EXPERIMENTAL AND THEORETICAL DESCRIPTION OF A ROTATING LIQUID JET

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Summary The industrial process of prilling, which is used in the manufacture of small pellets, involves liquid jets emerging out of holes on the surface of a rotating cylinder. These jets are curved because of the rotation and gravity, and break up into droplets because of surface tension. The dynamics of a curved liquid jet is examined both experimentally and by using a mathematical model. The break up is discussed for inviscid, viscous and non-Newtonian liquid jets, in a vacuum and in air. Convective and absolute instability is examined.

EXTENDED SUMMARY

A liquid jet can be curved by the action of gravity, wind drag or if the orifice from which the jet emerges is rotating. Surface tension driven instabilities cause the jet to lose coherence and break to form droplets. The sizes of the drops formed from such jets are in general not uniform, ranging from drops with diameters of the order of the jet diameter to droplets with diameters which are several orders of magnitude smaller. This problem arises in the manufacture of fertiliser and magnesium pellets using the prilling process, where there is a great demand for pelleted products which have a closely defined size and shape. While the break-up of straight jets falling under gravity has received considerable attention in the literature, there is a comparable paucity of published information on break-up of curved jets.

This presentation details an experimental investigation of the effects of changing operating parameters on the break-up of curved liquid jets in stagnant air at standard temperature and pressure. The curved jets were formed from an orifice at the bottom of a rotating can of 0.085 m diameter which was continuously filled with liquid to maintain a constant liquid height in the can. The rotational speed (0 – 300 rpm), orifice size (1 and 3 mm), and liquid level in the rotating can were varied. A spatially static high speed camera capable of frame rates up to 3000 fps was used to visualise the trajectory and break of the liquid jet into droplets. The effect of liquid dynamic viscosity upon the surface tension driven instabilities was considered by use of a different liquids (water and glycerol solutions of concentrations ranging from 20-80% vol.) which gave dynamic viscosities ranging from 0.001 to 0.09 Pa.s.

Over the range of experimental parameters studied, four different break-up modes have been identified. For each mode, considerable differences in the break up mechanism and in the drop size distributions produced could be observed. Dimensional analysis has shown that the break-up modes can be predicted from a plot of Reynolds number (ratio of inertial to viscous forces) against Weber number (ratio of inertia to surface tension forces). The break up mode observed is a strong function of viscosity and highly non-linear effects were observed with the most viscous solutions used.

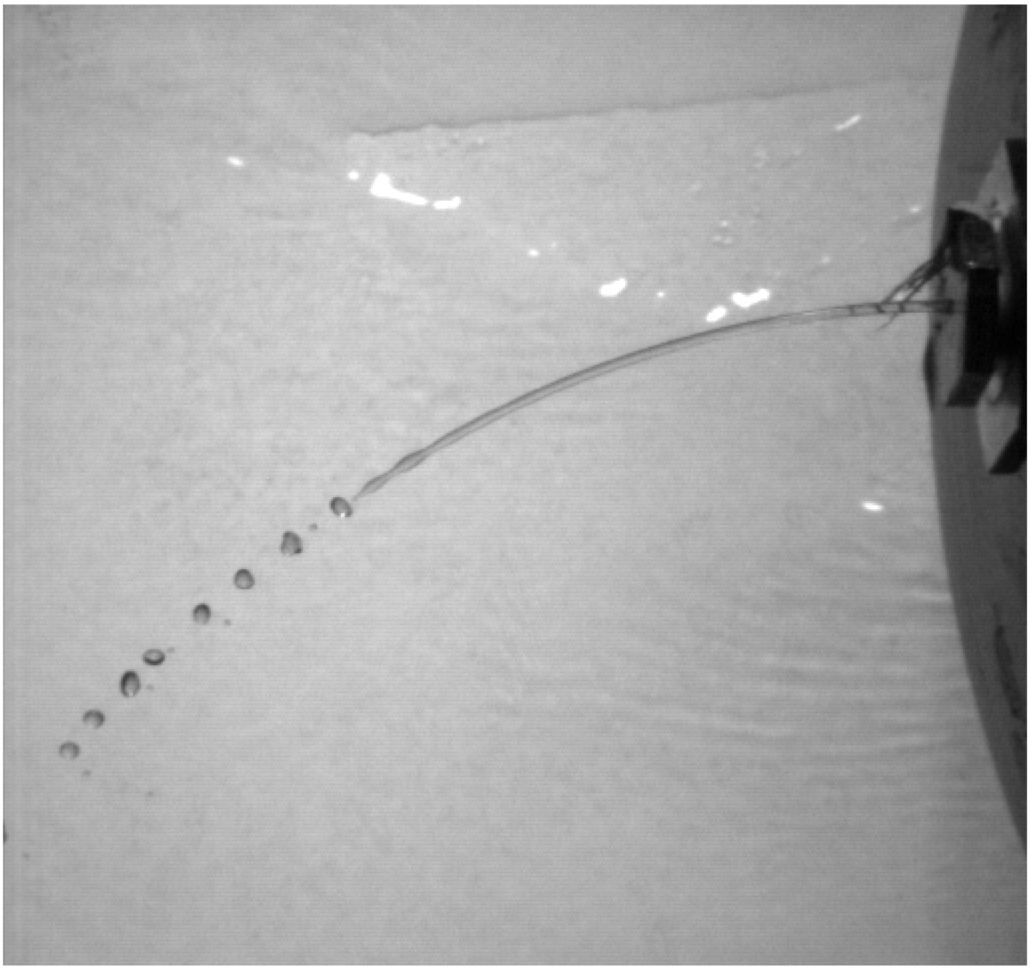
A theoretical analysis of these jets has also been considered. A novel coordinate system was developed in which the (initially unknown) trajectory of the jet forms a coordinate axis. The Navier-Stokes equations are solved in this system with the usual viscous free surface boundary conditions, using an asymptotic method based upon a slender jet assumption, which is clearly appropriate from experimental observations of the jet. This model allows us to determine theoretical predictions for steady solutions, including the trajectory of the jet, which compare very well to experimental observations. A linear stability analysis is then also considered for viscous convective modes, using both a temporal and spatial stability approach. This is extended to consider absolute instability for small Weber number jets. These observations again compare well to experiments.

We also present nonlinear temporal simulations of the break up of the liquid jets using our slender theory. These simulations based upon both a steady trajectory assumption, and the more general equations which allow for an unsteady trajectory, show all the break up modes viewed in experiments.

Detailed comparisons are made between theory and experiments for the break up length of the jet, the most unstable wavelength and wave speed, the droplet sizes produced by the jet, including the standard deviation of droplet sizes and the dynamics of the break up mechanisms. These comparisons are found to produce good agreement between theory and experiments. The effects of the rotation rate of the container on these statistics are highlighted.

This work is extended to consider the effects of the air flow around the moving container on the liquid jets both experimentally and theoretically. Non-Newtonian liquids will be considered too. Finally, methods to control the instability process to produce droplets of a desired size are considered.

PHOTOGRAPH OF A TYPICAL JET



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