Multi-Scale Porous Medium Model for Brain Mechanics

Bercan Siyahhan, sbercan@ltnt.iet.mavt.ethz.ch **Dr. Vartan Kurtcuoglu,** vartan.kurtcuoglu@ethz.ch **Prof. Dr. Dimos Poulikakos,** dimos.poulikakos@sl.ethz.ch	Laboratory of Thermodynamics in Emerging Technologies, Department of Mechanical and Process Engineering, ETH Zurich 8092, Zurich, Switzerland

Abstract

Porous media models have been applied to various types of biological tissues [1]. In this work, we explore the possibility of modeling the brain as a single fluid phase deforming porous medium. The interaction of brain tissue and the interstitial fluid (ISF) that it is surrounded by play a critical role in the development of various pathological conditions within the cranium. In order to gain a better understanding of these conditions, we are developing a single fluid phase deforming porous medium model, comprised of ISF as the fluid phase and the brain tissue as the deforming solid skeleton.

The ISF exhibits properties similar to water and its flow around the brain tissue lies well within the Stokes regime. Therefore, the volume averaging method outlined in [2] can be applied to the governing equations of the model. With the application of this volume averaging method, two coupled domains – a macroscale domain, where the averaged flow quantities are resolved and a microscale domain, where the deviation from the averaged flow quantities are simulated – are obtained. To validate the volume averaging method, we have developed a test case for a porous medium with a single fluid phase and a non-deforming solid matrix. The test case domain is a channel with a microscale configuration of a square arrangement of cylinders. The application of the volume averaging method promotes the solution of three generic problems in the form of Stokes equations on the microscale mesh to form the permeability matrix, which is then used on the macroscale to solve Darcy’s equation. In the test case, we obtained coupling between the micro- and macroscales by calculating of the permeability matrix. The application built for this case initiated by solving three generic problems on the microscale mesh to form the permeability matrix. Then we modified porousZone libraries of OpenFOAM to handle specification of full tensors instead of principal directions and resistances to obtain the averaged flow quantities on the macroscale. The pressure drop for the channel was predicted within a relative error margin of 3%.

Since it is not possible to simply obtain tensors for the purpose of coupling the micro and macro scales in the case of a deforming solid matrix, an alternative approach has to be taken. The macroscale and the microscale domains are to be coupled, as a result of the volume averaging method, to each other through source terms emanating from the other domain. Hence, for a given flow field on the macroscale, a source term based on the flow variables has to be calculated and applied to the microscale to solve for the deviation of flow variables at this scale. Then, the microscale domain must be deformed according to the variables obtained, and from the new configuration of the mesh and averaging of the variables on the microscale, source terms for the macroscale must be calculated to update flow field. So in contrast to the non-deforming case, there is a two way coupling; the microscale must be updated based on the macroscale and in turn, the macroscale must be updated based on the microscale.

The procedure outlined for the deforming case introduces additional challenges in OpenFOAM. First, a source term that resembles spatially varying gravity must be introduced into the SIMPLE algorithm. Then, a model for the deformation based on the stress state on the microscale must be introduced. Also, the parallel processing has additional complexities. There are two different meshes that have to exchange information, in which case the decomposition is not straightforward.

We kindly acknowledge the financial support of the Swiss National Science Foundation through SmartShunt – The Hydrocephalus Project.

Key words: Deforming porous medium, Volume averaging, Hydrocephalus, Multi-scale model

References

[1] A.R.A Khaled, K. Vafai: The role of porous media in modeling flow and heat transfer in biological tissues, International Journal of Heat and Mass Transfer (46), 4989-5003, 2003

[2] S. Whitaker: Flow in porous media III: Deformable media , Transport in Porous Media (1), 127-154, 1986