Upscaling in Fractured Heterogeneous Media: Permeability and Mass Exchange Coefficient

Moussa Kfoury, Benoît Noetinger, Michel Quintard, Rachid Ababou

Upscaling in Fractured Heterogeneous Media: Permeability and Mass Exchange Coefficient.

Moussa KFOURY[1,2], Benoît NŒTINGER[1], Michel QUINTARD[2] & Rachid ABABOU[2]

[1]*Institut Français du Pétrole , 1 et 4 avenue de Bois-Préau, 92852 Rueil-Malmaison Cedex, France*

[2]*Institut de Mécanique de Fluides de Toulouse, Allée Prof. C. Soula, 31400 Toulouse, France*

Moussa.kfoury@ifp.fr

In this paper, we discuss the sequential upscaling of fluid transport equations in fractured media consisting of the fractures themselves and a heterogeneous porous matrix. We consider only the case of single-phase flow in a slightly compressible medium. We distinguish three scales (FIG.1): (i) the local-scale characteristic of the fracture aperture, (ii) an intermediate scale called the unit-scale and, (iii) the large-scale of the reservoir called also the block-scale. To describe the flow at the block-scale, we have two main possible approaches. The first approach is to upscale the properties in one single step from local-scale to block-scale. The second approach is to calculate equivalent properties at the unit-scale and then to average flow equations at this level to identify block-scale properties. We assume that flow at the local-scale is described by simple Darcy-type equations. We also assume that flow at the unit-scale is described by a system of matrix-fracture equations according to the dual continuum model of Barrenblatt and Zheltov (1960). This model was further developed by Warren and Root in 1963, and by many other contributors, e.g. Lough et al. (1996), Quintard et al. (1996). In this paper, we use the general formulation developed theoretically by Quintard et al.(1996):

$$\begin{cases} \phi_m c_m \dfrac{\partial}{\partial t}\{P_m\}^m = \nabla.\left(\dfrac{1}{\mu}\mathbf{K}_{mm}.\nabla\{P_m\}^m + \dfrac{1}{\mu}\mathbf{K}_{mf}.\nabla\{P_f\}^f\right) - \dfrac{\alpha}{\mu}\left(\{P_m\}^m - \{P_f\}^f\right) \\ \phi_f c_f \dfrac{\partial}{\partial t}\{P_f\}^f = \nabla.\left(\dfrac{1}{\mu}\mathbf{K}_{fm}.\nabla\{P_m\}^m + \dfrac{1}{\mu}\mathbf{K}_{ff}.\nabla\{P_f\}^f\right) - \dfrac{\alpha}{\mu}\left(\{P_f\}^f - \{P_m\}^m\right) \end{cases}$$

In this dual medium model, the first equation describes matrix flow, the second describes fracture flow, and the term "α" models fluid exchange between matrix and fracture systems. Without going into details, let us emphasize that the upscaling from unit scale to block scale may lead to (two) different classes of flow equations. If conditions are such that a single continuum model is valid, we only need to identify the equivalent permeability and the equivalent compressibility. But if a mechanical non-equilibrium model is required at the large scale, for instance in the form of dual medium model, then there will be more large scale parameters to be identified, e.g.: the permeability tensor of the matrix, the permeability tensor of the fracture system (region), the cross-permeability tensors between matrix and fractured regions, and the matrix-fracture exchange coefficient (upscaled version of "α").

In this paper, we will present some methods that we have developed to identify large-scale parameters. We start from a fine grid where Darcy's equations are applicable in each grid cell. We have a fine grid permeability map to be homogenized. A direct simulator based on implicit finite volume discretization has been developed to describe transient flow at the block-scale with different boundary conditions, and to calculate the effective permeability at this level. In addition, we have developed a solver for the "closure problem" (Quintard and Whitaker, 1996; Landereau et al., 2001), which yields all the required permeability tensors and the matrix-fracture exchange coefficient at the different scales. In the figure (FIG.2), we study an example of a fractured porous medium. The volume fraction of the fracture system (region) is around 9%, and the ratio of fracture permeability to matrix permeability at local-scale is around 1000. At local-scale, we build a fine grid with 2048x2048 cells. We then choose to partition the domain into units of several different sizes, leading to several possible partitions (4x4 units, 8x8 units, 16x16 units, and 32x32 units). For each partition, we have calculated a "map" of the matrix-fracture exchange coefficient "α" and of the first principal component of the equivalent permeability tensor K_{EQ}^{XX}, and we have plotted their histograms in FIG.2.

References

1. G.I. Barenblatt, I.P. Zheltov, and I.N. Kochina. Basic concepts in the theory of seepage of homogeneous liquids in fissured rocks. J. Appl. Math., 24 :1286–1303, 1960.
2. P. Landereau, B. Noetinger, and M. Quintard. Quasi-steady two-equation models for difffusive transport in fractured porous media : large-scale properties for densely fractured systems. *Advances in Water Resources*, 24(8) :863–876, 2001.
3. M.F. Lough and J. Kamath. A new method to calculate the effective permeability of grid blocks used in the simulation of naturally fractured reservoirs. *SPE Journal,* 493-499, 1996.
4. M. Quintard and S. Whitaker. Transport in chemically and mechanically heterogeneous porous media i : Theoretical development of region-averaged equations for slightly com-pressible single-phase flow. *Advances in Water Resources*, 19(1) :29–47, 1996.
5. J.E. Warren and P.J. Root. The behavior of naturally fractured reservoirs. *SPE Journal*, (3) :245–255, 1963.

