Report on Short Research Visit ‘Controlling nematic microfluidics: a merger of modelling, simulation and experiments’

Investigator: Dr Apala Majumdar (University of Bath)
Host: Dr Ian Griffiths (University of Oxford)

This research project focuses on hydrodynamics theories for nematic liquid crystals.

Nematic liquid crystals are classical examples of partially-ordered materials that combine the fluidity of liquids with the orientational order of crystalline solids. The hydrodynamic theory of nematic liquid crystals is very rich, offering new mechanical and rheological properties compared to isotropic Newtonian fluids. The essential mathematical framework comprises the continuity equation, an evolution equation for the nematic flow field and an evolution equation for the nematic order parameter, which describes the state of orientational ordering or material anisotropy. The evolution equations for the flow field and order parameter are intrinsically coupled, so that, informally speaking, the evolution equation for the flow field is the Navier-Stokes equations with an additional coupling stress between the flow field and nematic order parameter, which can introduce strikingly different flow profiles compared to solutions of the classical Navier-Stokes equations. Conversely, the flow field influences the nematic order parameter and can even create defects or locally disordered regions.

In this project, we have studied two distinct hydrodynamic theories for nematic liquid crystals, namely the Ericksen-Leslie and Beris-Edwards theories for nematodynamics, in the context of a microfluidic problem. The emphasis has been on spatio-temporal pattern formation in both frameworks and how the solution profiles depend on the pressure gradient, geometry, boundary conditions and material constants, including the effects of inclusions such as nanoparticles. This project has led to three co-authored research articles, a joint PhD studentship in collaboration with Merck at InFoMM Oxford, for which Ian Griffiths and Apala Majumdar are joint supervisors, and potential funding applications to GCRF (Global Challenges Research Funding) schemes.

Publications:

[1] M. Crespo, A. Majumdar, A. Manuel Ramos & I.M. Griffiths (2017) Solution landscapes in nematic microfluidics. *Physica D* **351–352**, 1–13.

We use a combination of analytical, asymptotic and numerical methods to study steady-state solutions and time-dependent solutions in the Ericksen-Leslie framework, as a function of the pressure gradient and the boundary conditions on the channel walls.

[2] S. Mondal, A. Majumdar & I.M. Griffiths (2017) Nematohydrodynamics for colloidal self-assembly and transport phenomena. *Under review in Journal of Colloid and Interface Science*.

We study the dynamics and aggregation of disc-like inclusions in a two-dimensional microfluidic channel; such inclusions could model certain types of nanoparticles. These inclusions can assemble into chains or agglomerates of different shapes and there is intricate coupling between the dynamics, the inclusion sizes and the boundary conditions imposed on the inclusion. Figure 1 illustrates the dynamics of three disc-like inclusions in a nematic microfluidic channel and shows that the long-time behaviour tends to a triangular agglomerate of the three inclusions.

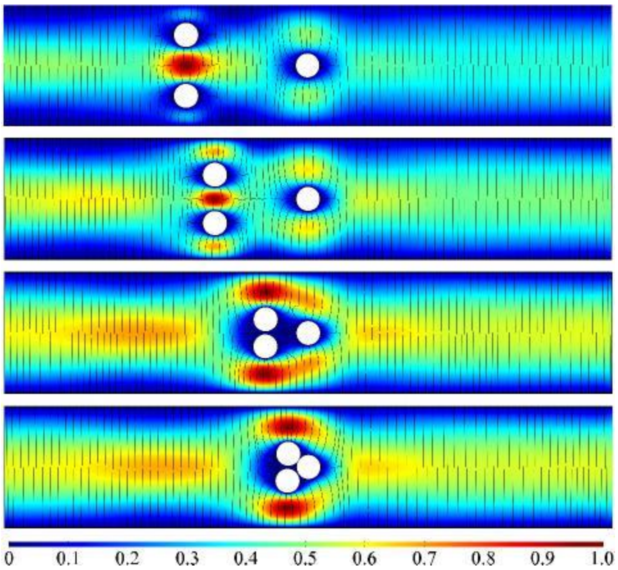

Figure 1: The time evolution of three disc-like inclusions in a nematic microchannel, with the initial condition at the top and the final state at the bottom. From [2], with permission.

[3] S. Mondal, Ian M. Griffiths, Florian Charlet and Apala Majumdar (2018) Flow and nematic director profiles in a microfluidic channel: the interplay of nematic material constants and backflow. *Invited research article to appear in* Fluids *(MDPI).*

In this paper, we are able to prescribe model conditions under which backflow or flow-reversal is expected in a nematic microfluidic channel, i.e. when the flow field is in the same direction as the pressure gradient, again as a function of material constants, temperature, Reynolds number and the Ericksen number. The UK Fluids Network SRV grant has been invaluable in providing pump-priming support to this collaborative project, which has now taken shape with a well-defined future research agenda.

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Research Team:

(i) Dr Apala Majumdar (University of Bath)
(ii) Dr Ian Griffiths (University of Oxford)
(iii) Dr Sourav Mondal (Postdoc at the University of Oxford, now faculty at IIT Kharagpur India)
(iv) Dr Maria Crespo Moya (Universidad Complutense Madrid, now postdoc in France)
(v) Mr Florian Charlet (ENSTA, France)