Pressure Inlet and Outlet Boundary Conditions for SPH, Applied to Permeability Modelling

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ABSTRACT

The use of numerical methods to evaluate the permeability of real porous media is well established in the literature, particularly for geomechanics [1]. Smoothed Particle Hydrodynamics (SPH) is a method that would seem ideally suited to such modelling, due to the demonstrated ability to simulate problems involving multi-phase flows and transport [2]. In spite of this, examples applying the method to real porous media are scarce [3]. A key limitation of the method arises due to the challenges associated with implementing natural inlet and outlet conditions on a highly irregular flow domain (as with porous rocks, bone, bioengineered ceramics, etc.). To achieve an accurate digital analogue to the conditions experienced during physical permeability testing, the use of existing techniques like periodic boundaries [3], or pre-defined velocity profiles [4], are inadequate and can cause significant error.

In this work, to address these shortcomings, we have developed new authentic pressure inlet and outlet conditions for SPH that allow the natural development of in- and out-flow velocity profiles for any complex and irregular domain shapes and flow paths. The method works by interpolating fluid velocity, pressure and density values at calculation points on an inlet or outlet boundary interface. These values are then propagated to adjacent inlet/outlet zone ghost particles. The key aspect of the method is the correction that is imparted to the velocity before propagation. As the interpolated value of local interface pressure deviates from a specified target value, the local ghost zone particle velocity is adjusted to correct this by feeding more or less mass into, or out of, the system. The correction magnitude is derived directly from the SPH governing equations, and has been found to be highly robust, requiring only the specification of boundary pressure and no additional parameters or tuning.

To demonstrate the accuracy and effectiveness of the developed boundary method, we will present verification and benchmarking work on ideal 3D porous media, as well as several key real porous media flow examples. Principally, we apply the approach to the evaluation of trabecular bone, and a tissue engineered ceramic material, that are used as scaffold materials for repair of large bone defects. Permeability is proposed as a surrogate measure to evaluate blood vessel ingrowth within a scaffold material, a key factor in tissue regeneration. We have used SPH to identify that the permeability of the tested engineered ceramic scaffold material is several orders of magnitude less than natural bone, suggesting increased permeability as an area that could improve the effectiveness of ceramics.

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