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Removal of Viruses by Soil Passage: Overview of Modeling, Processes, and Parameters

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ABSTRACT: In this article, the modeling of subsurface virus transport under saturated conditions and the factors that affect adsorption and inactivation are evaluated. Both equilibrium and kinetic adsorption are considered. Equilibrium adsorption is found to be of little significance. Adsorption appears to be mainly kinetically limited. At pH 7 and higher, conditions are generally unfavorable for attachment, but viruses may preferentially attach to a minor surface fraction of soil grains that is positively charged. The relation of pH with surface charge and their effects on sticking efficiencies are evaluated. Dissolved organic matter decreases virus attachment by competition for the same binding sites and thus reduces attachment. Bonded organic matter may provide hydrophobic binding sites for viruses and thus enhance attachment. Dissolved organic matter may disrupt hydrophobic bonds. The enhancing and attenuating effects of organic matter are very difficult to quantify and may be responsible for considerable uncertainty when predicting virus removal.

Values of inactivation rate coefficients for attached viruses were calculated using data from some batch studies. Enhanced or reduced inactivation is found to be virus-specific and almost independent of adsorption. Temperature is the most important factor that influences virus inactivation. Probably the inactivation rate coefficients of free and attached viruses change similarly with temperature.

Some frequently used bacteriophages are evaluated as model viruses. MS2 and PRD1 meet the requirements for worst-case model viruses, at water temperatures less than about 10°C, at pH 6 to 8, and if the soil does not contain too many hydrophobic sites and not too much multivalent cations. Bacteriophage φX174 may be a relatively conservative model virus, because of its low hydrophobicity and stability. Together in a cocktail, these three viruses span a range of properties, like size, surface charge, and hydrophobicity. F-specific RNA bacteriophages (FRNAPHs) may be very useful naturally occurring worst-case viruses. FRNAPHs that are present in surface water or treated wastewater that is used for recharging groundwater, consist of stable and poorly adsorbing viruses.

An inventory of parameter values from field studies is made. Attachment appears to be the major process that determines virus removal. Still, only very few data are available on attachment and detachment of viruses under field conditions. Removal of viruses by soil passage, $\log(C/C_0)$, appears to decline nonlinearly with distance due to heterogeneities within the soil as well as within the population of transported virus particles. Predictions of virus removal at larger distances are severely overestimated if they are based on removal data from column experiments or from short-distance field studies.

KEY WORDS: virus adsorption, virus inactivation, virus transport models, virus removal, model viruses, MS2, PRD1, φX174, F-specific RNA bacteriophages.

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