



Short communication

The effect of spatially varying velocity field on the transport of radioactivity in a porous medium

Soubhadra Sen^{*}, C.V. Srinivas, R. Baskaran, B. Venkatraman

Radiological Safety Division, Indira Gandhi Centre for Atomic Research, Kalpakkam, 603 102, India

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ABSTRACT

In the event of an accidental leak of the immobilized nuclear waste from an underground repository, it may come in contact of the flow of underground water and start migrating. Depending on the nature of the geological medium, the flow velocity of water may vary spatially. Here, we report a numerical study on the migration of radioactivity due to a space dependent flow field. For a detailed analysis, seven different types of velocity profiles are considered and the corresponding concentrations are compared.

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1. Introduction

The increasing demand of energy has forced the human civilization to look for a nuclear route of power generation. During the operation of a nuclear reactor, fissile atoms undergo fission causing the generation of fission products along with the release of energy. In the back end of a fuel cycle, the radioactive waste is isolated, then classified according to the activity level (low, intermediate and high) and subsequently disposed off following the safety norms. The low and intermediate category of wastes are immobilized and then stored in near earth surface repositories. On the other hand, high level wastes are vitrified in a glass matrix, then sealed in a tank called canister which is subsequently buried deep inside the earth surface (inside a rocky medium) to isolate the same (Wattal, 2013). In the event of a leak from the underground storage facility, the waste may come in contact with the flow of underground water. In such a situation, the radionuclides would migrate within the geological medium due to the combined effect of advection and diffusion. This is a serious issue related to environmental and radiological safety and thus requires an in-depth study.

There are two ways to model the migration mechanism. Fig. 1 shows a schematic picture of a rock where solid porous blocks sit within the network of tiny fractures through which the laminar

flow of water occurs. Thus the concentration of the contaminant at a given point (as a function of time) can be estimated following a random walk approach (Williams, 1992; Giacobbo and Patelli, 2008; Sen and Mohankumar, 2013). On the other hand, this problem can also be addressed by considering a neat geometry of a rock (Fig. 2) where an infinite array of identical parallel fractures are separated by porous blocks of same width (Sudicky and Frind, 1982; Chen and Li, 1997; Mohankumar, 2007; Sen and Mohankumar, 2011, 2012, 2014; Sen et al., 2015). In all these works, it is assumed that the flow of water is constant in all the fractures and this in turn requires that the concentration of the dissolved species is same at a given horizontal distance along all the fractures (Fig. 2). This is clearly a very gross assumption to simplify the computation. From Fig. 1, one can easily notice that the geometry of a rock demands a spatial distribution of flow velocity. This point can be illustrated in a more detailed way by Fig. 3 where velocities at the points A, B, C, D, E, F and G cannot be the same. The key concept of this work is to point out that the transport of a dissolved contaminant depends largely on the space dependent flow field of water. To mimic the actual flow, one has to generate the velocity profile very accurately. In a bit simplified approach, we can estimate velocities at some nodal points (like A, B, C, D, E, F and G in Fig. 3) and fit into a polynomial to approximate the flow profile. This fitted profile can be utilized to estimate the transport through a selected path. This approach may raise another important question that the concentration of the dissolved radionuclide should also change from fracture to fracture at a given horizontal distance

^{*} Corresponding author.E-mail addresses: ssen@igcar.gov.in, senjournalpaper@gmail.com (S. Sen).

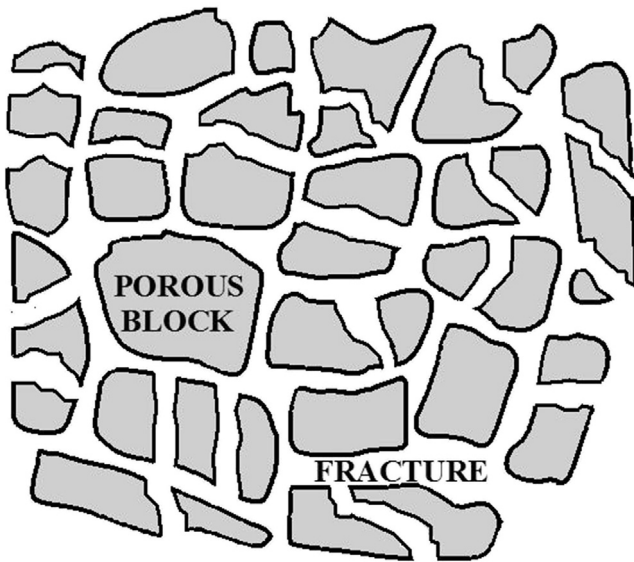


Fig. 1. Schematic picture of a rock.

