ME Seminar

Complex Flows Across Scales: From Industrial Yield-Stress Material Processing to Biomimetic Transport Networks

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ABSTRACT

Understanding fluid flow through complex geometries is a key challenge across scales, with relevance to natural systems, like vascular networks, plant xylem, and porous soils, as well as for engineering applications, ranging from industrial food processing and biomedical devices to microfluidic diagnostics and energy-efficient transport. In this talk, complex flow phenomena from nano- to macro-scales will be explored through my research path that integrates theory, experiments, and modelling. The discussion will focus on two specific themes involving macroscale and microscale flows. First, the fluidisation of yield-stress materials such as molten chocolate and Carbopol gels under vertical vibration will be addressed, an issue with direct implications for food manufacturing, drilling fluids, and additive manufacturing. Despite the widespread use of mechanical forcing in industry for processing yield-stress materials, some fundamental questions remain or poorly understood: How do these materials, which behave like solids under low stress, undergo fluidisation when subjected to external forcing? Which parameter govern the fluidisation? What roles do yield stress, elasticity, viscous dissipation, and inertial effects play in governing this transition? To investigate these questions, the sessile drops of molten tempered chocolate and Carbopol microgel placed on a uniform layer of the same material has been studied under vertical sinusoidal oscillations. Although both materials exhibit similar yield stress and shear-thinning behavior, they respond differently due to variations in nonlinear viscoelasticity and transient yielding. Carbopol spreads rapidly but requires much higher forcing than chocolate. This behavior is captured using a proposed modified Saramito model with nonlinear elasticity derived from thermodynamic principles, and validated by rheological data. Further, a depth-averaged model is derived, revealing that while yield stress governs the onset of fluidisation, the extent of spreading is controlled by the interplay of elastic, viscous, and inertial forces. These findings highlight the critical role of nonlinear elasticity in suppressing spreading and provide a new framework for investigating yield transitions in elastoviscoplastic materials. Second, flow optimization in self-similar, tree-like branching networks will be examined by deriving scaling laws for power-law and yield-stress fluids under fixed volume and surface-area constraints. This work addresses engineering-relevant questions: How does non-Newtonian rheology reshape classical optimization conditions? How do material properties influence throughput and pressure drop in constrained geometries? The resulting framework generalizes the Hess–Murray law to nonlinear rheology and provides design principles for vascular-inspired microfluidic systems, thermal networks, and hierarchical heat exchangers. Collectively, these studies highlight the coupled influence of rheology and network geometry and bridge fluid physics and engineering design, offering quantitative tools to guide the development of resilient, energy-efficient fluidic systems across multiple length scales.

ABOUT THE SPEAKER

Dr. Ashish Garg completed his PhD in Applied Soft Matter Physics at the University of Manchester, followed by postdoctoral research at IIT Delhi and the Raman Research Institute. Prior to his doctoral studies, he earned his Master's degree in Aerospace Engineering from the Indian Institute of Science (IISc), Bangalore. He founded the GATE Aerospace Forum, mentoring aspirants nationwide. He combines expertise in fluid mechanics with practical engineering, developing next-generation micro-turbojet engines as a CTO in a startup. His research centers on non-Newtonian fluid dynamics, combining theory, experiments, and modelling to study fluid behavior across nano- to macro-scales. His interdisciplinary work spans rheology, droplet spreading, wetting, fluid-structure interactions, non-reciprocal systems and flow in complex geometries, including tree-like networks and deformable channels. Applications of his work include green packaging, micro-turbojet propulsion, and impact-absorbing materials. Dr. Garg's broader vision focuses on translating fundamental physical insights into advancing soft, sustainable, and resilient fluid-driven systems for science and engineering.

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