Simplified lattice Boltzmann approach for magnetohydrodynamic turbulence in pipe flows

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Magnetohydrodynamics (MHD) describes the behaviour of electrically conductive fluids and plasmas, which are observed both in natural phenomena and industrial processes. In industrial applications, the magnetic Reynolds number R_m is frequently much less than 10^{-2}. Due to numerical difficulties, many works in MHD in the lattice Boltzmann literature have been restricted to cases where the magnetic Prandtl number is close to 1, i.e., cases where the magnetic and kinetic time scales are similar.

In this work, we consider a recently proposed[1] simplified lattice Boltzmann method, coupled with an improved explicit immersed boundary method, for the simulation of MHD flows with curved boundaries for a wide range of magnetic Prandtl numbers. By taking advantage of a multi-GPU architecture, we perform parallelized simulations to achieve the fully developed turbulent regime in pipe flows.

We first investigate the role of the magnetic Prandtl number in the energy balance, both for uniform and non-uniform magnetic field configurations. For the latter, we explore an arrangement of six magnets around the pipe, depicted in Figure 1[1,2], which holds significant relevance in the oil industry for addressing challenges such as limescale formation, also investigated in the research.

Our main objective is to study the effects of different magnetic Prandtl numbers and non-uniform magnetic fields on rich phenomena such as relaminarization[3] and the formation of coherent structures[4]. The proposed method proves to be a highly convenient setup for this purpose.

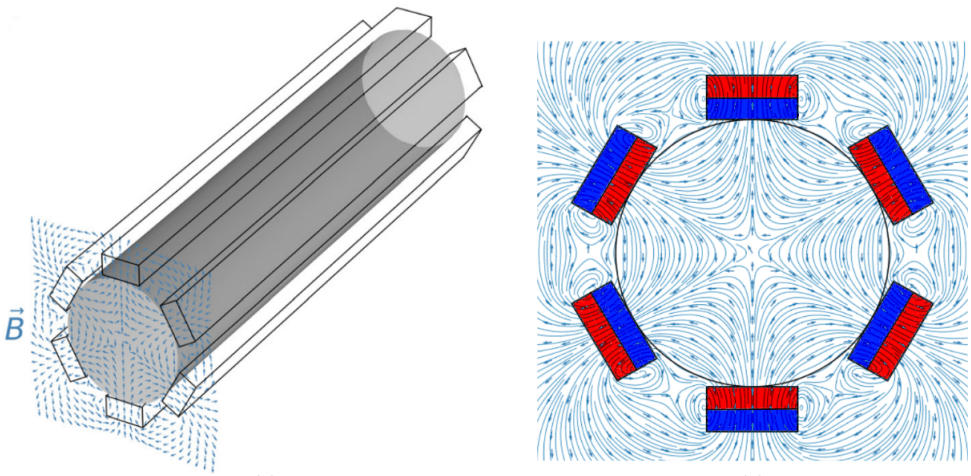

Figure 1: (a) Configuration of a pipe flow with a representation of the positions of the six magnetic plates. (b) The magnetic field lines generated by the set of magnets with alternating poles forming a hexagonal structure.

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[2] Magacho et al., *Physics of Fluids* **35**, 013610 (2023)
[3] Dechamps et al., In: *44th AIAA Plasmadynamics and Lasers Conference, San Diego, California, USA* (2013)
[4] Magacho et al., *Physics of Fluids* **36**, 085103 (2024)