Modeling Spray Droplet Size in Order to Environmental Protection

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Received: November 10, 2011 Accepted: January 19, 2011 Published: February 1, 2012
doi:10.5539/sar.v1n1p151 URL: http://dx.doi.org/10.5539/sar.v1n1p151

Abstract

Million liters of annual toxic solutions are used to combat pests and plant diseases and weeds in farms. Drift is one of the most critical problems which chemical applicators have to deal with. Wind drift would be highly controlled if the droplet size could be kept almost constant in stable atmospheric conditions.The most important factor in spraying is droplet size which is influenced by several factors including; spraying pressure, nozzle orifice diameter, the chemical viscosity and wind speed in the region. In this study factors affecting particle size have been studied using statistical methods. Nozzle orifice diameter and spraying pressure were considered as independent variables and particle size was chosen as the dependent variable. Analysis of variance showed that the effect of pressure and nozzle diameter and their interactive effect on particle volume mean diameter (VMD) were statistically significant at the 1% level. In order to compare the results estimated from regression equations and observed particle diameter chi-square test was used. Based on this test, the difference was not significant .

Keywords: Maintaining, Particle size, Pressure, Spraying

1. Introduction

Each year about 25 to 35 percent of total world agricultural crops be devastated by insects, weeds and plant pathogenic. This amounts increase to 80 percent in non-combat status(Mansourirad, 2005). Drift (toxin movement by air currents) of the distributed place may lead to contamination of nearby crops that are grown for human consumption or animal. Droplet size and distribution of pesticides are the main factors that will determine the treatment efficiency. Liquid pesticides may be contact or absorption type. With Contact pesticides, pets are disappeared. To have full effect this material is better to be distributed as fine particles at all levels. Absorbed toxins are absorbing by the organs of the plant and move within theirs. These materials do not need to be sprayed at all levels. They are better to be in a coarse size. They are less susceptible to drift.

Use of pesticides, has improved quality and quantity of products, but the widespread use of chemical pesticides has resulted to some serious environmental issues. One of the most critical issues is movement of pesticide droplets that happens by air travelleing during or after spraying to elsewhere other than the desired location. Pesticide residues can be removed from products by surface water ,waste and air containing these substances into the environment. Problems with this issues can be reduced if pesticides are applied by controlling particle size in accordance with purpose of spraying and environmental conditions and climate while decreasing contamination to the environment. Determining and applying desired droplet spectrum for any purpose is desired. Fine particles are slower deposite than the coarse particles due to be having larger aerodynamic drag forces than the particle mass. Movement of pesticide will become even more dangerous in the future when applicators use more genetically modified crops owing to small amount of these herbicides can result serious damages on neighboring crops. (Zhu, 2005). Determining and applying the desired droplet spectrum for each targeted pest can help us to mininize the spray dirift and problems that followed by.

Droplet size spectrum has been considered as the variable that has the most influence the wind movement of spray droplets (SDTF, 1997).

Water-sensitive papers (wsp) are often used as an indicator for the presence of spray deposition Water in the spray stains the wsp and the spot size can be observed or measured (Syngenta, 2002). Womac *et al*. (1997) reported that droplet spectrum varies with every combination of tip style, size, operating pressure, and spray liquid. Some spray deposition tests use water-sensitive papers (wsp) as an indicator of the spray droplet spectrum (Matthews, 2000).

Another issue is that the smaller particles instead of depositing in the target sites may be travelling and scattering several thousands away. Also vaporized chemical active ingredients in the atmosphere may sever this happening that ultimately lead to more pollution in environment. So It is better to use the appropriate spectrum of the droplets size due to good coverage and minimize drift.

The median diameter of particles based on the number, length, surface or volume can be divided into two equal half. Usually D_{xf} be used for the median diameter. Where instead of x can be placed V for the volume, A for the area, L for the length or N for the number of drops and the f is percentage of the cumulative frequency. (VMD=$D_{V0.5}$) is the volume median diameter that means 50% of the volume of the particle diameter is less than the median and 50% of the particles is more than the median.