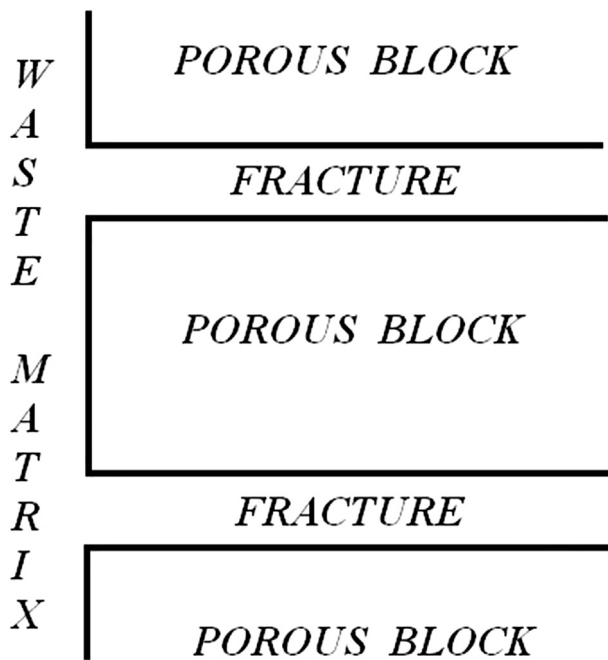


Fig. 2. Waste matrix and fracture geometry in parallel fracture model.

from the source. To avoid further complicity, in our present work we stick to the assumption that the concentration remains same at a given horizontal distance in all the fractures. Below we list out the two most important assumptions of this work:

- The flow velocity of water through a rock has a space dependent profile.
- The concentration of the dissolved contaminant is same in all the fractures at a given horizontal distance from the source at a given instant of time.

In reality, all the transport related parameters (density of fractures, diffusivity, width of the fracture and other parameters) may vary spatially. As a sequel of our earlier works (Sen and

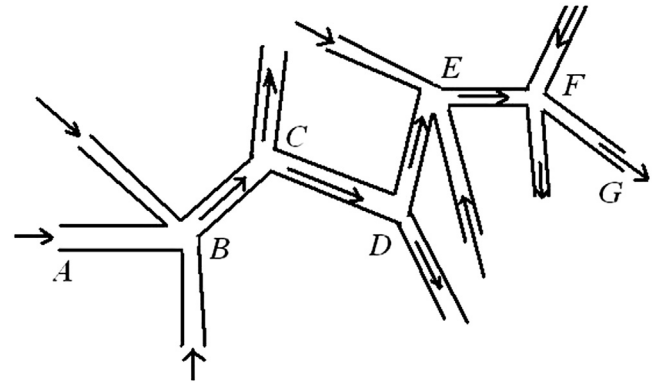


Fig. 3. Schematic picture of water flow through a rock medium.

Mohankumar, 2011, 2012, 2013; Sen et al., 2015), we consider the transport to be dominated by advection and so the spatial variation of the diffusion coefficient is ignored. Moreover, for simplification other parameters are assumed to be constant. To highlight the importance of considering a proper field, we consider a basic 1-D model along with some simple space dependent velocity profiles. For a real life problem, we need to take some samples of the given medium and estimate the flow rates at some given spatial locations along a selected path for a given inflow at the source end. Now by fitting into a polynomial, the collected data can be used to generate a space dependent velocity profile along the path. It is important to note that the flow velocity may change from path to path. In such a case, the velocity of water in each path is needed to be estimated and this is not practically possible. In the parallel fracture model, the waste matrix is considered to be infinite which is also not a very correct assumption (Fig. 2). So for a waste matrix of finite size, flow velocities along the dominant paths (at the depth where the canister is buried) along a particular direction are enough for the simulation (for example horizontal direction in Fig. 2). Now along all such paths, we can experimentally measure the velocities at some nodal points and obtain a fitted function for the flow velocity. If the flow related characteristics of the medium (density of fractures, diffusivity, width of the fracture and other parameters) do not change drastically from region to region (a general assumption for a numerical simulation), the flow velocity profile would also remain nearly the same along all the paths. In such a case, an average velocity function can be used for all the paths and one may opt to use the parallel fracture modal to simulate the transport of radioactivity through the medium under consideration in a more accurate way. On the other hand, if the flow rate changes drastically from path to path or region to region, the space dependent velocity function for each path has to be considered separately. In this work, the limitation of the assumption of a constant flow velocity through all the paths is pointed out by considering a few theoretical velocity profiles. The main objective of this study is to estimate the migration of activity in a porous medium under the influence of a spatially varying velocity field.

2. Radioactivity migration in a porous medium

We consider a simple one dimensional advection-diffusion equation to model the activity transport as given below.

$$\frac{\partial C}{\partial t} + \frac{1}{R} \frac{\partial}{\partial x} (vC) - \frac{1}{R} \frac{\partial}{\partial x} \left(D \frac{\partial C}{\partial x} \right) + \lambda C = 0, \quad x \geq 0, \quad t \geq 0 \quad (1)$$

Here, $C(x, t)$ is the concentration of the active species, v is the flow velocity of water, D is the diffusion coefficient, R is the

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