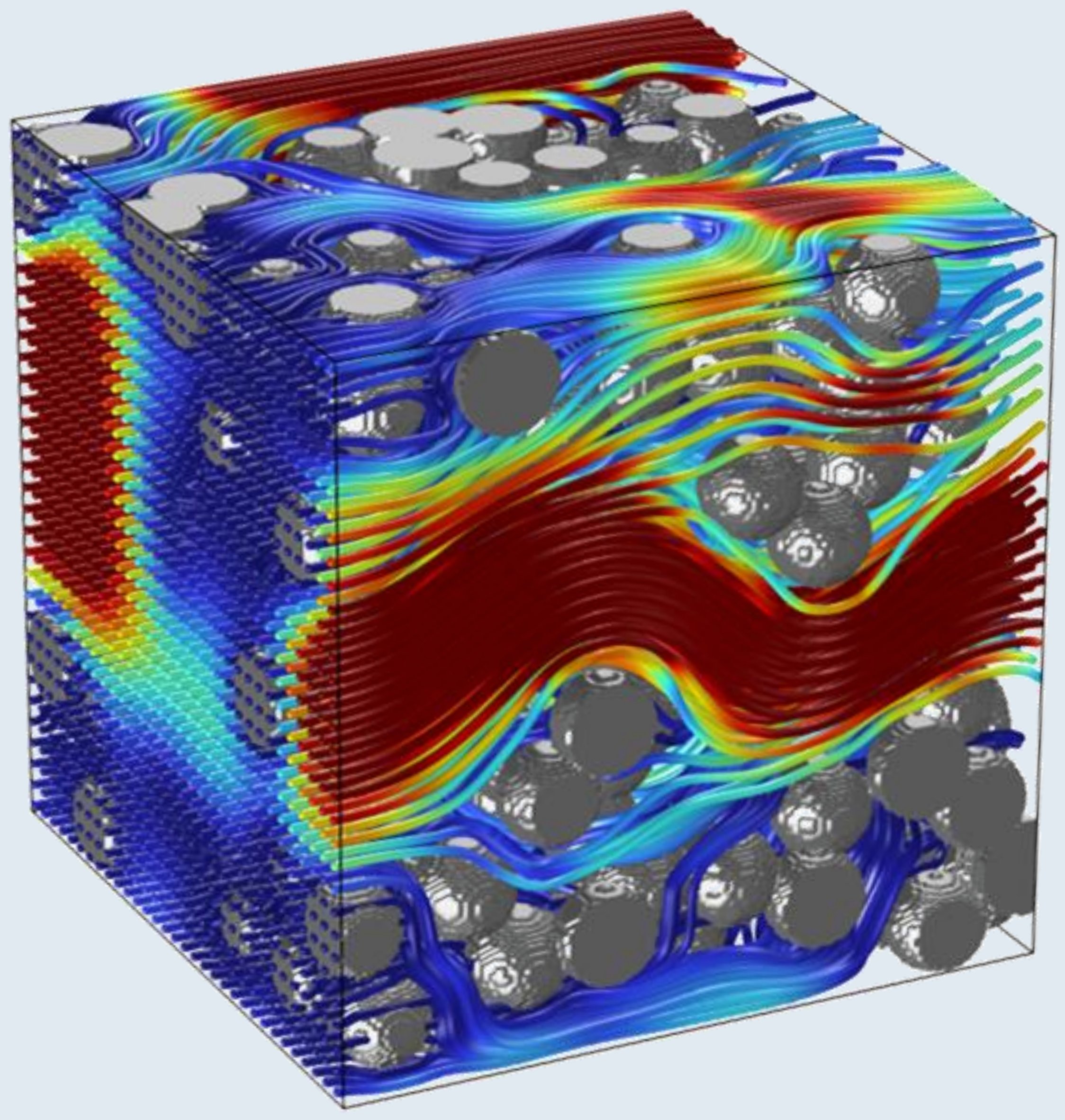

3D Fluid Flow Modeling in Porous Media

Macroscopic modeling of fluid flow in porous media relies on the accurate estimation of equivalent properties such as permeability. This property is strongly influenced by the complex 3D topology of the microstructure and the nature of the flow regime at the pore scale. In this work, a detailed three-dimensional analysis of microscopic transport phenomena is realized by importing realistic microstructures into representative elementary volumes (REV).

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Modeling & Simulation

An automated procedure for numerically generated 3D microstructures under physical constraints has been fully linked between COMSOL Multiphysics® and an external homemade software [1]. It enables statistical studies of fluid effective properties in porous media within the same COMSOL Multiphysics® environment by using the Application Builder functionalities. After numerical validation of mesh discretization and numerical penalty parameter (imposed on volume drag force), 3D fluid flow model at microscale gives consistent results with analytical solutions.

