Published in : Aspects of Applied Biology (2006), vol. 77.
Status : Postprint (Author's version)

Experimental evaluation of a spray drift Gaussian tilting plume model

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Summary

An experimental evaluation of a Gaussian tilting plume model adapted to ground spraying drift is presented. The spray drift deposit of each droplet diameter class measured by a laser particle analyser is computed independently. The summation of these footprints results in the global drift of the nozzle. The methodology is applied to derive from the model the drift of a flat fan nozzle located in a wind tunnel. Discrepancies from experimental data are commented and potentialities for further improvement of this approach are discussed.

Keywords : drift ; Gaussian tilting plume model ; spray nozzle ; droplet spectra

Introduction

The objective of this paper is to evaluate some adaptation to the Gaussian tilting plume model to better take into account the characteristics of the spray application, as those model have proved their efficiency in aerial pollution dispersion where they describe the diffusion of a particle cloud emitted upward from a point source (Reible, 1998). To be applied successfully to the spray drift, the evaluated model has to give accurate predictions of the deposit regarding the spray and material characteristics (nozzle type, boom speed, spray height, pressure, distances between nozzles, nozzle orientation, liquid properties, crop kind and growth) as well as the weather parameters (mean wind speed and direction, wind turbulences or atmospheric stability, relative humidity, temperature.). To reach this objective, the model parameters must be correctly set based on theoretical and experimental data.

Materials and methods

Footprint parameters settings

The drift dispersion model proposed by Stainier et al. (2006) can evaluate the spray drift deposits under a moving boom as long as the spray deposits, i.e. computed using a spray deposits model (Lebeau, 2004), are convolved with the drift of the nozzles. The drift estimation lies on the following theoretical equation (equation 1), further called "footprint," where the particle flow rate at ground level is given by the product of sedimentation speed and the particle concentration reaching the ground.

$$q_m = v_p C(x,y,0;Hs) = \frac{Q_m v_p}{2\pi\sigma_y\sigma_z U}\exp\left[-\frac{y^2}{2\sigma_z^2}\right] - \left[\frac{\left\{\left(Hs - \frac{v_p x}{U}\right)\right\}^2}{2\sigma_z^2}\right] \quad (1)$$

with q_m: particle deposit rate ml/(m^{2}s).
v_p: sedimentation speed of particles (m/s).
C(x,y,z;Hs): deposits in function of the position in the win direction (ml/m^3);
x: horizontal distance along the wind direction (m);
y: horizontal distance along the perpendicular direction of the wind (m);
z: height from the ground (m);
H_s: modified height of the particles emission point (discharge height) (m);

Q_m: particle flow rate (ml/s);
$\bullet_y$: dispersion coefficient along y axis (m);
$\bullet_z$: dispersion coefficient along z axis (m); U: mean wind speed along x axis (m/s);

In the drift model, some of the footprint function parameters are essentially dependent on the droplet size. It is therefore needed to evaluate the footprint of each droplet size, or at least of a sufficient number of homogeneous droplet class independently. The global footprint can then be evaluated as the sum of footprints obtained with homogeneous droplet size class reflecting the spray droplet spectra. At the present stage of research, the effect of the droplet diameter on the footprint function parameters was evaluated from fluid mechanics equations and available literature resources to get a first glance at the model capabilities and limitations.

Modified discharge height (Hs): The modified discharge height reflects the nozzle height less the distance travelled by the droplets from the nozzle under the effect of their initial speed, vertical drag force and gravity. To estimate the length to be subtracted from *h* in the proposed model to evaluate *Hs* as a function if the droplet diameter, an analogy with Miller (1996) considerations was used: Within the spray fan, smaller droplets slow down faster than larger ones do. Ghosh and Hunt (1994) have estimated the variation of droplet velocity with distance below the nozzle by:

$$V_l = V_{l0} e^{-\lambda(r-r_0)} \qquad (2)$$

$$\text{Where} \qquad \lambda = \frac{3C_D \rho_a}{8a\rho_l} \qquad (3)$$

With V_l: droplet velocity at a distance 1 from the orifice (m/s)
V_{l0}: initial droplet velocity (m/s) r: distance from the nozzle (m)
r_0: length of the liquid sheet below the nozzle where droplets form (m)
C_D: drag coefficient
$\bullet_a$: air density (kg/m^3)
$\bullet_l$: liquid density (kg/m^3) a: droplet radius (µm)

Modifying the equations (2) and (3) it is possible to estimate a distance from the nozzle where the droplet decelerates to a fixed velocity. It is assumed that under a set velocity, the droplet is subject to drift transport. The value of this critical velocity has to be adjusted. *Hs* is evaluated for each droplet class with Vl/Vl_0 as the parameter to fit.

