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Mass transport and velocity field within a high permeable porous medium

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Hyporheic exchange has been extensively studied in the literature. The majority of papers present the results of field studies and the associated engineering simulation models, such as the widely used Transient Storage Model [Bencala and Walters, 1983]. The number of laboratory studies is smaller. Most of them are focused on the bulk scale effects such as the influence of the bed forms [Marion et al., 2002; Marion et al., 2008], or the bed heterogeneity [Salehin et al. 2004] on the hyporheic flow and interface mass transport. An exception is a recent study of Reidenbach et al. [2010], who present detailed measurements of flow and mass transport within the surface flow close to the sediment-water interface for a range of sediment sizes.

Measurements within the sediment bed at the grain scale are also rare. It is possible to measure pressure within the sediment bed [Vollmer et al., 2002], but measurement of velocities and concentrations at the scale of grains is very difficult. Measurement within the pores of a permeable bed becomes possible for some idealized pore configurations. Pokrajac and Manes [2009] and Manes et al. [2009] use constant diameter spheres packed in a cubic pattern, which form straight pores (with variable cross-sectional area) in three orthogonal directions. This configuration allows measurement along a longitudinal pore, using Ultrasonic Velocity Profiler, and across a part of the middle plane within the same pore, using Particle Image Velocimetry (PIV). Their results include detailed velocity measurements and the characteristics of turbulence at the fluid/porous interface, but not the mass transport. Similar results for undisturbed flow through the same porous material are presented in Horton and Pokrajac, [2009]. The study reported here uses the same porous medium and extends this work by including grain-scale mass transport measurements.

This paper reports the results of the first stage of the experimental project focused on the mass transfer above and within a highly permeable material. The first stage involves hydrodynamics and mass transport within the undisturbed flow through the porous medium.

The experiments are carried out in a facility composed of two constant head tanks connected by a rectangular channel that houses the porous medium. The porous medium is made of 12mm diameter plastic spheres, packed in a cubic pattern. This arrangement was chosen in order to allow measurements of the velocities and solute concentration within a pore. The measurement window covers a central section of a longitudinal pore, which is visible through a lateral pore.

Majority of experiments is run with turbulent flow i.e. with the Reynolds number higher than 350 (the threshold value for onset of turbulence reported in Horton and Pokrajac [2009], for identical porous medium), and with the maximum Reynolds number well above this value.

The velocity field is measured by means of the PIV, and the concentration field is measured using the Laser Induced Fluorescence. These two techniques allow simultaneous non-intrusive measurements within a single pore. An experiment produces the time series of velocity components and tracer concentrations across the measurement window. Velocity components and the corresponding concentrations are subsequently statistically analyzed. The results include statistical moments of velocity and concentration, turbulent momentum flux, advective mass flux, turbulent mass flux, and diffusive mass flux. The relationship between the turbulence generated within the porous medium and mass transport is discussed. These results will serve as a reference for the subsequent study of mass transport at the fluid/porous interface.

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