Ultraviolet disinfection application to a wastewater treatment plant

Tapas K. Das

Abstract Considering most benefits of using ultraviolet (UV) radiation, the Lacey, Olympia, Tumwater and Thurston County (LOTT) wastewater treatment plant located in the City of Olympia was the first major POTW on the U.S. West Coast to install and successfully operate a UV disinfection system that processes about 22 MGD of wastewater. The LOTT's secondary treatment process is a biological nutrients removal system, and has the capabilities of removing more than 90% total suspended solids (TSS), biological oxygen demand, and nutrients (including phosphorus). This high quality effluent with low TSS contributes to achieving a highly efficient UV disinfection system with monthly geometric mean values in the range of 4–48 fecal coliform per 100 ml, well below the NPDES permit limit set to 200 counts per 100 ml. This paper summarizes the results and conclusion from the pilot study conducted at LOTT prior to installing a full-scale UV system, with references to other updated work reported elsewhere.

Introduction

In rural areas of India, Bangladesh, Brazil, Peru, China, and other third-world nations, waterborne diseases such as typhoid, cholera, hepatitis, and gastroenteritis, infect and kill many infants and children each day, according to the World Health Organization (WHO 1996). Wastewaters or water can contain an incredibly large variety of microorganisms; some are harmless, but many are disease causing. These microorganisms must be destroyed before the water is safe to discharge into a receiving body of water or it is safe to reclaim and reuse it. With increasing emphasis on promoting a sustainable ecological future and concern over introducing a toxic chemical in the water, the design of the disinfection process is increasingly leaning toward technologies that destroy the pathogens while balancing the effects of this disinfected wastewater on the population of aquatic biota or a drinking water supply.

Due to current fire codes and public health concern, some municipalities are limited to a certain amount of chlorine they can store at any given time at a plant, which makes it difficult to manage the chlorination process and to meet the National Pollutant Discharge Elimination System (NPDES) permit limits for a major treatment plant in the U.S.A. Furthermore, the U.S. regulatory concern over toxic chemicals in water leads to limits on the amount of chlorine discharging into the receiving water or to the establishment of total residual chlorine (TRC) limits on the wastewater effluent. These limits could be, and usually were, met by designing an additional processing step, called dechlorination, into the disinfection process. However, the dechlorination process uses yet another chemical, sulfur dioxide, to remove chlorine from the effluent before it is discharged to the receiving water. In addition, the chlorination and dechlorination of wastewater was not environmentally acceptable because it produces possible carcinogens and it destroys the aquatic biota in the receiving waters. Across the U.S.A. the environmental protection agencies (EPA) started to look for an alternative wastewater disinfection system. Various governments, municipalities, (USEPA 1992; LOTT 1994; Ecology 1998; Das and Ekstrom 1999) and corporations sponsored research (Scheible and Forndran 1986; Scheible 1987; White 1992; Loge et al. 1996a; Loge et al. 1996b) to show that the ultraviolet (UV) disinfection of wastewater was effective and economical. Another most important development was the parallel flow open channel modular UV system. This new design of UV system for wastewater treatment in the early 1980s opened up UV disinfection for both the retrofit market and new wastewater treatment plants. To promote a friendlier discharge to the marine environment, designers have begun to prefer alternative disinfection technologies, which emphasize sustainable and clean ecological disinfectants – such a clean technology is UV disinfection. Since UV irradiation is not a chemical additive, it does not leave or produce any toxic compounds in the wastewater. Therefore, the use of UV does not affect the drinking water supply or the aquatic biota in receiving waters.

