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Wastewater Technology Fact Sheet
Ultraviolet 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. Some common microorganisms found in domestic wastewater and the diseases associated with them are presented in Table 1.

An Ultraviolet (UV) disinfection system transfers electromagnetic energy from a mercury arc lamp to an organism's genetic material (DNA and RNA). When UV radiation penetrates the cell wall of an organism, it destroys the cell's ability to reproduce. UV radiation, generated by an electrical discharge through mercury vapor, penetrates the genetic material of microorganisms and retards their ability to reproduce.

The effectiveness of a UV disinfection system depends on the characteristics of the wastewater, the intensity of UV radiation, the amount of time the microorganisms are exposed to the radiation, and the reactor configuration. For any one treatment plant, disinfection success is directly related to the concentration of colloidal and particulate constituents in the wastewater.

The main components of a UV disinfection system are mercury arc lamps, a reactor, and ballasts. The source of UV radiation is either the low-pressure or medium-pressure mercury arc lamp with low or high intensities.

TABLE 1 INFECTIOUS AGENTS POTENTIALLY PRESENT IN UNTREATED DOMESTIC WASTEWATER

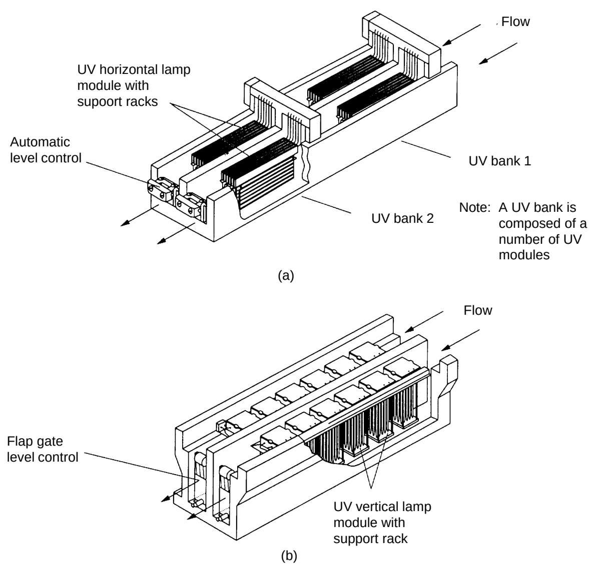
Organism	Disease Caused
Bacteria	
Escherichia coli (enterotoxigenic)	Gastroenteritis
Leptospira (spp.)	Leptospirosis
Salmonella typhi	Typhoid fever
Salmonella (=2,100 serotypes)	Salmonellosis
Shigella (4 spp.)	Shigellosis (bacillary dysentery)
Vibrio cholerae	Cholera
Protozoa	
Balantidium coli	Balantidiasis
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.

The optimum wavelength to effectively inactivate microorganisms is in the range of 250 to 270 nm. The intensity of the radiation emitted by the lamp dissipates as the distance from the lamp increases. Low-pressure lamps emit essentially monochromatic light at a wavelength of 253.7 nm. Standard lengths of the low-pressure lamps are 0.75 and 1.5 meters with diameters of 1.5 - 2.0 cm. The ideal lamp wall temperature is between 95 and 122°F.

Medium-pressure lamps are generally used for large facilities. They have approximately 15 to 20 times the germicidal UV intensity of low-pressure lamps. The medium-pressure lamp disinfects faster and has greater penetration capability because of its higher intensity. However, these lamps operate at higher temperatures with a higher energy consumption.

There are two types of UV disinfection reactor configurations that exist: contact types and noncontact types. In both the contact and the noncontact types, wastewater can flow either perpendicular or parallel to the lamps. In the contact reactor, a series of mercury lamps are enclosed in quartz sleeves to minimize the cooling effects of the wastewater. Figure 1 shows two UV contact reactors with submerged lamps placed parallel and perpendicular to the direction of the wastewater flow. Flap gates or weirs are used to control the level of the wastewater. In the noncontact reactor, the UV lamps are suspended outside a transparent conduit, which carries the wastewater to be disinfected. This configuration is not as common as the contact reactor. In both types of reactors, a ballast—or control box—provides a starting voltage for the lamps and maintains a continuous current.



Source: Crites and Tchobanoglous, 1998.
(a) adapted from Trojan Technologies, Inc.
(b) adapted from Infilco Degremont, Inc.

