Modeling, simulation and experimental verification of the trajectory and break-up of a particle laden spiraling liquid jet

S. Gramlich*, M. Piesche
Institute of Mechanical Process Engineering, University of Stuttgart, Germany
gramlich@imvt.uni-stuttgart.de and piesche@imvt.uni-stutgart.de

Abstract

A physical-mathematical model is presented which is able to predict the drop size, that results from the break-up of a particle laden rotating liquid jet with laminar flow. The model is based on the perturbation theory. Thus the flow is decomposed into a time steady motion and the motion of small time dependent disturbances.

The equations of motion for the time steady flow are derived by means of a force balance on an infinitesimal jet segment and result in the contour and the spiraling trajectory of the jet. The contour contracts due to the centrifugal force and thus the time averaged velocity increases along the jet. The suspension is treated as a liquid with shear thinning fluid flow properties with two plateau viscosities, which can be expressed by the Carreau-Yasuda model. The drag force due to the relative motion of the surrounding gas phase is considered. The necessary drag coefficient depends on both the Reynolds number of the relative gas flow and its angle of incidence and is determined by computational fluid dynamics. The resulting equation of motion in axial direction results in an ordinary differential equation of second order with only one boundary condition known. The solution method for this type of equation is developed using a "backward shooting"-method with an approximate solution serving as the second boundary condition.

The small transient perturbations of the jet contour are treated with a linear stability analysis, which results in a critical wave number that leads to break-up of the jet into droplets. The description of the solid and liquid motion is carried out in Eulerian formulation. Hence each phase is treated as a continuum with separated balances for mass and impulse. The interaction between the particulate solid and the liquid phase are included by additional terms in the impulse balances.

The perturbation method leads to the dispersion relation, which can be solved with regard to a temporal absolute or a spatial convective instability. Both solutions are compared to the experimental results gained by shadow imaging technology. The shadow images are evaluated with regard to the drop size and the break-up length of the jet, which serves the model as a boundary condition. Figure 1 shows a comparison of the calculated jet contour of the temporal stability analysis (left) and the spatial stability analysis (right) as an overlay over the experimental result. The spatial stability analysis describes the perturbations of the jet surface more accurate than the temporal stability analysis.

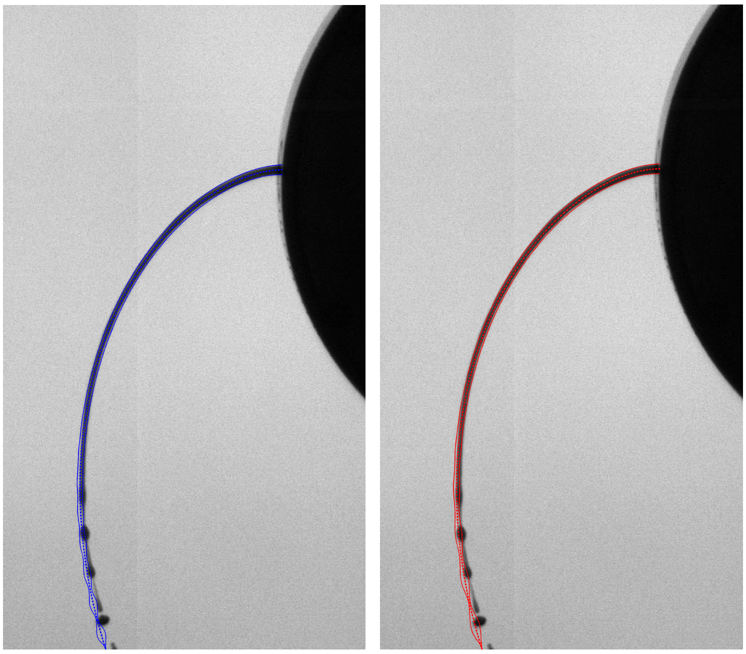

Figure 1. Comparison of calulated (coloured) and experimental jet contours from temporal (left) and spatial (right) stability analysis.

Based on an extensive parametric study the centrifugal acceleration, the surface tension, the viscosity as well as inertia were found to have a major effect on the drop size resulting from the break-up of a rotating liquid jet with laminar flow. The solid phase does not show an influence on the drop size. Neither in the time steady motion nor in the motion of the small disturbances significant changes due to different particle concentrations, particle sizes or particle densities are observed. Experimental findings support this result.

*Corresponding author: gramlich@imvt.uni-stuttgart.de