Farooq *et al*. (2001) studied the spray from an agricultural flat fan nozzle in a wind tunnel with a non–uniform crosswind velocity profile to examine the movement of the droplets in the wake of the spray pattern. the pressure and mean cross wind were 275 kPa and 5 km/h. The results indicate droplets <100 µm diameter were separated from large droplets and moved downwind.

Womac and Bu (2001) in order to operate with variable-rate technique designed a sample nozzle was as VFFN. Three examples of this type of spray nozzles with angles of 50, 70.90, was built and evaluated. With pressure adjusting of 138 to 414 kPa, ranges of $D_{V.5}$, $D_{V.1}$ and $D_{V.9}$ Was controlled from 190 to 58 mm, 522-141 mm and 850-300 mm respectively. Direct control of flow rate and droplet size spectrum was achieved by separately varying line pressure and control pressure.

Wolf *et al*. (2009) concluded that nozzles with smaller droplet spectra tend to have better coverage and deposition. He used water sensitive paper (wsp) for collectting spray droplets. Flow rate for Laboratory comparisons of nozzles was 0.95 L/m. Operating pressures were 193, 276 & 483 kPa. He found significant differences between all three droplet characteristics. The venturi TTI11002 at 483kPa had the largest $D_{V0.5}$ and least coverage .The XR11003 nozzle at 193 kPa had the smallest $D_{V0.5}$ and most coverage.

Zhu *et al*. (2005) has offered a computer program(DRIFTSIM) to estimate the mean drift distances of the water particles discharged from atomizers on field sprayers. The effect of various parameters like wind speed, particle diameter and height of pesticide spraying on the drift is obtained with a flow simulation program (FLUENT).

2. Materials and Method

During application it is desired to keep the particle size constant which affects drift and amount of chemical on the target In this study effect of spray pressure and nozzle orifice diameter on volume median diameter was obtained from the regression equation. No known study is available on the effect of pressure spraying and nozzle orifice diameter on spray droplet size. For this study the use of a full spraying circuit was inevitable. the primary step in this research is design and fabrication of full spraying circuit. The system included an electropump(source of the power), specific nozzles (different in exit diameter) and the test panel.

According to previous studies, the maximum pressure spraying was considered 5 bar. Water was used as chemical application. The plastic hose was used for liquid transfer. Dynamic viscosity of water is 0.98 Mpa.s. By according to the specifications of nozzles (corresponding to the maximum pressure) maximum flow rate was achieved (Tabel 1). Profile nozzles are shown in Table 2. Three solid cone nozzles were used**.** Maximum pressure of the nozzles was 40 psi in the equivalent of 2. 785 bar. In 5 bar pressure, 5.765 liters per minute was gain as maximum flow rate. Usually there are no leaks in the new system. To ensure safety 20% of the maximum flow rate was accounted as leakage. Flow rate obtained at a pressure of 5 bar was multiplied at 1.2 to calculate the total flow rate. Reynolds number was obtained by the equation1 (Behrouzilar, 2000).

$$\mathrm{Re} = \frac{4.c'.\rho.Q}{\pi.\mu.d} \tag{1}$$

R_e: The Reynolds number

ρ ($\frac{kg}{m^3}$): Specific gravity of fluid

C': Unit conversion constant equal to 16.67

Q($\frac{L}{\min}$) : Current through the conductor

μ(mpa.s): Viscosity of the fluid dynamics

d(mm): The inner diameter of the conductor

Total length of using hose was 370 cm with 15 mm as inner diameter. The Reynolds number was gained 9993.76. because of the being the Reynolds number more than 4000 the flow was considered as turbulent. For fully turbulent flow, pressure drop was calculated from the equation 2 (behrouzilar 2000).

$$\frac{\Delta p}{L} = \frac{/0333\mu^{0/25}\rho^{0/75}Q^{1/75}}{d^{4/25}} \tag{2}$$

