ATOMISATION OF AGRICULTURAL SPRAYS: INFLUENCE OF SOME LIQUID PROPERTIES

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ABSTRACT

The sprays produced by agricultural nozzles are influenced by surface tension and viscosity of the liquid. In the following study, four different liquid solutions have been sprayed through a flat fan and a turbulent nozzle. Droplet velocity and diameter have been compared using PDA measurements at 8 cm and 15 cm below the nozzle exit. Moreover, shadowgraph images allow the visualisation of the instantaneous spray formation.
The influence of a thickener agent leads to liquid sheet length increased for the both nozzles, whereas the influence of a surfactant seems to depend on the atomisation regime: concerning the turbulent nozzle, the liquid sheet length is shortened with the addition of a surfactant; concerning the flat fan nozzle, the liquid sheet is lengthened but the first perforation distance is shortened with the addition of a surfactant.

INTRODUCTION

An agricultural pesticide spraying commonly involves ejecting a liquid mixture made up of active molecules and adjuvants. These adjuvants have several roles linked to formulation conservation, operator usability and safety, or treatment efficiency. Most of them have a significant effect on physical properties of the liquid mixture. For instance, surfactants allows the surface tension decrease and are used in order to increase the spreading on the crops, whereas the thickener agents impart thixotropy to the mixture and avoid deposit of the formulation in the can.

The liquid is atomised into droplets and is directed towards the crop or the soil. The initial size of droplets formed from the liquid jet or sheet is fundamental [1,2]: small droplets will be able actually to drift away from their intended target, whereas the large ones will be able to stream down the crop.

In this study, influence of surfactant and thickener agent on the atomisation of the liquid (droplets size and velocity) is examined experimentally.

MATERIAL AND METHODS

Nozzles

Two types of agricultural nozzles were used: a flat fan nozzle (**NOZAL 80 015**) and a turbulent one (Albuz ceramic 80° hollow cone ATR). The nozzles were mounted in an x-y-z transporters (cf. Figure 1) so that the spray fan could be moved above the measuring instrument allowing the full width and thickness to be sampled. Injection pressure used was equal to 5 bars for the turbulent nozzle and 3 bars for the flat fan one.

Figure 1) Experimental set-up

Liquids

Four liquid solutions are tested. They were chosen to change separately atomization properties and to cover a range of chemical types and used at concentrations with manufacturer label recommendation. Table 1 gives the values of the dynamic viscosity and the surface tension coefficient for the four liquid solutions.
The water + surfactant solution consists in water containing 0.3 % (in volume) Nonylphenol 14 OE.
The water + thickener solution consists in water containing 0.2 % Rhodopol 23.

	Dynamic viscosity (Kg/m/s)	Surface tension coefficient (N/m)
Water	1 e-3	62 e-3
Water + thickener	1.4 e-3	62 e-3
Water + surfactant	1 e-3	36 e-3
Water + thickener + surfactant	1.4e-4	36 e-3

Table 1: Properties of the four liquid solutions used

Measurements

PDA

A 1D Phase Doppler Anemometer (PDA Dantec) is used to simultaneously measure droplet velocities and diameters. An Argon laser (λ_1=514.5 nm) is used for vertical component velocity measurements. The measurement volume is 240 µm long (the PM slide width is 100 µm) with a diameter and fringe spacing of 150 µm, 4.2 µm and 142 µm, 3.8 µm for the streamwise and the transverse direction respectively. The receiving optics are placed 32° to the forward scatter direction to minimize the contribution of reflected light. The signals are processed by Burst Spectral Analyzers and all data are transferred to a PC before being post processed by specific Matlab programs. A sample is generally composed of 50,000 droplets.

For each case, radial profiles at two axial positions (X=8 cm and 15 cm) profile are measured. The behaviour of the polydispersion is analysed by separating the drops into several size classes of 30 microns.

Shadowgraph

The project used a standard shadowgraph technique with a 16-ns flash lamp. The size of the images is approximately 30x20 mm. The numerical camera is a PCO sensicam 12 bits with a resolution of 1280x1024 pixels, corresponding to 23µm per pixel. For each testing condition, several images (100 images) were taken and used to determine the amplitude and wavelength of the surface.

