Mathematical Modelling of the Impact of Liquid Properties on Droplet Size from Flat Fan Nozzles

Presented by Syngenta

Flat fan nozzles are the industrial standard in agriculture for atomising crop protection products for application onto plant and soil surfaces. The need for atomisation is to distribute active ingredients on the target surfaces. Spray nozzles are always designed as a compromise as to ensure products perform small droplets are desired to give good coverage and retention of active ingredient particles on target surfaces. However, small droplets are likely to drift due to wind which can lead to multiple issues such as contamination of groundwater and non-target organisms, injury to non-target crops or exposure of residents. Therefore the ideal spray application has a very narrow droplet size of the “right” size.

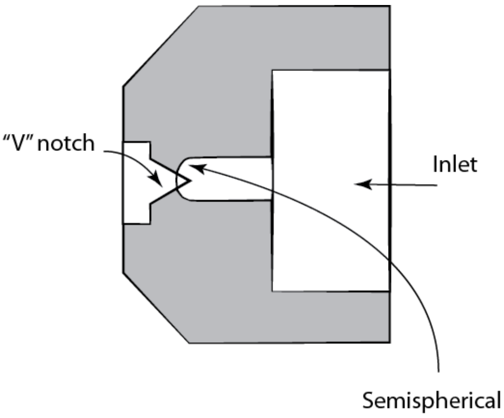

Figure 1 - Flat fan nozzle geometry (wikipedia.com)

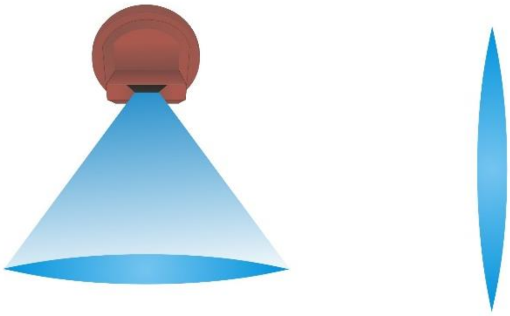

Figure 2 - Spray morphology (Sprayers101.com)

Flat fan nozzles have an orifice shaped as per Fig. 1 which produces a spray in the shape shown in Fig. 2. The nature of this spray is that immediately upon exiting the nozzle the spray is in the form of a liquid sheet travelling at around 25-30m/s. This liquid sheet has a shear force imparted upon it by the surrounding static air. This shear force leads to instabilities forming on the surface of the liquid sheet. As these instabilities are amplified they can form surface waves and eventually lead to the sheet breaking up into ligaments and droplets. This is known as wavy sheet breakup (Fig. 3 red and Fig. 4) and is the primary breakup mechanism. There are two additional breakup mechanisms present in sheet breakup. The first of these, perforation breakup (Fig. 3 purple and Fig. 5), is when the local instabilities in a certain area of the spray sheet lead to a hole, or perforation. Once this hole has been initiated the surface tension of the liquid causes the hole to rapidly enlarge to form a series of interconnected ligaments which subsequently breakup into droplets. These droplets are larger than those produced by wavy sheet breakup. The final breakup mechanism is rim break up (Fig. 3 blue). This occurs on the thin edge of the spray where the instabilities and surface waves from two directions interact to “pinch off” droplets. These droplets are larger than those produced by wavy sheet breakup.

