Available online at www.sciencedirect.com

ScienceDirect

Journal of Hydro-environment Research 8 (2014) 223–233

Journal of Hydro-environment Research

www.elsevier.com/locate/jher

Research paper

Contaminant transport through fractured-porous media: An experimental study

P.K. Sharma*, Umang Dixit

Department of Civil Engineering, Indian Institute of Technology, Roorkee, Roorkee 247667, India

Received 13 June 2012; revised 28 July 2013; accepted 9 August 2013
Available online 31 August 2013

Abstract

In this paper, an experimental study has been carried out to investigate the behavior of solute transport through fractured-porous media. Experimental set-up consists of fractured-porous media which has been created with clay (matrix) and a single fracture is created in middle of the clay matrix in flow direction. During experiment, the clay matrix is saturated with fresh water and solute tracer is injected in the fracture at inlet and the samples are collected from out let for different times of interval. Concentration profiles of experimental data of chloride and fluoride are simulated with developed numerical model to estimate transport parameters. Results show that the value of matrix-diffusion coefficient depends on fracture velocity and residence time till to reach in equilibrium condition. It is also found that higher value of diffusion coefficient leads to reduce the magnitude of solute concentration in the fracture. The experimental results indicate that there is substantial diffusion and sorption in the fractured-porous matrix. The estimated parameters and numerical model can be used for design of waste disposal system in the fractured matrix system. Finally, numerical results of various temporal moments have been predicted to study the behavior of reactive solute in the fracture, and it was found that the behavior of solute mass recovers, mean arrival time and second time moment are nonlinear along the travel distance for solute in the fracture in the presence of matrix-diffusion and decay rate coefficient.

Keywords: Fractured media; Solute transport experiment; Concentration profiles; Temporal moments

1. Introduction

Transport of contaminants in the fractured-porous media is important phenomenon that arises in connection with many contemporary groundwater pollution problems. It is also affected due to various processes such as advection, dispersion, diffusion and sorption in fractured matrix system (Freeze and Cherry, 1979). During past few decades, various studies have been carried out on contaminant flow through fractured-porous media. Solute transport through fractured media is described by advective–dispersive transport equation, which is dominant in the fracture, and diffusive transport, which is dominant in the matrix (Grisak and Pickens, 1980a,b). The effect of the value of the solute diffusion coefficient in the matrix (termed as matrix-diffusion coefficient) is illustrated by solute breakthrough curves and concentration profiles in the fracture as well as in the matrix. Neretnieks (1980) developed an analytical solution for solute transport in a fracture under assumption that dispersion and diffusion are negligible. Tang et al. (1981) developed analytical solution for the contaminant transport along a discrete fracture in the porous matrix incorporating advective transport and longitudinal dispersion along the fracture and molecular diffusion perpendicular to the axis of the fracture along the advective flow. Sudicky and Frind (1982) developed generalize solution of advective–dispersive transport equation for solute transport through fractured-porous media. It was found that a small spacing results in greater penetration distance along the fracture axes because of limiting the capability of matrix to store the

* Corresponding author. Tel.: +91 (0)1332 285684.
E-mail addresses: pramod_6s@rediffmail.com, drpksharma07@gmail.com (P.K. Sharma), umangtarang@gmail.com (U. Dixit).

