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Review

A review of virus removal in wastewater treatment pond systems

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ABSTRACT

Wastewater treatment ponds (lagoons) are one of the most common types of technologies used for wastewater management worldwide, especially in small cities and towns. They are particularly well-suited for systems where the effluent is reused for irrigation. However, the efficiency of virus removal in wastewater treatment pond systems is not very well understood. The main objective of this paper is to critically review the major findings related to virus removal in wastewater treatment pond systems and to statistically analyze results reported in the literature from field studies on virus removal in these systems. A comprehensive analysis of virus removal reported in the literature from 71 different wastewater treatment pond systems reveals only a weak to moderate correlation of virus removal with theoretical hydraulic retention time. On average, one $\log_{10}$ reduction of viruses was achieved for every 14.5–20.9 days of retention, but the 95th percentile value of the data analyzed was 54 days. The mechanisms responsible for virus removal in wastewater treatment ponds were also reviewed. One recent finding is that sedimentation may not be a significant virus removal mechanism in some wastewater ponds. Recent research has also revealed that direct and indirect sunlight-mediated mechanisms are not only dependent on pond water chemistry and optics, but also on the characteristics of the virus and its genome. MS2 coliphage is considered to be the best surrogate for studying sunlight disinfection in ponds. The interaction of viruses with particles, with other microorganisms, and with macroinvertebrates in wastewater treatment ponds has not been extensively studied. It is also unclear whether virus internalization by higher trophic-level organisms has a protective or a detrimental effect on virus viability and transport in pond systems. Similarly, the impact of virus-particle associations on sunlight disinfection in ponds is not well understood. Future research should focus on the interactions of viruses with particles and with other organisms, as well as the development of a model for virus removal in pond systems that can be used for design purposes, and to inform future editions of the WHO Guidelines for Wastewater Use in Agriculture.

Abbreviations and acronyms: CFD, computational fluid dynamics; DLVO, Derjaguin–Landau–Verwey–Overbeek; dsDNA, double-stranded deoxyribonucleic acid; dsRNA, double-stranded ribonucleic acid; HRT, hydraulic retention time; NOM, natural organic matter; PBS, phosphate buffered saline; ssDNA, single-stranded deoxyribonucleic acid; ssRNA, single-stranded ribonucleic acid; TIS, tanks-in-series; US EPA, United States Environmental Protection Agency; UV, ultraviolet; UVA, ultraviolet light in the 315–400 nm range; UVB, ultraviolet light in the 280–315 nm range; UVC, ultraviolet light in the 100–280 nm range; WTP, wastewater treatment pond.

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Contents

1. Introduction

Wastewater treatment ponds (WTPs), also known as lagoons, are one of the oldest and most prevalent types of technologies used to treat domestic wastewater in the world. More than half of the wastewater treatment facilities in the United States and in New Zealand utilize ponds (Mara, 2003; US EPA, 2011). They are also the most common technology used to treat domestic wastewater in Mexico, the Dominican Republic, and Brazil (Noyola et al., 2012). In France, there are approximately 2500 WTP systems (Mara and Pearson, 1998), and in Colombia, there are approximately 100 WTP systems (Miguel Peña Varón, personal communication). The low cost and simplicity of their construction, operation, and maintenance has caused them to be considered one of the most important wastewater treatment technologies, especially for small cities and towns, and in particular when the effluent is land-applied (Mara, 2003; Oakley, 2005; Peña Varón et al., 2000). In fact, the land application of WTP system effluent can reduce the eutrophication potential, embodied energy, and carbon footprint of wastewater management over the life cycle (Cornejo et al., 2013); but pathogen removal for safe nutrient recovery from these systems may be an increasingly important priority for some small cities and towns (Verbyla et al., 2013a). The removal of fecal indicator bacteria in WTP systems has been well-documented (von Sperling, 2005), but it is not a good indicator for virus removal (Maynard et al., 1999).

Viruses are intracellular parasites with a genome contained inside a protein capsid. They can be divided into groups according to their genome type: double-stranded DNA (dsDNA), single-stranded DNA (ssDNA), double-stranded RNA (dsRNA), and single-stranded RNA (ssRNA) (Flint et al., 2009). Of more than 100 known species of viruses that are excreted in human waste (Bosch, 1998), some are particularly resistant to wastewater treatment. Symonds et al. (2009) detected adenoviruses, enteroviruses, noroviruses, and picobirnaviruses in treated wastewater from 12 different cities throughout the United States. Though they are not necessarily specific markers of human waste (Harwood et al., 2013), bacteriophages (viruses that infect bacteria) have been used as surrogates to study enteric virus removal in WTP systems (Castillo and Trumper, 1991; Omura et al., 1985). Pepper mild mottle virus, a plant pathogen of dietary origin, has been recently proposed as a surrogate for enteric viruses (Rosario et al., 2009), but its application to the study of WTPs has been limited to one publication (Symonds et al., 2014).

The efficiency of virus removal in WTP systems with respect to theoretical hydraulic retention time (HRT) has been widely debated in the literature, with different authors reaching contradictory conclusions over the past 40 years (Fig. 1). In one early review, virus removal in WTPs was described as being "erratic" (Berg, 1973). In another report (Feachem et al., 1983), it was concluded that WTP systems with temperatures exceeding 25 °C were capable of reducing