

## ***Interactive comment on “Bench scale laboratory tests to analyze non-linear flow in fractured media” by C. Cherubini et al.***

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. The main point that deserves clarification is the experimental boundary conditions. Drilling holes is an easy way to inject or collect water; but it makes the experiment interpretation not straightforward because of the planar geometry of fractures. The authors use numerical simulations to manage this issue, and derive the intrinsic fracture parameters. Although critical to interpret experiment results, these simulations are only shortly described, and several points deserve to be clarified: - The first issue is about the uncertainty of the flow simulations, which can be due either to the 3D reconstruction, or to the flow variability within each fracture. I suspect the latter to prevail, and to produce quite large uncertainty (or variability) in the  $a_f$  and  $b_f$  coefficients. Can the

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authors comment this?

In the returned flow simulations the aperture variability in space for each fracture has not been modeled. The finite element model presents only the shape of fracture network and the geometry of holes.  $a_f$  and  $b_f$  coefficients are representative of each configuration of ports. In other words for each configuration of ports we have obtained by means of flow simulation the equivalent parameters ( $a_f$  and  $b_f$ ) constant for the whole geometry of fracture networks. These parameters are representative of linear and non linear pressure drops due not only to the roughness of fractures faces but also to the shape of fractures (curvature), the contact area of fractures, fracture intersections, the geometry of in-let and out-let ports. Therefore the estimated parameters are equivalent parameters that characterize each single path. In particular way in Figure 9 (added to the paper) is showed the shape of fracture in correspondence of hole 7. The particular shape of this fracture gives rise to a higher contact between fracture surfaces if compared with the others. In fact the path that contains this fracture presents a very high hydraulic loss.

- The second issue is about the inverse procedure and its parameter space. Are the transmissivity parameters constant everywhere, in each fracture, or in each mesh? Is each experiment analyzed independently of the others? Is there a consistency analysis for the whole set of experiments (i.e. same mesh parameters for all the experiments)? With the description provided in the manuscript, it is difficult to criticize the result given in Table 4.

For each inlet – outlet ports configuration several flow experiments have been conducted. A relationship between hydraulic head difference  $dH$  and the flow rate  $Q$  of polynomial kind (equation 12) has been found. Therefore once assigned a ports configuration and  $dH$  we are able to obtain an estimation of  $Q$ . A finite element model has been carried out in order to estimate  $a_f$  and  $b_f$  coefficients. Fracture transmissivity is function of  $a_f$ ,  $b_f$  and of the hydraulic gradient by means of the equation (7). For each ports configuration several steady state simulations have been conducted vary-

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ing the hydraulic head difference between the inlet and outlet ports. For each imposed hydraulic difference it is possible to compare the flow rate obtained from polynomial equation (12) and the flow rate that results from the numerical model in correspondence of the inlet port. The experiments are analyzed independently from each other. In other words for each ports configuration we obtain equivalent  $a_f$  and  $b_f$  coefficients. The finite element mesh is equal to all experiments.

2. The introduction could be better organized. For instance, the Forchheimer equation is given two pages after being cited first. The authors could also acknowledge gravity effects to cause non-Darcian flow (see for instance, Tenchine and Gouze, AWR 2005).

The introduction has been reorganized. The part concerning the equations has been put before the experiments, so Forchheimer equation is given before being cited in the examples. Moreover, according with the reviewer's request, the following text has been added "A non-Fickian behavior is also valid in case of high-concentration brine transport, where the assumption that the linear Darcy law holds as shown in Watson et. al.(2002). On the other hand, Tenchine & Gouze (2002) carried out density driven flow simulations in a rough walled natural fracture extracted from a limestone quarry and observed measurable non-linearity between the velocity growth rate and the velocity indicating that the N-S formulation must be used."

3. It is not clear in the text if the broken limestone block have been split into pieces in order to measure fracture apertures, or if the measurements have been carried out from the block faces. Fractures are not supposed to be self-affine rather than pure fractals (Table 2).

The measurements have been carried out from the block faces. It has been specified in the text "The fracture network has been made artificially through 5 kg mallet blows. The fissured system and the fracture aperture on the block surfaces have been recorded with high resolution digital camera from the block faces." Fractal dimension of fractures reported in table 2 have been evaluated supposing that the one-dimensional profile

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of fracture traces is a self – affine fractal (Hernández et al. 2010; Campos et al., 2005; Mourzenko et al. 2000). Box-counting technique has been applied in order to estimate fractal dimension utilizing the method illustrated in Turcotte (1997), pag. 135. Fractal dimension of fracture trace presents a value intermediate between 1 and 2. Fractal dimension of fracture surface has been calculated adding the unit to the fractal dimension of fracture traces. However according with the other reviewer the fractal dimension values reported in table 2 have been dropped.

4. There are a lot of references about tortuosity in fractures that deserve to be cited (see (Wang, WRR 1984) for instance).

The reviewer has right in saying that the term tortuosity has been mentioned in the abstract and then just later on in the discussion, while the introduction lacks any definition of the term and reference to the literature. So the following text and citations have been inserted. "Tortuosity, that usually characterizes the ratio of the effective path length connecting two locations in porous media to the geometric distance (Tenchine & Gouze (2002) has been found to affect significantly fluid flow in fractured media under certain conditions (Tsang Y.W. 1984, Wang & Narasimhan, 1985). Yeo & Ge (2005) identified a criterion parameter function of the roughness and tortuosity for the applicability of the Reynolds equation to fluid flow in rock fractures."

5. There are a few typos in the manuscript. The typos have been corrected, according also with the other reviewer's comments.

Please also note the supplement to this comment:

<http://www.hydrol-earth-syst-sci-discuss.net/9/C2673/2012/hessd-9-C2673-2012-supplement.zip>

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