

Nonlinear rheology and mass transport in bacterial biofilms: a polymer-network perspective.

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Biofilms are aggregates of bacteria embedded in a self-secreted extracellular polymeric substance (EPS) matrix [1]. From a physical perspective, they can be regarded as living complex fluids [2]: soft, heterogeneous polymer networks that undergo large deformations, display strongly nonlinear rheology, and simultaneously regulate the transport of chemical species. These coupled properties contribute to the remarkable persistence of biofilms across medical, industrial, and environmental settings, yet the physical mechanisms linking microstructure, mechanics, and transport remain poorly understood.

In this talk, I will present a physics-driven framework that treats biofilms as structured polymer networks whose macroscopic behaviour emerges from coupled nonlinear mechanics and hindered mass transport, operating alongside organism-specific biological regulation. Using microfluidic platforms combined with in situ imaging and numerical modelling, we probe biofilm responses under controlled mechanical deformation and chemical exposure, with the aim of identifying general physical principles that govern nonlinear rheology and transport in biofilms. On the rheological side, I will focus on the role of extracellular DNA (eDNA), a near-ubiquitous EPS component that acts as a load-bearing structural backbone. I will demonstrate how the eDNA network controls the assembly and nonlinear rheology of flow-suspended biofilms, enabling them to withstand flow fluctuations [3]. On the transport side, I will then show how the properties of eDNA–polysaccharide networks regulate permeability, mass transport, and chemical gradient formation, thereby directly shaping chemical protection, antimicrobial tolerance, and biofouling.

By linking nonlinear mechanics and transport through the physics of polymer networks, this work reframes biofilm resilience as an emergent property of a living complex fluid, modulated — but not fully dictated — by biology. This perspective opens new routes for predictive modelling of biofilm properties and for rational strategies to disrupt their integrity in real-world applications.

Keywords:

nonlinear rheology, mass transport, bacterial biofilms

References:

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