stream.

It is critical that all ozone disinfection systems be pilot tested and calibrated prior to installation to ensure they meet discharge permit requirements for their particular sites.

APPLICABILITY

Ozone disinfection is generally used at medium to large sized plants after at least secondary treatment. In addition to disinfection, another common use for ozone in wastewater treatment is odor control.

Ozone disinfection is the least used method in the U.S. although this technology has been widely accepted in Europe for decades. Ozone treatment has the ability to achieve higher levels of disinfection than either chlorine or UV, however, the capital costs as well as maintenance expenditures are not competitive with available alternatives. Ozone is therefore used only sparingly, primarily in special cases where alternatives are not effective.

ADVANTAGES AND DISADVANTAGES

Advantages

- Ozone is more effective than chlorine in destroying viruses and bacteria.

- The ozonation process utilizes a short contact time (approximately 10 to 30 minutes).

- There are no harmful residuals that need to be removed after ozonation because ozone decomposes rapidly.

- After ozonation, there is no regrowth of microorganisms, except for those protected by the particulates in the wastewater stream.

- Ozone is generated onsite, and thus, there are fewer safety problems associated with shipping and handling.

- Ozonation elevates the dissolved oxygen (DO) concentration of the effluent. The increase in DO can eliminate the need for reaeration and also raise the level of DO in the receiving stream.

Disadvantages

- Low dosage may not effectively inactivate some viruses, spores, and cysts.

- Ozonation is a more complex technology than is chlorine or UV disinfection, requiring complicated equipment and efficient contacting systems.

- Ozone is very reactive and corrosive, thus requiring corrosion-resistant material such as stainless steel.

- Ozonation is not economical for wastewater with high levels of suspended solids (SS), biochemical oxygen demand (BOD), chemical oxygen demand, or total organic carbon.

- Ozone is extremely irritating and possibly toxic, so off-gases from the contactor must be destroyed to prevent worker exposure.

- The cost of treatment can be relatively high in capital and in power intensiveness.

PERFORMANCE

Belmont and Southport Wastewater Treatment Plants in Indianapolis, Indiana

In 1985, the City of Indianapolis, Indiana, operated two-125 million gallons per day (mgd) advanced wastewater treatment plants at Belmont and Southport using ozone disinfection. The rated capacity of the oxygen-fed ozone generators was 6,380 pounds per day, which was used to meet geometric mean weekly and monthly disinfection permit limits for fecal coliforms of 400 and 200 per 100 ml, respectively.

Disinfection was required at both Indianapolis treatment plants from April 1 through October 31, 1985. Equipment performance characteristics were evaluated during the 1985 disinfection season and consequently, disinfection performance was optimized during the 1986 season. The capital cost of both ozone systems represented about 8% of the plants' total construction cost. The ozone system's Operation and Maintenance (O&M) cost represented about 1.9% and 3.7% of the total plant O&M costs at the Belmont and Southport plants, respectively.

In 1989, a disciplined process monitoring and control program was initiated. Records indicated a significant effect on process performance due to changes in wastewater flow, contactor influent fecal coliform concentration, and ozone demand.

Previously, ozone demand information was unknown. Several studies were conducted to enable better control of the ozone disinfection process. These included the recent installation of a pilot-scale ozone contactor to allow the plant staff to measure ozone demand on a daily basis. Also, tracer tests were conducted to measure contactor short-circuiting potential. Results demonstrated a noticeable benefit of adding additional baffles. Results also indicated operating strategies that could maximize fecal coliform removal, such as reducing the number of contactors in service at low and moderate flow conditions.

OPERATION AND MAINTENANCE

Ozone generation uses a significant amount of electrical power. Thus, constant attention must be given to the system to ensure that power is optimized for controlled disinfection performance.

