Abstract Submitted
for the DFD17 Meeting of
The American Physical Society

Pressure drop for inertial flows in elastic porous media[1] MARTIN PAUTHENET, Institut de Mécanique des Fluides de Toulouse, ALESSANDRO BOTTARO, University of Genoa, YOHAN DAVIT, MICHEL QUINTARD, Institut de Mécanique des Fluides de Toulouse, POROUS MEDIA TEAM — The effect of the porosity and of the elastic properties of anisotropic solid skeletons saturated by a fluid is studied for flows displaying unsteady inertial effects. Insight is achieved by direct numerical simulations of the Navier-Stokes equations for model porous media, with inclusions which can oscillate with respect to their reference positions because of the presence of a restoring elastic force modeled by a spring. The numerical technique is based on the immersed boundary method, to easily allow for the displacement of pores of arbitrary shapes and dimensions. Solid contacts are anelastic. The parameters examined include the local Reynolds number, Re_d, based on the mean velocity through the reference unit cell and the characteristic size of the inclusions, the direction of the macroscopic forcing pressure gradient, the reduced frequency, f^*, ratio of the flow frequency to the natural frequency of the spring-mass system, and the reduced mass, m^*, ratio of the solid to the fluid density. Results demonstrate the effect of these parameters, and permit to determine the filtration laws useful for the subsequent macroscopic modeling of these flows through the volume averaged Navier-Stokes equations.

[1]IDEX Foundation of the University of Toulouse and HPC resources of the CALMIP supercomputing center

Martin Pauthenet
Institut de Mécanique des Fluides de Toulouse

Date submitted: 17 Jul 2017 Electronic form version 1.4

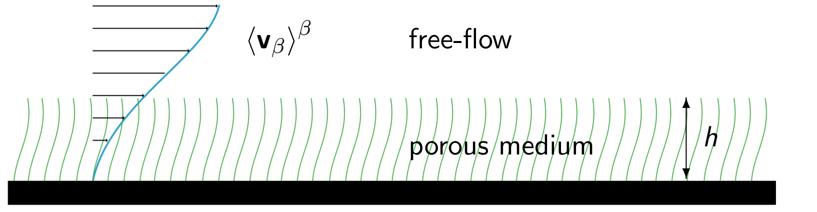
Pressure drop for inertial flows in elastic porous media

M. Pauthenet[1,*], Y. Davit[1,2], A. Bottaro[3] and M. Quintard[1,2]

[1]Université de Toulouse ; INPT, UPS ; IMFT (Institut de Mécanique des Fluides de Toulouse), Allée Camille Soula, F-31400 Toulouse, France
[2]CNRS ; IMFT ; F-31400 Toulouse, France
[3]DICCA, Scuola Politecnica University of Genova, 1 via Montallegro, 16145 Genova, Italy

November 20, 2015

Poro-elastic layer

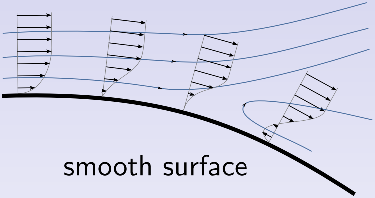


Parameters:

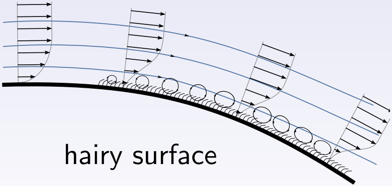
- rigidity: restoring force vs hydrodynamic load
- form of the fibers
- macroscopic Reynolds number: $\frac{hU}{\nu}$
- sparsity, dimensions $\cdots$

Final goal is to capture the large scale turbulence (honami).

