Presented at International Conference for Water and Wastewater Microbiology, Newport Beach, CA, USA, February 8 - 11, 1988. 88-002

MODELING MICROBIAL TRANSPORT IN POROUS MEDIA

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INTRODUCTION

The dynamics of microbial populations in the subsurface are influenced by a complex and often heterogeneous set of environmental conditions (Characklis et al., 1986). As a consequence, the biofilm processes occurring in porous media flow are more difficult to monitor than in other common reactor types such as tanks, reservoirs and pipelines. Subsurface biofilm accumulation, for example, is influenced by fluid and nutrient transport which, in a porous media, occurs along tortuous flow paths of varying dimension and geometry. Similarly, the wide distribution of pore velocities introduces considerable variation in the processes of adsorption, desorption, attachment and detachment. Deposition of particulate material by filtration mechanisms must also be considered. An understanding of cause and effect relationships which influence these biofilm processes (see Figure 1) is essential to describe net subsurface biofilm accumulation. This paper attempts to further this understanding by presenting a method for modeling the transport of microbial cells and nutrients in saturated porous media. Relevant model applications include 1) analysis and mitigation of porous media biofouling, and 2) analyses of schemes for in-situ biodegradation of organic groundwater contaminants.

MODEL CONCEPT

The model concept presented here is based on the solution of the advection/dispersion equation (Bear, 1979) governing solute transport in porous media. This equation considers the change in solute concentration with time (within a prescribed porous media control volume) to be the algebraic sum of 3 terms: 1) concentration change due to advection, 2) concentration change due to hydrodynamic dispersion, and 3) concentration change due to solute adsorption or reaction with surroundings. Solutes of interest here include concentrations of suspended cells and nutrients occurring along a porous media flow path.

Advection

Advection is the component of mass transport resulting from the velocity of flow through porous media which is typically taken as the average linear pore velocity. In this context, advective transport is a macroscopic process which defines the linear rate of solute migration in the direction of flow for which pore velocity is measured. This representation of advection transport is considered adequate for describing the migration of tracers, nonreactive groundwater contaminants and other solutes whose transport depends mainly on the bulk properties of the porous media. However, in the transport of solutes such as nutrients, reactive chemicals and microbial cells it may be necessary to consider the true microscopic pore velocity distribution in order to adequately characterize the interaction of such solutes with microbial processes in porous media.

