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Efficient numerical method for fluid interacting with a poroelastic structure

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We model the displacements occurring in oil filters due to pressure from the oil during the process of filtration. This is a complicated multiphysics problem of fluid interacting with a poroelastic structure. Modeling the fluid and solid phase of the porous media on micro level is extremely expensive of computational point of view. We use the upscaled Darcy equation for the flow in the porous region to obtain numerical experiments in reasonable amount of time. Setting different equations for the fluid flow in the free and porous domains requires setting boundary conditions to couple these two problems. When the flow is parallel to the boundary of the porous obstacle in addition to continuity of the velocity and the normal component of the stress tensor Bevers-Josef condition can be imposed (see e.g. [1]). As we are interested in a more general case when the fluid flow can be also perpendicular to the boundary of the porous obstacle it is not clear how to impose the necessary boundary conditions. To avoid this problem we use Brinkman equation

$$(1)\ \nabla p = -\frac{\eta}{k} v - \frac{\eta}{\phi} \Delta v .$$

We use this equation to model the fluid flow in both the free domain and in the porous media. With v, p and η we denote the fluid velocity, its pressure and its dynamic viscosity. The coefficients k and ϕ are the permeability and porosity. We set these two parameters in such way that in the porous region (1) reduces to the Darcy equation and in the free region (1) reduces to the Stokes equation. The described approach reduces the problem of imposing boundary conditions to a problem with high coefficient jumps.

Having a model for the fluid flow now we have to account for the deformations of the porous media. The Biot system describes the deformations in a porous body due to external forces (see [2]). However solving this system of equations is complicated and requires a lot of computational time. In many of the industrial oil and air filters the thickness of the filtering media is small compared to the planar dimensions such that the porous structure can be modeled as plate or shell. We use a shell model to resolve more complicated geometries.

The interaction between the fluid flow and the poroelastic deformation is implemented through iterations between the two different problems. First we compute the fluid flow through the initial free- and Darcy- flow regions. From these computations we obtain the stresses occurring on the boundaries of the porous domain. We use them as boundary conditions for the poroelastic problem. After calculating the displacements we construct the new region for the porous media and repeat the procedure. As we are so far interested in small displacement no complicated remeshing procedures are needed.

Trough numerical experiments we show the described model to be accurate for a variety of geometries. In the same time the model allows complicated problems to be resolved with numerical simulations on a single computer.

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