Image processing

The analysis of the images acquired with the numerical camera required the specific development of program. The role of this image processing is to determine the border starting from the original image. To make a success of this operation, we apply various filters, which we will present now.

The first stage consists in calculating the gradients of grey level in the image starting from a Sobel filter. Then a threshold separates spray boundary from the background image. After a tracking software follows the spray boundary from the nozzle to the liquid sheet disintegration. This image processing allows the calculation of wavelength, amplitude and length of the liquid sheet.

RESULTS

Experimental Condition

For the study, we take the same axial velocity (Uz) for the two nozzles. This velocity is measured by LDV; For this measurement, small glass particles (less than 20µm) are added to water for the seeding. Axial exit velocity is equal to 20 m/s. Table 2 shows Reynolds, Weber and Ohnesorge number for the four liquids tested based on this velocity value, and a length scale r equal to 1 mm.

$$\mathrm{Re}_l = \frac{u.r}{\nu_l},\ We_g = \frac{\rho_g u^2 r}{\sigma},\ Z = \frac{\sqrt{We_l}}{\mathrm{Re}_l} = \frac{\mu_l}{\sqrt{\sigma \rho_l r}},\ We_l = \frac{\rho_l u^2 r}{\sigma}$$

U=20 m/s	Re_l	We_g	Z_l
Water	20000	7.74	0.004
Water+ thickener	14300	7.74	0.0056
Water+ surfactant	20000	13.3	0.0053
Water+ thickener + surfactant	14300	13.3	0.0074

Table 2: Reynolds, Weber and Ohnesorge numbers of the four cases

Velocity and diameter profile are measured at 8 cm and 15 cm below nozzle. Velocity measurements is corrected by transit time function [3, 4].

Main characteristic of the two nozzles

In this section we present main characteristics of the two sprays generated by the two nozzles with water. In figure 2a radial evolution of the Sauter Mean Diameter (D32) at 8 cm and 15 cm from the nozzle is presented.

Spray spreading can be observed with axial distance: for the turbulent nozzle for instance, droplets can be found at 70 mm from the spray axis at 8 cm below the nozzle, whereas they can be found at 130 from the spray axis at 15 cm below the nozzle.

Moreover, concerning the hollow cone spray (left curves) D32 are close to 50 µm in the centre up to 250 µm at the edge of the spray, for the two axial distances from the nozzle. This is an effect of Stokes number, small droplets (low stokes number) move to the centre of the spray by the air entrainment and big droplets (high stokes number) stay in the direction of the liquid sheet.

Concerning the flat fan spray, it is not as polydispersed as the hollow cone one, and the mean diameter is larger. We can notice the presence of large droplets (>300µm) at the spray edge which have been created by stripping break-up as we could see with figure 5.

Figure 2b shows radial velocity profiles. As the exit axial velocity is equal to 20 m/s, we can notice that axial velocity decreases more slowly for the flat fan spray than for hollow cone one. This is an effect of the presence of biggest droplets and less air entrainment.

Figure 3 shows the axial velocity in function of the droplets diameter across test section. Axial velocity of the largest droplets (> 200 µm) reaches the double of the one of the small ones.

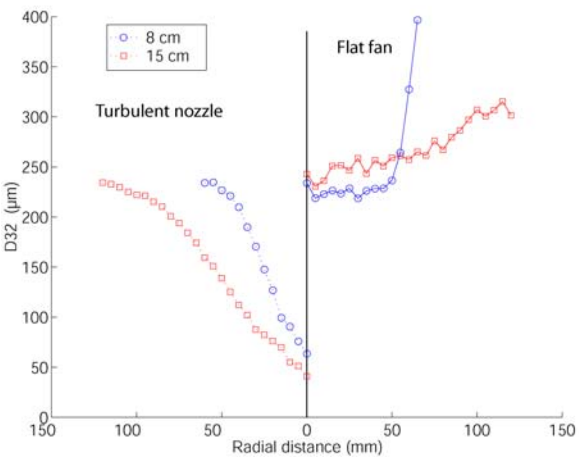


Figure 2a)

