The influence of pore size distribution on transport properties of rocks

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Introduction

It is important to understand pore size distribution in rocks, because of its control on flow behaviour, hydraulic conductivity, elastic moduli of the effective medium, as well as their response to external stresses. An improved understanding of flow characteristic across the porosity might provide further insight on reservoir characterization and monitoring. Kang [2015] showed that the heterogeneity in a porous medium has an important control on the fluid outflow pattern. This study aims to investigate the possibility of inferring pore size distribution from the breakthrough curve by a particle transport experiment.

Methods

The heterogeneity of the hydraulic conductivity, which directly relates to the pore-size by a cubic law, can be represented by two parameters: variance and the autocorrelation length. To simulate a realistic random conductivity field, we assume its heterogeneity follows lognormal distribution with particular correlation lengths [Ruan and McLaughlin, 1998]. In this study, we considered conductivity field with lognormal variance ranging from 0.01 to 7.5, and the correlation length ranging from $L/1000$ to $L/10$, where L is the domain length. We then provided a normalized pressure of 1 and 0 on the left and right boundary respectively to drive a Darcy flow across the domain. At each node on left boundary, particles were injected to travel through the network with a Continuous Time Random Walks (CTRW) model [Kang, 2011].

Results and Discussion

We recorded the time for particles to breakthrough at the right boundary for each permeability field configuration. We showed the experiment results using two different random conductivity fields in Figure 1. Despite the flow paths of scenarios variance 7.5 and correlation length $L/250$ (Figure 1a) and that with variance 1 and correlation length $L/20$ (Figure 1b) being significantly different, the breakthrough curves, shown as the probability function of the particle density, are hardly differentiable from one another.

To define a quantitative measure of the shape of the breakthrough curve, we used the 90% confidence breakthrough interval (i.e. the normalized time interval between 5% and 95% breakthrough) as a characteristic parameter. We plotted the measured 90% confidence interval in Figure 2 as the simulation spans a wide range of variance and correlation length. In general, larger variance and higher correlation length result in breakthrough curves that are more spread out. However, Figure 2 showed a clear trade-off between the two critical parameters: similar flow transport behavior can be achieved by multiple sets of variance and correlation length.

Conclusions

We observed from flow and transport simulations that increasing variance in hydraulic conductivity or increasing correlation length generally increase the time interval between 5% and 95% breakthrough, reflecting a wider spread of the breakthrough time of the majority particles. However, the combination of variance and correlation length cannot be uniquely defined from a single transport experiment due to their trade-off effects on the breakthrough curve. This suggested that additional information, such as elastic, electrical resistivity, or stress dependence data, is necessary to uniquely characterize the pore size distribution.

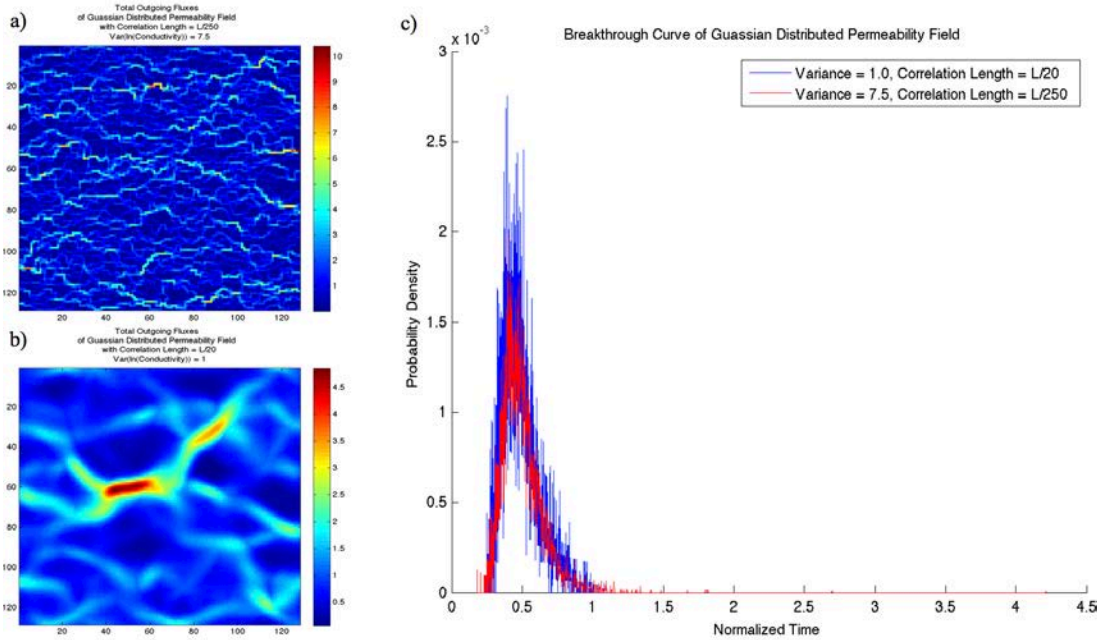

Figure 1: Hydraulic flux map of permeability field with (a) variance 7.5, correlation length L/250, (b) variance 1, correlation length L/20; and (c) comparison of their breakthrough curves.

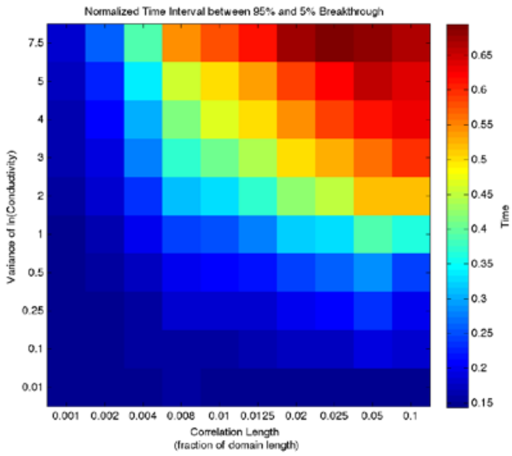

Figure 2: Normalized time interval between 95% and 5% particle breakthrough under Gaussian distributed permeability field with various variances and correlation lengths.

Acknowledgements

Joseph Ma acknowledges the support of A*STAR with Singapore International Graduate Award (SINGA). The authors thank Dr. Peter K. Kang for his input with CTRW modelling and Economic Development Board of Singapore for their support of the Petroleum Engineering Professorship.

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