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Combined Sewer Overflow Technology Fact Sheet

Alternative Disinfection Methods

DESCRIPTION

Combined sewer overflows (CSOs) occur when flows exceed the hydraulic capacity of either the wastewater treatment plant (WWTP) or the collection system that transports the combined flow of storm water and sanitary sewage to the WWTP. When an overflow occurs, the excess flows tend to be discharged into a receiving body of water. CSOs typically discharge a variable mixture of raw sewage, industrial/commercial wastewater, polluted runoff, and scoured materials that build up in the collection system during dry weather periods. These discharges contain a variety of pollutants that may adversely impact the receiving water body, including pathogenic microorganisms, viruses, cysts, and chemical and floatable materials. Health risks associated with bacteria-laden water may result through dermal contact with the discharge, or through ingestion of contaminated water or shellfish.

Preliminary reduction of microorganisms and bacteria may be accomplished through physical reduction of solids in the wastewater, primarily through sedimentation, flotation, and filtration. Following solids reduction, most systems further reduce bacterial concentrations through disinfection. Disinfection occurs as the wastewater is brought into contact with oxidizing chemicals (such as chlorine, bromine, ozone, hydrogen peroxide, and related compounds).

Chlorine has long been the disinfectant of choice for most disinfection systems. It offers reliable reduction of pathogenic microorganisms at reasonable operating costs. (See EPA's CSO Technology Fact Sheet 832-F-99-021, Disinfection-Chlorination, for more information).

While chlorine disinfection is the most common method used to kill pathogenic microorganisms at wastewater treatment plants, this methodology may not be feasible at all CSOs for several reasons, including:

- CSOs occur intermittently and their flow rate is highly variable, thus making it difficult to regulate the addition of disinfectant.
- CSOs have high suspended solids concentrations.
- CSOs vary widely in temperature and bacterial composition.
- Residual disinfectants from chlorine disinfection may be prohibited from receiving waters.
- CSO outfalls are often located in remote areas and thus may require automated disinfection systems.

In addition to these problems, the increased health and safety concerns regarding the use of chlorine to disinfect CSOs has prompted the development of alternative disinfectants, which often pose fewer problems and hazards. Alternatives to chlorine have been developed and evaluated for continuous disinfection of wastewater discharges to small streams or sensitive water bodies, and are now being considered for treatment of CSOs and other episodic discharges.

This fact sheet addresses the use of chlorine dioxide, ozonation, ultraviolet radiation, peracetic acid and Electron Beam Irradiation (E-Beam) to treat CSOs.

Chlorine Dioxide

Studies have shown that chlorine dioxide is an effective wastewater disinfectant, although its use in the United States is limited. Chlorine dioxide is applied to wastewater as a gas that is generated on-site using excess chlorine. Although it is relatively easy and economical to produce chlorine dioxide is unstable and reactive and any transport is hazardous.

Chlorine dioxide is effective at oxidizing phenols, but does not react with aquatic humus to produce trihalomethanes (THMs). However, any excess chlorine remaining from the generation of chlorine dioxide would react with THM precursors and form THMs. Therefore, operators must be careful to use the correct amounts of chlorine when generating chlorine dioxide. And while chlorine dioxide will not react with wastewater to form chloramines, it can produce potentially toxic byproducts such as chlorite and chlorate.

Ozonation

Ozone is a strong oxidizer and is applied to wastewater as a gas. Its use in CSO treatment facilities for wastewater disinfection is relatively new in the United States, and there are few facilities currently using ozone for disinfection. This can be potentially attributed to high initial capital costs associated with ozone generation equipment. Ozone is equal or superior to chlorine in "killing" power, but it does not cause the formation of halogentated organics as does chlorination.

Ultraviolet (UV) Radiation

UV radiation is one example of electromagnetic radiation used for disinfection. UV disinfection incorporates the spectrum of light between 40 nanometers and 400 nanometers. Germicidal properties range between 200 and 300 nanometers, with 260 nanometers being the most lethal. The primary method for utilizing UV disinfection is to expose wastewater to a UV lamp. Historically, most UV disinfection facilities have been designed to utilize Low Pressure Low Intensity UV lamps for disinfection. For example, low-pressure mercury arc lamps emit approximately 90 percent of their light energy around 254 nanometers.

UV disinfection works by penetrating the cell walls of pathogenic organisms and structurally altering their DNA, thus preventing cell replication and function. No hazardous chemicals are produced or released while treating CSOs with UV.

Because UV is not a chemical disinfection method, it disinfects without altering the physical or chemical properties of water. However, UV efficiency is affected by suspended solids in the wastewater, which can scatter and absorb light. Thus, UV disinfection is not effective in wastewaters with a high TSS level.