1570-6443/$ - see front matter
http://dx.doi.org/10.1016/j.jher.2013.08.003

contaminant. Neretnieks et al. (1982) studied the migration of radionuclide in natural fissure of granite core. The fissure was oriented parallel to the axis in a cylindrical core of 30 cm long and 20 cm in diameter. From analysis of the breakthrough curves for the nonsorbing tracers, it was observed that channeling occurs in the single fissure. A field example of measuring the dispersive properties of a single fracture in fractured plutonic rock is presented by Novakowski et al. (1985). The experimental technique involves, injecting a slug of conservative tracer into a "steady" groundwater flow field between a pumping and recharging borehole and monitoring the tracer breakthrough by sampling the withdrawal water directly. Birgersson et al. (1993) performed a tracer experiment in a fracture zone of crystalline rocks and it was observed that few flow paths dominate the flow as well as the tracer transport. Experimental investigations had shown the great influence of matrix diffusion on transport causing slowdown in the migration of solute and a decrease in the concentration peaks (McKay et al., 1993). A field experiment in fractured clay for solute transport was done which shows behavior of bromide, chloride and isotopes of O/H. The experiments show that dissolved contaminants, although strongly retarded by matrix diffusion, can still migrate laterally at significant rates in some fractured clay deposits. Birkholzer et al. (1993a,b), Rubin and Buddemier (1996), and Rubin et al. (1996, 1997) had studied mixing process of contaminants in the fractured permeable formations, considering advection in the porous matrix block as well as in the fracture. Kennedy and Lennox (1995) had developed a control volume model for solute transport through a single fracture in the porous matrix. They used an upstream weighting scheme based upon the exact solution of the steady state one-dimensional advection dispersion equation. A model of radionuclide transport in the fractured rock including the sorption kinetics and the surface diffusion was developed by Xu and Worman (1999). Bardsley (2003) analyzed temporal moments for pulse conservative tracer into parallel stream tubes with different advective–dispersive transport and steady flow.

Srivastava et al. (2004) derived analytical expressions for the temporal moments of reactive solute affected by multiple reactions in homogeneous porous medium. West et al. (2004) derived transient and study-state analytical solutions for a system of evenly spaced, parallel discrete fractures, to simulate solute transport in both the fracture and the continuous porous matrix. Field observations by Neretnieks (2006) have shown that most of the water in fractured rocks flows in a small part of the fractures. It is also found that a deep geologic repository for nuclear waste repository in granitic rock the diffusion into stagnant waters adjacent to the flowing channels can contribute to the retardation of solutes. Moreno and Crawford (2009) showed that the radionuclide transport at site characterization and performance assessment timescales is governed by the same retardation mechanisms. Also, diffusion and sorption in the matrix determine the solute transport time under performance assessment conditions and the fracture aperture is not needed for radionuclide transport calculations. Dai et al. (2009) developed a scaling methodology for modeling sorption coefficients for fractured-rock systems by characterizing both the tortuosity field and retardation factor field in the rock matrix at field scale. Wu et al. (2010) proposed a conceptual model of fracture-flow-enhanced matrix diffusion, which correlates with fracture-flow velocity. They incorporated an additional matrix-diffusion process, which is induced by rapid fluid flow along the fractures. Deng et al. (2010) developed upscaling equations for tortuosity and the sorption coefficient in the fractured rocks with multimodal mineral facies by volume averaging of mass transfer coefficients in the dual-porosity model. Dai et al. (2012) considered two sorption processes (equilibrium and kinetics) for modeling of neptunium and uranium sorption in the fractured rock.

In this study, experiment has been conducted in the lab for solute transport through fractured-porous media. Experimental data of chloride and fluoride has been observed at different location along the fracture. Also, numerical model is developed for reactive transport through fractured-porous media. Breakthrough curves of experimental data are simulated using numerical model and appropriate transport parameters are estimated. Finally, numerical results of zeroth, mean and second time moments have been analyzed for reactive solute in the fracture.

2. Experimental set-up

The experiment is carried out in a set-up of rectangular tank, made up of iron. The size of the tank is of 3 m × 1 m × 2 m and it also contains clay of 30 cm depth. Clay was kept inside the model. Air-dry clay was carefully packed in small increments into container avoiding any soil particle size segregation. Small air gap is created in middle part of the clayey soil which acts as single fracture along the flow direction in the tank. The size of fracture was kept 2 mm and a photograph of experimental set-up with rectangular tank is shown in Fig. 1. The head in the supply tank was kept constant at the time of flow of solute through the tank. The flow was allowed only in the fracture and no flow in the clay matrix. The clay contains organic and inorganic substances so before measurements, the clay in container was washed out by water for time duration of 6–8 h. The flow of solute was measured at various intervals of time along the fracture. The physical properties of clay are given in Table 1.

3. Governing equations

The conceptual model for fractured-porous model is described in Fig. 2. The transport processes in single fracture matrix system can be described by two coupled equations, one for the fracture and other for the porous matrix. The coupling is provided by continuity of fluxes and concentrations along the interface. The differential equation for the fracture can be obtained by balancing the total mass of contaminant in the fracture.

The groundwater velocity in the fracture is assumed constant, and a solute source of constant strength is assumed to