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Modeling macroscopic unsteady inertial flow in porous media should take into account the process history

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H21L-1923: Upscaling unsteady inertial flow in homogeneous porous media

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Modeling **macroscopic unsteady interial flow** in porous media should take into account the **process history.**

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Introduction

- Unsteady flow in porous media is relevant in applications ranging from seismic waves to super fluid flow.
- This process is usually modeled using the heuristic momentum equation inferred from Darcy's law:
$$\rho\frac{\partial\langle\mathbf{v}\rangle^\beta}{\partial t} = -\nabla\langle p\rangle^\beta - \mu\varepsilon\mathbf{H}^{-1}\cdot\langle\mathbf{v}\rangle^\beta$$
- Many analyses have been performed in the frequency but not in the time domain.

Pore-scale equations

$$\nabla\cdot\mathbf{v} = 0$$
$$\rho\frac{D\mathbf{v}}{Dt} = -\nabla\tilde{p} + \mu\nabla^2\mathbf{v} - \underbrace{\nabla\langle p\rangle^\beta}_{source}$$
$$\mathbf{v} = \mathbf{0}, \text{ at the solid-fluid interface}$$
$$\mathbf{v} = \underbrace{\mathbf{v}_0}_{source}, \text{ when } t = 0$$
$$\psi(\mathbf{r}+\mathbf{l}_i) = \psi(\mathbf{r}),\ \psi = \mathbf{v}, \tilde{p},\ i = 1,2,3$$
$$\langle\tilde{p}\rangle^\beta = 0$$

Formal solution

$$\mathbf{v} = \frac{1}{\mu}\left(-\int_{t_0=0}^{t_0=t}\left.\frac{\partial\mathbf{D}}{\partial t}\right|_{t-t_0}\cdot\nabla\langle p\rangle^\beta\big|_{t_0}\,dt_0 + \mathbf{m}_0\right)$$
$$\tilde{p} = -\int_{t_0=0}^{t_0=t}\left.\frac{\partial\mathbf{d}}{\partial t}\right|_{t-t_0}\cdot\nabla\langle p\rangle^\beta\big|_{t_0}\,dt_0 + n_0$$

Upscaled model

$$\nabla\cdot\langle\mathbf{v}\rangle = 0$$
$$\langle\mathbf{v}\rangle = -\frac{1}{\mu}\int_{t_0=0}^{t_0=t}\frac{\partial\mathbf{H}_t}{\partial t}\cdot\nabla\langle p\rangle^\beta dt_0 + \boldsymbol{\alpha}$$

where $\mathbf{H}_t = \langle\mathbf{D}\rangle$ and $\boldsymbol{\alpha} = \langle\mathbf{m}_0\rangle/\mu$.

Closure problems

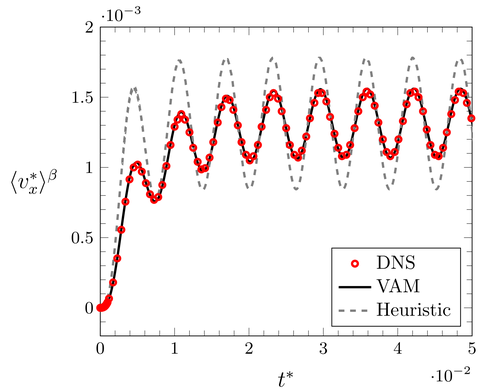
Problem I

$$\nabla\cdot\mathbf{D} = \mathbf{0}$$
$$\frac{\rho}{\mu}\frac{D\mathbf{D}}{Dt} = -\nabla\mathbf{d} + \nabla^2\mathbf{D} + \mathbf{I}$$
$$\mathbf{D} = \mathbf{0}, \text{ at the solid-fluid interface}$$
$$\mathbf{D} = \mathbf{0},\ t = 0$$
$$\langle\mathbf{d}\rangle^\beta = \mathbf{0}$$
$$\psi(\mathbf{r}+\mathbf{l}_i) = \psi(\mathbf{r}),\ \psi = \mathbf{D}, \mathbf{d},\ i = 1,2,3$$

Problem II

$$\nabla\cdot\mathbf{m}_0 = \mathbf{0}$$
$$\frac{\rho}{\mu}\frac{D\mathbf{m}_0}{Dt} = -\nabla n_0 + \nabla^2\mathbf{m}_0$$
$$\mathbf{m}_0 = \mathbf{0}, \text{ at the solid-fluid interface}$$
$$\mathbf{m}_0 = \mu\mathbf{v}_0,\ t = 0$$
$$\langle n_0\rangle^\beta = 0$$
$$\psi(\mathbf{r}+\mathbf{l}_i) = \psi(\mathbf{r}),\ \psi = \mathbf{m}_0, n_0,\ i = 1,2,3$$

Comparison with DNS



Dynamics of the average velocity for an oscillatory macroscopic pressure gradient for a porosity of 0.4 and $Re = 10^6$.

Conclusions

- Unsteady flow is described by a macroscopic model that is non-local in time and that considers the influence of the initial condition.
- The performance and accuracy of the model is validated with DNS.
- The heuristic model is inappropriate in the general case.