Disinfection of Wastewater Effluent: Comparison of Alternative Technologies

The disinfection landscape of the U.S. is changing. It is moving away from chlorine gas and toward alternatives such as hypochlorite, UV, and ozone. All of these technologies have distinct advantages relative to chlorine gas, but no alternative is perfect with respect to all of the concerns that a facility might face. A number of new technologies are under development, and the use of combined disinfection is being explored. Many questions and uncertainties still remain on other issues that are key decision criteria for facilities considering these disinfection alternatives.

Wastewater treatment plants must consider and prioritize many site-specific factors when they begin to upgrade their disinfection methods.

This research examined a wide range of disinfection technologies, their frequency of use, and information on their implementation at major publicly owned treatment works (POTWs) in the U.S. The document focuses on the mature disinfection methods: chlorine, UV, and ozone. It discusses a number of emerging alternatives: peracetic acid (PAA), ferrate, brominated compounds, pasteurization, ultrasonic cavitation, electron-beam and gamma irradiation, and photocatalysis. It also includes a discussion of the relatively new trend of combining individual disinfection technologies (combined disinfection).

Disinfection Technologies

For major POTWs, the disinfection landscape can be divided into two categories: mature and other. Mature technologies have existed at a number of full-scale facilities for a number of years or even decades. The “other” technologies are present at bench- to pilot-scale or operated at demonstration scale for a short period. These technologies do not have a track record of capital and operation and maintenance (O&M) costs that cover the range of flows (1->100 MGD) of the major POTWs.

Survey of Use

Researchers identified approximately 4,450 major POTWs. Chlorination remains the most common form of disinfection (~75% of all major POTWs) although its use has been declining over the last 20 years. Recently, the use of gaseous chlorine has declined significantly, while the use of aqueous hypochlorite has increased significantly, and on-site generation has become a viable alternative for some POTWs. UV use has grown over the last 10 years. About 21% of all major POTWs currently apply UV disinfection, and roughly 40% of all UV systems currently in use were installed between 2001 and 2005 (the last year for which data were available).

Only a small fraction of POTWs currently use ozone, although it is a mature technology that is commonly applied to drinking water treatment. Currently there are seven major POTWs using ozone with a median design flow of 10 MGD and a range of 3-34 MGD. A number of POTWs adopted early ozone technologies, but maintenance and operational problems caused most facilities to abandon ozone. Nevertheless, ozone technologies have improved since, and a few POTWs are planning or designing ozone facilities. It is the only mature disinfection alternative capable of partially or completely removing trace organic compounds (e.g., pharmaceuticals, hormones, and precursors for disinfection byproducts such as THMs) at typical disinfection doses.

The “other” disinfection technologies (chlorine dioxide, peracetic acid, ferrate, bromine compounds such as BCDMH [1-bromo, 3-chloro, 5,5-dimethylhydantoin], pasteurization, ultrasonic cavitation, electron beam and gamma irradiation, photocatalysis, and combined technologies) are not yet used for full-scale wastewater disinfection. Based on literature published thus far,

BENEFITS

- Compares advantages and disadvantages of disinfection alternatives.
- Provides a framework for selecting an appropriate disinfection technology.
- Provides a snapshot of the experiences with design, installation, and operation of approximately 10% of the major POTWs with UV systems.
- Identifies gaps in the collective knowledge on each of the disinfection alternatives.

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Table 1. Wastewater Disinfection Alternatives.