In our case, the parameters were estimated respectively as: V_l = 4.6m/s; V_{l0} = 20 m/s; r = 0.5 m; r_0 = 0.025 m; C_D = 1; $\bullet_a$ = 1.293 kg/m^3; $\bullet_l$ = 1000 kg/m^3

Particle flow rate (Q_m): The particle flow rate in a particular droplet class was evaluated as the droplet percentage in that class multiplied by the nozzle output (0.781/min).

Dispersion coefficient along y-axis ($\bullet_y$) and dispersion coefficient along z-axis ($\bullet_z$) : The Dispersion coefficients were set to 0.05 m corresponding to the turbulence intensity on bare ground in stable conditions (Anonymous 2002).

Mean wind velocity along x-axis (U): The mean wind speed was set equal to 2 m/s.

Sedimentation speed (v_p):. Sedimentation speed of the different droplet sizes was evaluated using strokes law, neglecting the Cuningham correction factor (Reible, 1998).

Experiments

Spray characteristics: The droplet size spectra of a Lechler 120-02 flat fan nozzle (FF110/0.8/3.0) was measured at 3 bar pressure, perpendicular to the nozzle distribution main axis using a Malvern Particle Analyser (Mastersizer S) 150 mm down the nozzle tip, at 3 locations: centred under the nozzle and 30 mm left and right from this position. These 3 measurements of spray droplets size distributions were used to determine the percentage of spray within 30 droplet classes.

Spray drift trials: The drift of this nozzle for water was determined in the aerodynamic wind tunnel facility at Gembloux Agricultural University, Belgium. This is a closed loop recirculating wind tunnel able to generate a range of 0 to 6m/s wind speed. To minimise inherent turbulence intensity, the wind tunnel has a1m long honeycomb with a monoplane wind-break grid upstream and a porous textile sheet downstream to produce the desired turbulence intensity and mean uniform velocity profile. The test section of the wind tunnel is 2 m wide, 2 m high, 6 m long and located 1 meter downstream of the fabric. The blower located at the loop opposite to the test section drew air through the tunnel at the desired velocity within the range 0-6 m/s. During the tunnel measurements, relative humidity and temperature are set using air conditioning and atomisation nozzles placed before the blower. The wind speed (2m/s±1%), relative humidity (80±1%) and temperature (20±1°C) are controlled and recorded by an industrial controller.

The nozzle spraying (3 bars ±0.5%) is moved horizontally through the wind tunnel thanks to a computer controlled servo-motor traversing mechanism at a 2 m/s speed, perpendicular to the air flow. It was chosen to perform the drift measurement after 10 passes of the nozzle across the working section of the wind tunnel in order to increase the spray deposits. The drift was evaluated by measuring the ground spray deposits on 50cm^2 glass fibber collectors using a fluorescent tracer dye technique. A 2 m/s wind speed and 0.5 m nozzle height were chosen. The deposits were measured every 0.1 m from 0.7 m before the nozzle to 6.1 m downwind the nozzle. Four fibber glass collector, 25 mm wide and 50 mm long were fixed to a clean tile with a rubber band for each sampling point to avoid unwanted contamination of the sampler with some residue on the tunnel floor. The rubber band was parallel to the air flow to limit the effect on the collector efficiency. The samplers were collected directly after the trial in 50 ml plastic tubes and stored in darkness. Fluorescein sodium salt (Sigma-Aldrich) was extracted after 5 minutes agitation in di-potassium phosphate buffer solution (K_2HPO_4, pH9) and quantified using a RF-1501 Shimadzu fluorometer with a combination of a primary and secondary filter of respectively 460 nm and 540 nm. From the reading of the fluorometer, the calibration line, the collector surface area, the dye concentration and the volume of solution, the amount of spray deposit per unit area was calculated.

Spray pattern: the two-dimensional spray distribution was measured inside the wind tunnel facility. The nozzle was set centred static in the tunnel section. 50mmx50mm Glass fibre collectors were centred under the nozzle rectangular 100mm edge square sampling grid, 1800mm wide and 800mm long. The nozzle was controlled to spray 2s without any wind and the 144 collectors deposits were measured as for the drift trials.

Model computation

The drift deposit was computed using Matlab 7.1 (MathWorks inc, Natick, MA) follows next steps:

- Based on granulometer measurement, the spray droplet population may be divided into 29 non-zero homogeneous size droplet class (20µm wide classes for example, Hobson et al., 1993)

The spray distribution under the moving boom passing ten times perpendicularly across the wind tunnel was evaluated using the model developed by Lebeau (2004), using the measured static spray pattern.