In most areas of the U.S.A. and Canada the use of UV irradiation for the disinfection of wastewater has become the accepted alternative to chlorination or chlorination/dechlorination. Considering most of the benefits of using a UV disinfection system, the Lacey, Olympia, Tumwater,
and Thurston County (LOTT) wastewater treatment plant (WWTP) in the City of Olympia, Washington, decided to install a comprehensive UV disinfection system. In addition, LOTT’s WWTP disinfection system does not use any other oxidizing agent (i.e., H$_2$O$_2$) along with UV, and LOTT is the first major plant on the U.S. West Coast to install and operate such a system. The Washington Department of Ecology provided some assistance and support, and worked with LOTT during the pilot study and through the completion of the UV project (LOTT 1994). The LOTT system treats wastewater primarily from over 100,000 residences, along with a brewery and some light industries. The secondary treatment process is a biological nutrients removal (BNR) system, and has capabilities to remove over 90% of biological oxygen demand and total suspended solids (TSS), and nutrients (including phosphorus) before it discharges about 22.0 MGD (average) to Budd Inlet of Puget Sound Waterbody. LOTT also treats storm water, and during the winter months the WWTP receives high storm water flows, sometime totaling 55 MGD (typically November through February). Due to the higher flow going through the WWTP during the winter months, the total retention time in the clarifiers goes down and consequently the TSS and turbidity level rise slightly. To match with the flow rate, higher doses are provided using one or two additional UV channels out of six total channels available for disinfection. During the other months of the year, normally two UV channels are used to provide an adequate level of disinfection, maintaining the operating UV transmittance in the range of 60–70. An effluent grab sample is taken daily and analyzed for fecal coliform counts to determine the compliance with the permit. A 24-h composite sample is taken daily and analyzed for TSS to determine the compliance with the permit. The results of fecal coliform counts and TSS concentrations for 1998 and 1999 are presented in the results and discussion section towards the end of this paper. The UV mechanisms, transmission, dose, lamp life, effluent TSS, turbidity, iron, hardness, and distribution of microorganisms all have an effect on the UV disinfection process. These will be discussed with respect to fecal coliforms and other microorganisms. The bacterial repair mechanism called photoreactivation was also studied in glass bottles and in a receiving stream, and the implications of photorepair will also be discussed.

**What is UV light and the mechanism of germicidal action?**

The power of sunlight to destroy microbial life has long been known and appreciated. Effective disinfection in air, on surfaces, and in water has been accomplished by exposure to the direct rays of the sun. Sunlight is an important factor in the self-purification of water in streams and in impounding reservoirs. The ability of sunlight to destroy bacteria, particularly intestinal bacteria, has been reported many times. The ordinary rays of sunlight play little part in this bactericidal action. The effects are caused by UV rays. Sources of high intensity UV light have been developed which can be used to disinfect water, wastewater, air etc.

The term “UV light” or simply “UV” is applied to electromagnetic radiation emitted from the region of the spectrum lying beyond visible light and before X-rays. The upper wavelength limit is 400 nm (1 nm = 10$^{-9}$ m) and the lower wavelength limit is 100 nm, below which radiation ionizes virtually all molecules. The narrow band of UV light lying between the wavelengths of 200 and 300 nm has often been called the germicidal region because UV light in this region is lethal to microorganisms, including bacteria, protozoa, viruses, molds, yeasts, fungi, nematode eggs, and algae. Figure 1 shows that the most destructive wavelength is 260 nm, which is very close to the wavelength of 254 nm produced by germicidal low-pressure UV lamps. Figure 1 also shows the similarity between UV light’s ability to kill the fecal coliform, *Escherichia coli* and the ability of the coliform’s genetic material (i.e., nucleic acid) to absorb UV light. UV light causes molecular rearrangements in the genetic material of microorganisms and this prevents them from reproducing. If a microorganism cannot reproduce then it is considered to be dead (USEPA 1999).

**How does UV light work?**

UV light disrupts the division of the deoxyribonucleic acid (DNA) (genetic material, chromosomes) and the production of enzymes by the following mechanism (Fig. 2). The components within the DNA that absorb the UV light are the nucleotide bases: adenine, guanine, thymine, and cytosine. Although proteins fulfill many vital functions in cells, their UV absorption compared with that of DNA is of minor consequence. Although the nucleotide

![Fig. 1. Comparison of the action spectrum for inactivation of *E. coli* with the absorption spectrum of nucleic acids (Harm 1980)](image)