Peracetic Acid

Peracetic acid (CH_3COOOH) (PAA), also known as ethaneperoxoic acid, peroxyacetic acid, or actyl hydroxide, is a very strong oxidant. Based on limited demonstration data for disinfection of secondary treatment plant effluent, peracetic acid appears to be an effective disinfectant and should be evaluated further for treating CSOs. The equilibrium mixture of hydrogen peroxide and acetic acid that produces PAA is too unstable and explosive to transport, and so PAA must be produced on site. The decomposition of PAA results in acetic acid, hydrogen peroxide and oxygen.

Electron Beam Irradiation

Electron Beam Irradiation (E-Beam) uses a stream of high energy electrons that are directed into a thin film of water or sludge. The electrons break apart water molecules and produce a large number of highly reactive chemical species. There are a few reactive species formed during this process and include oxidizing hydroxyl radicals, reducing aqueous electrons and hydrogen atoms.

APPLICABILITY

A brief summary illustrating the general applicability of chlorine dioxide, peracetic acid and UV radiation as alternative CSO disinfectants is provided in Table 1. While ozonation and the E-Beam process are discussed in this fact sheet as potential alternative disinfectants for CSOs, they are not currently considered practical for CSO disinfection and thus they are not included in Table 1. Because ozone must be generated on-site and the amount generated is dependent on the demand, ozone is not currently considered practical for intermittent use in situations where the system would be frequently turned on and off or where there are wide fluctuations in flow rate and disinfection demand, such as in CSO treatment applications. The E-Beam system was initially developed for the disinfection of municipal wastewater treatment plant sludge and the destruction of hazardous organic compounds, and it has not been evaluated for CSO disinfection. EPA will continue to evaluate the E-Beam system as a promising innovative technology for wastewater technology.

ADVANTAGES AND DISADVANTAGES

As discussed above, one of the primary reasons for seeking alternatives to chlorine disinfection of CSOs is the growing concern over safety in handling gaseous chlorine and the possible toxic side effects of treatment with chlorine. Studies on alternative disinfectants such as peracetic acid, ozone, E-Beam, and UV, have shown that these alternatives serve as good substitutes for chlorine because they produce no toxic byproducts. Although chlorine dioxide does produce byproducts and residuals, the limited use of chlorine dioxide in this country has made it difficult to assess these byproducts for toxicity.

The alternatives to chlorine for CSO disinfection are not problem-free, however, and their effectiveness depends on the physical and chemical characteristics of the wastewater (e.g., the presence of large particles may hinder disinfection). They require certain storage and use precautions, and disinfection residuals and byproducts may be a concern in receiving waters.

As discussed above, Table 1 provides comparative data for chlorine dioxide, peracetic acid, and UV radiation to help in determining which compounds may be most advantageous for specific applications. The following sections summarize the advantages and disadvantages of using ozonation and E-Beam as alternative CSO disinfectants.

Ozonation: Advantages

- More powerful disinfectant than most chlorine compounds.
- Inactivates most strains of bacteria and viruses and is noted for destroying chlorine-resistant strains of both. Highly effective for Cryptospiridium eradication.
- Will oxidize phenols with no negative residuals such as trihalomethane production.
- Does not produce a disinfection residual that would prevent bacterial growth.
- Degenerates into oxygen, which can elevate oxygen levels in treated water. It does not alter pH of water.
- Increases coagulation.
- Helps remove iron and manganese.
- Has taste and odor control properties.
- Requires short contact time

Ozonation: Disadvantages

- More costly than traditional chlorinated disinfection techniques.
- Forms nitric oxides and nitric acid which can lead to corrosion.
- Ozone is chemically unstable as a gas, and hazardous to transport. It must be generated on site and used immediately.

TABLE 1 SUMMARY OF GENERAL ATTRIBUTES OF CHLORINE DIOXIDE, PAA AND UV RADIATION

	ClO_2	PAA	UV RADIATION
Stability	Moderate	Low	High
Persistent Residual	Moderate	None	None
Potential Byproduct Formation	Yes	No	No
Reacts with Ammonia	No	No	No
pH Dependent	Moderate	No	No
Ease of Operation	Moderate	Complex	Simple to Complex
Temperature Dependent	Moderate	Complex	Simple to Complex
Contact Time	Moderate	Low	Low
Safety Concerns	High	High	Low
Effectiveness as Bactericide	High	High	High
Effectiveness as Viricide	High	High	High
Likelihood of Regrowth	None	None	High

Source: Compiled from various sources.

