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Selection of Suitable Type of Nozzles for Development of Electrostatic Induction Nozzle

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The electrostatic induction mechanism, which superimposes charges on pesticide spray droplets, creates an impact on deposition and wraparound effect on leaf surfaces Smaller droplets have a higher capability to charge accumulation over the surface of the droplet as compared with larger droplets. This paper studied the effect of nozzle type (flat fan, hollow cone, and full cone nozzle), orifice area (1 and 1.5 mm^2), and operating pressure (3-5kg cm^{-2}) on spray droplet characteristics on soil bin. Water-sensitive papers were analysed by image analysis software to get the droplet characteristics. The smallest droplets of a hollow cone, flat fan, and full cone were 130, 142, and 279.76 µm respectively produced at 5kg cm^{-2} and orifice opening 1 mm^2. With an increase of pressure droplet size and relative span was decreased for all selective nozzle. From the selected nozzles, the lowest relative span of 0.89 was found with a hollow cone nozzle at 5 kg cm^{-2} pressure and orifice size of 1 mm^2. Among all the selected nozzles hollow cone nozzle produced the smallest droplet sizes and lowest relative span for all selected parameters.

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Keywords: Spray characteristics; VMD; Relative span; hollow cone nozzle.

1. INTRODUCTION

A typical practice that reduces the effect of the pest in agriculture yield is chemical application. To mitigate crop losses, there are more than a thousand pesticides of both chemical and biological origin used around the world. Proper plant protection equipment and technique used for applying the pesticide are important to create an impact on pest control. According to previous research studies, with traditional sprays, sometimes only 30-40 percent of applied spray liquid reaches the targets [1,2]. According to law [2], comparatively effective, chemical pesticides add over 25 billons dollars annually to the world's crop production costs, and 2.25 billons kilograms of active pesticides were annually entered into our environment. This may risk the environment, ecological balance, and human health worldwide.

Entomological studies have found that biological efficacy per unit mass of spray application was greater for smaller droplets than the larger droplets for accomplishing insect control [3]. Smaller droplets are established to be more efficient for insecticide and fungicide sprays in laboratory tests [4]. But smaller droplets were vulnerable to spray drift. It is critical to increasing, not just the effectiveness of droplet deposition, but also the spatial distribution of deposited droplets across the plant canopy, particularly under the leaf, where pests prefer to live. The introduction of electrical charge to agricultural sprays can provide greater control of droplet transport towards the target. By using electrostatic spraying, the application efficiency can be improved up to 80 percent with a 50 percent reduction of spray chemical ingredients [5-7].

In India, a few trials were conducted on the development of an electrostatic nozzle. To introduce superior technology like electrostatic spray improving the system in the Indian farms not only distribution and deposit rate on targets but also reduces the usage quantity thereby cost of operation is brought down and adsorption uniformity is improved. Moreover, the development of an electrostatic spray charging system for the existing agricultural hydraulic spray nozzle will be very helpful to the Indian farmer. This paper studied different types of nozzles which are locally available, to develop an electrostatic induction nozzle.

2. MATERIALS AND METHODS

The spray droplet size is a significant factor for the development of an electrostatic induction nozzle. The major factors that influence droplet size were nozzle characteristics (type of nozzle and orifice size) and operating pressure. This paper is on selection of a type of nozzle based on droplet size.

2.1 Type of Nozzle

The type of nozzle had significantly affected the droplet size due to the design and shape of the orifice. Three different types of commercially and locally available hydraulic nozzles with two orifice sizes (1 and 1.5 mm^2) were selected. Selected nozzles with specifications were listed in Table 1.

2.2 Operating Pressure

The operating pressure is an important factor that influences the droplet size. Applied pressure creates turbulence inside the nozzle and due to that spray droplet formation has happened. For the experiment, the selected operating pressure was 3, 4, and 5 kg cm^{-2}.

2.3 Orifice Size

The droplet size of the hydraulic spray nozzle affects the droplet size of the spray [8]. For the experiment, the selected orifice size was 1 and 1.5 mm^2.