- Each droplet class footprint was computed modifying the size sensitive parameters

- Drifted spray deposits for each class are computed as a two dimensional convolution of the product of the percentage of droplets multiplied by the spray distribution with the corresponding footprint

Global drifted spray deposits are calculated as the sum of the drifted spray deposits for every droplet classes.

Results and discussion

Nozzle spray pattern : Figure 1 presents the result of the two-dimensional static spray pattern. The nozzle was mounted with the recommended angle used to avoid adjacent spray interference

Number of droplet classes: the Malvern measurements shown in figure 2 are composed of 30 classes that are used as model input classes.

Modified discharge height (Hs): by combining the equations (2) and (3) it is possible to find a distance from the nozzle where the air velocity reaches a fixed value. An optimum value of the droplet speed that minimise the sum of square deviates was computed. The best fit was found for 5.6m/s terminal velocity. This model results in a linear function of height. Figure 3 presents the resulting modified discharge height, where negative values are set to zero.

Measured and computed drift deposit: Figure 4 presents measured and modelled drifted spray deposits along the wind direction axis. The model presents a good general agreement with the measured deposits. However, the discrepancies appear to be systematically located. In the spray pattern zone, from -0.7 to 1 m, it is observed that the modelled nozzle spray pattern is a bit wider and displaced to the right than the measured one. This reflects a too large diffusion and wind transport of the large droplets, what means that their sensitivity to drift transport and diffusion is overestimated. Furthermore it is observed that the measured deposits present irregularities in the bell-shaped curve that can be related to the nozzle spray pattern. These irregularities are smoothed by the model, what can reflect an exaggerated diffusion of the big droplets but most probably that the dynamic effect of the nozzle movement (Lebeau, 2004) on the spray pattern was not taken into account. This last effect can also be related to the simplistic and erroneous assumption of even distribution of the spray droplets diameters inside the spray. In the drift zone, from 1 to 6.1 m, it is observed that the spray deposits are underestimated, what reflects that the effect of drift on small droplets is underestimated. However, the drift further that 5.8 meters appears again overestimated. A better estimation of the footprint parameters is thus needed to further improve the model performance.

