Stability of Molten Liquid Jets Undergoing Solidification

Monisha Natchiar[1] S.R., D.S. Pillai[2], S. Pushpavanam[3]

The breakup of a capillary jet into drops is mainly attributed to instabilities driven by surface tension. Capillary breakup of jets under isothermal conditions, wherein there is no heat transfer between the jet and the ambient fluid have been extensively studied [1]. In this work, we study the scenario wherein the jet loses heat to the ambient fluid and thereby in the process undergoes solidification. The motivation for this work rests in its application for safety design of pool-type Fast Breeder nuclear reactors. In the event of a core disruptive accident in a pool-type nuclear reactor, the nuclear core material melts and falls as a jet into a pool of coolant. As the molten core descends, it loses heat to the coolant, solidifies and breaks into drops [2]. Solidification of the molten jet during its fall significantly affects its breakup dynamics. We develop a simple mathematical model to capture the effect of solidification of jet on its breakup dynamics.

In the present study, we assume the jet to be slender, i.e., the length of the jet is much larger compared to its radius. Thus, the problem consists of a small parameter called the slenderness ratio (ratio of the radius of jet to its length). We then proceed by expanding the dependent variables as a power series in terms of the slenderness ratio and obtain simplified equations to the lowest order called the *slender jet equations*. These one-dimensional coupled nonlinear partial differential equations govern the evolution of the interface position and the axial velocity of the jet. These equations are solved using method of lines on a staggered grid.

The effect of solidification is included by assuming the presence of a solid crust at the interface of the jet and the ambient fluid. The normal stress condition at the interface between the jet and the ambient fluid is then suitably modified to accommodate for the additional stress generated due to deformation of this solid cylindrical crust. The additional stress generated due to the crust formation however depends on the thickness of the solid crust, which is not known a priori. The thickness of the crust depends on the total time taken for the jet to breakup. Thus an iterative scheme is used to carry out an overall heat balance on the jet and determine the thickness of the crust and thereby predict the breakup dynamics.

[1] monishanatchiar@yahoo.co.in (Corresponding author)
[2] dipinsp@gmail.com
[3] spush@iitm.ac.in

This work thus aims to present a simple mathematical model to take into account complex effects of solidification on the breakup dynamics of the jet. The main advantage of this model is its computational elegance and the physical insight that it provides as compared to a conventional CFD simulation.

References

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