STATIONARY VISCOSITY-DOMINATED ELECTRIFIED CAPILLARY JETS

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When a jet of an electrically conducting liquid is injected into a dielectric medium subject to an electric field, the field induces a conduction current in the liquid that carries electric charge to its surface. The action of the field on this charge leads to an electric shear that stretches the jet and may reduce its diameter to values which are orders of magnitude smaller than the diameter of the injection orifice. This mechanism is put to use in electrosprays, where sprays of fine and nearly monodisperse drops are produced by the breakup of the electrified jet due to a varicose instability, and also in the electrospinning of nanofibers, where the jet is made of a polymer solution or melt that solidifies after intense stretching but before it may break up into drops [1]. In this latter application, most of the stretching occurs during the growth of a bending instability whereby the jet begins to spiral violently at some distance downstream of the nozzle. The development of the varicose or bending instability is preceded by a region where the jet is stationary and axisymmetric, at least if the viscosity of the liquid is sufficiently high. This initial region is of interest because it contributes to the stretching of the jet, controls the onset and character of the instability, and determines the electric current carried by the jet as a function of the liquid properties and the flow rate.

The flow in the initial region of the jet has been studied before using quasi-unidirectional models coupled with a slender body approximation for the electric field induced by the charge of the jet and the image charges on the electrodes [2,3]. In this paper the full equations governing the stationary and axisymmetric flow are numerically solved for the case of a Newtonian liquid with negligible inertial effects which is immersed in a uniform electric field. The electric current carried by the jet is computed as a function of the parameters of the problem, showing that it increases with the conductivity and flow rate of the liquid and with the intensity of the electric field. The current also depends on the wetting conditions of the liquid at the injection orifice. Scaling laws for the electric current and other properties of the solution are worked out that fit the numerical results and are in qualitative agreement with experimental data.

References

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