Modeling Physical Properties of Porous Media

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Abstract

Knowledge of the physical properties of a porous media is necessary as they can be used to evaluate the potential and behaviour of a subsurface formation. Moreover, determining these properties at the pore-level can significantly improve the predictions of the flow behaviour at the macroscopic level. In this work, we model the physical properties of a natural porous media, and use numerical simulation tools in order to calculate the porosity, permeability, and electric properties, as well as perform NMR studies for determining the pore size distribution. We further model the effects of anisotropy on the flow properties. The important features here are that we can model any porous media pattern and obtain fast and accurate numerical simulation results to the quantities of interest which are later validated with experiment.

We consider the COMSOL natural porous media pattern shown in Figure 1. We impose a pressure drop of 10 Pa and determine the permeability using Darcy's law. The slow, creeping flow of fluid in the subsurface can be modelled by the Stokes' equation ignoring inertial terms. The pressure and velocity distributions are readily computed using COMSOL as shown in Figure 2, where Darcy's law is then used to obtain a permeability of 9.15 D.

We now simulate the flow of ions where for example, salt water is filled in the pore space with an electrical conductivity of 4.8 S/m. We further impose a potential difference across of 1.0 V. The electric current density is then determined from Ohm's law to be 0.52 A/m, and white arrows in Figure 3 depict the electric potential. The electric resistivity of the porous medium is then evaluated to be 0.95 Ω m. The formation factor can then be determined from electric conductivity and the porosity.
NMR relaxation time measurements in porous media are made on fluid saturated samples and are used to determine a volumetrically average distribution of pore sizes spanning several orders of magnitude. In the absence of magnetic field gradients, the governing equations which describe the relaxation and are incorporated into COMSOL are given by

$$\frac{\partial M}{\partial t} = D_o \nabla^2 M - \frac{M}{T_{2b}}$$

$$D_o \nabla M + \rho M = 0 \text{ on S}$$

where M is the magnetization, D_o is the bulk diffusivity, ρ is the surface relaxivity strength of the pore wall material and S represents the surface of pore wall. We also consider an initial magnetization of $M = M_o$ at $t = 0$. In our computer simulation we take $D_o = 2.5 \times 10^{-9} m^2$/s, M_o=100 mol/m^3, and ρ = 4.4 × 10^{-4} m/s, and bulk relaxivity time T_{2b}= 3 s. It is expected that the as the molecules diffuse, then reach a grain surface and eventually relax and have a zero magnetization. Those molecules in the larger pores take longer to relax, compared to narrower pores and the molecules closer to the grain surface. The NMR simulation in Figure 4 a) shows the magnetization levels of the excited protons after 20 ms. Figure 4 b) keeps track of the excited protons and plots the amplitude versus the transverse time T_2 where it is seen that after 500 ms the excited protons are all relaxed largely due to the surface relaxation. The red curve represents the integral of the amplitude.

It is possible to model anisotropy on the flow in a porous media. We consider the same pattern except we reduce the length four times, thus elongating the pores. We then compare the numerical results obtained for the permeability and the electrical resistivity when the inlet is at the side as in Figure 5 a) and at top as in Figure 5 b). From the sides we obtain a permeability of 0.3 D and an electrical resistivity of 3.5 Ω m, and from the top we obtain a permeability of 1.6 D and an electrical resistivity of 0.6 Ω m which is five times difference between the two flow patterns.

We have demonstrated some physical properties of a porous media at the micro-scale. With appropriate mathematical models, we can solve for a variety of these properties. We can determine other properties based on our numerical solutions such as the formation factor. We are able to determine these properties for any porous media, and we will demonstrate their accuracy through validation with experimental results done using glass models. This part of the work is still in progress.

