SIMULATION OF REACTIVE PROCESSES RELATED TO BIODEGRADATION IN POROUS MEDIA

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1. Introduction

This paper presents the simulating reactive transport in porous media using sawdust as a material to improve the efficiency of biodegradation processes. The transport part of the model computes the changed in concentration over time caused by the processes of advection and dispersion. The kinetic sub model describes the heterotrophic metabolisms of several groups of bacteria. To model a complete redox sequence (aerobic oxidation, denitrification, Mn (IV)-reduction, Fe (III)-reduction and sulfate reduction) four functional bacterial groups (X1, X2, X3 and X4) are defined.

2. Model Processes

The model used in this study is based on the reactive solute transport and biological processes. It describes the interactions between O_2, NO_3^-, CH_2O, Mn^{2+}, Fe^{2+} and SO_4^{2-} concentrations and bacteria growth. The model takes into account three different phases: mobile pore water phase, immobile bio phase and matrix phase; the bio phase is assumed to include all bacteria growth and biological processes. Matrix phase is organic matter in soil, it assumed to include sawdust material.

Fig. 1 shows the chemical species considered in the model and mass transfer processes.

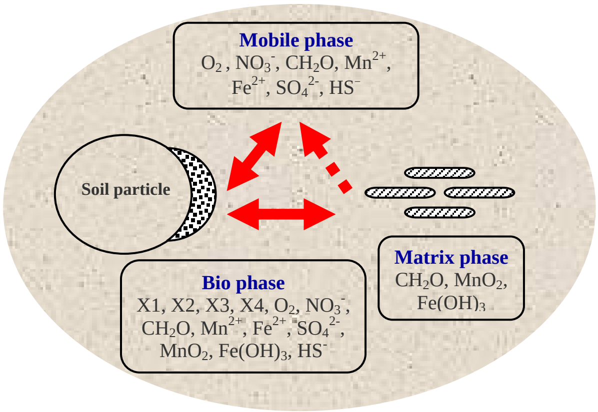

Fig. 1 Chemical species considered in the model and mass transfer processes between different phases.

3. Reactive-Solute Transport

The fundamental one-dimensional partial differential equation governing the advective-dispersive solute transport of contaminants can be written as:

$$\frac{\partial C_{mob}}{\partial t} = \frac{\partial}{\partial y}\left(D_L \frac{\partial C_{mob}}{\partial y}\right) - v'\frac{\partial C_{mob}}{\partial y} + S_i \qquad (1)$$

where C_{mob} is the concentration of solute in the mobile phase, D_L is the longitudinal dispersion coefficient, v' is the average pore velocity, t is the time, y is the distance, and S_i is the chemical source-sink term representing the exchange processes.

4. Bacterial Growth

Bacteria can utilize several substrates simultaneously. Bacteria growth is often controlled by availability of substrates. The specific growth rate is assumed to be a function of the concentration of the substrates.

The growth of bacteria is described by the Double Monod kinetic equation can be written as:

$$\frac{\partial X}{\partial t} = v_{\max}\frac{C_1}{K_{s1}+C_1}\cdot\frac{C_2}{K_{s2}+C_2}X \qquad (2)$$

where v_{max} is the maximum growth rate, C_1 is the primary substrate concentration in bio phases, C_2 is the secondary substrate concentration in bio phases, K_{s1} is the primary substrate half-saturation constant, K_{s2} is the secondary substrate half-saturation constant, and X is the bacteria concentration.

5. Column Experiment and Numerical Simulation

The column experiment was carried out using glass columns. The columns were packed to a height of 30 cm with different mixtures of soil and sawdust.

The parameters used for the simulation were taken from several studies related to wastewater treatment modeling and simulation of redox processes and adjusted to obtain the best fit of the model to the experimental data.

6. Results and Discussions

The simulated concentrations of the electron acceptors (nitrate, manganese, iron, and sulfate) and the electron donor (carbon) agreed well with the measured concentrations as shown in **Figs. 2** to **6**.

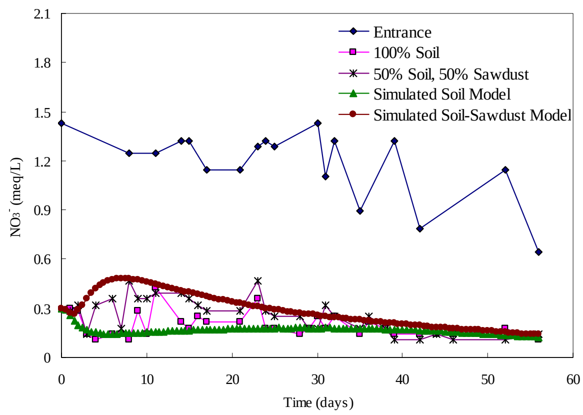

Fig. 2 Comparison between measured and simulated NO_3^-.

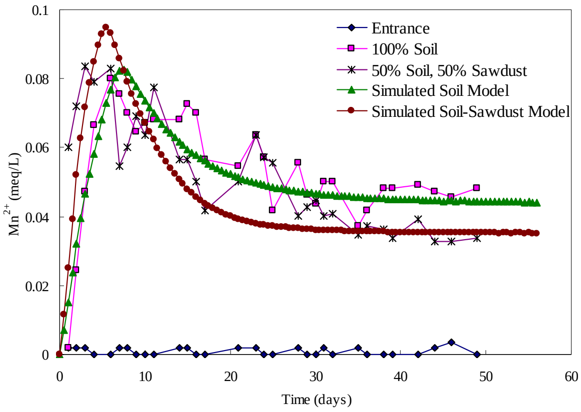

Fig. 3 Comparison between measured and simulated Mn^{2+}.

