Macroscopic model for unsteady slip flow in porous media

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In this work, a macroscopic model of unsteady gas flow in a homogeneous porous medium in the slip regime is derived. The starting point is the unsteady creeping, isothermal slip flow model at the microscale (the pore-scale), considering a first-order slip condition at the solid-fluid interface [1,2]. An adjoint method with a Green's function formulation [3], coupled to a simplified version of the volume averaging technique [4], is employed to obtain the macroscopic model using the Laplace transform. Under the assumption of slightly compressible flow, the macroscopic mass conservation equation keeps a form similar to its counterpart at the pore-scale. Moreover, the macroscopic momentum balance is a modified version of Darcy's law that does not correspond to a heuristic model that has been often postulated for this type of flow, as already highlighted in [5]. It involves the convolution product of the time-derivative of the apparent permeability tensor ($\boldsymbol{K}_{st}$, function of the macroscopic Knudsen number, $\xi\bar{\lambda}^*$) with the (time-dependent) macroscopic pressure gradient. In addition, the effect of the initial flow condition is accounted for by an effective memory term, $\boldsymbol{\alpha}_s$. Both $\boldsymbol{K}_{st}$ (which symmetry and positiveness are analyzed) and $\boldsymbol{\alpha}_s$ are determined by a single unsteady closure problem, that depends on the Knudsen number, to be solved in a representative elementary volume (periodic unit cell) of the porous structure under consideration [6].

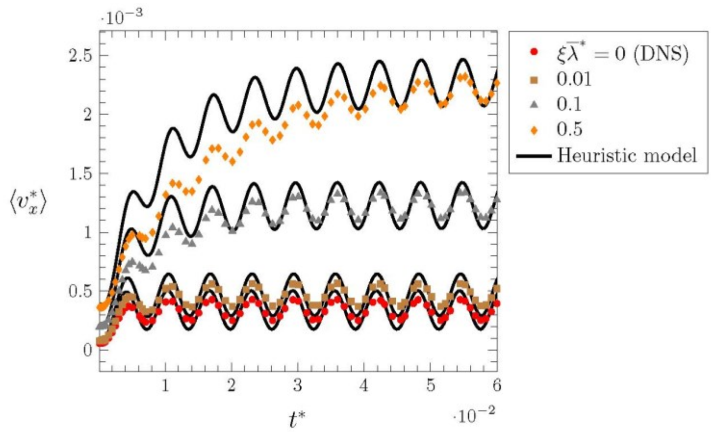

Fig.1: *x*-component evolution of the average velocity within a square pattern of parallel cylinders resulting from an oscillatory pressure gradient in the *x*-direction, corresponding to a lattice axis orthogonal to the cylinder axes [6].

The dependences of $\boldsymbol{K}_{st}$ and $\boldsymbol{\alpha}_s$ upon $\xi\bar{\lambda}^*$ are analyzed and the validity of the macroscopic model is illustrated through a comparison with pore-scale direct numerical simulations (DNS). This is carried out in a two-dimensional model structure made of a square pattern of parallel cylinders of uniform circular cross section, with flow orthogonal to the cylinder axes (*i.e.*, in the *x*-direction). An oscillatory macroscopic forcing along the *x*-axis is considered at $t \geq 0$, following a constant pressure gradient in the same direction for $t < 0$. As shown in Fig.1, where the evolution of the *x*-component of the average velocity is represented, the prediction of the macroscopic model is in excellent agreement with the pore-scale DNS. Moreover, it is further evidenced that the heuristic model is inadequate, in general.

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