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# LABORATORY VALIDATION OF A DUAL-PERMEABILITY RESERVOIR CODE

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## INTRODUCTION

A large number of studies have been published in the past 10 to 12 years dealing with solute transport in fractured media. The vast majority of this work deals with solute transport in single fractures. Much of this work has been motivated by the need for a repository for storage of nuclear wastes that is safely sequestered from man and the environment.

A number of papers deal with dual porosity aquifers, where fractures occur in a rock that also contains primary porosity. Usually, the permeability of the matrix blocks is considered insignificant relative to the permeability of the fracture system (Baca et al., 1981; Huyakorn, 1982; and Travis, 1984). The matrix blocks do not participate in fluid flow through the rock, but can be involved in heat transfer and solute retardation phenomena. Diffusive transfer between fractures and the rock matrix is the mechanism for heat transfer and retardation of solutes. None of the approaches deals with advective transport between fracture and matrix. Solute transport in the fracture is either by advection alone (McKinley and West, 1982; Rundberg et al., 1981) or by advection and dispersion based on a one dimensional solution to the advection-dispersion equation (Nuttall and Ray, 1981; Tang et al., 1981; Travis Nuttall, 1982).

In dealing with large, complex fracture systems, it may not be possible to explicitly simulate all the fractures. Under these conditions, the major fracture sets and faults would be explicitly simulated, with lesser fracture sets being treated by a continuum approach (Figure 1). Matrix, in this type of simulation, could have significant permeability as well as porosity. Research at EG&G is currently oriented at perfecting techniques for simulation of this type of dual permeability fracture system. Simulation capabilities are provided by the FRACSL reservoir code, and laboratory experiments are being conducted on dual permeability models to collect data for validation of the algorithms in the FRACSL code.

## DESCRIPTION OF MODELS

### FRACSL

This code is a reservoir level simulation code for dealing with flow in porous media, discrete fractures, and dual permeability media (Miller, 1983; Clemo and Miller, 1984). It uses the ACSL simulation language (Mitchell and Gaither Assoc., 1981) to solve the numerical equations, and so is called FRACSL. It is an isothermal, two-dimensional, finite difference code. Current capabilities include transient and steady-state solutions for flow in porous, fractured, and dual-permeability media, transport of conservative solutes, and advective and diffusive transfer of solutes between fractures and matrix blocks. Fractures can be vertical, horizontal, or diagonal across a cell. The code solves for one pressure distribution for both matrix and fractures.

Flow in the fractures is calculated from the cubic law, which is based on the assumption that fractures are essentially parallel plates. Dispersion in fractures is simulated mechanistically by a combination of velocity profile effects and transverse dfffusion between stream lines. No dispersion

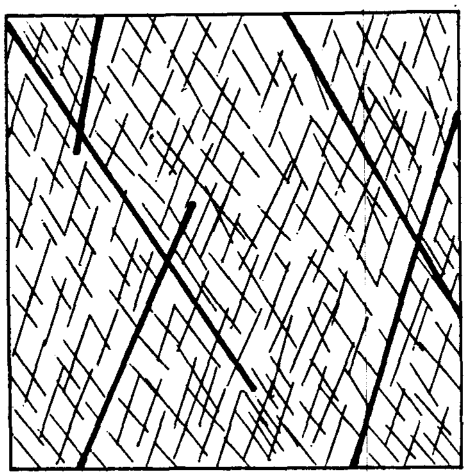

Figure 1. Conceptual dual-permeability fracture network.

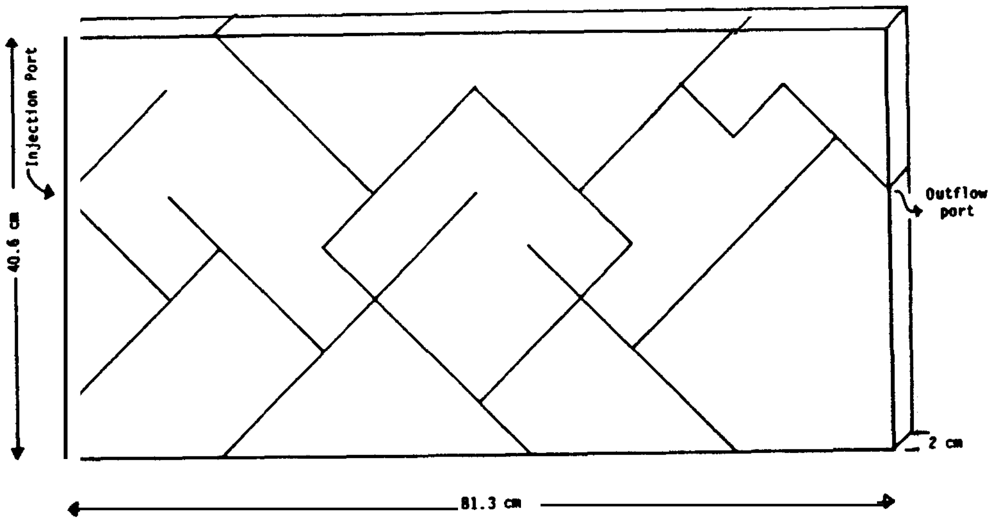


Figure 2. Dual-permeability fracture network model used in laboratory experiments.

coefficient is used for fractures. Dispersion in the matrix is calculated by a random walk particle tracking algorithm.

Laboratory Model

The dual permeability fracture model allows for both fractures and porous matrix blocks that participate in the flow system. A broad range of materials were considered including corrundum, scintered glass, scintered metal, glass and plastic beads, natural rocks, porous ceramic, and porous polyethelene. The material selected was porous polyethelene. It is available in sheets 1 m by 1 m by 2 cm thick with a pore size of 40 microns. This material could not be fractured to create "natural" fractures, but could be machined easily. This allowed an elaborate fracture network to be designed, one that included deadend fractures (Figure 2). The porous polyethelene is somewhat like a sandstone in properties.

