

Rheological control of mixing and heat transfer by laminar chaotic advection

Efficient transport of mass (mixing) and heat in fluid media are of paramount importance to a number of practical applications related to several key industrial sectors including (but not limited to) food industry, chemical and petro-chemical, oil and gas, mining, water and waste-water treatment. A classical method of achieving efficient transport of mass and heat in fluids consists of triggering hydrodynamic instabilities and turbulent flow states. However, this method is often prohibitive from an energetic standpoint. Therefore, in the global context of the energy transition, alternative heat and mass transport mechanisms need to be studied and implemented. One such mechanism is the laminar chaotic advection which triggers Lagrangian chaos in the flow in the absence of inertial instabilities and turbulence Aref, H. (1984). For Newtonian fluids the efficiency of the heat and mass transport by laminar chaotic advection depends on several factors: stirring protocol (kinematics) and stirring parameters (strength and frequency) El Omari et al. (2021), Kiwan, M. (2025).

The non-Newtonian flow behavior dramatically alters the dynamics of the mixing process and the Lagrangian dynamics of the flow. It has been shown both experimentally that the presence of yield stress and/or shear thinning lead to a significant decrease of the efficiency of chaotic mixing, Moguen Y. (2023), Kiwan, M. (2025) while the elasticity generally increases it (Burghelea, T., unpublished).

The global aim of the present project is to propose a novel approach to the optimization of the mixing and/or heat transport processes by means of tweaking the rheological properties of the fluids. Thus, the fundamental question to be addressed, what should be the proportion of shear-thinning, yield stress and elastic effects (which can be simultaneously accounted for in a Saramito type elasto-viscoplastic model) that, for a given mixing protocol (operating flow rates, strength and frequency of the external forcing), maximizes the efficiency of the mixing process and/or heat transport.

The rheological optimization process will be studied in a cellular flow mixing configuration.

The project will be carried on along three parallel tracks: direct numerical simulations, optimization, table - top experiments (coupled to rheological measurements). Along the first track, a fully parallelized using adaptive-meshing code developed in-house under Basilisk will be used. The results of numerical tests will be fed into optimization algorithms developed at LteN. Along the third track, a dedicated experimental setup able to quantitatively assess both the mixing efficiency and the efficiency of the heat transport will be built and instrumented.

Aref, H. (1984). Stirring by chaotic advection. *Journal of fluid mechanics*, 143:1–21.

Kiwan, M. (2025). PhD thesis, Nantes University.

El Omari, K et al. (2021) Active chaotic mixing in a channel with rotating arc-walls, *Phys. Rev. Fluids* 6, 024502.

Moguen, Y. et al. (2023) Active chaotic mixing of yield stress fluids in an open channel flow, *Theor. And Comput. Fluid Dynamics*, Volume 37, pages 203–239 (2023).