Table 1. Selected nozzles and specifications

S.no	Type of nozzle	Model	Orifice size
1	Hollow cone nozzle	Lechler TR80 001	1 mm^2
2	Hollow cone nozzle	Lechler TR80 015	1.5 mm^2
3	Flat fan nozzle	Lechler VP 80 001	1 mm^2
4	Flat fan nozzle	Lechler VP 80 015	1.5 mm^2
5	Full cone nozzle	Local manufacture	1 mm^2
6	Full cone nozzle	Local manufacture	1.5 mm^2

2.4 Experimental Setup to Determine the Droplet Size

An experimental test was conducted in a soil bin for simulating the field condition in the laboratory. The experimental setup consists of the functional units are soil bin, and trolly with variable speed-drive, developed sprayer-setup, and artificial plant. The experimental setup consists of a portable nozzle testing unit as shown in Fig. 2. The nozzle testing unit consists of the main structural frame for the accommodate tank with a hydraulic pump, liquid distributor with pressure regulating valve, pressure gauge, and nozzle assembly. The mainframe with a rectangular base made up of 25.4 mm angular has the dimensions of as shown in Fig. 1. the pump was placed at the bottom base for easy flow of liquid from the tank to pump by gravitational flow. The pressure gauge and pressure regulating valve (bypass valve to regulate the return flow) were placed side of the tank frame to regulate the pressure as shown in Fig. 2.

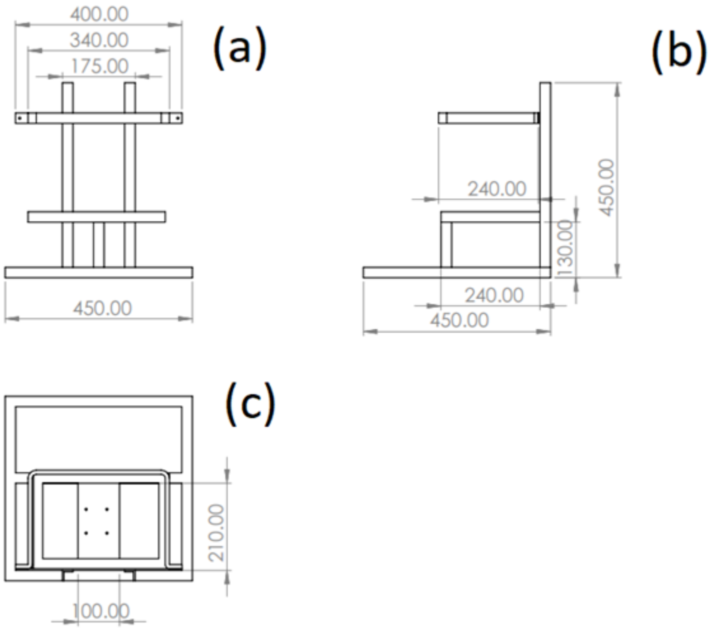

Fig. 1. (a) Front view, (b) side view, and (c) top view of the Portable nozzle testing setup.