Category	Wastewater Disinfection Alternatives
Mature technologies	
■ Chloramination Chlorine gas Sodium hypochlorite Calcium hypochlorite On-site generation (0.8%) On-site generation (12%) ■ Breakpoint chlorination Chlorine gas Sodium hypochlorite Calcium hypochlorite On-site generation (0.8%) On-site generation (12%)	■ UV irradiation Low-pressure low-output (LPLO) lamps Low-pressure high-output (LPHO) lamps Medium pressure (MP) lamps ■ Ozonation Ozone generated from air Ozone generated from oxygen
Practicable technologies, but rarely used	■ Chlorine dioxide ■ Peracetic acid
Combination of technologies	
■ Breakpoint chlorination and chloramination[1] ■ UV and chloramination[2] ■ UV and breakpoint chlorination[2]	■ UV and ozonation[3] ■ UV and peracetic acid[4]
Emerging/innovative technologies	
■ Pasteurization ■ Catalysis ■ Brominated chemicals	■ Ferrate ■ Pulse UV ■ Many others

[1] Five options are possible based on the different forms of chlorine: gas, sodium hypochlorite, calcium hypochlorite, onsite generation of 0.8% sodium hypochlorite, and onsite generation of 12% sodium hypochlorite.

[2] A total of 15 alternatives are possible based on three types of UV lamps (low-pressure low-output, low-pressure high-output, and medium pressure) and five forms of chlorine.

[3] A total of six alternatives are possible based on three types of UV lamps and two types of ozone generation methods (air or oxygen).

[4] Three alternatives are possible based on three types of UV lamps.

chlorine dioxide and cavitation are unlikely to be widely used as stand-alone technologies for wastewater disinfection. Chlorine dioxide does not have significant advantages over chlorine, and retains some of the key disadvantages such as safety issues and the formation of disinfection byproducts. Cavitation is economically unfavorable due to the energy required for sufficient disinfection. However, cavitation does break up particles, which could enhance the effectiveness of the other technologies, and may therefore be useful in combination with those technologies. Implementation issues remain for photocatalysis and e-beam/gamma irradiation, and must be resolved before these technologies can be widely used at large scales. Photocatalysis has only been tested in batch experiments at the laboratory bench scale, and catalysts that act quickly enough for practical application are still under development. E-beam and gamma irradiation require a water depth of less than 7 mm at the point of use, which may limit its applicability, particularly at large facilities. However, these irradiation methods have been shown to disinfect treated wastewater at the pilot scale, and also have the potential to remove trace organic contaminants in water.

Of the developing alternatives presented, peracetic acid (PAA), ferrate, BCDMH, pasteurization, and the combined technologies have the highest potential to become viable disinfection alternatives in the near future. All these alternatives have been tested at the pilot scale, and all provide the benefit of eliminating or significantly reducing the levels of the disinfection byproducts associated with chlorine and ozone. However, each alternative has distinct advantages and disadvantages; as with the mature technologies, their use will depend on site-specific constraints and preferences.

Finally, the use of combined disinfection alternatives will remain limited until more data are available on their operations and their ability to disinfect effectively across the wide range of conditions found at POTWs.

Technology Selection

As POTWs begin to upgrade their disinfection methods, they must consider and prioritize many site-specific factors. The report compares the various mature disinfection technologies on a variety of criteria. Issues include safety, disinfection efficacy, effects on effluent water quality, sensitivity to influent water quality, design and O&M issues, costs and, a framework for choosing a disinfection technology based on the selection criteria of the facility and the relative importance of those criteria are presented.

CONTRACTOR

Lawrence Y.C. Leong, Ph.D., QEP
Kennedy/Jenks Consultants

CO-PRINCIPAL INVESTIGATORS

Jeff Kuo, Ph.D., P.E.
California State University, Fullerton

Chi-Chung Tang, Ph.D., P.E., DEE
Sanitation Districts of Los Angeles County

PROJECT SUBCOMMITTEE

Bethany Acquisto, Ph.D.
U.S. Environmental Protection Agency

Ricardo DeLeon, Ph.D.
Metropolitan Water District of Southern California

Kimberly Kunihiro,
Orange County Utilities

George Tchobanoglous, Ph.D., P.E.
University of California at Davis

Elliot Whitby, Ph.D.
Calgon Carbon Corporation

COLLABORATORS

Sanitation Districts of Los Angeles County

WEF Disinfection Committee

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