E-Beam: Advantages

Currently, there is insufficient information on the E-Beam process to make a full determination of its usefulness for CSO disinfection, but a pilot study performed for the New York City Department of Environmental Protection (NYCDEP) determined several advantages of the E-Beam system:

- No disinfectant chemicals required.
- No toxic byproducts are known to be produced.
- Short contact time required.
- Potential to deactivate a wide range of pathogens.
- Potential to penetrate waste streams with high solids concentrations.

E-Beam: Disadvantages

- Increased safety considerations due to use of high- voltage technology and the generation of X-ray radiation.
- No full scale application experience for CSOs.
- High capital costs.
- High O&M costs.
- Thin process flow stream.
- Abundant pretreatment straining of influent is required for this delivery system.

DESIGN CRITERIA

Design criteria for different disinfection systems will differ based on site-specific needs. However, the following general factors should always be considered when evaluating disinfection alternatives.

- Safety (transport and storage in inhabited areas, potential for release)
- Effectiveness (ability to reduce indicator organisms to target levels, reliability, conditions of use)
- Cost (capital cost, operation and maintenance, amortization cost)

- Complexity of use (on-site generation, application and control, flexibility)

- Environmental/adverse effects (aquatic toxicity, persistent residuals, formation of toxic or bio-accumulating byproducts)

- Flow and wastewater characteristics (range of flows, duration of event, TSS concentration, downstream channel conditions, monitoring and control points)

Generally, the efficacy of a disinfectant depends on factors such as the flow rate, volume, pH, TSS concentration, and temperature of the wastewater. For CSOs, these factors vary from location to location, and even from discharge event to discharge event, and thus a typical concentration, contact time, and mixing intensity for a particular disinfectant is difficult to characterize. CSO facilities will need to conduct preliminary baseline studies to characterize the range of conditions that exist for a particular area and the design criteria to be considered.

Chlorine Dioxide

Chlorine dioxide is an effective bactericide and viricide that works over a wide range of pH values but is unstable and explosive as a gas. On-site generation of ClO_2 may be accomplished by combining sodium chlorite with either aqueous or gaseous chlorine (Reaction 1). ClO_2 can also be produced by combining sodium chlorite with hydrochloric acid (Reaction 2).

Reaction 1:

$2NaClO_2 + Cl_2 \rightarrow 2ClO_2 + 2NaCl$ (chlorine)

Reaction 2:

$5NaClO_2 + 4HCl \rightarrow 4ClO_2 + 5NaCl + 2H_2O$ (hydrochloric acid)

Reaction 1 requires 1.34 grams of sodium chlorite to react with 0.526 grams of chlorine to produce 1 gram of ClO_2 (pH of chlorine water 1.7-2.4). Reaction 2 requires 1.67 grams of sodium chlorite to react with hydrochloric acid to produce 1 gram of ClO_2. Excess chlorine is typically required in both of these reactions, potentially resulting in chlorinated byproducts.

A new method of ClO_2 generation that does not involve chlorine is to radiate sodium chlorite with UV radiation as follows:

Reaction 3:

- NaClO2 + hv (254 nanometers) $\rightarrow Na^+ + ClO_2$

- $Na^+ + H_2O \rightarrow NaOH$

Chlorine dioxide produced via UV radiation does not use aqueous or gaseous chlorine, involves a single chemical reactant, and is cheaper while not producing any toxic by-products.

A chlorine dioxide disinfection system requires chlorine dioxide generation on site by one of the three generation methods above. An adequate reactor vessel with metering pumps and ancillary piping is required. Chlorine dioxide is directed from the generator into an ejector, with the rate of flow controlled by a chlorinator. The ejector is a hydraulic chamber designed to carry a fraction of wastewater flow through it, thereby creating a vacuum or negative pressure. The chlorinator, which uses a negative pressure diaphragm valve, is triggered by the vacuum and releases gas into the ejector as wastewater flows through. Once in the ejector, chlorine dioxide enters into solution and is sent to a diffuser where it is mixed with wastewater. Mixing can be accomplished using one of four available methods:

- A diffuser can be placed in the center of a pipe or channel with flow running at full turbulence.

- A hydraulic structure may be placed in the flow stream to induce turbulence (e.g., submerged weir, hydraulic jump).

- A mechanical mixer (propeller, turbine) can be used in conjunction with a small residence time mixing chamber and the ejector.

- A jet mixer can discharge disinfectant solution at high pressure into the wastewater.

The degree of mixing at the point of disinfectant application affects the initial rate of inactivation. After mixing, wastewater enters into a contact basin to be held for sufficient time until desired microbial inactivation has been attained. The discharge pipe or channel may be used for contact if sufficiently long distance is available. If a contact chamber is to be built, baffles should be used to provide the longest possible pathway for flow to minimize dispersion and approach plug flow conditions. The design of the contact chamber is dependent on the disinfectant dose, the nature of the wastewater, and the required level of disinfection.