Δp (MPa): pressure decrease

L (m): Conductor length is equal to the pressure drop occurred in

$$\Delta p_1 = 6/424\ kPa$$

Transmission path consists of the right hose and four siphon hose. According to Hydraulic laws , equivalent length and pressure drop data for the siphon hose was obtained (Dalayeli & Madineh):

$$L_e = 154/141\ cm$$
$$\Delta p_2 = 2/675\ kPa$$

The maximum total drop pressure added pressure spraying (5 bar) to calculate the total pressure.

$$\Delta p = 6/424 + 2/675$$
$$\Delta p = 9/099\ kPa$$

Total pressure of the system was set up by:

P=50+9 /099

P=59 /099 kPa

In this device transmission was done directly from the Electro pump. A pump power was calculated by pressure spraying and the mechanical efficiency. Mechanical efficiency of pumps that can be used to estimate this power is usually considered 60-50%. The equation 3 was used for the pump power (Behrouzilar, 2000).

$$P = \frac{Q*p}{60000*\eta_m} \tag{3}$$

P = 118/198 kPa

P (kW): power

Q $(\frac{L}{\min})$: flow rate

p (kPa): pressure

η_m: Mechanical efficiency

power for the total pressure can be obtained as follows:

Power =13/628 W

The electro pump was selected with regard to Market Features and Calculations obtained (figure1).

Profile pumps are :

Maximum height (pressure) = 45 m

Max Flow = 50 (L / min)

Production capacity by electro pump was obtained by equation 4.

$$P = Q * \rho g h \tag{4}$$

P = 367 W

So the prepared Electro pump can easily privide the test operations.

After making this device, tests were performed to determine the mathematical relations between independent variables and the dependent variable (tabel 3). After preparing the test panel, nozzle hight was set in 75cm. The pressure for each treatment was created by using a flow control valve. pressure gauge were used to monitor the pressure for each treatment. The treatment solution was tap water. The exit nozzle diameter and pressure were regarded as independent variables and particle size as the dependent variable. Each factor with three levels were evaluated in a factorial experiment with five replications. Experiments were done in 24 ºC environmental temperature and 40% humidity(Accordance with the the average summer condition in East Azarbaijan in Iran). With the use of special papers (wsp) on the table, samples were collected. After all treatments and replications were completed and dried, the collection papers were placed in prelabeled-sealable bags for preservation. Data envelopes were used to organize and store the papers until analysis was complete. Water-sensitive papers were scaned with HP Scanjet 3800 scanner by 300 dpi resolution. Marcal and Cunha (2008) evaluated a fully automated method based on image processing to improve water quality and sensitive to the toxins in papers. Scan samples were tested with different resolution **.**The maximum scanning resolution was gain in 600 dpi. By consideration the scanner features and a proper speed of processing, 300 dpi resolution was chosen. SIBA software was used to analyze the papers. The software is used on the prestigious research centers such as East Azarbaijan Engineering Research Center. Output data analysis display on the Notepad page. Analysis of particle numbers, the number of pixels for each particle, particle surface area per mm^2, and the center coordinates of particle diameter is based on mm. Statistical analyses of the data were conducted with spss software Statistics 18.

3. Results and Discussion

Pressure and nozzle diameter were considered as independent factors and VMD (volume median diameter) as independed factor. Significant differences were found in volume median diameter ($D_{V0.5}$) for the three nozzles and three pressure levels. The data obtained had normally distribution in accordance Kolmogorov-Smirnov test. Kolmogorov-Smirnov test is based on the maximum absolute difference between the observed cumulative distribution functions for both samples. When this difference is significantly large, the two distributions are considered different (help of spss 18 software). The analysis of variance on pressure and nozzle orifice diameter versus VMD is shown in Table 4. Effect of each factor alone and their interaction was significant in the level 1% probability. Graph of the interaction showed the differance is the kind of change in value (figure 2).

