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TRANSPORT THROUGH LOW POROSITY MEDIA - MICROSTRUCTURE AND UNCERTAINTY ANALYSIS

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Transport through low-porosity media-- microstructure and uncertainty analysis

1.Introduction

While many models of repository performance are by necessity detailed and elaborate there is also a need for simpler models. The detailed models function as reference basis and to perform analysis at the level of regulatory compliance. The simpler models have the more modest purpose of providing an *understanding* of the relationship between experimental investigations and disposal facility designs. This understanding would then help to better define the experimental data needs. These models require many fewer input measurements to have reliable descriptive capability. The process description may involve a sophisticated basis but the computational requirements are modest. Such models would enable uncertainty analysis to be performed giving probabilistic estimates of various parameters in a reasonably reliable manner. In the present work an example of this approach would be described.

Transport of contaminants through low-porosity media (saturated and unsaturated) is an important issue in assessing the performance of waste repositories [1]. Examples of such media include bentonite-type diffusion barriers used for engineered barrier system and natural rock matrix [2]. One key transport parameter is the contaminant diffusivity and its dependence on the media microstructure. In this work a model of the effective contaminant diffusivity D_{eff} in these environments has been proposed. The parameter D_{eff} includes microstructural (i.e., porosity) and chemical sorption effects and has been incorporated into a diffusive transport model that is linked to current descriptions of waste glass corrosion via boundary conditions [3]. This model has been applied to an analysis of the contaminant retention times in bentonite. Monte Carlo analysis was used to examine the uncertainty in the retention time arising from uncertainty in the materials properties such as porosity.

2. Work description

Low-porosity diffusion barriers are usually made up of highly compacted materials that have a clay-type component, usually bentonite. Such materials offer low porosity (5 to 15%) and high sorption capacity. The water-filled interconnected pores are the principal transport pathways. It has been well known in the geological community that the ratio of, the *electrical* resistivity of a fluid -bearing rock (R_r) to the resistivity of the fluid itself (R_f) is proportional to θ^{-m}, where θ is the porosity of the rock and m is an exponent called the cementation factor. For many porous materials, m is within a narrow range of 1.3-2.5 [4]. The ratio R_r/R_f is known as the formation factor F. The scaling relationship between the formation factor and the porosity, which is a summary expression of a vast amount of geological data, is known as Archie's law [4,5]. The basic factor underlying Archie's law is the influence of the complex microstructure on fluid-solute transport. One of the key features of many porous media is that long-range interconnected porosity exists down to a few percent porosity due to the nonrandom porosity distribution. To take into account the spatial correlation in porosity distribution, a differential effective medium approach [6] has been used in this work. An effective porous medium is constructed by repeated incremental addition of a mixed solid-fluid phase to the existing materials, starting from the pure fluid. In this self-consistent procedure, connectivity of the fluid phase is maintained at all stages. This ensures that the barrier material would permit solute transport through it even down to very low porosity.

3. Results and Discussion

Microstructural effects in a bentonite barrier have been treated by a differential effective medium approach. Figure 1 shows the calculated result (solid line) obtained from this approach. Reasonable agreement with experimental data [5] has been obtained. The deviation at very low porosity is due partly to the mean-field (i.e., the averaging) nature of the present approach. Using our calculated result and incorporating the chemical sorption retardation factor we derived D_{eff} using the Nernst-Einstein relation.

Utilizing the above D_{eff} we then solve the diffusive transport model via Green's function technique [7]. A characteristic retention time (τ) in an diffusion barrier for a radionuclide was thereby obtained. Our analysis indicates that τ is a sensitive function of the porosity, which frequently has a range of uncertainty from measurements and actual variation in the microstructure of the materials medium itself. A Monte Carlo analysis led to an unsymmetric long tail of the probability distribution for τ arising from the nonlinear dependence on the porosity in the D_{eff} .The present analysis indicates that τ can decrease by an order of magnitude with modest changes in the mean porosity.

4. Conclusion

In summary we have formulated a relatively simple model that described radionuclide transport through low porosity diffusion barriers. Chemistry and microstructural effects were found to be important design parameters for choice of low-porosity barrier materials. Monte Carlo analysis indicates that the retention time of waste species in diffusion barriers is a sensitive function of the porosity. The present methodology is able to provide stochastic analysis in a relatively simple manner. In the next stage this approach will be generalized to address issues concerning very low-porosity media such as far-field transport in a rock matrix.

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Fig.1 Formation factor vs. Porosity