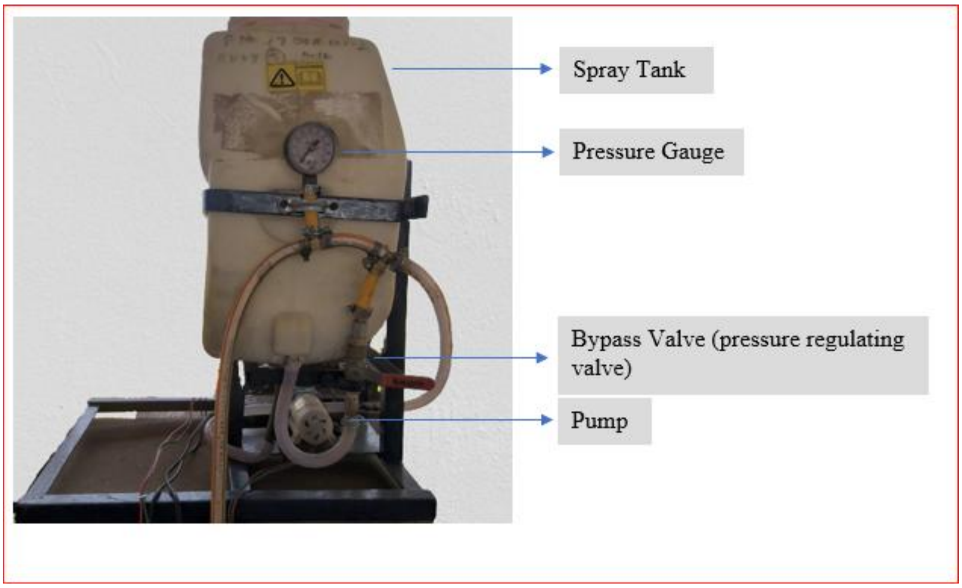

Fig. 2. Developed experimental nozzle setup

2.5 Determination of Nozzle Characteristics

2.5.1 Discharge rate

When the pressure of liquid flowing through the nozzle gets stabilized, the discharge of liquid through a single nozzle is collected for one minute in the measuring jar. The process was repeated three times at the working pressures of 3, 4, and 5 kg/cm2. The average volume of collected liquid at each pressure was the discharge rate at that pressure.

2.6 Experimental Procedure to Determine the Droplet Size

The experimental setup consists of the developed sprayer unit mounted on the test rig. Test rig consist of a trolly powered with the 10 hp dc motor which was regulated by variable speed drive. The motor and the drive wheel shaft were connected by the chain and sprocket mechanism. The induction motor speed was regulated by the frequency and voltage difference applied to the induction motor by the frequency regulator. The trolly has a platform to accommodate the experimental setup. The nozzle height was adjusted with a slot and bolt mechanism. The height of the nozzle was varied from 30 to 200 cm from the base of the soil bin. The artificial plant targets are placed below in the path of spray from the nozzle as shown in Fig. 4. To intrude the spray on the targets, six exactly similar artificial plant targets as shown in Fig. 3, were placed below the center line of the nozzle. Six artificial plants at a spacing of 50 cm were placed at the test rig. Water-sensitive papers of size 2.5 cm x 7.5 cm were clamped on the upper side of the selected leaves. The water-sensitive papers attached to the leaf of artificial plants were placed in a test rig. The selected speed of the trolly was 2 km/hr and the height of the nozzle was 50cm from the top of the plant. Three replications were taken for each experiment and water-sensitive paper strips were collected for analysis.

2.7 Analysis of the Water Sensitive Papers (WSP)

The water-sensitive paper collected from the soil bin experiment was analyzed using deposit scan image analysis software. WSP cards collected from the experiment were scanned by using the Samsung scanner cum printer (SCX-4250fs model). The WSP cards were scanned at 600 dpi value and saved as a JPEG image file. The images were analyzed by deposit scan image analysis software. The obtained results were viewed and saved in the excel sheets. $D_{V0.1}$, $D_{V0.5}$ (or) (Volume Median Diameter, VMD), and $D_{V0.9}$ (the diameter of droplets representing 10%, 50%, and 90% of the sprayed volume, respectively), were chosen from among the available options offered by the data produced by the deposit scan software were used to characterize droplet size spectra.