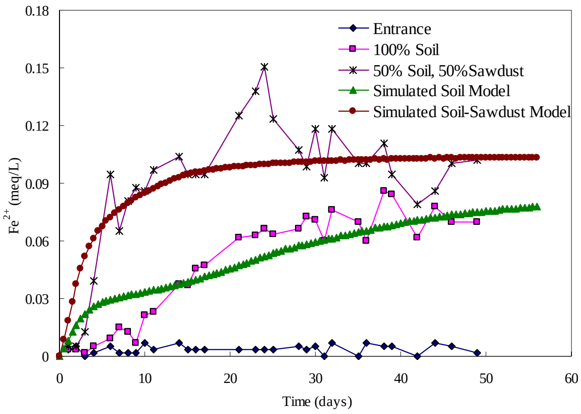

Fig. 4 Comparison between measured and simulated Fe^{2+}.

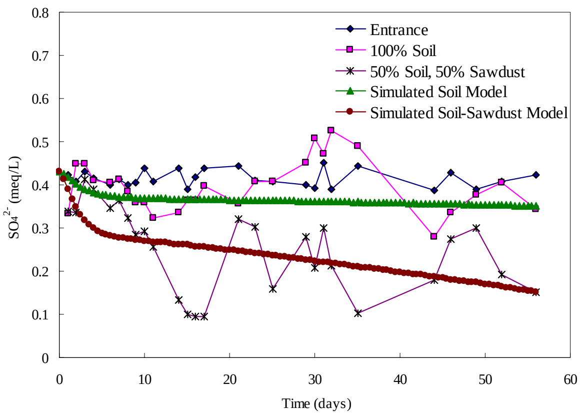

Fig. 5 Comparison between measured and simulated SO_4^{2-}.

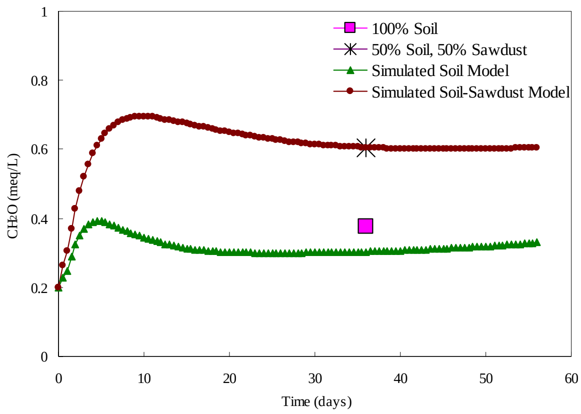

Fig. 6 Comparison between measured and simulated CH_2O.

Fig. 2 shows that the column packed with 100 % soil of low permeability (1.45 x 10^{-3} cm/sec) yielded significant nitrate reductions, while the column, packed with a mixture of 50% soil and 50% sawdust of high permeability (7.39 x 10^{-2} cm/sec) showed significant nitrate reductions either. Additional advantage of using the sawdust is that the permeability of the column material can be increased

Fig. 3 shows the simulated and measured results of soil and soil-sawdust columns for the concentration of manganese. There is a small difference between the results of soil and soil-sawdust columns.

Fig. 4 shows that the column packed with soil-sawdust yielded significant iron hydroxide reduction more than that yielded by the column packed with soil only.

Fig. 5 also shows that the column packed with soil-sawdust yielded significant sulfate reductions more than that of the column packed with soil only.

Fig. 6 shows that the average carbon concentration of soil-sawdust column increased about 50% more than the average carbon concentration of soil column. It shows that the sawdust materials have proven to be promising materials for supplying a sufficient carbon to enhance microbially mediated processes when the carbon concentration of treated water is low. The carbon concentration was also measured once for verification. The value obtained was in good agreement with the simulated one for that time.

7. CONCLUSION

The results from this study showed that it was generally possible to simulate the laboratory experimental results with a mathematical numerical model. A detailed comparison between the experimental and the simulation results showed that good agreement was obtained.

The carbon source utilized in the microbial degradation comes from two different sources, dissolved organic carbon from secondary wastewater and solid organic carbon from the sawdust and soil.

Sawdust materials have proven to be promising materials for controlling and increasing the permeability and removal of pollutants from wastewater. The results from the laboratory column experiments showed significant reduction in pollutant concentration and increase the permeability when sawdust was used as a carbon source to enhance microbial activity.

Using sawdust for removing pollutants would benefit both the environment and the wood agriculture. For example, contaminated waters would be cleaned, and a new market would be opened for the sawdust.

References

1. Eljamal, O., Jinno, K., and Hosokawa, T. (2006). “Modeling of biologically mediated redox processes using sawdust as matrix.” Annual Journal of Hydraulic Engineering, JSCE.

2. Lensing, H.J., Vogt, M. and Herrling, B. (1993) “Modeling of biologically mediated redox processes in the subsurface.” Journal of Hydrology, 159, 125-143.