FIGURE 1 ISOMETRIC CUT-AWAY VIEWS OF TYPICAL UV DISINFECTION SYSTEMS

ADVANTAGES AND DISADVANTAGES

Advantages

- UV disinfection is effective at inactivating most viruses, spores, and cysts.
- UV disinfection is a physical process rather than a chemical disinfectant, which eliminates the need to generate, handle, transport, or store toxic/hazardous or corrosive chemicals.
- There is no residual effect that can be harmful to humans or aquatic life.
- UV disinfection is user-friendly for operators.
- UV disinfection has a shorter contact time when compared with other disinfectants (approximately 20 to 30 seconds with low-pressure lamps).
- UV disinfection equipment requires less space than other methods.

Disadvantages

- Low dosage may not effectively inactivate some viruses, spores, and cysts.
- Organisms can sometimes repair and reverse the destructive effects of UV through a "repair mechanism," known as photo reactivation, or in the absence of light known as "dark repair."

- A preventive maintenance program is necessary to control fouling of tubes.

- Turbidity and total suspended solids (TSS) in the wastewater can render UV disinfection ineffective. UV disinfection with low-pressure lamps is not as effective for secondary effluent with TSS levels above 30 mg/L.

- UV disinfection is not as cost-effective as chlorination, but costs are competitive when chlorination dechlorination is used and fire codes are met.

APPLICABILITY

When choosing a UV disinfection system, there are three critical areas to be considered. The first is primarily determined by the manufacturer; the second, by design and Operation and Maintenance (O&M); and the third has to be controlled at the treatment facility.

Choosing a UV disinfection system depends on three critical factors listed below.

- Hydraulic properties of the reactor: Ideally, a UV disinfection system should have a uniform flow with enough axial motion (radial mixing) to maximize exposure to UV radiation. The path that an organism takes in the reactor determines the amount of UV radiation it will be exposed to before inactivation. A reactor must be designed to eliminate short-circuiting and/or dead zones, which can result in inefficient use of power and reduced contact time.

- Intensity of the UV radiation: Factors affecting the intensity are the age of the lamps, lamp fouling, and the configuration and placement of lamps in the reactor.

- Wastewater characteristics: These include the flow rate, suspended and colloidal solids, initial bacterial density, and other physical and chemical parameters. Both the concentration of TSS and the concentration of particle-associated microorganisms determine how much UV radiation ultimately reaches the target organism. The higher these concentrations, the lower the UV radiation absorbed by the organisms. Various wastewater characteristics and their effects on UV disinfection are given in Table 2.

TABLE 2 WASTEWATER CHARACTERISTICS AFFECTING UV DISINFECTION PERFORMANCE

Wastewater Characteristic	Effects on UV Disinfection
Ammonia	Minor effect, if any
Nitrite	Minor effect, if any
Nitrate	Minor effect, if any
Biochemical oxygen demand (BOD)	Minor effect, if any. Although, if a large portion of the BOD is humic and/or unsaturated (or conjugated) compounds, then UV transmittance may be diminished.
Hardness	Affects solubility of metals that can absorb UV light. Can lead to the precipitation of carbonates on quartz tubes.
Humic materials, Iron	High absorbency of UV radiation.
pH	Affects solubility of metals and carbonates.
TSS	Absorbs UV radiation and shields embedded bacteria.

UV disinfection can be used in plants of various sizes that provide secondary or advanced levels of treatment.

PERFORMANCE

Gold Bar Wastewater Treatment Plant in Edmonton, Alberta, Canada

The Gold Bar Wastewater Treatment Plant (GBWTP) in Edmonton, Alberta, was required to use disinfection to meet water quality standards for contact recreation in Alberta. During that period, the average and peak design flow rates for this treatment facility were 82 and 110 million gallons per day (mgd), respectively. A pilot study was conducted to review current UV disinfection systems, effectiveness of lamp intensities, and costs. UV disinfection was determined to be the most efficient disinfection system to achieve the required treatment levels.

Lamp fouling is a potential problem among UV systems, but with proper cleaning and O&M, it should not interrupt the system's disinfection capability. Lamp cleaning at the GBWTP was achieved by a mechanical wiping mechanism accompanying each cluster of lamps. Lamps were cleaned on a regular basis using an in-channel cleaning system. The safety concerns for both low-pressure and high-intensity UV systems regarding exposure to UV radiation and electrical hazards are low under normal operating conditions. However, precautionary measures should be taken when operating high-intensity lamps to avoid overexposure. The risk was not considered major by the GBWTP and was outweighed by the potential savings of using high-intensity UV systems. At the GBWTP, a medium-pressure, high-intensity system was found to be more economical than the conventional low-pressure systems in both capital and life-cycle costs.

