Stability of subcritical electrohydrodynamics in dielectric fluids

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We present the results of modal and non-modal linear stability analyses and then a weakly nonlinear stability analysis of electrohydrodynamics (EHD) in dielectric fluids, subject to the strong injection and confined between two infinite parallel electrodes, in both cases with and without cross-flow. The effect of electric charge diffusion has been taken into account and discussed thoroughly.

For the linear stability analysis, we found in hydrostatic EHD that the fluctuation energy growth due to the linear non-normal effect is limited, which is thus not able to account fully for the subcritical features of hydrostatic EHD, nor the discrepancy between the theoretical T_c and the experimentally determined T_c (T: the electric Rayleigh number). The charge diffusion exerts a destabilizing effect on the flow in both modal and non-modal analyses.

When a pressure-driven cross-flow is added in EHD, our results indicate that the cross-flow becomes more unstable and its transient growth is higher under the influence of electric field. From a point of view of the non-normal mechanism, this pronounced transient growth is due to the enhanced lift-up mechanism in the channel flow by the vertical flux provided by the electric field, helping to form the streamwise rolls.

For the weakly nonlinear analysis, we found in hydrostatic EHD that the stronger the electric charge diffusion is, the smaller the destabilising effect of weakly nonlinear EHD flow is in the early phase of the disturbance development. From these results, we can infer that the actual finite-amplitude critical T_f should be higher than the values predicted in the previous works without taking into account the charge diffusion effect.

The weakly nonlinear EHD flow subject to a Poiseuille-flow is then considered. Our results show that the electric field destabilizes the Poiseuille flow in the weakly nonlinear phase. Therefore, the subcritical Poiseuille flow becomes more vulnerable in its transition to turbulence. Interestingly, by looking into the detailed physical mechanism of this process, we found that it is not the electric field that contributes directly to the subcriticality of the EHD-Poiseuille system, but rather, the modified Poiseuille flow field by the electric field that renders the whole flow system more subcritical.