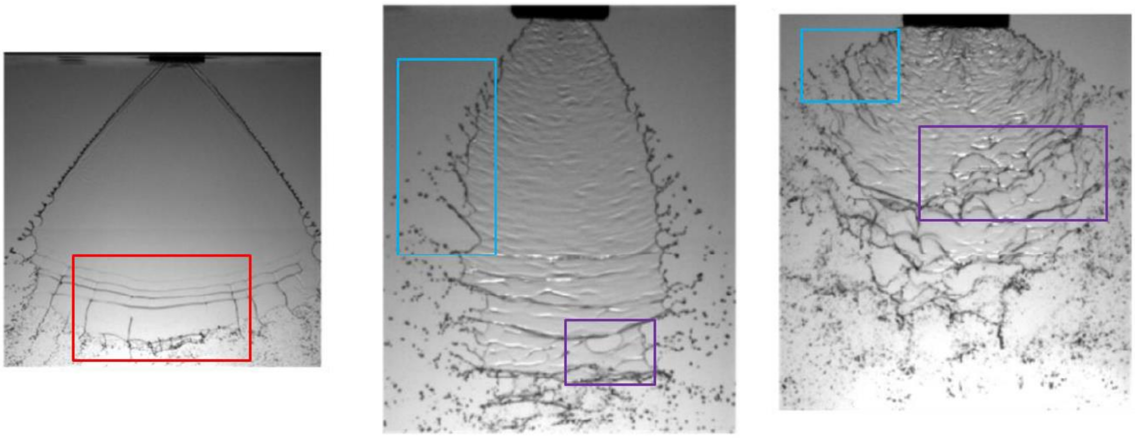

Figure 3 - Different break up mechanisms (wavy sheet - red) (rim - blue) and (perforation - purple)

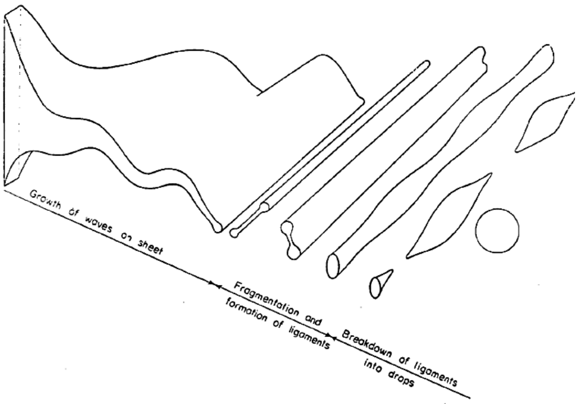

Figure 4 - Wavy sheet breakup model (Dombrowski and Johns)

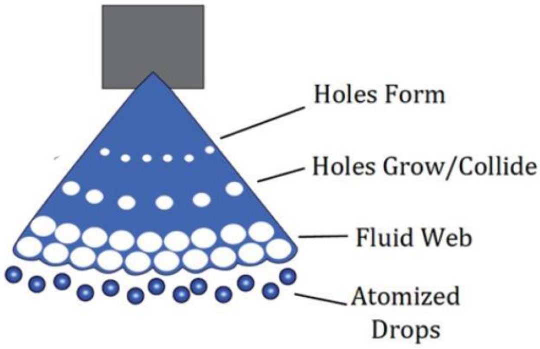

Figure 5 - Perforation breakup model

Our interest is in being able to predict some features of the atomisation based on certain input parameters which we can control to some degree. These input parameters are the physical properties of the liquid sprayed through these nozzles, with the key parameters being (dynamic) surface tension, density and viscosity (both Newtonian and non-Newtonian) and the presence of inhomogeneities some as emulsified oil droplets within the fluid. Agrochemical formulations are designed to have certain characteristics for various reasons. For example a formulation may have low surface tension to improve retention and wetting on leaf surface.

Surface tension has a well-known effect that a low surface tension will allow smaller droplets and ligaments to be produced in the chaotic regime of wavy sheet breakup. High viscosity can retard breakup as the increased viscous energy dissipation within the fluid reduces the energy remaining to produce small droplets. Density has not been studied at length for agrochemical formulations as they are normally diluted into water at a rate in the range 50:1 so the density is nearly always close to 1. The effect of inhomogeneities is less well understood. Current knowledge has shown that these inhomogeneities can increase the level of perforation breakup although there are a number of proposed explanations for the mechanisms available in the literature (suggested authors to search: Hillz, Dexter, Butler Ellis, Qin, Cloeter, Vermeer, Western).

The value of solving the problem to ourselves is that we could design our formulations to produce a spray with the “perfect” droplet size spectrum to ensure good product performance while minimising drift. Thus far we have not put significant effort into approaching the problem using experiments as the work necessary to characterise the entire experimental matrix is unfeasibly large. Therefore we are looking at the problem from a mathematical viewpoint at the moment, but could do a small number of experiments to support the conclusions of this mathematical approach.