Northwest Bergen County Utility Authority Wastewater Treatment Plant in Waldwick, New Jersey

The use of UV disinfection for wastewater treatment has increased dramatically in the last few years due to the impact of chlorinated organics from sewage effluent on receiving waters. Such was the case with the Northwest Bergen County Utility Authority (NBCUA) Wastewater Treatment Plant located in Waldwick, New Jersey. In 1989, the treatment plant had to convert from chlorination to an alternative disinfection technology with zero residual after treatment. This change was brought about when the "zero residual" regulation was imposed by the New Jersey Department of Environmental Protection with the passage of the Toxic Catastrophic Prevention Act.

Several factors, such as public safety and recent findings and concerns over the environmental impact of chemical releases and spills, have led to more stringent permit requirements for chlorine. Also, there were other conditions that the treatment plant had to meet if chlorine use was to continue. To avoid the escalated costs that could be incurred and to be in compliance with the new regulations, the wastewater treatment plant switched to UV disinfection. The UV system was installed within the existing chlorine contact tanks, along with an extension to the existing building for easy maintenance during bad weather. The UV system at NBCUA was able to meet fecal coliform levels (200 count per 100 ml) better than chlorination since its installation in August 1989.

OPERATION AND MAINTENANCE

The proper O&M of a UV disinfection system ensures that sufficient UV radiation is transmitted to the organisms to render them sterile. All surfaces between the UV radiation and the target organisms must be clean, and the ballasts, lamps, and reactor must be functioning at peak efficiency. Inadequate cleaning is one of the most common causes of a UV system's ineffectiveness. The quartz sleeves or Teflon tubes need to be cleaned regularly by mechanical wipers, ultrasonics, or chemicals. The cleaning frequency is very site-specific, some systems need to be cleaned more often than others.

Chemical cleaning is most commonly done with citric acid. Other cleaning agents include mild vinegar solutions and sodium hydrosulfite. A combination of cleaning agents should be tested to find the agent most suitable for the wastewater characteristics without producing harmful or toxic by-products. Noncontact reactor systems are most effectively cleaned by using sodium hydrosulfite.

Any UV disinfection system should be pilot tested prior to full-scale operation to ensure that it will meet discharge permit requirements for a particular site.

The average lamp life ranges from 8,760 to 14,000 working hours, and the lamps are usually replaced after 12,000 hours of use. Operating procedures should be set to reduce the on/off cycles of the lamps, since their efficacy is reduced with repeated cycles.

The ballast must be compatible with the lamps and should be ventilated to protect it from excessive heating, which may shorten its life or even result in fires. Although the life cycle of ballasts is approximately 10 to 15 years, they are usually replaced every 10 years. Quartz sleeves will last about 5 to 8 years but are generally replaced every 5 years.

COSTS

The cost of UV disinfection systems depends on the manufacturer, the site, the capacity of the plant, and the characteristics of the wastewater to be disinfected. Total costs of UV disinfection can be competitive with chlorination when the dechlorination step is included.

The annual operating costs for UV disinfection include power consumption; cleaning chemicals and supplies; miscellaneous equipment repairs (2.5% of total equipment cost); replacement of lamps, ballasts and sleeves; and staffing requirements.

Costs have decreased in recent years due to improvements in lamp and system designs, increased competition, and improvements in the systems' reliability.

Medium-pressure lamps cost four to five times as much as low-pressure lamps. However, the reduced number of lamps necessary for adequate disinfection could make medium-pressure lamps cost-effective. Table 3A summarizes the costs of some of the lamps used in UV disinfection. This information was collected in a study conducted by the Water Environment Research Federation in 1995 for secondary effluents from disinfection facilities at average dry weather flow rates of 1, 10, and 100 mgd (2.25, 20, and 175 mgd peak wet weather flow, respectively). Table 3B describes the typical capital and O&M costs that are associated with a UV disinfection.

TABLE 3A LAMP COSTS FOR UV DISINFECTION SYSTEMS

Item	Range*	Typical*
UV lamps	($/lamp)	($/lamp)
1-5 mgd	397-1,365	575
5-10 mgd	343-594	475
19-100 mgd	274-588	400
Construction cost for physical facilities	(% of UV lamp cost) 75-200	(% of UV lamp cost) 150

* Costs are based on a 1993 Engineering News Record Construction Cost Index of 5,210.
Source: Adapted from: Darby et al. (1995) with permission from the Water Environment Research Foundation.

TABLE 3B CAPITAL AND O&M COSTS FOR UV DISINFECTION SYSTEMS

Cost Item	UV System Cost ($)
Capital Costs	
Equipment	120,000
Structural modifications	64,000
Electrical	20,000
Miscellaneous	40,000
Total:	**244,000**
Annual operating and maintenance costs	
Energy	3300
Lamps and chemicals	2840
Cleaning	1180
Maintenance	1440
Process control	6240
Testing	4160
Total	**19,190**

Source: Hanzon and Vigilia, 1999.

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