Université
franco-allemande
Deutsch-Französische
Hochschule

Abstract

Bacteria colonise interfaces by the formation of dense aggregates. In this thesis, we develop and analyse simple models to clarify the role of passive physico-chemical forces and processes - such as osmosis, surface tension effects and wettability - in the spreading of bacterial colonies at solid-air interfaces. In particular, we focus on two spreading mechanisms: The osmotically driven spreading and the promotion of spreading by the presence of bio-surfactants. The models are based on a hydrodynamic description for thin films of liquid mixtures and suspensions that is supplemented by bioactive processes. They explicitly include surface tension effects and wettability.

The first part of the thesis focuses on the osmotic spreading mechanism of bacterial colonies that relies on the generation of osmotic pressure gradients. The bacteria secrete a polymeric matrix which acts as an osmolyte and triggers the influx of nutrient-rich water from the moist substrate into the colony. The analysis of the model shows that in accordance with the experimental observation, the colony first swells and subsequently expands laterally with a nearly constant contact angle at the advancing contact line. In addition, we find that wettability crucially affects the spreading dynamics and determines whether the colony is able to expand laterally over a substrate or not. At low wettability, the expansion is arrested, albeit the colony is biologically active. However, a small reduction of the sur- face tension and the resulting improvement of the wettability suffices to induce continuous spreading. This can, e.g., result from the production of bio-surfactants, i.e. surface-active molecules, by the bacteria. This is a widespread strategy that allows bacterial colonies to efficiently expand over substrates. In addition to improving the wettability, gradients in the surface concentration of surfactant at the edges of the colony result in Marangoni fluxes that drive cooperative spreading.

In the second part, we lay the groundwork for the incorporation of a non-uniform surfactant concentration into the model by studying passive liquid films covered by insoluble surfactant. We first consider static drops and establish the link between the mesoscopic and macroscopic descriptions of the system by energetic considerations. The requirement of consistency of the two approaches relates the solid-gas interfacial tension in the macroscopic description to the mesoscopic wetting energy. We find that in the presence of surfactants, the structural form of Young’s law remains unchanged. However, the surfactant concentrations and the resulting interfacial tensions adapt self-consistently.

In the third part, we develop and study a model for the surfactant-driven spreading of bacterial colonies. The model includes the production of bio-surfactants and accounts for Marangoni fluxes arising due to a non-uniform surfactant concentration. We show that the interplay between wettability and Marangoni fluxes strongly affects the expansion behaviour and morphology of bacterial colonies. The presence of bio-surfactants can enable a bacterial colony to expand laterally under conditions which are otherwise unfavourable. In addition, it may cause an instability of the circular shape of bacterial colonies. We find that variations in the wettability and surfactant production are sufficient to repro- duce four different types of colony growth, namely, arrested and continuous spreading of circular colonies, slightly modulated front lines and the formation of pronounced fingers. In the final part, we take a first step towards the incorporation of active collective bacterial motion in the employed thin-film framework and present a phenomenologically derived model for active polar films. The approach couples a thin-film equation for the film height to the dynamics of a polarisation field connected to self-propulsion and active stresses. It can describe resting and moving drops of active liquids.