A statistical analysis was then conducted to determine the influence of the microstructure topology on the permeability of the effective medium. Interesting results enable us to bridge the gap between the different effective analytical formulations and the real microstructure approach. This approach could be considered as a guideline regarding the choice of upscale effective flow properties for porous media. Different local flow regimes and particles organizations have been shown to strongly influence effective permeability value [2][3].

Numerical Strategy

Development of an automated procedure:

3D CFD Resolution at microscale:

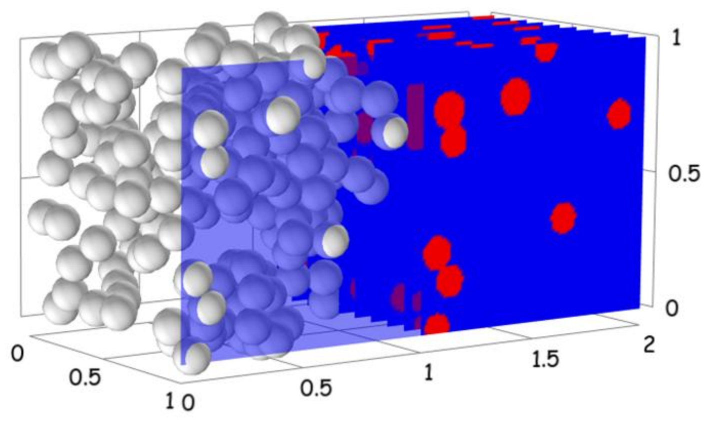
$$\nabla \cdot (\rho \boldsymbol{v}) = 0$$

$$\rho \left(\boldsymbol{v} \cdot \nabla \right) \boldsymbol{v} = \nabla \cdot \left[-pI + \boldsymbol{K} \right] + \boldsymbol{F}$$

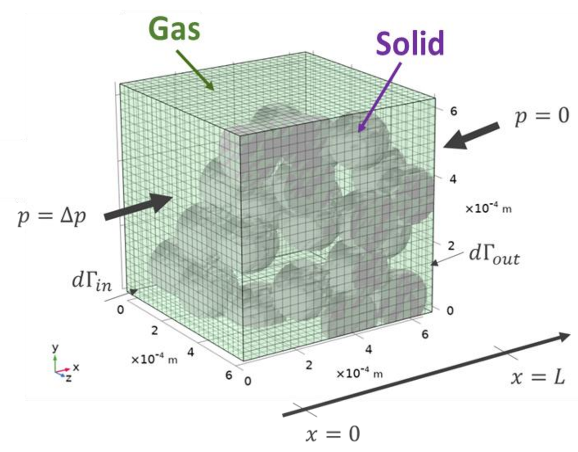
with the viscous stress tensor $K = \mu(\nabla \boldsymbol{v} + \nabla \boldsymbol{v}^T)$
and a volume drag force $\boldsymbol{F} = -K_{num}(x, y, z) * \boldsymbol{v}$

$for\ 1 \leq n \leq 100$

New microstructure generation by setting ε, d_p, L ...



Random microstructure generation and import in COMSOL Multiphysics®



$$K_{eq} = \frac{\eta \bar{v} \varepsilon L}{\Delta p}$$

Computation of the effective permeability

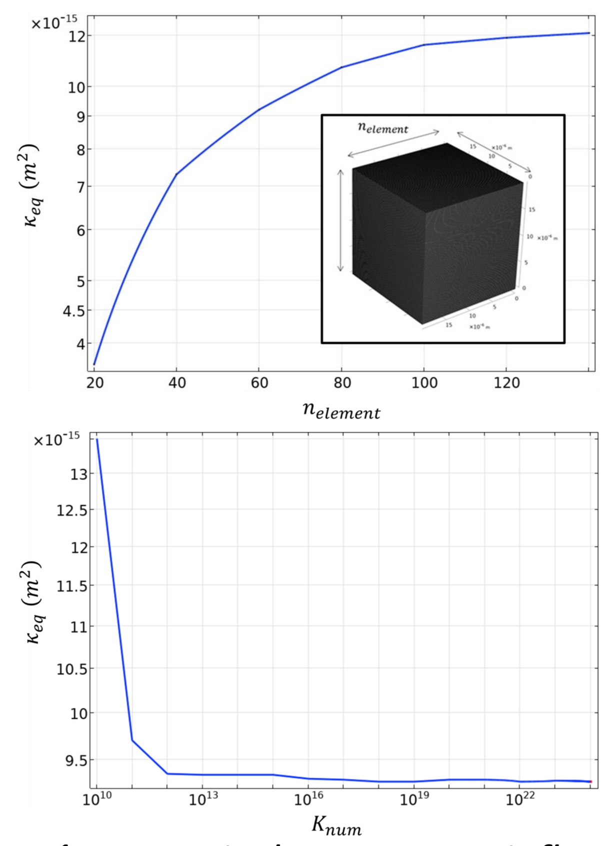


Figure 1. *Numerical parameters influence on the permeability evolution – Mesh (top) - K_{num} (bottom)*

