Primary atomization under the simultaneous action of Rayleigh-Taylor and Kelvin-Helmholtz mechanisms

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Abstract

The possibility of employing both Rayleigh-Taylor (R–T) and Kelvin-Helmholtz (K–H) mechanisms simultaneously as equal contributors to the primary destabilization process is discussed. A linear stability analysis is performed to develop an understanding of a primary atomization under this combined action. Three–dimensional disturbances are considered in order to predict the breakup structure (ligaments) observed in experiments. The fluids are assumed to be inviscid and incompressible. From the governing equations and the boundary conditions, a dispersion relation is derived and analyzed for a single as well as two interfaces. Four different regimes have been shown to be possible, based on the most unstable axial (k^*) and circumferential (m^*) wavenumbers. They are (i) Taylor mode ($k^* > 0, m^* = 0$). (ii) flute mode ($k^* > 0, m^* > 0$), (iii) sinuous mode ($k^* = 0, m^* = 1$) and (iv) helical mode ($k^* > 0, m^* > 0$). In order to represent the simultaneous action of k^* and m^*, a characteristic length scale ($\mathcal{L}^*$) is defined as $\mathcal{L}^* = \min\left(\frac{2\pi}{k^*}, \frac{2\pi}{m^*}, \frac{2\pi}{k^* m^*}\right)$, where $2\pi/k^*$ and $2\pi/m^*$ represent the two–dimensional length scales in the Taylor and flute modes respectively. The helical mode is represented by a scale given by $2\pi/k^* m^*$. This definition of $\mathcal{L}^*$ allows us to compare the deformation length scales in the three regimes, viz. Taylor, flute and helical mode using a single length scale measure. The dimensionless quantities relevant to this study are Bond number (Bo) representing the ratio of radial acceleration force to the surface tension force and Weber number (We) representing the ratio of the aerodynamic force due to the relative velocity to the surface tension force at each interface.

This study reveals that three-dimensional disturbances (helical modes) dominate the system behavior under certain parametric conditions, which is advantageous to interface distortion. In addition, this study also reveals that for a given energy, the length scale associated with destabilization due to radial acceleration (R–T mechanism) is significantly more efficient than the traditional way of destabilizing an interface using axial relative velocity (K–H mechanism).

In conclusion, the results of our study open up new avenues for designing atomizers to destabilize a liquid sheet by radial motion instead of axial motion. In addition, the onset of transition from absolute instability to convective instability, in the (Bo-We) space is identified.

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