MASS PRODUCTION OF MICROSPHERES BY FLOW FOCUSING AND ITS LIMITS: THE JETTING-DRIPPING TRANSITION PROBLEM

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In contrast to the slow dripping mechanism from a fluid source, or the uncontrolled stirring of two phases, a laminar steady capillary liquid microjet in a co-flowing immiscible stream is an ideal way to mass produce small fluid spheres. To this end, an optimum geometrical configuration to produce micro-jetting is the capillary Flow-focusing setup [1]: a nozzle emits a continuous fluid stream which is turned into a filament and pulled by a pressurized co-flowing fluid; both phases are evacuated through a coaxial orifice in the form of a nearly cylindrical co-axial stream.

Thus, to investigate the conditions under which steady jetting in a co-flowing stream is stable becomes paramount. A theoretical model describing wave propagation in open cylindrical flows has been adapted to our problem and further expanded to incorporate spatio-temporal stability considerations (convective/absolute -C/A- instability modes). The jetting-dripping (J-D) transition sets the minimum liquid flow rate issuing as a steady jet and breaking up into droplets whose size is commensurate with the jet diameter. At the onset of dripping, droplets become considerably larger than jetting droplets, under comparable flow parameters. A linear theory accounting for convective and absolute instability is provided, along with a detailed interpretation of the parametrical space, under realistic viscosity and density restrictions.

Our theoretical model is shown to retrieve the Leib-Goldstein [2] limit of a viscous jet in a vacuum, from small to large Reynolds numbers: in the low Reynolds extreme, the asymptotic critical Weber number is 0.227, while in the large Reynolds range the critical Weber number asymptotically approaches 3.112. On the other hand, the limit of a capillary jet made of vacuum in a co-flowing liquid stream is also studied. We show that, in this limit, no jetting is possible for any finite value of the Reynolds and Weber numbers, these defined with the co-flowing liquid properties.

We also study the jetting-dripping (J-D) transition of a flow-focused viscous liquid jet surrounded by a co-flowing immiscible, lower viscosity liquid. To this end, we use a well established analytical dispersion relation derived by Funada and Joseph [3] and adapted to our C/A analysis. Here, for a given liquid density and viscosity ratios, an interesting result shows that, in contrast with Leib and Goldstein, a certain critical value of the Reynolds exists below which jetting is not possible for any finite value of the Weber number. An experimental study sums up a collection of lab data illustrating the J-D transition to good agreement with the theory. Finally, we show that, in contrast with the limiting result of a vacuum jet in a liquid, when a the jet is made of a fluid of any finite density and viscosity in an unbounded co-flowing liquid there is always a critical Weber number above which jetting is possible, for any given Reynolds number. Again, a large data set is compared to our theoretical predictions, showing good agreement.

References

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