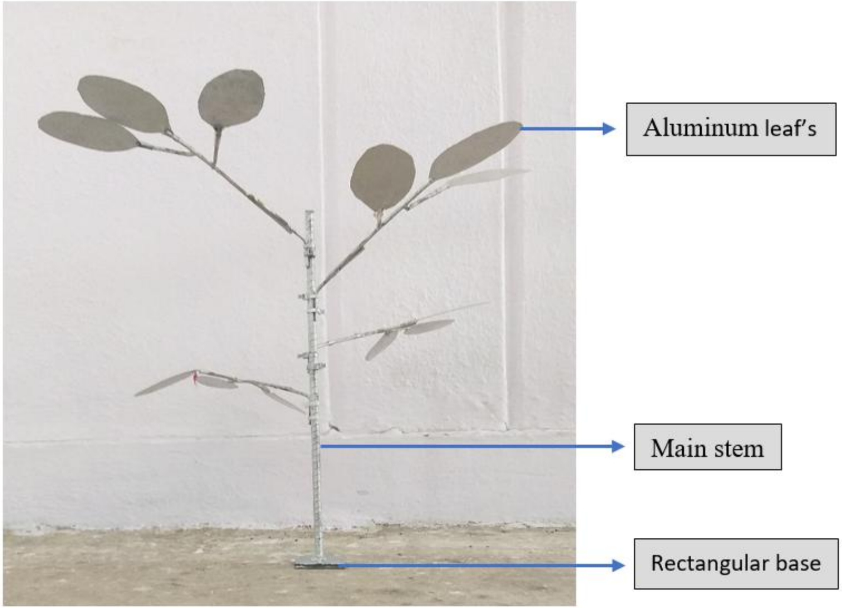

Fig. 3. Artificial plant

Fig. 4. Experimental setup to study effect operational parameters on droplet size of the nozzles on artificial plants

2.8 Relative Span

Relative span is a dimensionless statistic used to determine droplet size spectra homogeneity, with smaller values indicating a narrower spectrum. Relative spam ($R_{sf):}$ Relative span is the difference in diameter for $D_{V0.9}$ and $D_{V0.1}$ of the sprayed volume divided by the $D_{V0.5}$.

$$R_{sf} = \frac{(DV0.9 - DV\ 0.1)}{Dv0.5} \quad \text{--------------------} \ (1)$$

Statistical analysis and optimization of the selected variables of the obtained data from the experiment were done by Minitab software. The effects of pressure, orifice size, and type of nozzle on droplet size were analyzed by full factorial analysis.

3. RESULTS AND DISCUSSION

3.1 Selection of Suitable Nozzle for the Development of the Electrostatic Induction Nozzle

In this experiment, the selected nozzles were equipped with the developed experimental setup to determine the droplet size. Previous entomological studies reported that the smaller droplet size was proven for better pest control over large droplet size [4], and small size spray droplets get charged more compared to large size droplets [2], [9] and [10]. The selection of a suitable nozzle was depending on the droplet size.

3.2 Effect of Nozzle Characteristics on Droplet Size (VMD)

The type of nozzle on droplet size was evaluated by the collected water-sensitive papers in deposit scan software for the selected levels of variables. The hollow cone nozzle shows the lowest droplet size irrespective of pressure and orifice size. Nozzles were ranked by $D_{v0.5}$ (VMD) from smallest to largest were hollow cone, flat fan, and full cone nozzles. This is because of the droplet size in hollow cone nozzles, liquid supply is axial, the rotary motion of the liquid is generated by vanes. Axial-flow hollow cone nozzles allow producing the finest droplets achievable with a pressure-operated nozzle design. Whereas in full cone nozzles a uniform liquid distribution over a circular area. A rotary motion of the liquid is achieved with a swirl insert inside the free cross-sectional of the nozzle. Spray formation, liquid distribution, and shaping of droplets are influenced by the dimensioning and functional coordinates of the rotary motions and swirl flow with different axial and tangential speed components lead to overall coarser droplets than with a comparable hollow cone and flat fan nozzles. Droplet spectra for all the selected nozzles measured with the deposit scan image analysis software are reported in Table 2.

Table 2. Droplet characteristics of 18 nozzle-pressure combinations

Nozzle type	Pressure kg/cm2	Nominal flow l/min	Nozzle class*	$D_{v\,0.1}$ µm	$D_{v\,0.5}$ µm	$D_{v\,0.9}$ µm	R_{sf}
Lechler TR80 01	3	0.39	F	89.54	142.	254.12	1.02
	4	0.45	F	77.19	139.10	209.34	0.95
	5	0.51	F	72.14	130.00	187.84	0.89
Lechler TR80 015	3	0.59	M	102.07	209.65	330.59	1.09
	4	0.68	M	86.5	177.67	260.62	0.98
	5	0.76	F	79.35	163.00	229.31	0.92
Lechler VP80 001	3	0.39	M	104.45	200.07	346.53	1.21
	4	0.45	F	90.04	163.99	268.79	1.09
	5	0.51	F	84.15	142.60	241.01	1.1
Lechler VP80 015	3	0.59	M	117.97	214.64	388.41	1.26
	4	0.68	M	99.98	178.86	307.46	1.16
	5	0.76	F	91.72	158.29	278.50	1.18
Full cone 001	3	0.41	M	122.06	223.17	407.72	1.28
	4	0.47	M	99.23	181.44	311.51	1.17
	5	0.53	F	88.6	162.00	279.76	1.18
Full cone 015	3	0.62	M	143.9	258.37	492.70	1.35
	4	0.69	M	116.05	208.36	368.17	1.21
	5	0.77	M	98.35	176.58	308.48	1.19