At high pressure particles size were smaller than low pressure. Between different exit diameter of the nozzle there was a significant difference in VMD. Most VMD was obtained in the nozzle with 3.2 mm in hole diameter and its minimum was obtained in the nozzle with 1.6 mm. In hole diameter VMD range was obtained from 130 micrometer in the nozzle with 1.6 mm in hole diameter at 5 bar pressure to 885 micrometer in the nozzle with 3.6 mm in hole diameter at 4 bar pressure. VMD mean at different pressure levels and exit nozzle diameter can be seen in table 2. In this study, a linear modle express relation VMD with the nozzle exit diameter and pressure according to the treatments. Equation obtained for the mean volume diameter (Y) and pressure spraying (X1) and the nozzle diameter (X2) is:

$$Y= -95.60x (X1)+155.192x (X2)+ 518.269$$

Coefficient of determination in above equation was obtained (r^2=0.834). Standardized coefficient associated with the nozzle diameter was much greater than pressure . Thus the nozzle diameter had more effect on particle size than spraying pressure. The most amount of VMD was obtained in largest exit diameter nozzle at 4 bar spraying pressure (table 5). As evidenced in this study for a constant diameter nozzle, increasing pressure led to reduced droplets size. Difference between pressure 3 and 4 bar was significantly but between 4 and 5 bar was not dramatically different. For a constant pressure, by increasing nozzle exit diameter, particles size increased. Significant differences were found in pressure 3 and 5 bar on nozzles with 2.4 and 3.2 mm exit diameter but in pressure 4 bar there were uniformity difference among nozzles with different exit diameters. Considering the effects of each nozzle, pressure has less effect on volume mean diameter in nozzles with larger exit diameter.

Another finding of interest is that max VMD has occurred in 4 bar and the nozzle with 3.2 mm exit diameter. The results of Womac and Bu experiments showed that the volume mean diameter in the range 141-522 mm with a working pressure range 138-414 kPa was controlled. In the studies of Wolf *et al.* volume diameter was smallest of the XR 11003 nozzle with the smallest diameter of the nozzle 12 in working pressure of 483 kPa. VMD was the largest of the TTI 11002 nozzle that had the largest diameter in the rest of the nozzles at a pressure of 483 kPa. this nozzle had the minimal overlap and deposit in comparison with others. Womac and Bu achieved in the nozzles VFFN a linear relationship for the flow rate in VMD by using different working pressures. Coefficient for this equation was obtained at different pressures could be seen in Table 6.

$$D_{V0.5}=(slop).\ Q + intercept$$

As can be seen above the maximum working pressure coefficient has been obtained in maximum pressure.

After deriving the mathematical model, spraying system was adjusted based on that model and more tests were conducted to evaluate the model. In order to compare the results estimated from regression equations and observed particle diameter chi-square test was used. Based on this test, the difference was not significant. The minimum and maximum error were observed for the nozzle diameter 2.4 and 3.2 mm respectively. In nozzles with larger diameter, the error was higher due to adhesion of particles in water-sensitive cards. The results show that changing the pressure (due to the change in flow rate) particle size can be controlled. this is one of the most important issues in precise spraying. Different particle size (for any possible reason) can be diagnosed. Selecting appropriate nozzles and spraying pressure to obtain the desired particle diameter in every working conditions can prevent excess intake spraying. In addition drifting which has heavy reliance with Particle spectrum can be prevented.The diagrams obtained from the research of Zhu *et al.* showed that in particles with the range of 250-300 mm in any wind speed at 75 degrees Fahrenheit and 60% humidity environment, the drift distance was very small. Particles with a diameter of 50 mm had the maximum drift and particles with a diameter of 200 mm had the lowest drift.

4. Conclusions

Chemical pesticides had and will have a great role in the improvement of agricultural productions. By using these chemicals, quality and quantity of products are incremented. Using pesticides to control weeds have greatly reduced workforce. However, widespread use of chemical pesticides have resulted in some serious environmental issues. In order to reduce these destructive effects on the environment, some necessary actions should be carried out. Certainly, the most important issue is the control of particle size. Standardized coefficient associated with the nozzle diameter was greater than spraying pressure. So the nozzle orifice diameter had more effect on particle size.

