Coupled Electro-hydrodynamic Transport in Geological Fractures

Uddipta Ghosh[1], Tanguy Le Borgne[1], and Yves Méheust[1]

[1] *Université de Rennes 1, CNRS, Geosciences Rennes UMR6118, 35042 Rennes, France*

Fractures are very common features in subsurface crystalline rocks, where they are organized in networks of interconnected elements [1]. A number of essential mechanical properties of the rock formations, such as their mechanical strength and their transport properties (hydraulic and electrical conductivities), are dictated by the behavior of the fracture networks. Within these networks, individual geological fractures are the basic structural unit controlling the flow of fluids and the transport of solute chemical species. Their length is distributed over a very large range, which strongly constrains the connectivity and hydraulic behavior of the network [2]. Fracture wall roughness is responsible for flow channeling (and therefore, heterogeneity) within the fracture plane, which, at the fracture scale, impacts the fracture's transmissivitty [3, 4]. The characteristic length scale L_c at which the two fracture walls are matched [5, 6], plays a crucial role as it is the upper limit scale for flow heterogeneities [7]. When L_c is sufficiently large with respect to the distance between two intersections with other fractures, fracture wall roughness also impacts the distribution of fluxes in-between fractures of the network [8].

The most prevalent way of computing the transport properties and transmissivitty of a rough fracture in an efficient way and without resorting to a full three-dimensional flow simulation, is to use the lubrication approximation, which leads to a Darcy flow type equation for the pressure, the Reynolds equation [3]. This method has been used extensively to simulate the flow [3, 9], as well as the electric current (without flow) through a rough fracture [10]. However, the effect of the electrical properties of the fracture walls on the transport properties of a fracture still remains an open question, to the best of our knowledge. Since dissolved minerals and salts are ever present in the fluids inside the fracture, Electrical Double Layers (EDL) almost inevitably form at the fluid-solid interface [11], and their strength depends on the chemical properties of the rock and ionic strength of the fluid. Therefore, the ocurrence, at the fracture scale, of externally-imposed or naturally-occurring gradients in electrical potential and/or ionic concentration, can lead to significant changes in the fluid motion through the fracture, as compared to flows driven primarily by hydraulic head differences.

In this work, we attempt to explore the flow dynamics that result from such coupled electro-hydrodynamic forcings. To this end, we generalize the standard lubrication theory for flow, to include a description of the coupled transport of fluid massn, solutes, and electrical current under application of fixed differences in hydraulic head (or pressure), electrical potential and concentration across the fracture. By invoking the requirement of conservation of volumetric flow rate, ions and electrical charge fluxes, a coupled system of equations can be derived, which governs the spatial distribution of electrical potential, pressure and concentration in the bulk fluid within the fracture. This system of equations is the generalization of the Reynolds equation to the coupled transport of fluid mass, solutes, and electrical charges. It is solved using an iterative Finite Volume Method to gain insight into the dynamics of the coupled transport processes, in geological fractures with a realistic aperture field. We investigate in particular the role of the characteristic length scale L_c.

References

[1] Eric Bonnet, Olivier Bour, Noelle E Odling, Philippe Davy, Ian Main, Patience Cowie, and Brian Berkowitz. Scaling of fracture systems in geological media. *Rev. Geophys.*, 39(3):347–383, 2001.

[2] J. R. de Dreuzy, P. Davy, and O. Bour. Hydraulic properties of two-dimensional random fracture networks following a power law length distribution – 2. permeability of networks based on lognormal distribution of apertures. *Water Resour. Res.*, 37(8):2079–2095, 2001.

[3] Stephen R Brown. Fluid flow through rock joints: the effect of surface roughness. *Journal of Geophysical Research: Solid Earth*, 92(B2):1337–1347, 1987.

[4] Y Méheust and J Schmittbuhl. Geometrical heterogeneities and permeability anisotropy of rough fractures. *Journal of Geophysical Research: Solid Earth*, 106(B2):2089–2102, 2001.

[5] Stephen R Brown. Simple mathematical model of a rough fracture. *Journal of Geophysical Research: Solid Earth*, 100(B4):5941–5952, 1995.

[6] Stephen R Brown and Christopher H Scholz. Closure of rock joints. *Journal of Geophysical Research: Solid Earth*, 91(B5):4939–4948, 1986.

[7] Y. Méheust and J. Schmittbuhl. Scale effects related to flow in rough fractures. *Pure Appl. Geophys.*, 160(5-6):1023–1050, 2003.

[8] J.-R. de Dreuzy, Y. Méheust, and G. Pichot. Influence of fracture scale heterogeneity on the flow properties of three-dimensional discrete fracture networks (DFN). *J. Geophys. Res.: Solid Earth*, 117(B11):n/a–n/a, 2012. ISSN 2156-2202. doi: 10.1029/2012JB009461. URL `http://dx.doi.org/10.1029/2012JB009461`.

[9] P. W. J. Glover, K. Matsuki, R. Hikima, and K. Hayashi. Fluid flow in synthetic rough fractures and application to the hachimantai geothermal hot rock test site. *J. Geophys. Res.*, 103(B5): 9621–9635, 1998.

[10] Stephen R Brown. Transport of fluid and electric current through a single fracture. *Journal of Geophysical Research: Solid Earth*, 94(B7):9429–9438, 1989.

[11] Uddipta Ghosh, Shubhadeep Mandal, and Suman Chakraborty. Electroosmosis over charge-modulated surfaces with finite electrical double layer thicknesses: Asymptotic and numerical investigations. *Physical Review Fluids*, 2(6):064203, 2017.