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Mass transport at the interface between a highly permeable porous medium and an open channel flow

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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. The number of laboratory studies is smaller. Most of them are focused on the bulk scale effects, since the measurements within the bed at the grain scale are difficult and therefore rare.

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. Their results include detailed velocity measurements and the characteristics of turbulence at the fluid/porous interface, but not the mass transport.

The experimental study reported here uses the same porous medium and extends this work by including grain-scale mass transport measurements. The results presented involve the hydrodynamics and the mass transport at the fluid/pore interface and within the first pore under the surface of the medium.

The experiments are carried out in a 11m long and 40cm wide tilting flume. The porous medium, placed on the flume bed, is composed of 5 layers of 12mm diameter plastic spheres packed in a cubic pattern. This arrangement was chosen in order to have a regular matrix, thereby allowing 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.

The velocity field is measured by means of the Particle Image Velocimetry (PIV), and the concentration field is measured using the Laser Induced Fluorescence (LIF). These two techniques allow simultaneous non-intrusive measurements within a single pore.

The experiments involved uniform, fully developed turbulent flow. The experimental conditions were: bed slope = 0.01, water depth = 45mm, depth-averaged velocity = 0.5 m/s. A fluorescent dye is injected in the middle of the pore by means of a tiny pipe system which runs inside the beads themselves, in order not to disturb the flow. This is repeated for 9 adjacent beads, which together form a linear source perpendicular to the flow direction.

Two series of experiments were carried out under the same flow condition, one with the injection placed at the interface level, and another with the injection in the first pore under the top bead.

An experiment produced the time series of bed-parallel and bed-normal 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, and the evaluation of the main terms of the momentum and mass transport equations. The relationship between the turbulence and mass transport is also discussed.

These results can be used as a source of information to better understand the hyporeic mass exchange. Furthermore, they can serve as a reference for the application of practical engineering models.

References

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