** Classification of droplet size was based on ASAE S-572[11]*

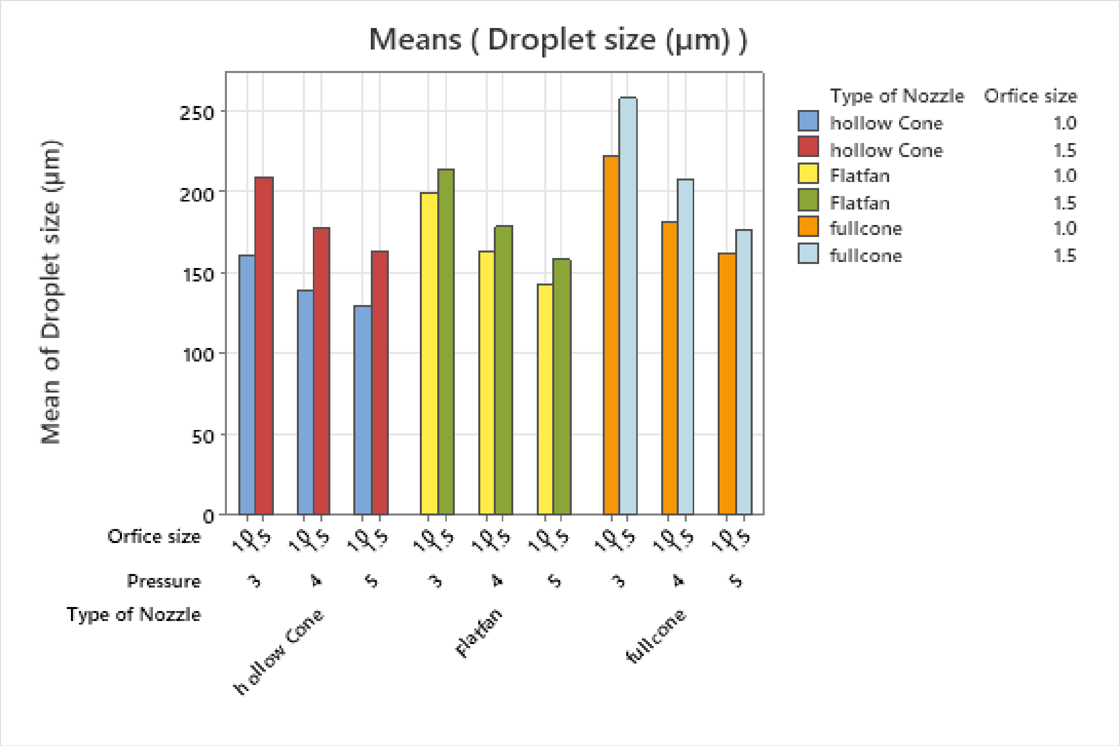

Fig. 5. Effect of nozzle characteristics on droplet size

Fig. 5 depicts the effect of the type of nozzle, orifice size, and pressure on the droplet size spectrum of a selected nozzle. Among all the selected nozzles, hollow cone nozzle produced the small droplets at a selected pressure and orifice area, followed by a flat fan nozzle and full cone nozzle. Hollow cone nozzles have internal groves that may create turbulence inside the nozzle, due to that hollow cone nozzle create smaller droplets compared other two nozzle varieties similar results were found with [12]. From Fig. 5 it is evident that the full cone nozzle provided the largest VMD followed by a flat fan nozzle and a hollow cone nozzle at 3 kg/cm^2 for a 1.5 mm^2 orifice area. Range of VMD, 130 to 209, 142 to 214, and 162 to 258 µm produced by hollow cone flat fan and full cone nozzles respectively at selected levels of pressures and orifice size. The smallest droplet size was produced by a hollow cone nozzle 130 µm at 5 kg cm^{-2} and 1.0 mm^2 orifice size, similarly, for flat fan nozzle and full cone nozzle produced the smallest droplet size of 142 and 162 µm at 5 kg cm^{-2} and 1.0 mm^2 respectively. The largest droplet size was obtained at 3 kg cm^2 pressure and orifice size of 1.5 mm^2 for all selected nozzle. From the Fig. 8 shows the effect of nozzle characteristics and pressure on droplet size. For all the types of nozzles were significantly different from each other at 1% significance shown in Table 3.

3.3 Effect of Pressure on Droplet Size (VMD)