A small matrix block model was constructed to test materials and to measure hydraulic and dispersivity characteristics of the porous polyethelene. The block is 15.25 cm long and 10.2 cm wide and has a porosity of 30%. Manifolds on two sides give constant head boundaries to control flow through the block. Flow tests were conducted where pressure drop and flow rate were measured. The hydraulic conductivity of the porous polyethelene was then calculated from Darcy's Law to be 0.2 cm/min. Electrodes were installed in the block, and mini-tracer tests conducted. Normalized tracer concentrations are plotted against a volume modifying function on probability paper (Brigham, 1974), and the variance determined from the plot used to calculate the dispersivity coefficient. The coefficient was determined to be 0.27 cm, and was independent of flow rate over a range of flow rates between 0.024 and 1.7 cm/min. The dispersivity, hydraulic conductivity, and porosity of the matrix blocks can therefore be input to the FRACSL code as independent parameters.

Fracture apertures in the model range from 380 to 1500 microns, and are log normally distributed Electrodes and piedometers are installed at various locations in the model, both in fractures and in matrix blocks, to monitor pressure and movement of tracer solutions.

FRACSL SIMULATIONS

The dual porosity model shown in Figure 2 has been simulated using estimated parameters and the indicated dimensions. Figure 3 shows the

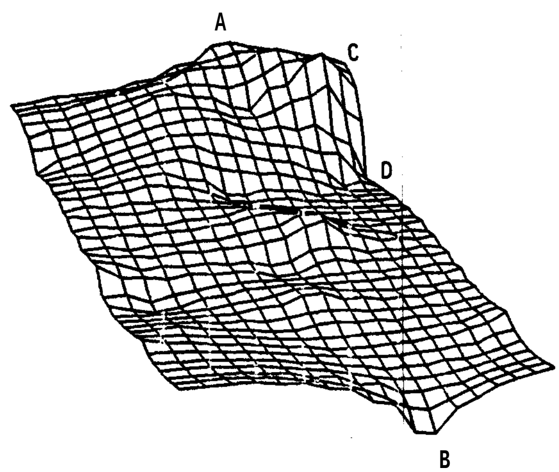


Figure 3. Steady-state pressure distribution in the dual-permeability laboratory model calculated using the FRACSL code.

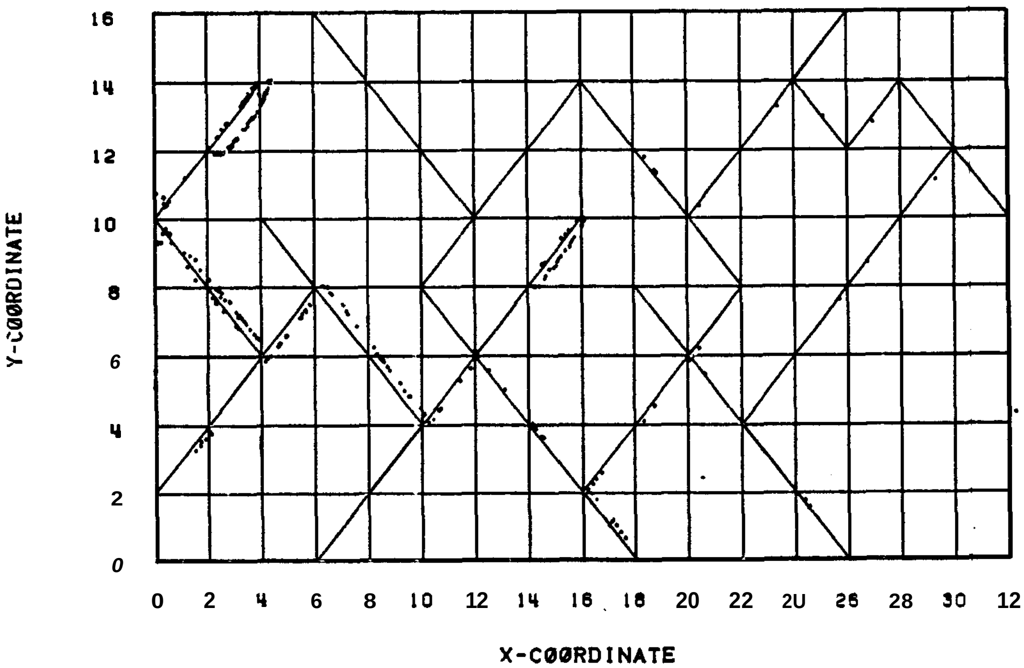


Figure 4. Positions of tracer particles, injected as a five-minute pulse, after 60 minutes of flow in the dual-permeability models. Predictions based on the FRACSL code.

predicted pressure distribution within the model under steady-state conditions. The fluid will be injected at point A and withdrawn at point B. The slope in the pressure gradient is not uniform from inlet to outlet, but shows some very steep discontinuities, the most prominent of which is between points C and D. This steep pressure gradient develops between two deadend fractures, which end close to each other, but are connected to the fracture network at very different locations. Thus, there is a very steep pressure gradient to drive solutes into the matrix between these two fractures.

Figure 4 is a map view of the fracture network, somewhat distorted, and shows position of tracer solution, injected as a 5 minute slug, after 60 minutes of moving through the fracture network. Tracer has moved into the matrix in a number of locations. After longer times tracer will connect to other fractures, and move out of the matrix into new fractures, and then back into the connected fracture system. This model design provides a number of very rigorous test for a fracture network simulation code, that provide a good test of code capabilities.

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