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# Comparison of low- and medium-pressure ultraviolet lamps: Photoreactivation of *Escherichia coli* and total coliforms in secondary effluents of municipal wastewater treatment plants

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ARTICLE INFO

*Article history:*
Received 19 May 2008
Received in revised form
9 November 2008
Accepted 12 November 2008
Published online 3 December 2008

*Keywords:*
Ultraviolet disinfection
Photoreactivation
Wastewater disinfection
Medium-pressure UV lamp

ABSTRACT

It has been reported that Medium-Pressure (MP) ultraviolet (UV) lamps have an advantage over low-pressure (LP) lamps for water disinfection in terms of the photoreactivation of pure cultured bacteria. However, few studies have investigated the behavior of microorganisms in wastewater. Hence, in this study, the degree of photoreactivation, after UV exposure using both LP and MP lamps, in municipal wastewater samples was examined under a variety of conditions. Pure cultured *Escherichia coli* was also used to provide a comparison with previous studies.

*E. coli* was found to undergo photoreactivation after both LP and MP exposure. The Colony Forming Ability (CFA) ratios were 0.60 and 0.32, and the percentage of photoreactivation was 50% and 20%, respectively, for LP and MP lamps with a germicidal UV dose of 5 mJ/cm$^2$. However, the advantage of the MP lamp was diminished for larger UV doses, since no photoreactivation was detected when the UV dose was 15 mJ/cm$^2$ for either LP or MP lamps. The microorganisms present in wastewater showed similar results to those of *E. coli*, however, no significant difference was found between the use of either a LP or a MP lamp. Also, when a UV dose of 40 mJ/cm$^2$ was applied, the percentage photoreactivation was less than 1%, no matter which type of lamp was used. From this work, it is concluded that the selection of the type of UV lamp for wastewater treatment plants, as regards photoreactivation of total coliforms, is not critical as long as the applied germicidal UV dose is greater than 40 mJ/cm$^2$.



## 1. Introduction

Safety concerns regarding wastewater for reuse is driving the pursuit of alternatives to chlorine disinfection, which produces disinfection byproducts (DBPs) (Magara et al., 1996; Örmeci et al., 2005). Ultraviolet (UV) disinfection is gaining more attention because of its several advantages, such as high disinfection efficiency with most viruses, bacteria and protozoa, no unidentified toxic DBPs and safe operation (Lazarova et al., 1998; Koivunen and Heinonen-Tanski, 2005; Hijnen et al., 2006). In recent years, UV disinfection systems have been installed in many water and wastewater treatment

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doi:10.1016/j.watres.2008.11.028

plants in North America and Europe, and more and more applications are being planned or are under construction.

Exposure to UV results in damage to the nucleic acids of the microorganisms (Hijnen et al., 2006), which is the basis of UV disinfection. But it is well-known that many microorganisms have the ability to repair UV-induced damage (Lazarova et al., 1999; Hijnen et al., 2006). Two repair mechanisms are reported. One is light independent, which is called dark repair (Jungfer et al., 2007). The other is photoreactivation, a phenomenon by which UV-induced lesions in the DNA can be repaired by utilizing the energy of near-UV light (310–480 nm) and the enzyme photolyase (Tosa and Hirata, 1999). This issue has received considerable attention because it can influence UV disinfection efficiency in a few hours after treatment. Hoyer (1998) investigated more than a dozen microorganisms as regards photoreactivation. He found that the minimum UV dose in order to achieve 4-$\log_{10}$ reduction of *Escherichia coli* ATCC11229, considering possible photoreactivation for 2 h, was 30 mJ/cm$^2$. In the absence of photoreactivation, he found that a UV dose of only about 10 mJ/cm$^2$ was sufficient. He found similar results with 16 other microorganisms, such as indicator germs (*E. coli* ATCC11229) and viruses (Polio virus and Rotavirus SA11). That means that photoreactivation reduces the UV disinfection efficiency, since if a given amount of cell reduction is required, higher UV doses need to be provided. Thus, more power must be applied. This will influence the operation of the UV disinfection process in water and wastewater treatment plants.