Fig. 6 depicts that VMD shows a decreasing trend with an increase in pressure. The decline in droplet size is attributed to the fact that higher pressure creates turbulence in the liquid flow in the nozzle [12,13]. For all selected nozzles, the VMD of the spray liquid followed the decreasing trend with an increase of pressure. The trend of interaction effects on VMD of the spray nozzles as shown in Fig 8. Table 2 shows that the effect of the pressure and type of nozzle significantly different on VMD. From Table 3, it is evident that major effects are significantly different at a 1% level of confidence. For the three types of nozzles tested at selected pressures, increasing the operating pressure significantly (P<0.01) reduces droplet size. At 5 kg cm^{-2} pressure produces the finest droplet sizes of all.

3.4 Effect of Orifice Size on Droplet Size

For two orifice sizes (1 and 1.5 mm) at three pressures and three nozzles (Fig. 5), the orifice size and type of nozzle had a greater influence on the VMD ($D_{v0.5}$) at selected pressures. The selected nozzles at nozzle size at 1mm^2 produced finest droplets at all pressures. The VMD shows a decreasing trend with increasing orifice size [12]. At a orifice size of 1.5 mm^2, the majority of nozzles is classified as medium (Table 2). From the Table 2, it evident that increasing the orifice size significantly (P<0.01) effects droplet size.

3.5 Relative Span Analysis

Table 1 depicts the hollow cone shows the lowest relative span compared with other nozzles at a selected pressure and orifice size. Hollow cone nozzle has the lowest relative span at a higher pressure and small orifice size (1 mm^2 and 5 kg/cm^2) and solid cone shows the larger relative span at 3kg/cm2 at an orifice size of 1.5 mm^2. Smallest and largest relative span values of the nozzles were 0.89 and1.09, 1.09 and 1.26, and 1.17 and 1.35 for hollow cone, flat fan, and