Results & Discussion

- With our automated procedure, several configurations have been performed from 60 to 202 to 478 particles under the same constraint (≈3x200 2D slices and 3x100 3D volumes) to obtain statistical data.
- The influence of the number of particles remains quite limited in 3D, confirming the representativeness of the REV.
- The variability of the effective permeability with the microstructure topology is significantly reduced in 3D.
- A good agreement is obtained with the Kozeny formulation as a mean value (solid line) and Brinkmann and Meyer as lower and upper bounds respectively (dashed and dotted lines).

$K_{Kozeny} = \frac{d_p^2}{180} \frac{\varepsilon^3}{(1-\varepsilon)^2}$ "conduit flow" with fitting constant for tortuosity

$K_{Meyer} = \frac{d_p^2}{36} \frac{\varepsilon^{4.1}}{(1-\varepsilon)^2}$ From [4]

$K_{Brinkmann} = \frac{d_p^2}{72} \left(3 + \frac{4}{(1-\varepsilon)} - 3.\sqrt{\frac{8}{(1-\varepsilon)} - 3} \right)$ "flow around submerged objects"

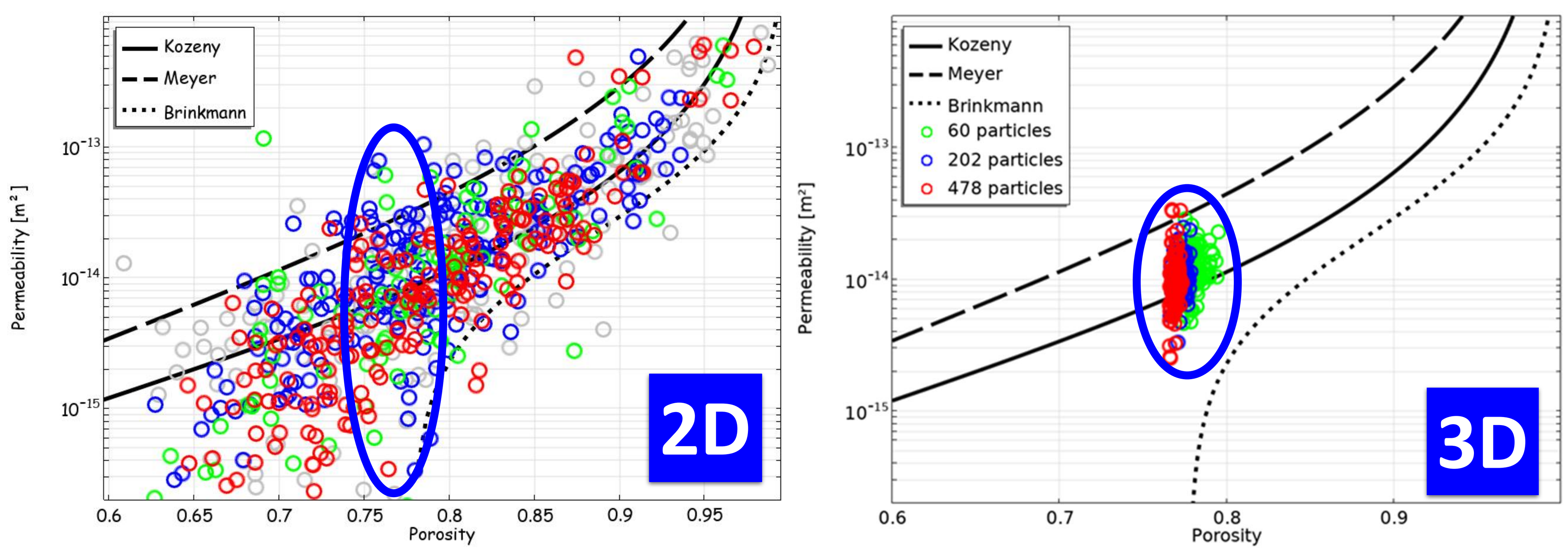


Figure 2. Equivalent Permeability Evaluation with 2D & 3D Approaches

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