Designs for an ejector should be based on the maximum capacity of the chlorinator, the inlet water pressure, the back pressure of the ejector outlet, and the distance between the ejector and the diffuser. The ejector should be located as close to the mixing point as possible to minimize both the lag in the solution line and the back pressure at the ejector. The vacuum line carrying gas between the chlorinator and ejector should have a pressure drop of less than 0.7 pounds per square inch. The temperature of the supply lines and impurities in the gas are chief concerns in the design of such a system.

Ozonation

Ozone disinfection is similar in most respects to chlorine disinfection. The major difference is that ozone is unstable, so it must be generated on site. For water treatment, ozone is produced by an electrical corona discharge or ultraviolet irradiation of dry air or oxygen. Ozone can be injected or diffused into the water supply stream.

Ozone can be generated from any gas containing oxygen molecules. The most common sources for ozone generation are oxygen gas or atmospheric air. Although the use of pure oxygen gas will result in a higher efficiency of ozone generation, it will also increase the initial cost of the gas source. On the other hand, using atmospheric air requires preparation of the gas source. Most ozone generators require clean, dry gas for optimal conditions. Therefore, atmospheric air must first be compressed, cleansed and dehumidified. Compression of the air serves to increase the concentration of ozone in the supply. The removal of foreign particulates such as dirt and dust is often accomplished through filtration. Air humidity is usually decreased by lowering the dew point through refrigeration.

The solubility of ozone in water is a function of temperature and pH. The amount of ozone in the system can be regulated in the generator by adjusting the voltage of the current or the flowrate of the gas. The maximum ozone concentration produced by a generator is 50 g/m^3 and the maximum solubility concentration of ozone in water is 40 mg/L.

Ozone has an average half-life of 20 minutes if it is not oxidized by particulates. Depending on the water quality at a given time, a portion of the dissolved ozone may pass through the system unoxidized. Regulations require the resulting concentration of ozone to be reduced to less than 0.002 mg/L before the water is released from the plant. Ozone degradation can be accelerated by the addition of hydrogen peroxide or by passing the system through a UVc system. Contact time can also be lengthened to allow for further ozone destruction.

Ultraviolet Radiation

The following factors must be monitored for the successful operation of a UV system: flow rate, suspended solids concentration, UV absorbency coefficient, initial and final coliform density, number of lamps in operation, average lamp output, and average transmissibility of the transmitting surface.

Two generic designs are available for disinfection with UV. The non-contact design suspends lamps away from contact with the wastewater. The contact reactor-type design uses lamps encased in a quartz sleeve submerged in wastewater at all times. The two primary types of submerged UV systems are:

- Open channel (horizontal and vertical); and
- Closed channel.

An open channel system submerges lamps in either a horizontal or vertical arrangement in an open channel from a self-supporting stainless steel enclosure. Lamps in both positions are arranged perpendicular to the horizontal flow. A closed channel system is a sealed disinfection chamber which can be used in pressurized systems. UV lamps are installed in a stainless steel chamber with removable ends for interior access. All lamps are housed on racks (ballasts) that require ventilation or cooling to reduce heat build up. Excessive heat causes failure of ballasts.

The water level in the channels must be kept fairly constant. Fluctuations in the water level may result in several problems. In horizontal systems, the top row of lamps can become exposed, or the depth of water above this row can become so great that adequate exposure of wastewater to UV does not occur. Automated control valves downstream from the UV lamps can control water level, but these systems require electrically-operated valves and electronic controllers. Self-adjusting level control gates can control upstream water levels over a wide range of flows. Although these gates are inexpensive and require little maintenance, they require proper installation and use more hydraulic head than an appropriately sized control valve or weir. Weirs may also be used to control water level in UV tanks. Weirs are inexpensive, reliable, predictable, and have no moving parts.

UV dosage is dependent upon the frequency and the intensity of UV radiation, the number of lamps and their configuration, the distance between the wastewater and the lamp surface, the chamber turbulence, the exposure time, and the absorption coefficient of the wastewater. Design considerations should account for the number of lamps required for disinfection and the number of channels required to minimize headloss. UV dose is usually expressed as milliwatt-seconds per square centimeter ($mW\text{-}s/cm^2$). Lamps emitting wavelengths in the range of 250 to 265 nanometers are usually adequate for disinfection. Preliminary sizing and design for a system should be based on 1.0 million gallons per day per UV kilowatt.