Applications



smooth surface

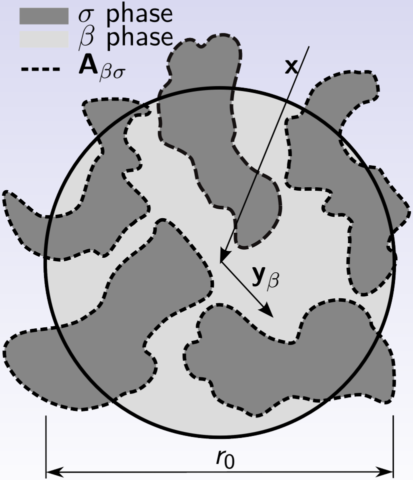


hairy surface

- vegetation management
- passive flow control

Representative elementary volume (REV)

$\ell_{micro} \ll r_0 \ll h$



Volume averaged Navier-Stokes equations

$$\frac{\partial \left\langle \mathbf{v}_\beta \right\rangle^\beta}{\partial t} + \left\langle \mathbf{v}_\beta \right\rangle^\beta \cdot \nabla \left\langle \mathbf{v}_\beta \right\rangle^\beta = -\frac{1}{\rho_\beta} \nabla \left\langle p_\beta \right\rangle^\beta + \nabla \cdot \frac{\mu_\beta}{\rho_\beta} \left[\nabla \left\langle \mathbf{v}_\beta \right\rangle^\beta + ^T \cdot \right]$$
$$+ \frac{1}{\rho_\beta} \underbrace{\mathbf{D}_{\beta\sigma}}_{\text{fluid-solid stress}} - \nabla \cdot \underbrace{\left\langle \tilde{\mathbf{v}}_\beta \tilde{\mathbf{v}}_\beta \right\rangle^\beta}_{\text{subgrid scale stresses}} ,$$
$$\nabla \cdot \left\langle \mathbf{v}_\beta \right\rangle^\beta = 0. \qquad (1)$$

filtering out small time scales $F(t) = \int_{t-\frac{\tau_0}{2}}^{t+\frac{\tau_0}{2}} f(u)du$

Separation of scales

- $\ell_{micro} \ll r_0 \ll h$
- $\tau_{micro} \ll \tau_0 \ll T_{macro}$

Goals of the present work

Small-scale data

- $\mathbf{D}_{\beta\sigma}$ from DNS
- values of ℓ_{micro}
- values of τ_{micro}

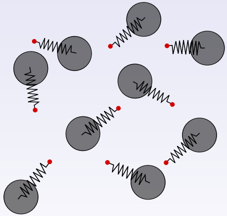
Issues

- $\mathbf{D}_{\beta\sigma} \gg \rho_\beta \nabla \cdot \langle \tilde{\mathbf{v}}_\beta \tilde{\mathbf{v}}_\beta \rangle^\beta$?
- $\ell_{micro} \ll h$?
- $\tau_{micro} \ll T_{macro}$?
- size of a REV?

Model medium

Case

- Periodic domain with mass-spring cylinders
- Instantaneous, elastic solid-solid collisions

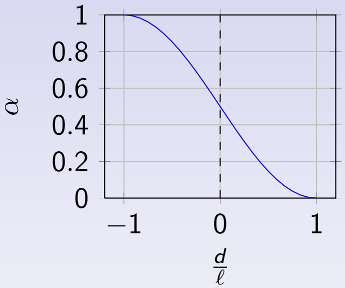


$$m^* \frac{d^2\mathbf{x}'}{dt'^2} = f^{*2} m^* \left(\mathbf{x}'_0 - \mathbf{x}'\right) + \mathbf{f}'_h$$

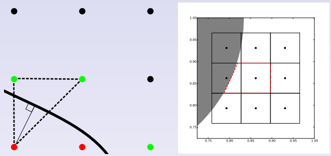
Parameters

- $m^* = \frac{\rho_\sigma}{\rho_\beta}$
- $f^* = \frac{\sqrt{k/m_\sigma}}{\left\langle \mathbf{v}_\beta \right\rangle_r^\beta / d}$
- $Re^r = \frac{d \left\langle \mathbf{v}_\beta \right\rangle^\beta}{\nu}$