Different measures to control photoreactivation have been proposed. A combination of chemical disinfection, such as ozone or peracetic acid, with UV disinfection has been widely studied (Dell'Erba et al., 2004; Koivunen and Heinonen-Tanski, 2005; Jung et al., 2008; Caretti and Lubello, 2003). Also the application of sufficiently high UV doses is proposed to control photoreactivation. Sommer et al. (2000) investigated photoreactivation in seven pathogenic strains (including three enterohemorrhagic *E. coli*) and one nonpathogenic strain of *E. coli* (AT11229). Although only a UV dose of 1.2 mJ/cm$^2$ was enough to inactivate *E. coli* O157:H7 to 6-$\log_{10}$ reduction, up to 30 mJ/cm$^2$ UV irradiation was required when photoreactivation was considered. Another strategy proposed is to switch from a low-pressure (LP) UV system to a medium-pressure (MP) UV system. That is because several studies of monocultures have shown that MP lamps are superior to LP lamps, in terms of the degree of photoreactivation for the same germicidal UV dose. Oguma et al. (2002) found that the broad range of wavelengths applied by MP lamps reduced subsequent photoreactivation, as compared to the use of LP lamps, emitting quasi-monochromatic light. For example, after LP UV exposure, 83% of the total UV-induced pyrimidine dimers in *E. coli* were repaired, while almost no pyrimidine dimers were repaired by fluorescent light exposure after MP UV exposure. Zimmer and Slawson (2002) also reported that *E. coli* underwent photorepair following exposure to a LP UV source, but no repair was detectable following exposure to a MP UV source at the initial doses of less than 10 mJ/cm$^2$ examined. Kalisvaart (2004) and Hu et al. (2005) showed similar results with *E. coli*. Quek and Hu (2008) indicated that photoreactivation following MP UV disinfection of *E. coli* was smaller than that following LP UV disinfection. But later, Oguma et al. (2004) found that *Legionella pneumophila* behaved in an equivalent manner as regards photoreactivation after LP and MP UV exposures. Bohrerova and Linden (2006) also reported that MP UV inactivation was not more effective in minimizing the photoreactivation of *Mycobacterium terrae*. In the case of *Cryptosporidium parvum*, no detectable evidence of photorepair was observed, after incubation under light conditions following either LP or MP lamp UV exposure (Zimmer et al., 2003). Li et al. (2008) found that *Giardia lamblia* trophozoites may survive or be reactivated following exposure to a UV dose (LP lamp) of up to 10 mJ/cm$^2$. Evidence of reactivation at a UV dose of 20 and 40 mJ/cm$^2$ was ambiguous and statistically inconclusive, while at 100 mJ/cm$^2$, there was no evidence of survival or reactivation. However, no relevant research for *Giardia* with a MP lamp has been carried out. Those results imply that *E. coli* may not always properly indicate a given microorganism's fate during UV disinfection. Also it cannot be easily concluded that a MP UV lamp has an advantage compared with a LP lamp in terms of photoreactivation. Whether or not MP exposure is better, is not a simple question.

The protocol for collimated beam tests, established by Bolton and Linden (2003), has become the standard method for such tests in UV disinfection. It has recently been found that the method of determining the germicidal UV dose using MP lamps is not always correct, according to that protocol. When using a MP lamp in the collimated beam apparatus, the germicidal UV dose may be overestimated, if one is using a radiometer detector that has significant sensitivity at wavelengths >300 nm. In this case, it is important to make corrections for the wavelength dependence of the sensor. In our case, we found that an additional correction factor of 0.778 must be applied, as documented by Guo et al. (2008). It may be that previous studies have not determined the germicidal UV dose of MP lamp correctly. It is very important to be able to show that the log inactivation versus germicidal UV dose curve is statistically the same for LP and MP lamps (Bolton and Linden, 2003; Zimmer et al., 2003; Bohrerova and Linden, 2006).

Most comparisons between LP and MP lamps have been carried out with *E. coli* or some other pure cultured microorganisms (Oguma et al., 2002; Zimmer et al., 2003). Few comparison studies have been carried out on real wastewater containing mixed microorganisms. Only photoreactivation after LP UV disinfection in wastewater treatment plants has been examined in several studies (Martin and Gehr, 2007; Nebot et al., 2007; Kashimada et al., 1996; Yoon et al., 2007). Martin and Gehr (2007) investigated photoreactivation of fecal coliforms in the effluent from one wastewater treatment plant in Canada. They found that, the average photoreactivation was 1.2 $\log_{10}$ after exposure under sunlight for 3 h. Kashimada et al. (1996) reported that, the coliform group and fecal coliforms from raw sewage, recovered immediately after irradiation and saturated within 120 min. So it is not clear yet, if MP lamps are better or not for controlling photoreactivation of mixed microorganisms present in wastewater. And also the question of whether or not higher UV doses can inhibit photoreactivation needs to be proven.

Consequently, the objective of this study was to use a strict and correct standard method for the determination of the germicidal UV dose to investigate the potential