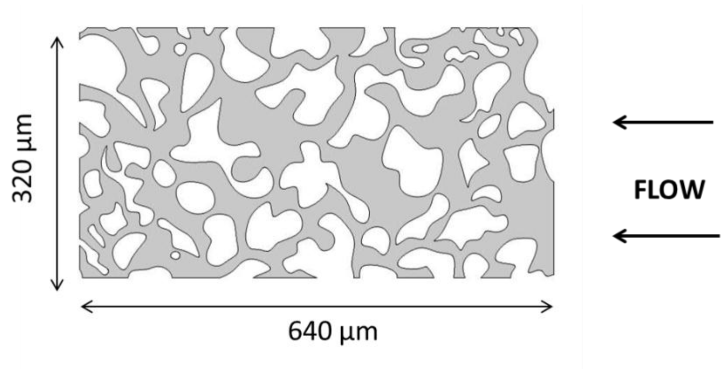
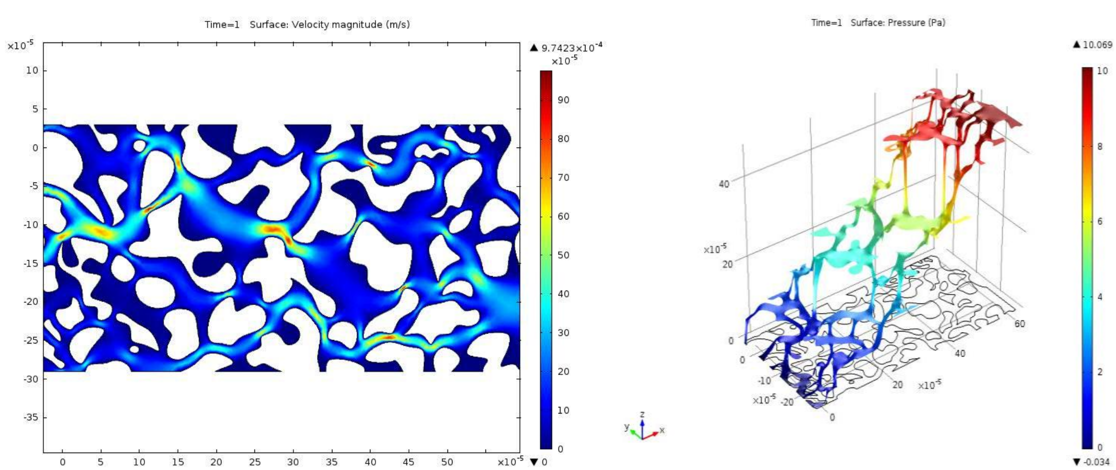
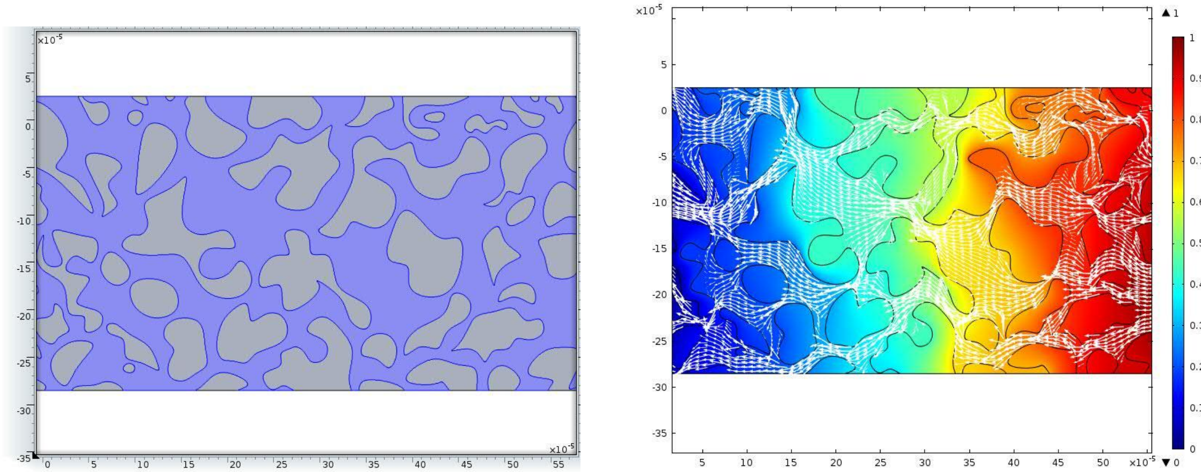