UV disinfection of CSO wastewater requires that proper UV intensity be applied to wastewater for sufficient time to render pathogens inactive. A spectrophotometer can be used in a UV system to ensure that proper light intensity is delivered. Unfortunately, many factors may limit the intensity of the light delivered for treatment. Suspended solids absorb and scatter UV light while shielding microorganisms in the particles from exposure to UV light. Studies have shown that reduced TSS concentrations are necessary to obtain adequate disinfection with UV systems; therefore, sedimentation or filtration prior to UV is usually required. Proper disinfection is also dependent upon the light transmitting surface remaining clear.

Peracetic Acid

Peracetic acid has been used as a disinfectant in demonstration projects for the treatment of primary effluent such as that found in CSOs. PAA is a very strong oxidizer, and is produced by combining glacial acetic acid, hydrogen peroxide, and water. Sulfuric acid is typically used as a catalyst for the reaction. A stabilizer chemical is also added to solution to slow biodegradation. Equilibrium concentrations are:

Peracetic Acid	15.0%
Glacial acetic acid	14.0%
Hydrogen peroxide	28.0%
Water	42.2%
Sulfuric Acid	0.8%

A 15 percent solution would be made with the following proportions:

Glacial acetic acid	39.4%
Water	38.8%
Hydrogen peroxide	21.0%
Sulfuric Acid	0.8%

Because of the high reactivity of the final product, liquid reactants must be delivered to the site in separate tanks, and mixed on an as-needed basis. PAA residuals appear to be non-toxic and are readily biodegradable in receiving waters.

Electron Beam Irradiation

A limited amount of information exists on the applicability, performance and optimum design features for E-Beam systems. To limit the size of particles to the E-Beam delivery system and prevent clogging of the delivery unit, the pilot study for NYCDEP allowed the wastewater to flow through a basket strainer equipped with either a 1/32-inch or a 1/64-inch screen basket before reaching the E-Beam. Water was then pumped through the E-Beam system using a progressive-cavity, positive displacement pump. The pump provided positive control of the wastewater flowrate discharge. The pump discharge was then fed to the E-Beam delivery system where the wastewater film was scanned by the electron beam. Thermocouples attached to the delivery system influent and effluent monitored the temperature change of the wastewater and were used to calculate the absorbed dose. According to the study, the absorbed E-Beam dose was determined as a function of wastewater temperature changes in the contact tank. A temperature increase of 1°C equates to an absorbed dose of 418.6 krads.

The E-Beam disinfection pilot was operated at a flow rate of 20 gpm. The pilot flow rate was held relatively constant during each of the test runs.

PERFORMANCE

Disinfectants for treating CSO events require "high rate" disinfection practices. Ideally, high bacterial kills should be accomplished with low contact times, a high mixing intensity, and an increased disinfectant dosage. Since most of the alternative disinfectants evaluated in this fact sheet are new and innovative, performance data is limited. In cases where actual CSO data were not available, primary and/or secondary effluent treatment data were used to evaluate the effectiveness of the disinfectant.

Comparisons of performance data from different applications may be further complicated by the fact that it is often difficult to determine the appropriate disinfectant concentration to apply to achieve the desired bacterial reduction. Concentrations of fecal and total coliform bacteria in the CSO are commonly used to assess the performance of the disinfection process in wastewater applications. However, the coliform count for storm flow is often uncorrelated to the pathogenic organism concentrations in the flow. Therefore, other methods may be more appropriate for determining the concentrations of disinfectants to add to the flow to achieve the desired results.

Chlorine Dioxide

The effectiveness of chlorine dioxide in treating CSO discharges is measured in terms of reduction in bacterial concentrations. According to a pilot scale study in New York, a dosage of 12 milligrams/liter ClO_2 applied for a two minute contact time achieved the following:

- Total coliform (TC) bacteria reduction to target levels of 1,000 colonies/100 milliliters.

- Fecal coliform (FC) and fecal streptococci (FS) bacteria reduction to 200 colonies/100 milliliters.

Ozonation

Venosa (1983) compiled data on several studies on ozonation as a CSO disinfectant. Venosa cites a 1977 study by Scaccia and Rosen showing that the disinfection efficiency of ozone is related to the amount of ozone transferred into the process water, regardless of the contactor type. Venosa also cites his own 1978 study demonstrating that the amount of ozone transferred to a municipal effluent is directly related to the reduction in the number of coliforms entering the disinfection system. In this study, Venosa also developed a model to predict the effluent coliform number based on the amount of ozone being transferred and the total chemical oxygen demand (TCOD). This and other research demonstrates that ozone disinfection is a function of the absorbed dose and the effluent's ozone-demanding properties. In addition, monitoring off-gas ozone levels can help to control disinfection efficiency.

