Description of the master’s thesis

In this work, a partitioned scheme for numerical simulation of the surface-coupled problem of fluid-porous-media interaction (FPMI) has been proposed. To this end, the conventional serial staggered (CSS) procedure of [1] is adopted in a way that facilitates an automatic spatial partitioning of the problem, and a serial treatment of the interacting components. Moreover, proceeding from the interaction between an incompressible bulk fluid with a saturated biphasic porous medium with intrinsically incompressible and inert constituents, the characteristics of the governing equations are scrutinized and the various constraints within the subsystems are identified.

Under the expression fluid-porous-media interaction, we defined a surface interaction among several non-overlapping subsystems composed of either a bulk fluid or a porous medium. This could be interaction of blood with a blood vessel, a body of water with an earth dam structure, water flow through cracks during fracking process, or acoustic waves with acoustic panels used in soundproofing, etc. The mathematical model of such a phenomenon comprises a coupled differential algebraic equation (DAE) system in space and time, including the governing equations of the subsystems subjected to specific consistency constraints at the interface. The solution of these equations reveals the behavior of the system in different circumstances specified by the initial and boundary conditions.

In order to solve this DAE system numerically, one can either follow a monolithic or a staggered approach. The conventional serial staggered algorithm (CSS) and the local Lagrange multipliers method (LLM) proposed by [2] are two of the most popular examples of the partitioned solution schemes. Furthermore, a common problem in case of using numerical solutions for the representation of the incompressible fluid behavior, i.e., Navier-Stokes equation, is oscillations in the pressure field which happens due to the fact that the pressure term is not directly present in the incompressibility constraint. In this work, the mentioned issue has been prevented by the artificial compressibility method of [3]. Using the artificial compressibility formulation, one relaxes the problem by allowing for some violations of the constraints addressing the continuity in each subsystem. This procedure will also transform the set of differential equations (DE) to the hyperbolic form which makes the numerical treatment easier.

In conclusion, combining the artificial compressibility method formulation of the subsystems with CSS method for partitioning of the domain yields a promising candidate for decoupled solution of the FPMI problem. To implement this solution strategy for modeling the fluid-porous-media interaction was the main purpose of this contribution.

For implementation of this solution, Porous media Adaptive Nonlinear finite element solver based on Differential Algebraic System (PANDAS) has been used, which is especially designed for solution of strongly coupled multi-phasic-porous-media problems. In order to do so, two different material routines for the inviscid and incompressible fluid and for the biphasic saturated porous medium has been defined. In addition, another environment was used to couple these two solvers together. The whole process was managed by a main code, which runs two different PANDAS solvers and then the results are sent back and forth between these two solvers at each time step and the result of one subsystem (e.g., velocity of the bulk fluid at the interface) is used as the boundary conditions for
the other subsystem. Then for the next time step, the main code updates the two problems based on the results gained from previous time step from each subsystem. This process is experienced for each subsystem at each sub-domain through the required time.

On the bulk fluid subsystem, the balance equations are solved for the fluid velocity with the help of modified Eulerian description (MED). The MED makes it possible to move the nodes on the boundary at the interface for fluid subsystem in each step. This is necessary in order to have continuity in the simulation (no gap between the bulk fluid and the porous medium). Utilization of the MED for representation of the fluid behavior is implemented as a material routine in PANDAS and the velocity of the fluid at the nodes at the interface are determined. For solid skeleton in the saturated porous medium, which is governed by the Theory of Porous Media (TPM) [4,5], the Lagrangean description was used. Furthermore, for the pore fluid, the modified Eulerian description was used via the seepage velocity vector denoting the fluid motion relative to the deforming solid skeleton. Utilizing finite-element method and also applying the proper boundary conditions, the response of the porous medium and pore fluid constituents were determined and the boundary conditions at the interface were updated at each time step for the solvers. After requested amount of steps, the model represents a simulation of the fluid-porous-media interaction.

References


