ELECTRIC FIELD DRIVEN FORMATION OF PARTICLE CONCENTRATION FRONTS IN SUSPENSIONS

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Micro-analytical systems are widely used in a variety of applications ranging from biological warfare agent detection to the healthcare industry [1, 2]. The first step in the operation of a micro-system consists of concentrating and separating the analytes of interest followed by positioning them into the selected locations for subsequent analysis. Compared to other available techniques, dielectrophoretic methods have been demonstrated to be particularly well-suited for the manipulation of minute particles in microfluidics [2, 3]. Although numerous papers published within the last decade have contributed to our knowledge about the fabrication of electro-microfluidics, very little has been achieved in mastering the phenomena that underlie the behavior of a suspension subject to a high-gradient strong electric field. In particular, the concepts currently favored for the design and operation of dielectrophoretic devices ignores the effects of the interparticle hydrodynamic and electric interactions on the suspension behavior [2, 3].

Surprisingly, we have recently demonstrated experimentally [4, 5] that the presence of the interparticle interactions can drastically affect the suspension behavior. A distinct front, separating regions enriched with and depleted of particles, was observed in suspensions subjected to high-gradient ac electric fields and a set of theoretical model equations for the particle concentration, containing no fitting parameters, was developed [4, 5]. This phenomenon suggests a new method for strongly concentrating particles in focused regions by forming a concentration front. Although the numerical solutions of the proposed model were found to be quantitatively consistent with the experimental observations, they did not provide sufficient information for elucidating the mechanism of the front formation due to the complexity of the equations. Here, we examine the model equations [4, 5] analytically for the special case in which they admit a similarity solution and establish the existence of shock solutions. Analytical theory indicates two limiting mechanisms of the concentration front formation: thermodynamic and hydrodynamic. The former corresponds to the thermodynamic equilibrium when dielectrophoresis is accompanied by a field-induced phase transition. The latter operates in transient regimes through the balance of the dielectrophoretic and hydrodynamic forces caused by the rapid local growth of the suspension viscosity due to the field-driven particle accumulation in certain areas of the domain.

References

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