Performance characteristics of a double chamber twin fluid nozzle

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Summary

The performance characteristics of a double chamber twin fluid nozzle are described. In the design, air is always supplied to one of the chambers but is only supplied to both when the air pressure is sufficient to open a diaphragm fitted in the air line. This arrangement allows low volumes of low pressure air to be directed to one of the chambers so as to generate extra coarse to coarse sprays. Increasing the air pressure opens the diaphragm and air enters the second chamber enabling coarse to fine spray sprays to be generated depending on air pressure and liquid flow. In this way spray qualities from fine to extra coarse were generated at flow rates from 800 to 1600 ml min^{-1} without changing the nozzle tip. Measurements of the spray volume distribution pattern when operating with three different spray liquids and a range of settings gave coefficient of variation values that were consistently less than 10%. Wind tunnel studies using an air pressure of 40 kPa and liquid flow rates of 800, 1200 and 1600 ml min^{-1} showed that drift was less than 75% of that from a conventional reference hydraulic flat fan nozzle.

Key words: Spraying, drift, droplet size, double chamber twin fluid nozzle

Introduction

Existing commercial designs of twin fluid nozzle enable a range of flow rates and spray qualities to be generated by varying both liquid and air input pressure (Young, 1991). However, their flexibility is limited particularly in their ability to generate a fine spray at liquid flow rates much above 1.0 litres min^{-1} and yet there is a need for up to 1.5 litres min^{-1} to accommodate the demand to increase sprayer speed (Combellack *et al.*, 2001). The nozzle design described in this paper creates a vacuum to help draw in both air and liquid and a second air stream is used to further enhance the flexibility of droplet generation (Combellack *et al.*, 2002). The droplets generated by all twin fluid nozzles contain air inclusions (Combellack & Miller, 2001). A simple way to estimate the volume of air included, based on density, has been reported (Combellack & Miller, 2001; Combellack *et al.*, 2002). All droplet size measuring instruments measure the volume of both liquid and air inclusions. It has been recognized that droplets with air inclusions behave differently from those from conventional nozzle designs and that conventional spray classification approaches are not appropriate (Miller *et al.*, 2002). Measured droplet sizes can be recalculated, by deducting the volume of included air, so that the VMD represents the liquid volume (Miller & Combellack, 2001). However, droplet behaviour will be different. Air inclusions in droplets reduce droplet density, thus resulting in lower velocities, which may have an adverse effect on spray drift (Walklate *et al.*, 2002). However other studies have shown that air inclusions do not always lead to increased drift (Combellack *et al.*, 1996; Combellack *et al.*, 2002). Wind tunnel tests were therefore conducted to ascertain the influence of air inclusions on both droplet size distributions and drift. It has been suggested that estimates of droplet numbers generated per unit volume of liquid is one of the most useful predictors of biological activity (Bals, 1969). Spray from nozzles that include large volumes of air in droplets appear very coarse and this has led to the perception that such nozzles generate too few droplets to effect reasonable coverage. Therefore estimates of droplet numbers per droplet class size have been calculated for this nozzle to judge the validity of the perception and to enable future observations on effectiveness of certain spray qualities on biological performance.

Materials and Methods

The double chamber twin fluid nozzle is based on a removable insert that creates a Venturi effect when liquid flows through its metering orifice. The vacuum created helps draw in pressurised air and liquid. There are two air entry locations so that the air impinges on the liquid at two points as it passes along the insert. As the two locations are physically separate, they require separate air delivery to each of the chambers. To accomplish this, air to one of the chambers was supplied directly from the main air supply line and delivered through two ports so that it was directed at right angles to the liquid stream close to the exiting point from the metering orifice. Importantly, air supply to the second chamber only occurred when the air pressure in the main air line was sufficient to open a 0.6 bar diaphragm. This air stream was directed at the partially atomised liquid via four ports to effect secondary droplet generation. For the system to work, the internal dimensions have to be such that they create a Venturi effect at both air entry locations. Droplet generation with this nozzle is mostly effected within the nozzle body and a commercial anvil nozzle tip (Lurmark AN 10) was used to distribute the spray.