Ultraviolet Radiation

A dose-response relationship exists between UV dose and reduction of TC and FC. The quality of wastewater will dictate what dose should be used. A 30 megaWatt-second/square centimeter (mW-s/cm^2) dose is recommended for a 4 log reduction in fecal coliform for wastewater with a 65 percent transmittance and a suspended solids concentration of 30 milligrams/liter. Results of several studies on UV disinfection are presented below. In several of these studies, bacterial concentrations are given in terms of the most probable number, or MPN:

- A simulated CSO study carried out at the Brampton WPCP in 1991 used a 60/40 blend of raw wastewater and final effluent. A UV dosage of 75 mW-s/cm^2 was needed to achieve a target bacterial concentration of 100 colonies/100 milliliters. Results from the Central Contra Costa Sanitary District facility (CCCSD) indicated that UV doses of 55 mW-second/square centimeter were required to achieve 240 MPN/100 milliliters TC bacterial densities in unfiltered secondary effluent (WERF, 1995). Doses less than 50 mW-second/square centimeter were required to achieve 2.2 MPN/100 milliliters total coliform bacterial densities in filtered effluent.

- A study using a UV dose of 40 mW-m/cm^2 on tertiary effluent with flows ranging from 9 to 30 liters/second was able to achieve a 3 log kill up to a 4.8 log kill (99.8 percent removal) of fecal coliforms, total coliforms, Pseudomonas aeruginosa, salmonellae, Staphylococcus aureus, F+ bacteriophage, and enterovirus.

- A study performed on wastewater being discharged into shellfish waters around St. Michael's, MD found that total coliform densities could be reduced to 70 MPN/100 ml or less with UV at 25,000 uW-second/square centimeter and UV transmittance at an average 65 percent (as cited in U.S. EPA, 1986).

- Under laboratory conditions, a study in Syracuse, NY, suggested that a dose of 500 mW-s/cm^2 would be required to achieve a residual coliform level of 2500 MPN/100 milliliters (as cited in U.S. EPA, 1986).

- A similar pilot scale study at CCCSD designed to examine UV and chlorine inactivation of the MS2 bacteriophage indicated that UV doses of 20 to 100 mW-s/cm^2 were sufficient to cause a 1 to 4.7-log reduction in these organisms. In comparison, chlorination using a dose of 30 to 300 milligrams/liter per minute achieved little or no inactivation of the MS2 bacteriophage.

Electron Beam Irradiation

According to the pilot study done for the NYCDEP, E-Beam is not appropriate for the disinfection of CSOs. The study showed no increased disinfection with an increase in disinfection dose for total coliform, fecal coliform, and *Escherichia coli*. A weak trend was observed for increased disinfection of the Enterococcous group with increased disinfection dose.

OPERATION AND MAINTENANCE

In order to assure proper operation and maintenance for CSO disinfection, operators and facility managers should have access to, and be aware of, all Material Safety Data Sheets on any chemicals being used. These data sheets provide information on several aspects of the chemical, including handling and storage, regulations, disposal considerations, and toxicological information.

Chlorine Dioxide

Proper operation and maintenance of a chlorine dioxide facility should include the following procedures.

- All tubing should be inspected every six months and faulty or corroded tubing should be replaced.

- Any gas filters should be inspected every six months.

- Chlorine dioxide pressure reducing valves should be cleaned with isopropyl alcohol or trichloroethylene.

- The valve spring should be replaced every two to five years.

- Ejectors should be disassembled and cleaned every six months.

- Chlorine dioxide analyzers (if used) should be inspected regularly. All lines should be inspected daily. Results from the analyzer should be compared with results from a manual analysis.

- Granular sodium chlorite should be stored in its own building equipped with sloped floors and equipment to hose down spills.

- Increases in temperature, exposure to light, changes in pressure, and exposure to organic contaminants should be avoided as they increase the chance of ClO_2 explosions.

Ozonation

Maintenance of an ozone residual at a given concentration for a specific period (detention time) is necessary for proper disinfection. Because ozone has a tendency to decompose naturally and is consumed rapidly, it must be contacted uniformly in a near plug flow contactor.

The ozone dosage must be calculated based on the gas flow and the concentration applied to the contactor versus the gas flow and the concentration out of the contactor and the aqueous ozone residual and flow. The calculation requires consideration of gas volume and concentration versus aqueous volume and concentration. Maintenance activities that should be addressed include:

- Prevent leaking connections or other leaks in or around the ozonator because this presents an electrical shock hazard.

- Schedule cleanings of ozonator and its parts.

- Lubricate compressor or blower as scheduled.

- Monitor ozone generator operating temperature.

- Clean the ozone generation cells periodically to maintain maximum efficiency.