Figure 1: Porous media pattern from COMSOL



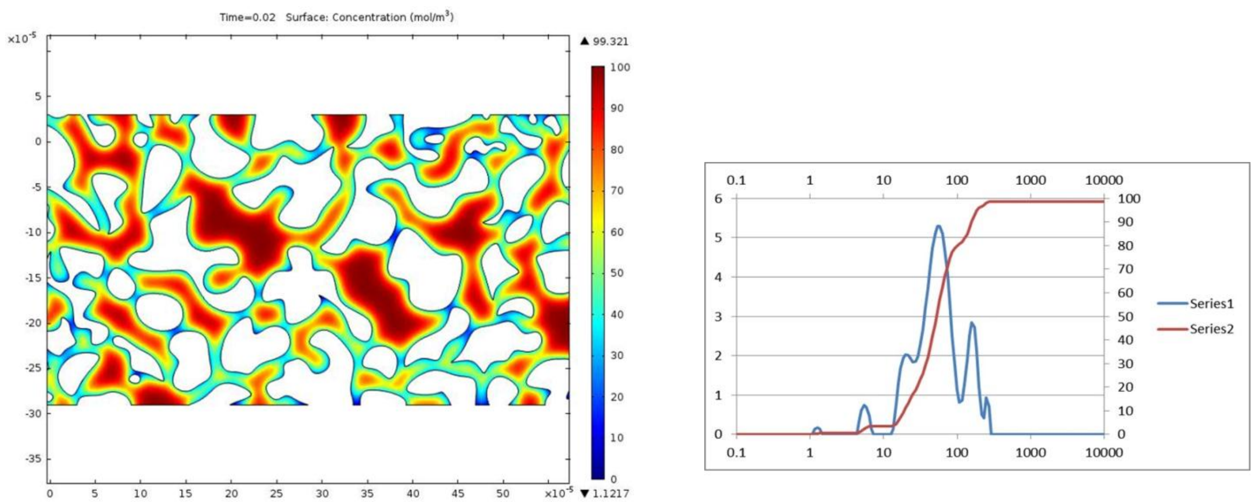
(a) **(b)**

Figure 2: a) surface velocity magnitude m/s. b) surface pressure Pa



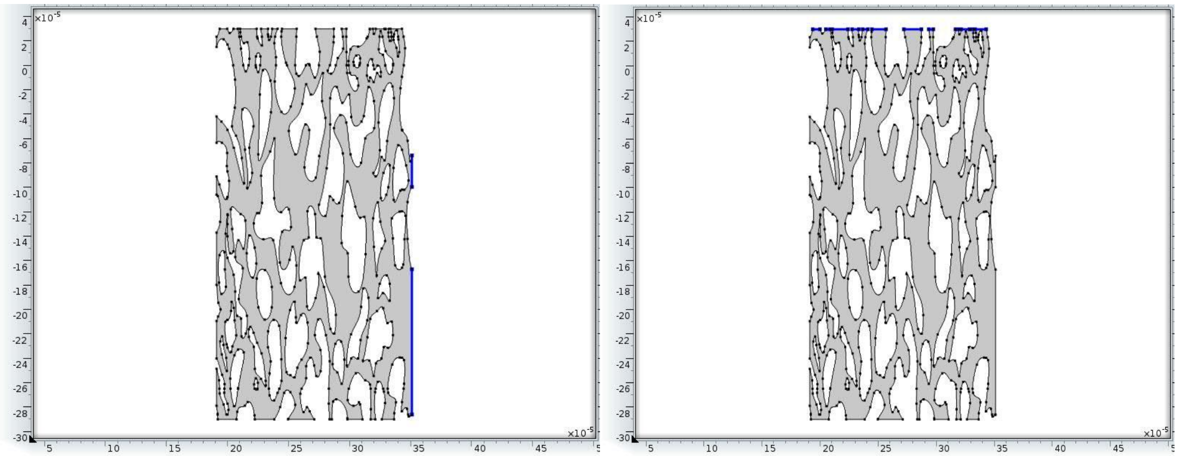
(a) (b)

Figure 3: a) Representation of the different materials of seawater in the pore spaces and sand grains. b) Depiction of the electric potential in porous media.



(a) (b)

Figure 4: a) surface concentration after t= 20 ms. b) Amplitude of the excited protons vs. T_2 series 1, integral of the amplitude vs. T_2 series2.



(a) (b)

Figure 5: a) Porous media patter with inlet at the sides. b) Same porous media with inlet at the top