The role of coordination number and pore size distribution on flow organization in porous media

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(Team Goal)

One of the objectives of our research group is to give transport predictions from the geometrical properties of a given sample. This has been divided in two big steps:

(Steps)

1. *Deduce the Eulerian velocity PDF from the geometrical properties of the medium*
2. *Give predictions for the transport from models parameterized by the Eulerian velocity PDF only*

Point 2 has been tackled is some studies, see for example:
Puyguiraud et. al, Stochastic Dynamics of Lagrangian Pore-Scale Velocities in Three-Dimensional Porous Media, Water Ressources Research, 2019
Dentz et al., Mechanisms of Dispersion in a Porous Medium, Journal of Fluid Mechanic, 2018

In this presentation, we focus on point 1.

- *Pore Networks can serve as simplified proxies of rock samples. They allow for easy modifications of their structure through the variations of key parameters such as distribution of throat radius or coordination number.*
- *When used to mimic an existing media, they can give results in terms of velocity statistics that are comparable to the existing medium results.*

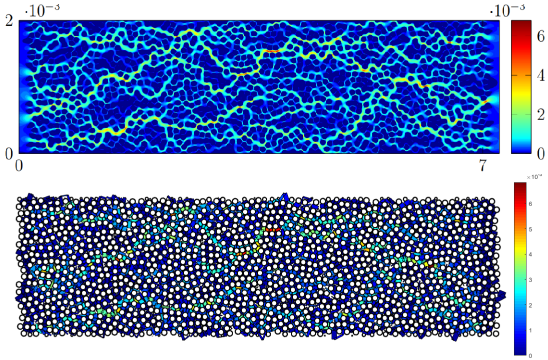


Figure: Illustrative example of a PNM mimicking an actual 2D medium. The velocity field and the main flow channels are preserved.

(Objective)

Deduce the Eulerian velocity PDF from the geometrical properties of the medium

(Method:)

We start from a fully crystalline PNM (either 2D or 3D) and vary three key PNM parameters. We investigate their impacts on the Eulerian velocity PDF. These 3 parameters are:

- *Coordination number (number of connections at a node)*
- *Distribution of radii (varies from a single radius for all throats to a broad distribution)*
- *Disorder (allows for displacing the nodes in a random directions and therefore breaking the symmetries from the original setup. Also creates different angles and distances between pore bodies)*

Divided in four steps:

1. *Compute the pressure from the resolution of the following linear system*

$$\sum_{i=1}^{n} Q_i = \sum_{i=1}^{n} K_i(P_i - P_j) = 0, \tag{1}$$

   where i is the index of the neighbors, Q_i is the flow rate originating from body i, K_i is the conductivity of the throat located between bodies i and j, and P_i and P_j are the pressure of neighbor bodies i and j respectively.

2. *Maximum velocity in a throat is then given by*

$$v_{max} = \frac{r^2}{4\mu}\left|\frac{\Delta p}{L}\right|, \tag{2}$$

   where r is the radius of the throat, μ is the dynamic viscosity, Δp is the pressure difference between the two ends, and L is the length of the pipe.

Divided in four steps:

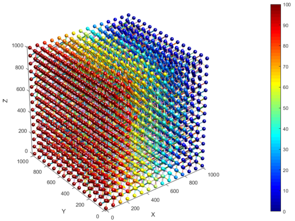
3. *Then, the velocity distribution in a throat is computed according to the maximum velocity in the pore, the length and the width of the throat, and according to the Poiseuille profile in 2D or 3D for a given radius λ:*

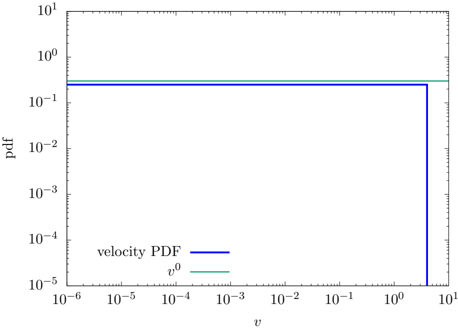
$$f_p(u|\lambda) = \frac{2}{\frac{\nabla p}{2\mu}\lambda^2\sqrt{1-\frac{8u\mu}{\lambda^2\nabla p}}} \quad \text{in 2 dimensions,} \tag{3}$$

$$f_p(u|\lambda) = \frac{1}{u_{max}} \quad \text{in 3 dimensions.} \tag{4}$$

4. *Sum the distributions in all the throats give the medium Eulerian velocity distribution.*

Crystalline with constant radius, coordination number set to 4 and no disorder





The pressure drop, throat radius and length are all the same, therefore the v_{max} is the identical for each throat. Thus, the Eulerian velocity PDF is equal to the velocity pdf of any of the throat and it is completely flat.