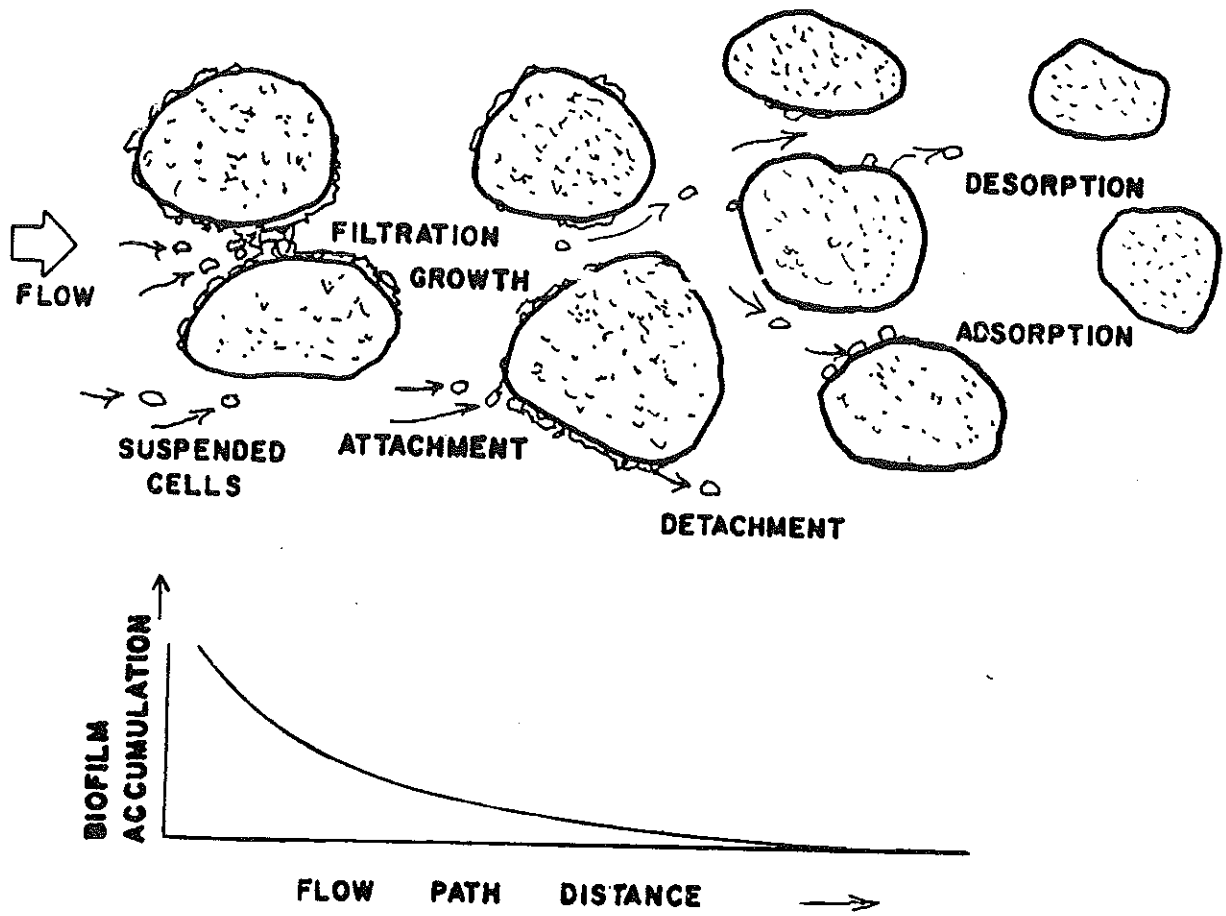

Fig. 1 Processes controlling biofilm accumulation in saturated porous media.

Hydrodynamic Dispersion

Hydrodynamic dispersion, the other physical process influencing solute flux, results from mechanical mixing and molecular diffusion. Dispersion is the net result of 3 processes: 1) mixing due to fluid velocity distribution within individual pore spaces, 2) mixing resulting from variation in true pore velocities among pore channels of different size and surface roughness, and 3) mixing caused by convergence and divergence of individual pore channels. These three processes increase spreading of a solute plume, in both longitudinal and transverse directions, from the path the plume would follow due solely to advection.

Adsorption/Reaction

This term accounts for the change in solute concentration due to interaction with biofilm attached to the substratum. Conceptually this term requires simultaneous mass balances for suspended cells, nutrients, and biofilm. Specifically these mass balances must be performed

for 1) substrate in suspension 2) substrate in biofilm 3) suspended cells 4) net detachment of cells from uppermost biofilm layer and 5) subsurface biofilm.

Solution of the differential equations which describe these mass balances requires characterization of pore space geometry. The modeling approach proposed herein considers the porous media within a control volume to be composed of a series of circular conduits of diameter equal to the average effective pore channel width. Radial flux of cells/nutrients within pores is calculated assuming diffusivities and velocity distributions representative of laminar flow conditions. The effects of filtration of suspended solids, as well as decreased permeability (due to plugging of pore spaces), will be accounted for with empirical relationships developed experimentally.

The model will be capable of simulating variations in nutrient concentrations (most notably substrate and oxygen), as well as biofilm accumulation with time and position along the flow path. If biofilm accumulation becomes large enough to significantly reduce the effective pore space, it will be necessary to adjust the permeability and pore velocity distribution thereby simulating microbial fouling within the porous media. Boundary condition required for modeling microbial transport and accumulation include influent concentrations of suspended cells and nutrients together with the initial distribution of pore velocities.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge support from the U.S. Geological Survey (14-08-0001-G1284) and Montana State University.

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