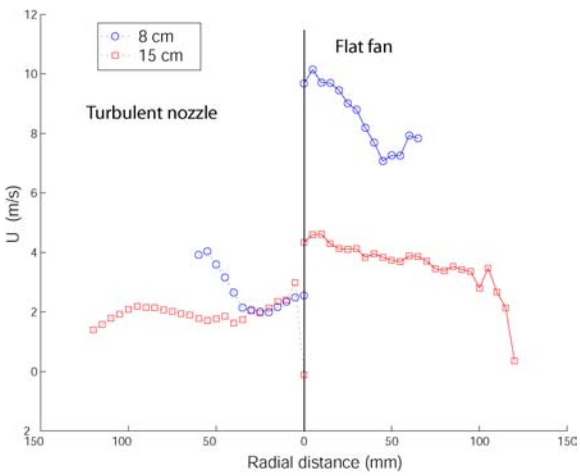


Figure 2b)

Figure 2: Evolution of Sauter mean diameter (2a) and axial velocity (2b) for the 2 nozzles at 8 and 15 cm

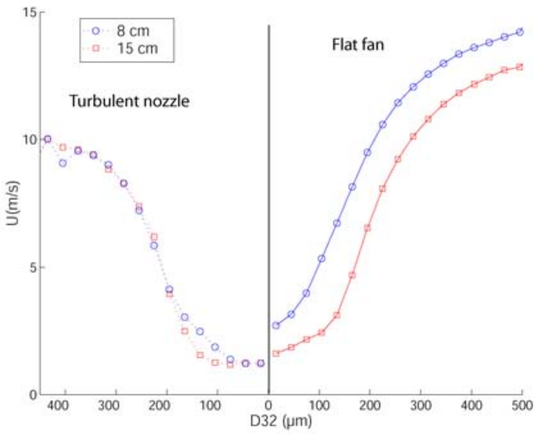


Figure 3) Axial velocity in function of the Sauter Mean Diameter for the 2 nozzles

Effect of fluid properties on liquid sheet length

The distance between the nozzle exit and the point where the sheet is totally atomised defines this length. The first perforation distance is defined as the distance from the nozzle exit to the first visible sheet perforation.

Hollow cone	Liquid sheet length (mm)
Water	4.69
Water+ thickener	5.06
Water+ surfactant	4.21
Water+ thickener + surfactant	4.48

Table 3: Liquid sheet length for hollow cone spray

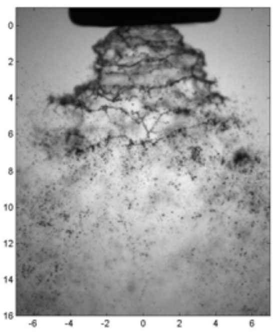
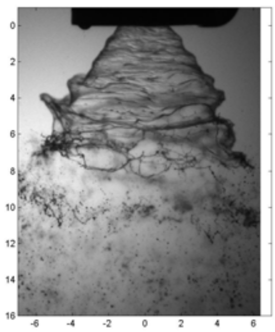
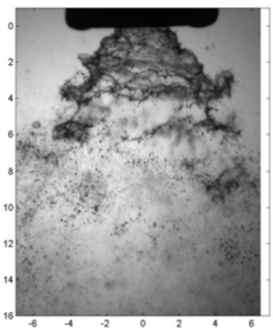
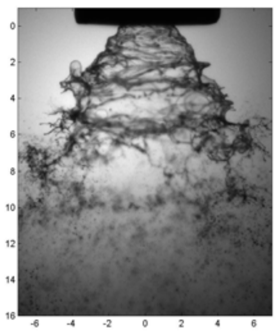
	Dynamic Viscosity = 1e-3 Pa s	Dynamic Viscosity = 1.4e-3 Pa s
Tension de surface = 62 mN/m		
Tension de surface = 36 mN/m		

Figure 4: instantaneous images for the turbulent nozzle

Flat fan	Liquid sheet length (mm)	First perforation distance (mm)
Water	18.57	18.25
Water+ thickener	20.75	15.39
Water+ surfactant	26.64	14.04
Water+ thickener + surfactant	21.89	12.68