Droplet sizes were measured at Silsoe Research Institute using water and a non-ionic surfactant (Agral - Syngenta Crop Protection Ltd) with a Malvern SprayTec fitted with a 450 mm lens. The nozzle was mounted on a computer controlled transporter at 350 mm above the laser beam and a single plane scan at a transporter speed of 20 mm sec^{-1} was used. Measurements were also made with reference to flat fan nozzles at defined operating pressures so as to enable estimates of spray quality to be made.

Spray volume distribution measurements were made by mounting a four nozzle boom, with nozzles spaced at 500 mm, 480 mm above a patternator. A height of 480 mm was used rather than the conventional 500 mm to account for the projection of the spray from the nozzles. Nozzle alignment was offset from that of the boom by 5° to prevent interference of sprays from adjacent nozzles. The patternator had a groove width of 75 mm and liquid collected in each groove from a timed application was weighed on a separate balance.

Measurements were made in a wind tunnel to determine the risk of drift from the double chamber twin fluid nozzle and compare this with a reference FF110/1.2/3.0 nozzle operating at a pressure of 3.0 bar. A single nozzle was mounted statically in the tunnel which has a working section 3.0 m wide, 2.0 m high and approximately 10 m long. All measurements were made in a wind speed of 2.0 m s^{-1} measured in the centre of the tunnel section with an ultrasonic anemometer. The air flow in the tunnel was approximately uniform with a low level of turbulence. The spray liquid was water with 0.2% of a tracer dye ("Green S" - Merck Chemicals) and 0.1% of a non-ionic surfactant (Agral - Syngenta Agrochemicals). Downwind deposits were captured on passive sampling lines positioned:

(i) in a horizontal array across the tunnel 100 mm above the floor and at distances of 2.0, 3.0, 4.0, 5.0, 6.0 and 7.0 m downwind of the nozzle;

(ii) in a vertical array 2.0 m downwind of the nozzle with lines across the tunnel at a vertical spacing of 100 mm.

Deposits were measured by recovering the collected tracer from the lines using a U-tube containing a measured volume of de-ionised water placed in an ultrasonic bath. The tracer concentration was determined using spectrophotometry.

Results

Droplet size measurements

The droplet size data are presented as Table 1. This table also includes estimated VMD's which have been calculated to account for included air.

Table 1. Measured and calculated droplet sizes for a nozzle with a 1.2 mm metering orifice when spraying non-ionic surfactant at 0.1%v/v

Air Pressure [kPa]	Liquid pressure kPa	Liq. vol. ml min^{-1}	Droplet size data µm Vol. < 100 µm	Meas. VMD µm	Calc. VMD µm	Spray Qual.
40	100	807	0.7	551	501	XC
	200	1306	0.9	510	464	XC
	400	1821	0.9	511	465	XC
	480	1.950	1.0	481	427	XC
100	120	468	14.9	181	165	F
	150	733	7.1	237	216	C
	160	798	6.4	248	225	C
	200	1034	4.9	274	249	C
	300	1477	4.6	295	268	C
	450	1903	3.4	315	286	C
150	200	739	13.5	186	169	M
	250	1039	8.7	217	197	M
	300	1271	7.7	233	211	M
	400	1651	6.7	252	223	C
	450	1821	5.7	263	239	C
200	250	747	20.5	151	137	F
	300	1037	13.0	183	166	F
	350	1284	10.9	199	181	M
	400	1416	9.5	211	192	M
250	350	1047	19.9	158	143	F
	400	1276	14.3	180	164	F
	450	1486	11.7	194	176	M

