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Comment on "A Method for Calculating Bacterial Deposition Coefficients Using the Fraction of Bacteria Recovered from Laboratory Columns"

SIR: Using an analytical solution to an advective-dispersive equation for bacterial transport, Bolster et al. (*1*) have correctly concluded that bacterial deposition coefficients in column experiments can be calculated based solely on the total influent and effluent bacterial concentrations. However, there are two important limitations of using their analytical and experimental approach. First, their analytical solution is not valid over the entire range of Peclet (*Pe*) numbers used in their analysis. Second, their method of measuring only the total recovery of bacteria in the effluent (rather than cells retained in the column) eliminates studying other important features of particle deposition within the column.

Bolster et al. (*1*) clearly illustrate how the deposition coefficient, κ_1, is related to the fractional recovery by

$$\kappa_1 = -\ln(\mathrm{fr}) + \left[\frac{[\ln(\mathrm{fr})]^2}{Pe}\right] \tag{1}$$

where fr = fractional recovery from the column, $Pe = vL/D$, v = superficial fluid velocity, L = column length, and D = dispersion coefficient. Although Bolster et al. (*1*) are the first to show the derivation of eq 1, they neglected to note that Harvey and Garabedian (*2*) had already presented and applied this relationship to bacterial transport in porous media. They also did not cite another study (*3*) where it was calculated that a dispersion coefficient would have to be very large ($> 10^{-3}$ cm^2 s^{-1}) in order to significantly alter calculated bacterial deposition rates. A survey of dispersion coefficients indicated that there was little support for a dispersion coefficient of this magnitude in bacterial transport column experiments (*3*).

Bolster et al. (*1*) correctly concluded that dispersion can be neglected for $Pe > 10$; unfortunately, their solution (eq 6) of the governing transport equation is based on an equation in Parlange et al. (*4*) that is only valid for $Pe > 4$. As a result, the effect of *Pe* on deposition, shown in Figure 1 of Bolster et al. (*1*), is not valid for $Pe = 1$.

In most column studies, the Peclet number will be high. In such cases, the dispersion term (relative to advection) will only be important in regions with sharp concentration gradients, where the characteristic length scale is $L/Pe^{1/2}$. This scaling results from a balance of the dispersive terms against the transport due to advection and can be obtained by recognizing that dispersion has advanced a distance proportional to $(Dt)^{1/2}$ over a time t (the dispersion velocity) relative to a fluid velocity v. In a column having a residence time L/v, the front is therefore spread over a distance $(DL/v)^{1/2} = L/Pe^{1/2}$. The fractional recovery of bacteria will accordingly be insensitive to dispersion for typical bacterial transport conditions since $L/Pe^{1/2} \ll L$ when $\mathrm{Pe} \gg 1$.

The contribution of dispersion to overall transport at low *Pe* is more difficult to model when mechanical dispersion is much larger than molecular diffusion, and different results occur depending on the choice of boundary conditions used to solve the governing transport equation. Solutions used by both Bolster et al. (*1*) and others (*3*) overestimate the effect of dispersion on particle removal at low *Pe*. We believe, based on our review of the literature concerning the appropriate choice of boundary conditions used to solve such equations (*4*, *5*) and recent work by Unice (*6*), that dispersion is unimportant for calculating the total mass of particles transported through the porous medium in column experiments. The boundary conditions chosen in Parlange et al. (*4*) require a mass balance at the column inlet and outlet but therefore fail to preserve the normal distribution of velocities (mechanical dispersion) that produce longitudinal dispersion in porous media. Mass and dispersion can both be preserved if it is assumed that the column is infinite or that the column ends do not affect dispersion. The infinite column assumption is reasonable as long as mechanical dispersion is large compared to molecular diffusion. An analysis based on a pulse input into an infinite column (see below) and that of Bolster et al. (*1*) indicates that dispersion can be neglected in calculating total bacterial recovery.

For an instantaneous pulse injection with an irreversible first-order reaction (rate constant, k_c), the one-dimensional transport equation is

$$\frac{\partial C}{\partial t} + v\frac{\partial C}{\partial x} = D\frac{\partial^2 C}{\partial x^2} - k_c C \tag{2}$$

where C is the concentration of suspended bacteria. This is the same equation as in Bolster et al. (*1*) except that desorption is neglected here. This equation can be solved with the initial condition

$$C(x,0) = \frac{M}{A\theta}\delta(x) \tag{3}$$

and the boundary conditions $C(\pm\infty,t) = 0$. The initial condition is written for a pulse injection of mass M, where A = cross-sectional area, θ = porosity, and $\delta(x)$ is the dirac delta function. Using the transformation $C = C^* e^{-k_c t}$, eq 2 becomes

$$\frac{\partial C^*}{\partial t} + v\frac{\partial C^*}{\partial x} = D\frac{\partial^2 C^*}{\partial x^2} \tag{4}$$

The solution to eq 4 with the above boundary conditions relative to a moving front is

$$C^*(x,t) = \frac{M}{A\theta\sqrt{4\pi Dt}}\exp\left[\frac{-(x-vt)^2}{4Dt}\right] \tag{5}$$

where the mass of bacteria is decayed over time at a rate dependent on the deposition coefficient, k_c, according to

$$M = M_0 e^{-k_c t} \tag{6}$$

for an initial mass of bacteria, M_0. The difference between our approach and that by Bolster et al. (*1*) is in our assumptions of how the column inlet and outlet affect dispersion. In the above approach, it is assumed that the ends of the column do not alter dispersion and, therefore, that the pulse moves in the same manner in the column as it would in an infinitely long (unbounded) system. Application of eqs 5−6 for bacterial transport in a column leads to the conclusion that the mass recovered in the column (i.e. that reacted away) after the passage of the pulse through the column does not depend on the dispersion coefficient for a first-order reaction. By superposition using a series of pulse injections, the same conclusion would be reached for an injection over a longer period of time.