Table 4 : Liquid sheet length and first perforation distance for flat fan nozzle

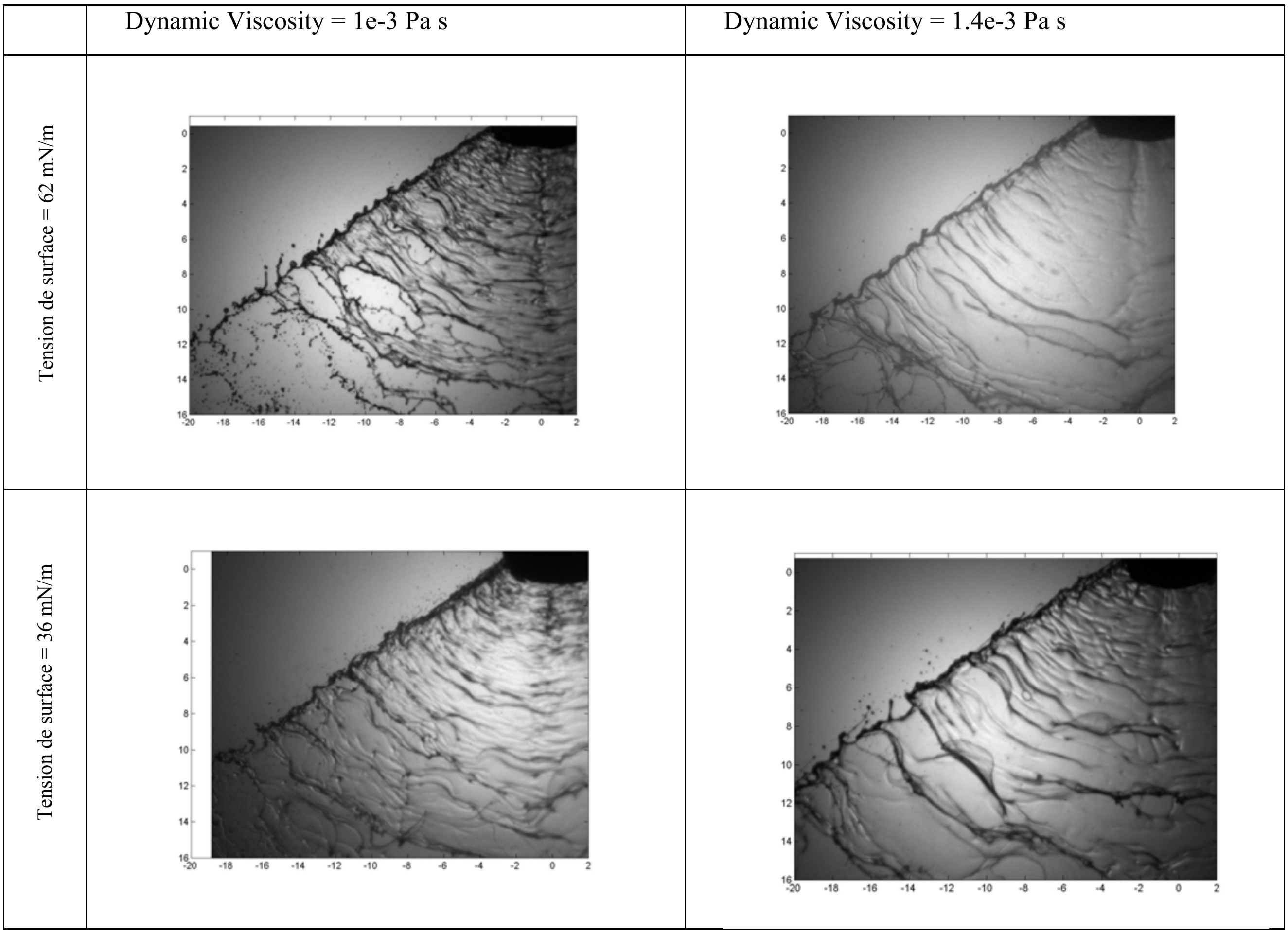


Figure 5 : Instantaneous images for the flat fan nozzle

Addition of a thickener agent increases the length sheet for two nozzles (cf. Table 3 and cf. .), because the wavelength of the more instable wave is increased also. The drift velocity between the liquid and the air creates this instability, which is dissipated by the fluid viscous forces [5,6]. On the contrary, addition of a surfactant decreases the intact length sheet, as the tension surface forces decreases. Addition of a thickener agent and a surfactant leads to a liquid length sheet smaller than in the case of water: influence of the surfactant seems to be more important than that of the thickener agent.

The reduction in surface tension gives a different effect according to the nozzle used. The reduction in the surface stress means a less great cohesion of the liquid and thus an acceptable reduction in the constraints by the liquid. In the case of the cone nozzle, two phenomena create constraints: oscillations due to the development of instabilities and the gyratory constraint due to the conical shape of the liquid sheet. This constraint is a function speed and axial distance. Thus if one decreases the surface stress of the liquid we arrive at the ultimate stress of the liquid at a lower distance, we thus decrease the length of liquid sheet In the case of the plane liquid sheet the constraints come from the development of instabilities. The reduction in the surface stresses causes to perforate the liquid sheet more close to the exit. However the perforation of the liquid sheet is not synonymous with atomization because as we said previously the surface stresses are responsible for the passage of filament in droplets. We thus obtain a perforated liquid sheet which will be atomized only when sufficient perforations developed. This fact the length of liquid sheet increases, but the length of the first perforation decreases.