The droplet size data instruct that it is possible to generate very fine to extra coarse sprays using the same nozzle simply by varying air pressure. The data indicate that at 40 kPa air pressure an extra coarse spray was generated over a flow rate range from 800 to at least 1600 ml min^{-1}. If the air pressure is set at 100 to 150 kPa then a medium spray quality can be generated over flow rate range of 500 to 1300 ml min^{-1} and a coarse spray from 700 to 2000 ml min^{-1}. At air pressures of 200 to 250 kPa a fine spray can be generated for flow rates from around 650 to 1400 ml min^{-1} and even a very fine spray from 500 to 800 ml min^{-1}. These data show that the one nozzle size can, by varying air pressure, generate commonly used spray qualities over at least a two fold change in flow rate without changing the nozzle. There is a need to more accurately judge likely biological effects if spray quality is varied. It is postulated that one of the most useful ways to do this is correlate biological effect with an estimate of droplet size/numbers per unit target area per unit volume of spray used. These have been calculated for the double chambered twin fluid nozzle using the droplet volume data per class size based on the measured droplet size distribution. These calculations are presented in Table 2.

Table 2. Estimated droplet numbers cm^2 for each 10 litres/ha application volume for nominated droplet size ranges for the double chamber twin fluid nozzle

Air Pressure, kPa	Liquid flow, $ml\ min^{-1}$ (spray quality)	Size categories, μm 100-200	200-300	300-400	400-500	Total droplet no. per cm^2 per 10 litres
		(volume of included air, ml per 10 litres)				
0.4	807 (extra coarse)	5.65 (520)	1.79 (880)	0.81 (1170)	0.47 (1490)	8.72
0.4	1950 (extra coarse)	6.41 (590)	2.15 (1060)	1.11 (1590)	0.67 (2110)	10.34
1.0	798 (coarse)	30.00 (2760)	6.17 (3040)	1.36 (1950)	0.31 (990)	37.93
1.0	1903 (coarse)	20.00 (1840)	5.10 (2510)	1.65 (2380)	0.55 (1750)	27.30
1.5	739 (medium)	45.43 (4180)	5.97 (2940)	0.67 (970)	0.11 (340)	52.18
1.5	1651 (medium)	30.44 (2800)	6.15 (3030)	1.28 (1840)	0.32 (1010)	38.19
2.0	747 (fine)	57.5 (529)	4.12 (203)	0.03 (42)	<0.01 (13)	61.65
2.0	1478 (medium)	40.44 (372)	6.17 (304)	0.08 (128)	0.02 (58)	46.71
2.5	1047 (fine)	52.83 (486)	4.71 (232)	0.03 (53)	0.01 (18)	57.58
2.5	1486 (medium)	44.57 (410)	6.15 (303)	0.06 (99)	0.01 (40)	50.79

The values in Table 2 were calculated by assuming that droplets <100 m in diameter contained no air inclusions and those with diameters between 100 and 500 m contained 25% of air.

These results show that, as expected, there are large numbers of droplets >100 μm cm^{-2} when even coarse sprays are generated. Also as expected, the numbers of droplets per unit area increase as median droplet size decreases. We have assumed that the "optimal" droplet size range is between 100 and 500 μm, where droplets less than 100 m are prone to drift and those over 500 m are too large to provide adequate coverage. On the basis of this assumption, these data imply that for this nozzle the numbers cm^{-2} /10 litres of spray volume would be : <15 for an extra coarse spray; 15 to 35 for a coarse spray, 35 and 50 for a medium spray and over 50 for a fine spray. The data therefore show that even an extra coarse spray delivers around 150 droplets cm^{-2} while at the same volume a fine spray delivers over 500 droplets cm^{-2}.

Spray patternation data

Calculated coefficients of variation for the measurements of the uniformity of spray volume distribution made with a patternator having collecting channels 75 mm wide are shown in Table 3.

Table 3. Effect of formulation, liquid flow rate and air pressure on coefficient of variation of spray volume distribution measured on a 75 mm patternator.