Ultraviolet Radiation

Maintenance for a UV disinfection facility would include area maintenance and component cleaning/repair. As with most surfaces exposed to wastewater, bacterial growth occurs in spite of the disinfecting ability of the UV radiation (the associated warmth facilitates growth). Bacterial growth on the quartz tubes surrounding the UV lamps gradually reduces the amount of UV radiation reaching, and disinfecting, the wastewater. UV systems have transmittance meters that measure the amount of UV light coming from the bulbs and passing through the wastewater. When the transmittance reading reaches a predetermined low level, the bulb covers must be cleaned, chemically and/or physically. Several methods are available for cleaning lamps including:

- In-place recirculation;

- Mechanical wipers;

- Dip tanks; and

- Removing modules (rinse, clean with chemical, rinse and return)

Several cleaning agents available for cleaning lamps include:

- Citric acid;

- Dilute HCl;

- Phosphoric acid;
- Tile/bowl cleaner;
- Lime away;
- Detergent; and
- Sulfuric acid.

Chemical cleaning may not restore the lamp covers to their original transmittance level. The amount of restoration is likely to be less with each subsequent cleaning. Ultimately, covers must be manually cleaned or replaced.

The period of time between cleaning is determined by the rate at which the quartz sleeves become coated and reduce the ultraviolet output. The coating composition and the rate at which it accumulates are site-specific and depend on the chemical properties of the water. Pilot studies are recommended to produce data that correspond to actual operating conditions.

The lamps themselves will ultimately burn out or lose their intensity. The normal life span of a UV lamp is approximately 14,000 hours. Strict inventory should be made of all lamp usage, relative output, and estimated cumulative operating life. Inventories should also be made on quartz sheaths, Teflon tubes, and ballasts. The ballast cages used to house the lamps will also need to be replaced approximately every 10 years. Reactors taken out of service should be rinsed with clean water, drained, and held in a drained, dry condition. A bypass should be constructed around the entire UV disinfection system for use during maintenance tasks.

Limited safety data is available on UV disinfection systems. Moderate skin exposure to UV can cause erythema, or reddening of the skin. Excessive exposure may cause bleeding and blistering. UV exposure to eyes can cause kerato-conjunctivitis or inflammation of the eye, retinal lesions, chronic yellowing of the lens, and cataract formation.

The following precautions are suggested to help reduce UV exposure:

- Open-channel lamps should be arranged in metal frames.
- Interlocks should be incorporated into the channel lamp design to allow for the shutdown of entire lamp blocks. Interlocks should also prevent lights from illuminating when they are not completely submerged.
- Protective goggles and a face shield should be worn at all times around UV lamps even when the lamps appear to be emitting little light.
- Protective electrical devices should be included in electrical designs for the facility.
- Precautions should be taken to avoid electrical shocks. Facility plans should provide limited access and traffic through electrical and equipment areas.
- Access to those areas should be limited only to necessary personnel.
- Hazard placards should be placed in appropriate areas of the facility describing the risks associated with the UV equipment.

Peracetic Acid

Maintenance for a PAA facility should include periodic inspections of feed lines, storage areas, leakage detection equipment, and chemical injectors. Blocked or silted sewer lines should be flushed and cleaned on a regular basis. Spent chemical containers should be discarded in approved receptacles. Spilled chemicals should be cleaned up immediately. The chemical housing facility should be cleaned and inspected periodically to ensure structural integrity. The explosive nature of the chemical agents stored at the facility requires that the sprinkler system be inspected regularly.

The following basic safety precautions should be observed while handling PAA. More detailed safety precautions are available from the manufacturer.

- Chemicals for use in PAA disinfection processes should be stored in a cool, dry, well-ventilated area and should be kept in their original, DOT-approved shipping containers with hazard labels intact. PAA is thermally unstable and decomposes explosively at high temperatures. The storage building should be constructed of materials with maximum resistance to fire and explosive potential, and should include deflagration venting. The facilities must be designed with interior walls capable of withstanding 125 pounds per square foot internal overpressurization and ceilings must be insulated. Storage buildings should have an automatic sprinkler system designed for 0.40 gallons per minute per square foot.

- The storage room should be kept separate from all other processes and should be separated from acids, alkalies, organic materials, and heavy metals.

- A backup power supply is necessary for housing structures at all times.

- No more than 4,800 gallons of the product should be allowed inside the facility at any one time; a greater quantity requires storage in separate buildings.

- PAA may only be stored in 30 gallon closed drums and cannot be stacked.

- Personnel must wear special protective clothing and positive pressure self-contained breathing apparatus.