Effect of fluid properties on the SMD

The last section compares evolution of SMD for the two nozzles with the four different liquids (figure 6) at 8 cm below the nozzle.

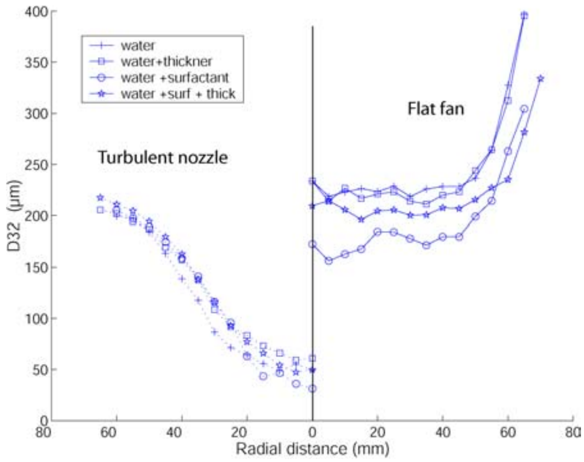


Figure 6 Evolution of Sauter Mean Diameter at 8 cm below the nozzles for 4 different liquids

For the turbulent nozzle, modifications of liquids property affect only small droplets (D32<100µm). Addition of a thickener agent means an increase of viscous forces, which prevent the hollow cone sheet from atomisation: D32 are therefore larger than in the case of water solution. . On the contrary, addition of a surfactant means a decrease of tension surface forces, which prevent the sheet from atomisation: D32 are therefore smaller than in the case of water solution [5, 7].

CONCLUSION AND PERSPECTIVES

The influence of liquid properties on spray formation has been experimentally studied. Four different liquid solutions and two nozzles have been chosen.

Shadowgraph images show the way the liquid is atomised into droplets: sheet perforation occurs for the flat fan nozzle, whereas the hollow cone sheet is atomised without perforation.

Droplet velocity and diameter PDA measurements have been performed in every case: addition of a thickener agent tends to increase the Sauter Mean Diameter whereas a surfactant liquid solution is atomised into smaller droplets.

Those results could be useful for numerical models of spray transport.

Anyway, in the future, more precise measures of air and droplets velocity leading to some information about liquid/air interactions could contribute to the spray formation comprehension.

NOMENCLATURES

Re_l : Reynold number of liquid (dimensionless)

Z : Ohnesorg number (dimensionless)

We_g:Weber number based on inertial gas forces (dimensionless)

We_l:Weber number based on inertial liquid forces (dimensionless)

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