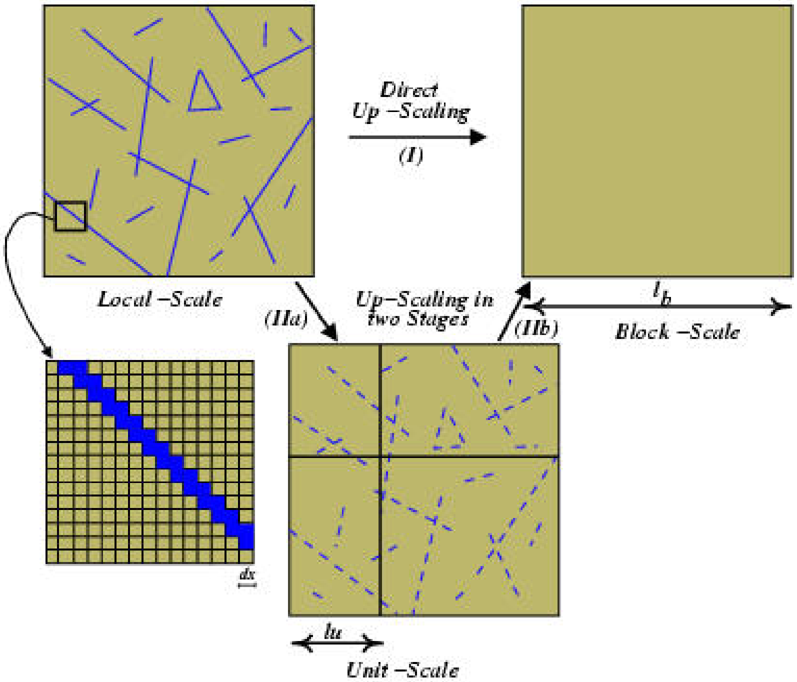

FIG. 1 - Two different up-scaling paths: (I) Direct upscaling from the local-scale (*dx*) to the block-scale (L_b), and (II) Up-scaling in two stages passing through the intermediate unit-scale(L_u).

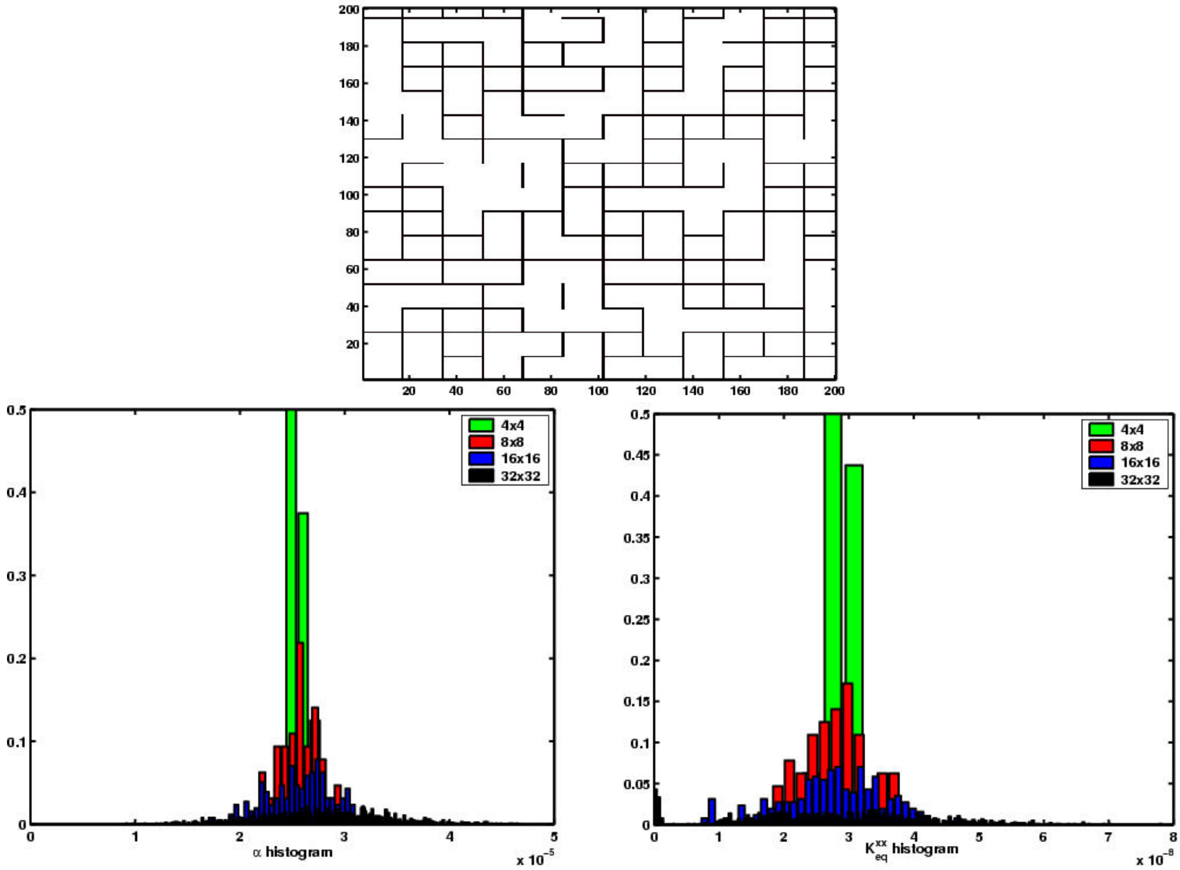

FIG. 2 - Above, we show an example of a fractured porous medium as envisioned in this work. Below, we show some results concerning the distribution of upscaled properties at unit scale: histogram of matrix-fracture exchange coefficient α (left), and histogram of first component K_{EQ}^{XX} of equivalent permeability (right).