- Release detecting equipment must be located near chemicals, and near valves and equipment that pose a potential threat. Releases in excess of 1 pound should be reported.

- Chemical spills must be contained and diluted with water.

COSTS

Costs for chlorine dioxide, ozonation, UV radiation, peracetic acid, and E-Beam processes cannot be easily compared due to the different variables and the varying application methods for the various disinfectants. Each alternative should be evaluated based on the characteristics of a particular site. Tradeoffs should be weighed to determine any overriding factors to be ultimately incorporated into the system. In a report prepared for the NYCDEP, a cost projection was created for chlorine dioxide and ozone. This data is presented in Table 2. Due to limited information on E-Beam processes there is no cost information currently available.

TABLE 2 CSO DISINFECTION PILOT STUDY COST PROJECTIONS

Conceptual Level Disinfection Costs						
Technology	Chlorine Dioxide			Ozone		
Peak Design Flow (cfs)	1,250	2,500	5,000	1,250	2,500	5,000
Capital Costs	$651,000	$1,085,000	$1,808,000	$18,000,000	$23,000,000	$28,600,000
Annualized Capital Costs	$66,000	$111,000	$184,000	$1,833,000	$2,343,000	$2,913,000
Annual O&M Costs	$275,000	$275,000	$275,000	$500,000	$550,000	$615,000
Total Annualized Costs	$341,000	$386,000	$459,000	$2,333,000	$2,893,000	$3,528,000

Source: NYCDEP, 1997.

Notes:
1. Costs are present worth in 1997 dollars.
2. Capital costs are based upon sizing to meet peak design flow and a 4-log reduction in fecal coliform.
3. Capital costs are for installation at Spring Creek and are for process equipment only. Costs do not include additional contact tankage (if required) or support facilities.

Chlorine Dioxide

Costs will vary for a chlorine dioxide generation system based on design specifications. The estimated cost for a chlorine dioxide system (wired and installed) capable of producing a feed rate of over 100 pounds ClO_2/day is approximately $21,000.

The system would convert chlorine dioxide from sodium chlorite or chlorine. Production of gas would be dependent upon demand and would not be affected by variations in flow rate.

Ultraviolet Radiation

A detailed cost analysis was obtained from a pilot demonstration project performed at the Downingtown WPCP in Downingtown, PA. This system was not used for treatment of CSOs; however, the equipment and O&M costs provide baseline estimates for similar treatment flows. Costs and equipment designs were based on the following data:

Peak Flow (GPM)	7297.5 (10.5 mgd)
Avg. Flow (GPM)	2919 (4.2 mgd)
Influent BOD mg/l	30
Influent SS mg/l	30
UV Transmission (%)	65

Based on this data, an open channel vertical system with the specifications shown in Table 3 would be required to produce effluent which meets the minimum fecal coliform count of less than 200 colonies per 100 milliliters for any 30-day geometric mean of daily samples at peak flow. The present worth analysis based on a life expectancy of 20 years and an 8 percent interest rate for both capital cost and operation and maintenance is approximately $446,897 for a vertical system and $492,517 for a horizontal system.

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TABLE 3 ULTRAVIOLET RADIATION COST FACTORS FOR AN OPEN CHANNEL VERTICAL SYSTEM CAPABLE OF PRODUCING AN EFFLUENT WITH A MAXIMUM FECAL COLIFORM COUNT OF LESS THAN 200 COLONIES PER 100 MILLILITERS

SPECIFICATION		
Number of Channels	2; Water Depth will be a maximum of 62", Minimum of 57.5"	
Number of Modules/Channel	6	
Total Number of Modules	12	
Number of Lamps/Module	40	
Total Number of Lamps	480	
Dose Level (megawatts per second per square centimeter)	36	
Retention Time (seconds)	12-38	
Headloss (inches)	<3"	
Power Requirement	(2) 208 v, 3 ph, 60 Hz, 60 amp	
Capital Cost: $278,400		
OPERATION AND MAINTENANCE		
Electrical Consumption	$.055/kWh	
Consumption/Lamp	$0.075/kW (Vertical) $0.085/kW (Horizontal)	
Lamp Replacement Cost	$55.00 every 8760 operating hours	
Cleaning Frequency	Once/month (may vary depending on site-specific conditions)	
Labor rate	$15.00/hour	
	Vertical	Horizontal
Number of Lamps “On”	160	176
Electrical	$5,782	$7,208
Replacement	$8,800	$9,680
Cleaning	$180 (30 minutes per channel per month)	$990 (15 minutes per module per month)
Replacement Labor	$2,400 (30 seconds per lamp per year)	$4,224 (8 minutes per lamp per year)
Total Replacement Costs	$17,162	$22,102

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