There must be no leaking connections in or surrounding the ozone generator. The operator must on a regular basis monitor the appropriate subunits to ensure that they are not overheated. Therefore, the operator must check for leaks routinely, since a very small leak can cause unacceptable ambient ozone concentrations. The ozone monitoring equipment must be tested and calibrated as recommended by the equipment manufacturer.

Like oxygen, ozone has limited solubility and decomposes more rapidly in water than in air. This factor, along with ozone reactivity, requires that the ozone contactor be well covered and that the ozone diffuses into the wastewater as effectively as possible.

Ozone in gaseous form is explosive once it reaches a concentration of 240 g/m^3. Since most ozonation systems never exceed a gaseous ozone concentration of 50 to 200 g/m^3, this is generally not a problem. However, ozone in gaseous form will remain hazardous for a significant amount of time thus, extreme caution is needed when operating the ozone gas systems.

It is important that the ozone generator, distribution, contacting, off-gas, and ozone destructor inlet piping be purged before opening the various systems or subsystems. When entering the ozone contactor, personnel must recognize the potential for oxygen deficiencies or trapped ozone gas in spite of best efforts to purge the system. The operator should be aware of all emergency operating procedures required if a problem occurs. All safety equipment should be available for operators to use in case of an emergency. Key O&M parameters include:

- Clean feed gas with a dew point of -60°C (-76°F), or lower, must be delivered to the ozone generator. If the supply gas is moist, the reaction of the ozone and the moisture will yield a very corrosive condensate on the inside of the ozonator. The output of the generator could be lowered by the formation of nitrogen oxides (such as nitric acid).

- Maintain the required flow of generator coolant (air, water, or other liquid).

- Lubricate the compressor or blower in accordance with the manufacturer's specifications. Ensure that all compressor sealing gaskets are in good condition.

- Operate the ozone generator within its design parameters. Regularly inspect and clean the ozonator, air supply, and dielectric assemblies, and monitor the temperature of the ozone generator.

- Monitor the ozone gas-feed and distribution system to ensure that the necessary volume comes into sufficient contact with the wastewater.

- Maintain ambient levels of ozone below the limits of applicable safety regulations.

COSTS

The cost of ozone disinfection systems is dependent on the manufacturer, the site, the capacity of the plant, and the characteristics of the wastewater to be disinfected. Ozonation costs are generally high in comparison with other disinfection techniques.

Table 2 shows a typical cost estimate (low to medium) for ozone disinfection system used to disinfect one mgd of wastewater. The costs are based on the wastewater having passed through both primary and secondary treatment processes of a properly designed system (the BOD content does not exceed 30 milligrams per liter [mg/L] and the SS content is less than 30 mg/L). In general, costs are largely influenced by site-specific factors, and thus, the estimates that follow are typical values and can vary from site to site.

Because the concentration of ozone generated from either air or oxygen is so low, the transfer efficiency to the liquid phase is a critical economic consideration. For this reason, the contact chambers used are usually very deep and covered.

TABLE 2 TYPICAL COST ESTIMATE OF AN OZONE DISINFECTION

Items	Costs
Capital Costs	
Oxygen feed gas and compressor	$245,500
Contact vessel (500 gpm)	$4,000-5,000
Destruct unit:	
Small (around 30 cfm)	$800
Large (around 120)	$1,000-1,200
Non-component costs	$35,000
Engineering	$12,000-15,000
Contingencies	30%
Annual O&M Costs	
Labor	$12,000
Power	90 kW
Other (filter replacements, compressor oil, spare dielectric, etc.)	$6,500

gpm = gallons per minute
cfm = cubic feet per minute

Source: Champion Technology, 1998.

The overall cost of an ozonation system is also largely determined by the capital and O&M expenses. The annual operating costs for ozone disinfection include power consumption, and supplies, miscellaneous equipment repairs, and staffing requirements.

Another consideration for the cost is that each ozonation system is site specific, depending on the plant’s effluent limitations. Chemical suppliers should be contacted for specific cost information.

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