Dispersion in porous media with Newtonian and non-Newtonian fluids using pulsed field gradient NMR

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Dispersion is the mixing of a solute in a fluid flow which combines the diffusive and advective transport phenomena. Dispersion in porous media remains, today, a highly topical subject. Mixing in flow through porous media is ubiquitous in engineering research (processes, environment, oil recovery . . .).

The nuclear magnetic resonance (NMR) provides a nearly ideal tracer method by marking and tracking the molecules in their movement. More precisely, we used the PFG-NMR (Pulsed Field Gradient NMR) technique [1] to derive the dispersion coefficients. The PFG-NMR method is now a standard method to measure the molecular diffusion coefficients. It is based on the measurement of molecular displacements between a matched pair of magnetic gradient pulses. It provides likewise a convenient means to measure dispersion coefficients which characterize the diffusive-convective transport. The average displacement of molecules regardless of the regime (asymptotic or not) is studied by the formalism of propagators (the probability distribution of displacements) [2]. The cumulant method is applied to measure the average velocity of the fluid in Stokes flow regime and to determine the longitudinal dispersion coefficient.

The technique has been validated for a Poiseuille flow (Péclet numbers between 25 and 100) in a capillary tube (diameter 0.2 and 1 mm) . For this simple case, regardless of the fluid, Newtonian or not, an analytical solution exists in the asymptotic (Taylor-Aris) and preasymptotic regimes. The PFG-NMR sequence is modelled using a stochastic simulation that takes into account the effects of advection (deterministic displacement) and diffusion of particles (random walks). The comparison between the results obtained by NMR and by stochastic simulations shows that the propagator formalism describes very well the dispersive effects particularly for non-local dispersion [3] .

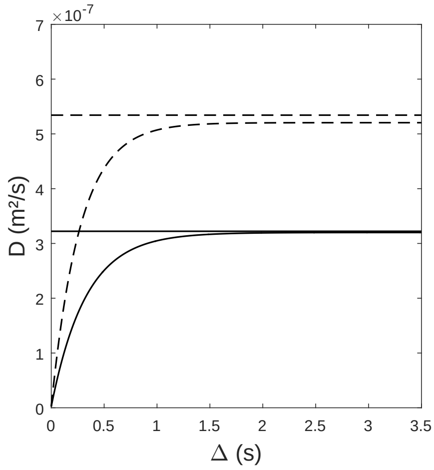

Figure 1: Longitudinal dispersion coefficients (D) vs evolution time Δ in a capillary tube ($d = 0.2$ mm) for water flow (dashed line) and for Xanthan flow (full line). The horizontal lines represent the theoretical Taylor values (Pe = 106).

We extended successfully the methodology to the more challenging case OF flows through porous media and investigated the influence of the fluid rheology. We worked with a random pack of spherical PMMA beads (diameter $d_p = 75 - 90$ μm) compacted in a plastic tube (porosity = 0.37). To determine the influence of the fluid rheology, we have worked with a shear thinning fluid, a Xanthan gum solution at 0.2wt%. Particular emphasis is placed here on a comparison of the dispersion mechanisms between Newtonian and non-Newtonian fluids. We show that regardless the value of Péclet number (Pe = 10, 20 and 40) in a packing of beads, the values of the dispersion coefficient for water are lower than those of Xanthan. The contrary observation had been made previously in a capillary tube.

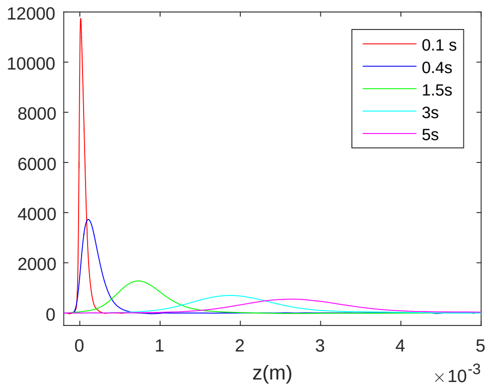

Figure 2: Longitudinal displacement distributions for Xanthan flow in porous media (PMMA beads) at different evolution times Δ (Pe = 10).

Currently, we study on an other non-Newtonien fluids family : threshold fluid (Carbopol). We face to new difficulties linked to the type of fluid (slip effect, high pressure loss...) that we have to solve before envisaging the measurement of dispersion coefficients.

References

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