Smoothed vs sharp interface $\mathbf{A}_{\beta\sigma}$

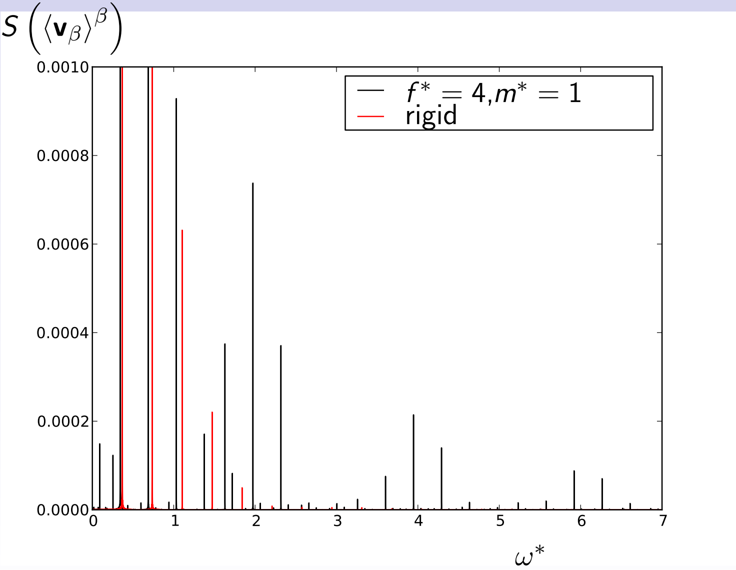


- $\mathbf{f}_\sigma = \alpha \frac{\mathbf{u}_s - \mathbf{u}*}{dt}$
- "pseudo" Poisson equation
- $\mathbf{f}_h = \int_{\mathbf{V}_\sigma \text{ phase}} \mathbf{f}_\sigma dV$



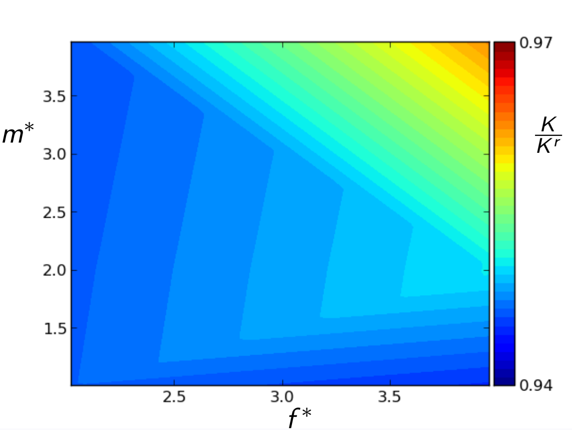
- ghost cells + cut-cells
- "true" Poisson equation
- $\mathbf{f}_h = \int_{\mathbf{A}_{\beta\sigma}} \mathbf{n} \cdot \mathbf{s}_\beta dS$

Power spectrum of $\langle \mathbf{v}_\beta \rangle^\beta$, $Re^r = 110$



Response surface, $Re^r = 110$, stiff case

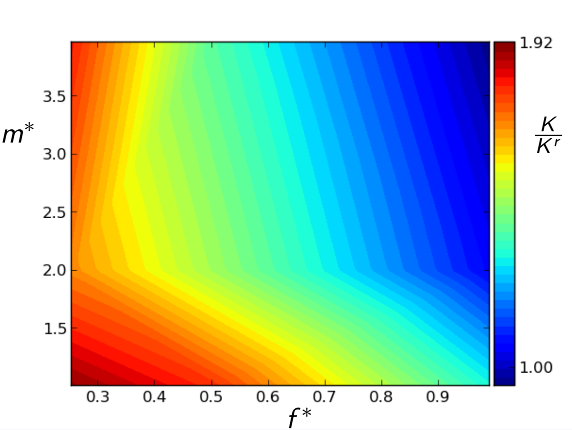
$2 < f^* < 4$
$1 < m^* < 4$



Response surface, $Re^r = 110$, soft case

$0.25 < f^* < 1$

$1 < m^* < 4$



Conclusion

- Macroscopic model of a canopy flow
- Effect of pore deformation on the permeability
- Small scale data from simulations on a periodic domain
- Large relaxation time scales
- Large length scales and REV size
- Choice of the numerical method
- High sensitivity to mesh refinement