Spray liquid	Liquid flow ml min^{-1}	Air pressure, bar 0.4	1.0	1.5	2.0
Water	800	7.0	6.1	4.3	7.0
	1200	8.1	9.5	9.0	6.8
	1600	6.9	8.1	8.2	8.4
BS 1000 [0.1% v/v]	800	10.7	NR	8.2	NR
	1200	5.7	NR	10.2	NR
	1600	2.9	NR	10.8	NR
Ulvapron [1.0% v/v]	800	6.8	NR	7.0	NR
	1200	5.4	NR	8.0	NR
	1600	2.6	NR	7.4	NR

The data show that the double chamber twin fluid nozzle when used with "AN10" anvil tips generated relatively uniform spray volume distribution patterns over the air pressure and liquid flow rate range tested. Coefficients of variation were less than 10% except when spraying the BS1000. Further, the data imply that the uniformity of spray liquid distribution was not greatly affected by the formulations evaluated.

Wind tunnel studies

Measurements of the total deposits on collecting lines used in the wind tunnel studies with both the double chamber twin fluid and reference nozzles are summarised in Table 4.

Table 4. Measured drift from the double chamber twin fluid nozzle

Nozzle	Air pres. kPa	Liq. pres. kPa	Liq. vol ml min^{-1}	Horiz. % c.f. reference	Vertical % c.f. reference
F110/03 (reference)	0	300	1.22	100	100
Double chamber twin fluid	40	100	800	-82	-80
	40	160	1200	-79	-79
	40	250	1600	-80	-83

The double chamber twin fluid nozzle at 40 kPa air pressure with liquid flow rates of 0.8 to 1.6 litres min^{-1} reduced horizontal drift by 79 to 82% and vertical drift by 79 to 83% compared to a reference conventional flat fan nozzle. These data show that the double chamber twin fluid nozzle generates very low levels of droplet drift when operated at 40 kPa air pressure. The results also show that air inclusions in the droplets does not appear to increase drift potential.

Interpretation of the measured horizontal sedimenting spray profiles measured in the wind tunnel tests using the procedures defined by Walklate *et al* (2002) showed that the nozzle was able to meet the requirements for a LERAP Low Drift three star rating at each of the settings given in Table 4. Calculations using the measured deposits on the vertical sampling array and following the procedures defined by Herbst (2000) gave Dix values of 16.4, 16.6 and 13.5% for the nozzle flow rates of 800, 1200 and 1600 ml min^{-1} from the double chamber twin fluid nozzle respectively.

Discussion

The droplet size data support previous studies (Combellack *et al.*, 2002) in showing that two separated air streams at air pressures between 100 and 200 kPa are able to generate coarse to fine spray qualities from a single nozzle tip. The wind tunnel studies showed that by delivering air through only one of the air chambers it is possible to use very low air volumes and generate a low level of drift. The data show that the double chamber twin fluid nozzle will comply with the requirements for a LERAP three star rating at volumes from 800 to 1600 ml min^{-1} which is greater than was possible with previous designs (Combellack *et al.*,2002). The drift results also support the findings of previous studies (Combellack *et al.*, 1996; Combellack *et al.*, 2002) that air inclusions do not increase drift. Reviews of literature that have considered the effect of droplet numbers per unit area by Combellack (1984) and Knoche (1994) reveal that there is no optimal number for all products. It is obvious from these reviews that the numbers per unit area vary with each species and herbicide used. Even so the authors consider it expedient to calculate the numbers of droplets cm^{-2} for each 10 litres of spray volume as these can be used by users as the basis to monitor the need in their situation. The estimates from the double chamber twin fluid nozzle data imply that <15 droplets between 100 and 500 μm cm^{-2} will be deposited for extra coarse, 15 to 35 for coarse, 35 to 50 for medium and over 50 for fine spray quality with this nozzle. Because spray patterns can vary with the spray solution used (Combellack & Miller, 2001) the data presented were generated using three spray solutions recommended. They show that the nozzle gives reasonable patternation over a wide range of flow rates and air pressures with the three different spray solutions and is comparable to the performance previously reported (Combellack & Miller, 2001).

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