The results of this study, considering droplet sizes, showed that nozzles with smaller exit diameter could produce smaller drolet size and higher spraying pressuretend to provide smaller droplet sizes. According to data from experiments droplets spectrums generally can be controlled by adjusting sprying pressure. This is one of the most complex issues in spraying with variable rate (VRT) that in modern agricultural is in special attention**.**

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Table 1. Pressure and flow characteristics of nozzles used in the experiment

30-DC-04	30-DC-06	30-DC-08		pressure (psi)
1/11	1/55	2/33	flow rate	20
1/36	1/89	2/73	(L/min)	30
1/59	2/20	3/18		40

Table 2. Profile of nozzles used

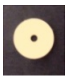
figure	Exit diameter nozzle	Nozzle number	Nozzle type
	3.2mm	DC- 08-30	White nozzle
	2.4mm	DC- 06-30	Yellow nozzle
	1.6mm	DC- 04-30	Red nozzle

Table 3. Different levels of experimental factors

levels	factor
P1=5 bar	Pressure spraying(P)
P2=4 bar	
P3=3 bar	
D1=1.6 mm	Nozzle diameter (D)
D2=2.4 mm	
D3=3.2 mm	

Table 4. ANOVA output pressure and nozzle diameter on a volume mean diameter

F	Mean Square	Degree of freedom	Source changes
**73.299	142214.668	2	Pressure(P)
**125.144	242804.470	2	nozzle orifice diameter (D)
**5.649	10961.058	4	P*D
	1940.195	36	Test Error

**Significant at one percent level

Table 5. VMD mean in different levels of each factor

Average value	Factor levels	Factor
423.400	5(bar)	
486.987	4(Bar)	pressure
614.600	3 (bar)	
11.37 = LSD $_{0.05}$		
400.277	1.6(mm)	
476.227	2.4(mm)	nozzle orifice diameter
648.933	3.2(mm)	
11.37 = $_{0.05}$ LSD		

Table 6. The coefficient of the equation in different pressure obtained by Womac and Bu

pressure	slope	intercept	r^2
138	13.99	554	0.857
207	26.16	408	0.805
276	35.45	297	0.868
345	34.63	225	0.853
414	34.24	169	0.940

Figure 1. Fabricated sprayer device

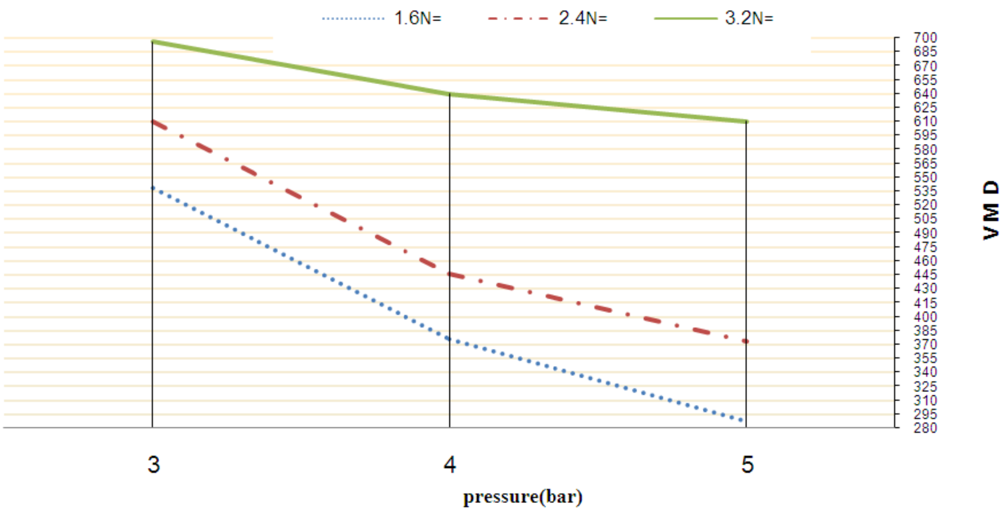


Figure 2. The effect of pressure and nozzle exit diameter on VMD