Figure 1 : *Spray pattern of the LU120-02 nozzle, water, 3 bars*

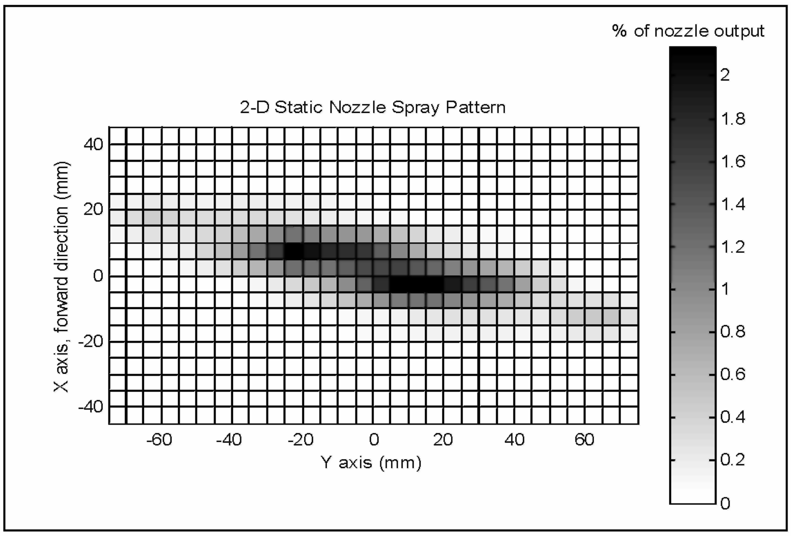


Figure 2 : *Spray droplet spectra of the LU120-02 nozzle, water, 3 bars*

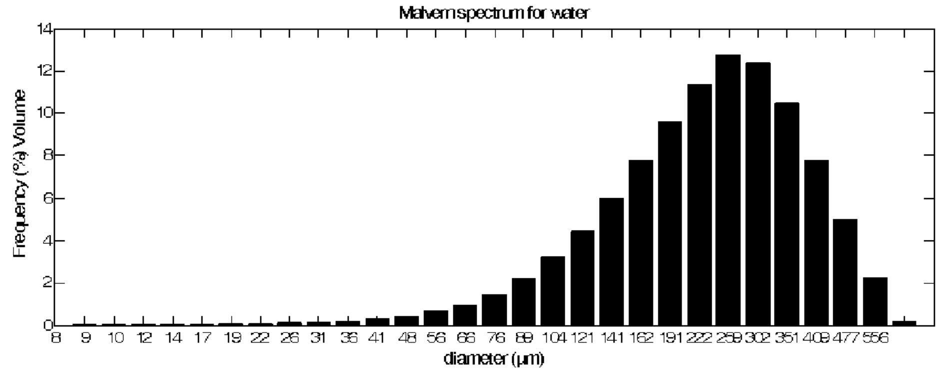


Figure 3 : *Modified discharge height as a function of droplet diameter*

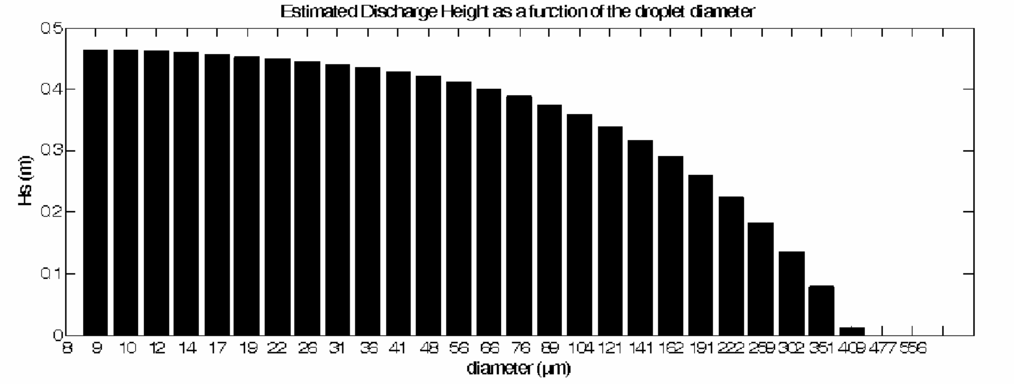
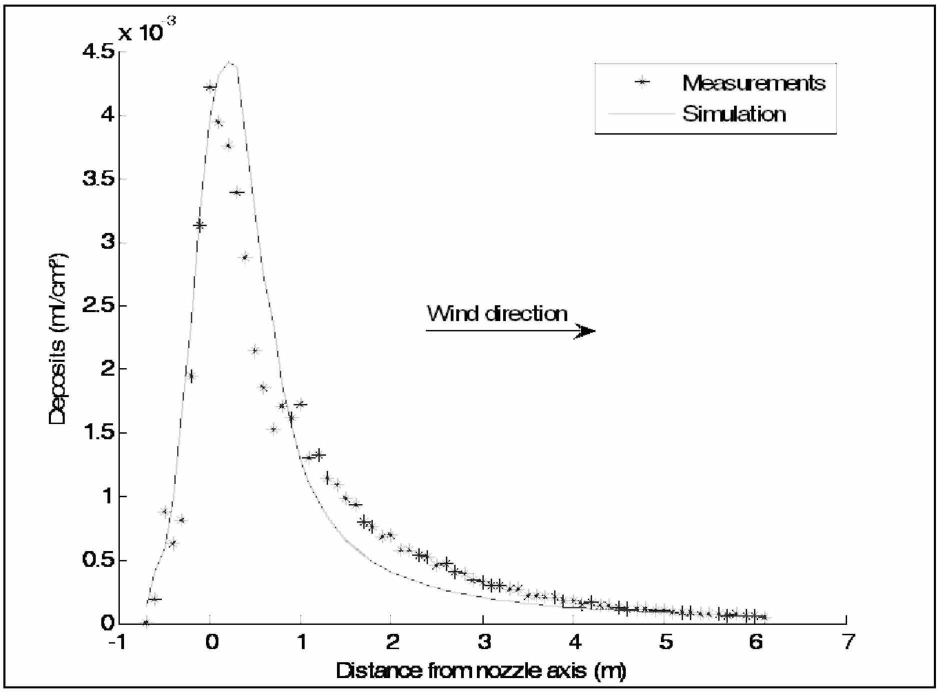


Figure 4 : *Measured and modelled drifted spray deposits*



Conclusion

Based on literature resource and fluid dynamic equations, the effect of the most important characteristics of spray droplets of an agricultural nozzle was included into a Gaussian tilting plume model by individualisation of the drift effect on the different droplet classes. Although the simple theoretical basis, the first evaluation of this approach showed that the model was capable to predict drift with a relatively good agreement with the experimental results. The remaining discrepancies could be explained to be related with the poor fitting of the different model parameters, suggesting further amelioration on the basis of parametrical optimisation.

Acknowledgements

This research was funded by the Walloon Region - General Directorate for Agriculture.

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