Crystalline with constant radius, coordination number set to 4 and a disorder of 25%

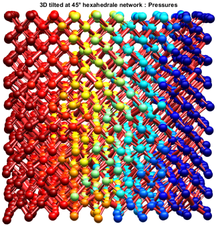
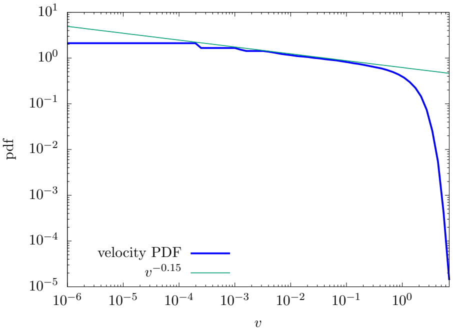


Figure: Note: On the picture the throat radii are distributed but it is not the case for the actual PNM



With the added disorder the angles and lengths of the throats differ from the previous case. This triggers a distribution of pressure drops which directly causes different maximum velocities for different throats. This results in a light slope of -0.15 *for low velocities.*

Results 3: Fully crystalline with 25% of disorder and distributed coordination number

Crystalline with constant radius, coordination number distributed between 2 and 8 and a disorder of 25%

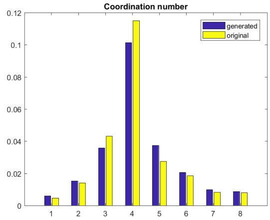
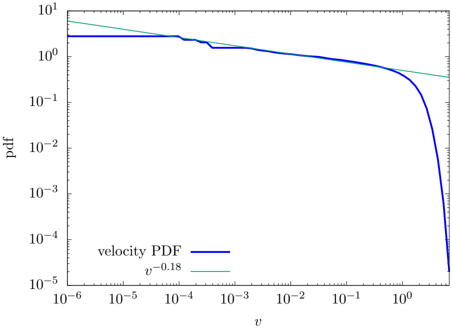
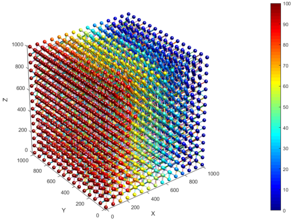


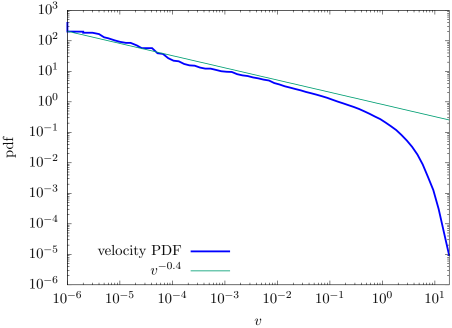
Figure: Same body placement but the coordination number is now distributed according to the blue histogram.



The distribution of coordination number has an impact on the pressure drop and therefore on the velocity PDF. It is however very mild in comparison to the disorder of the previous case. This results in very similar v-PDFs.

Crystalline with a coordination number set to 4, no disorder and the radii distributed over 2 orders of magnitude





Distributing the radii strongly impacts the velocity PDF. Here, we observe a slope of about $v^{-0.4}$ at low velocities.

Crystalline with a coordination number distributed between 1 and 8, a disorder of 25% and the radii distributed over 2 orders of magnitude

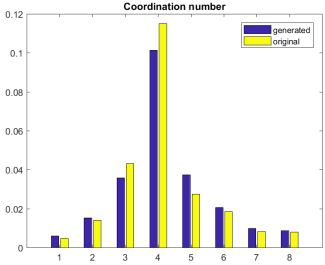
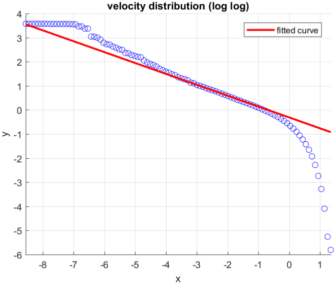


Figure: Same geometry but the coordination number is now distributed according to the blue histogram.



Coupling distribution of radii, distributed coordination number and disorder makes the slope steeper (-0.5). However, it remains comparable to the previous case (-0.4).

(Keep home message)

- *Variations of the coordination number triggers a light slope in the velocity pdf*
- *Increasing the disorder has a similar impact*
- *The distribution of the radius lengths is the main mechanism provoking the slope at low velocities*
- *Coupling the aforementioned variations make the slope of the v-PDF even steeper at low velocities*

(Current and future work)

- *Relate the distribution of radius to the slope of the Eulerian velocity PDF*

Thank you

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Thank you for reading