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Enhancing natural wastewater treatment systems: the role of particles in sunlight-mediated virus inactivation

Reporting

Project Information

PARVIRDIS

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Final Report Summary - PARVIRDIS (Enhancing natural wastewater treatment systems: The role of particles in sunlight-mediated virus inactivation)

Effective low-tech wastewater treatment systems are needed to combat the high level of population lacking basic sanitation. Constructed wetlands utilise natural treatment processes such as adsorption, sedimentation, and solar irradiation to attenuate the concentration of pathogens in water. These characteristics make them attractive candidates for sustainable, low-tech treatment. Two factors that limit the advancement of these systems are our inability to measure their efficiency in pathogen inactivation, and their poor removal of waterborne viruses, one of the most important classes of pathogens. Given these limitations, three major goals were planned for this project:

1. to improve molecular methods to measure virus infectivity;
2. to create an alternative wetland matrix with high viral removal capacity;
3. to couple the adsorptive and photoreactive properties of the matrix to enhance virus inactivation.

In two separate publications, we aimed to determine if qPCR, which measures genome integrity, could be used to estimate viral infectivity. Bacteriophage MS2 was used as the viral surrogate, and an exhaustive analysis of genome damage was done by assaying the entire coding region with qPCR. This assay was used to characterise damage after exposure to three common disinfection methods: heat, UV, and the reactive oxygen species called singlet oxygen. We found that the treatments had varying effects on genome integrity, with some treatments, such as heat, causing no damage to the genome. Using a genome-based method, like qPCR, to determine viral infectivity after treatments that do not affect the genome is therefore bound to fail. In a follow-up study, we created a framework for using quantitative PCR to estimate virus infectivity after UV inactivation. With this method we show damage to short sections of the genome (measured with qPCR) can be used to predict the total amount of genomic damage, and therefore, viral infectivity. These new methods were subsequently used to study virus adsorption and inactivation on wetland matrices.

Earlier studies had shown that metal-oxides were more effective at adsorbing viruses than the sand that is typically used as a wetland matrix. However, the fate of the viruses adsorbed onto these metal oxides was not fully understood. The new molecular methods would allow us to determine whether viruses had adsorbed or desorbed from the matrix, and whether they remained infective. In these studies, adsorption onto an iron-oxide coated sand (IOCS) caused >99.9 % reduction in the concentration of viruses in solution. Furthermore, a large quantity of viruses could be loaded onto the IOCS under standard conditions (maximum adsorption density of 4e10 infective viruses/g IOCS in pH 7.5 Tris buffer with conductivity of 1250 µS/cm). However, environmentally relevant changes in the pH and the concentration of dissolved organic material prevented the adsorption of unbound viruses and led to the release of previously adsorbed viruses. Unlike earlier studies, we found that the released viruses remained in an infective state.

Given that adsorption alone was not inactivating viruses, we attempted to take advantage of the photoreactive iron-oxide surface onto which the viruses were adsorbing. Iron-oxides can react with sunlight and hydrogen peroxide via a Fenton-like reaction to produce a highly reactive oxidant, the hydroxyl radical. Given their high reactivity, hydroxyl radicals are rapidly consumed in solution; therefore, their concentrations are highest at their source, in this case, the iron-oxide surface, and decrease to negligible levels after short distances. We hypothesised that the viruses adsorbed onto the IOCS would be directly adjacent to the hydroxyl radical-producing surface, and that their proximity would increase their inactivation rate. Indeed, viruses that were adsorbed onto IOCS and exposed to simulated sunlight were inactivated more rapidly than those in suspension.

Related documents

Final Report - PARVIRDIS (Enhancing natural wastewater treatment systems: The role of particles in sunlight-mediated virus inactivation)

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