Analysis of Disintegration of Planar Liquid Sheet Sandwiched between Gas Streams with Unequal Velocities and Resulting Spray Formation

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Abstract

A temporal stability analysis was carried out for a planar liquid sheet sandwiched between two gas streams moving with unequal velocities. A planar sheet is an idealized representation of an annular liquid sheet emanating from an injector owing to the high ratio of the radius of the liquid sheet to its thickness. To account for the nonlinearity of the breakup process, regular perturbation analysis was carried out up to second order using the initial amplitude of disturbance of the liquid sheet as the perturbation parameter. Unlike the case of planar sheets subjected to gas streams moving with equal velocity on either side, the present problem leads to para-sinuous and para-varicose modes giving phase differences between the two interfaces close to 0 and π respectively. In the present work, both these modes were investigated to determine the dominant break-up mechanism. On account of the high velocities typically encountered in injectors like air blast atomizers, both the liquid and the gas flows are assumed inviscid and irrotational. This enables use of velocity potentials for both the phases. The two phases are coupled through kinematic and dynamic boundary conditions at the interface. Assumption of normal modes for the perturbed interface and use of the kinematic and dynamic boundary conditions lead to dispersion relations at each order in the form of ordinary differential equations. These equations are solved using Laplace transform. The nonlinear stability analysis gives the ligament area and the breakup time corresponding to the most unstable wave numbers in para-sinous and para-varicose modes. Gaster transformation is used to obtain the breakup length from the breakup time. Secondary breakup of the ligament into droplets was modeled following Rayleigh mechanism.

Apart from modeling the breakup of the liquid sheet, droplet size and velocity distributions were predicted using Maximum Entropy Formulation (MEF). In the MEF approach, the joint size and velocity probability distribution that maximizes the information entropy subjected to certain constraints was considered the most probable distribution. In the present work, the constraints were based on the conservation of mass, momentum and energy of the liquid drops. The droplet diameter predicted by the breakup analysis is used as the mass mean diameter in the MEF and the breakup lengths obtained from the stability analysis are used in the constraints relations.

The results show that the asymmetry in the gas velocity significantly affects both the first order and the second order results. The liquid sheet profile shows considerably higher asymmetry before breakup compared to that observed with equal velocities. The range of unstable wavelengths, the maximum growth rate, the breakup length and the mean droplet diameters were found to be determined through a complex interaction of the gas phase velocities and their differences. In general, it is found that increase in difference the gas velocities on two sides of the liquid sheet leads to a significantly narrower size distribution in the spray though the velocity distribution is affected much less.

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