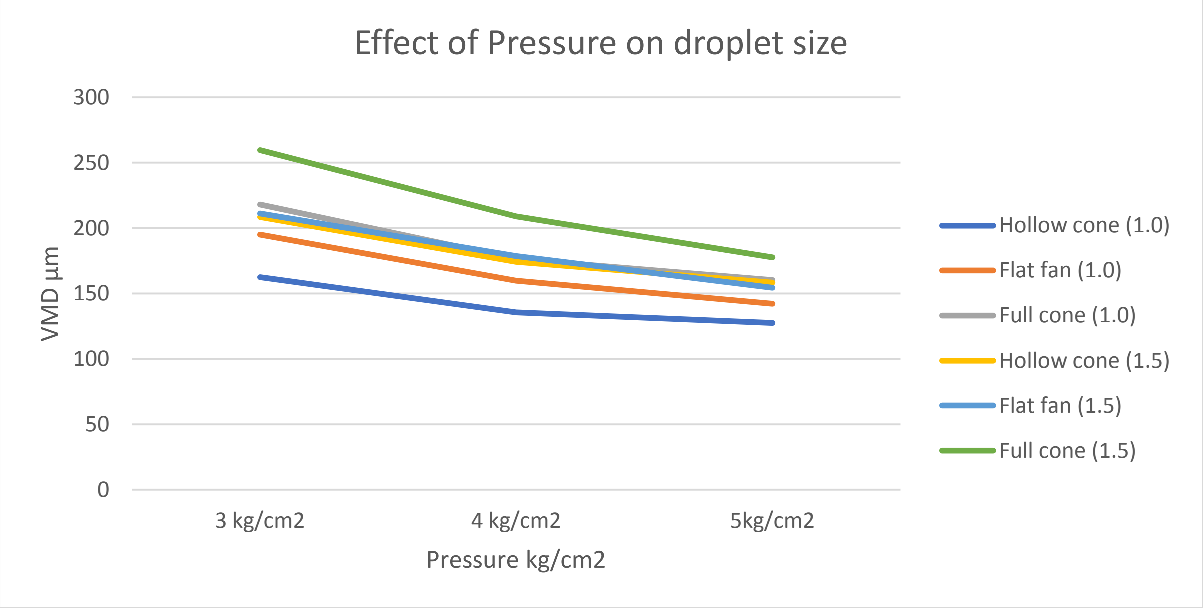

Fig. 6. Effect of pressure on droplet size

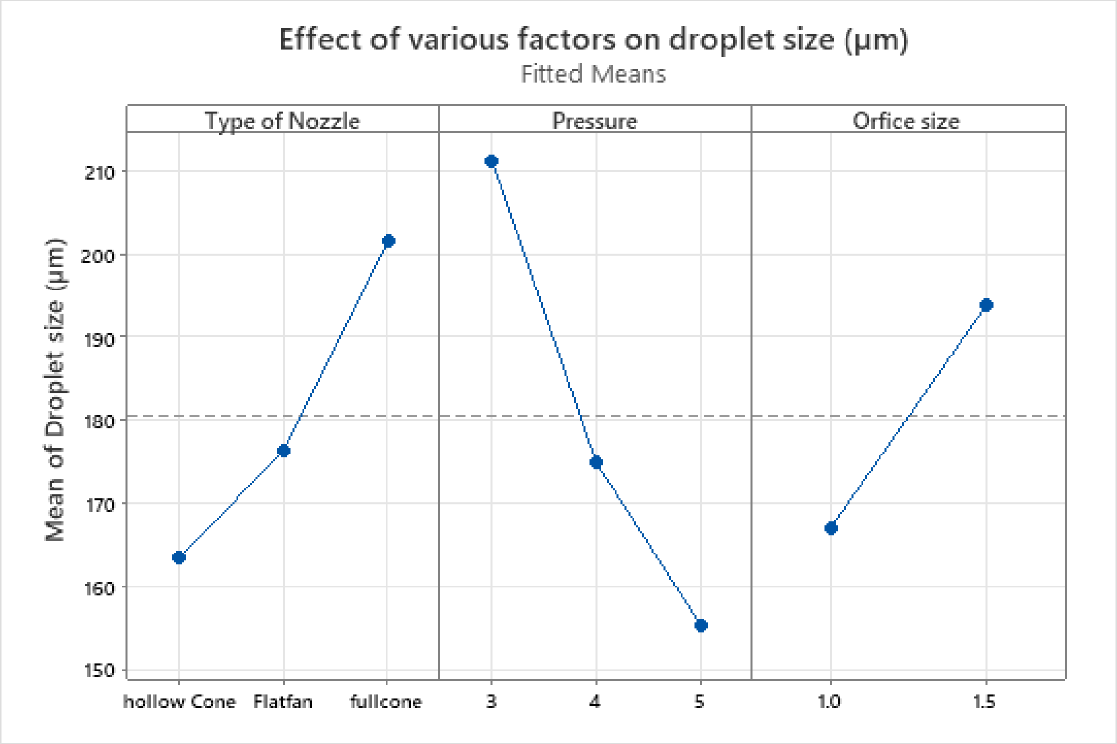

Fig. 7. Graph showing effects of operating parameters on droplet size

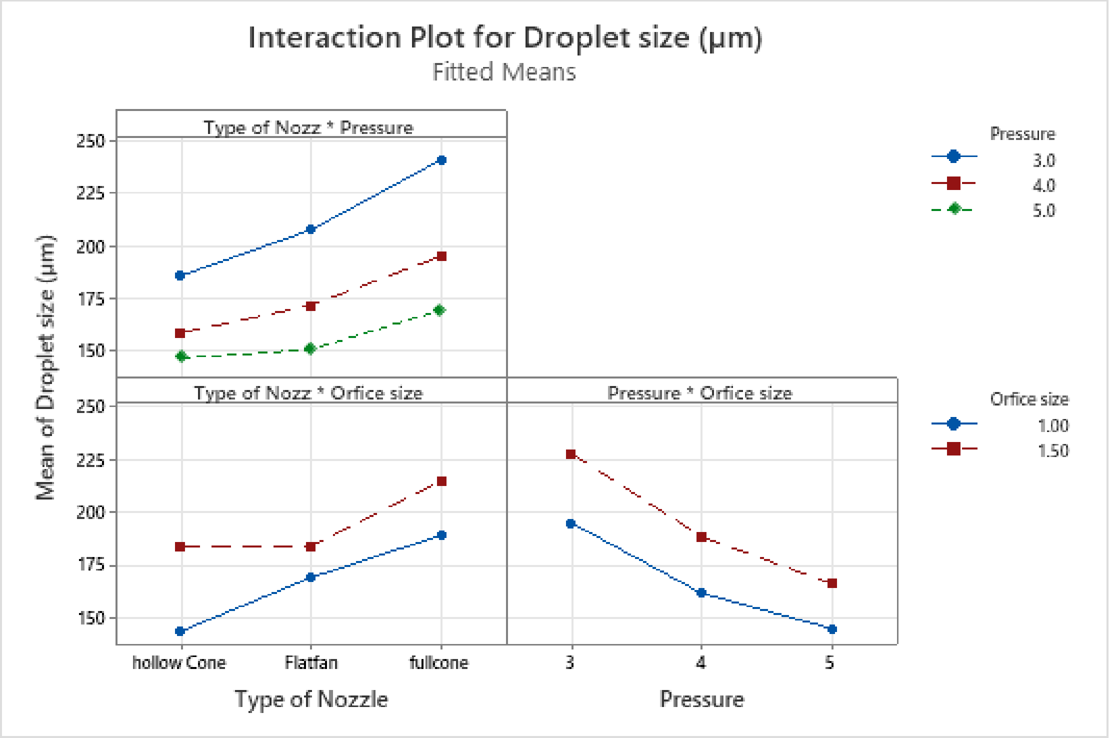

Fig. 8. Graph showing interacting effects of operating parameters on droplet size

full cone nozzles respectively. For all selected pressures and orifice sizes hollow cone nozzle produces the smallest relative span, which indicates the hollow cone nozzles provide less variation in droplet spectrum compared with other selected nozzles.

Table 3. Analysis of Variance table for droplet size

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	17	55703.4	3276.7	25.52	0.000
Linear	5	52186.3	10437.3	81.29	0.000
Type of Nozzle	2	13581.6	6790.8	52.89	0.000
Pressure	2	28868.4	14434.2	112.42	0.000
Orifice size	1	9736.2	9736.2	75.83	0.000
2-Way Interactions	8	3316.0	414.5	3.23	0.007
Type of Nozzle*Pressure	4	1605.7	401.4	3.13	0.026
Type of Nozzle*Orifice size	2	1407.6	703.8	5.48	0.008
Pressure*Orifice size	2	302.7	151.4	1.18	0.319
3-Way Interactions	4	201.1	50.3	0.39	0.813
Type of Nozzle*Pressure*Orifice size	4	201.1	50.3	0.39	0.813
Error	36	4622.4	128.4		
Total	53	60325.8			

4. CONCLUSION

Selection of suitable nozzle for development of electrostatic nozzle based on the droplet size produced by nozzles at selected levels of pressure, orifice size, and type of nozzle. The effect of selected levels of pressure, orifice size, and type of nozzles on droplet size and relative span were investigated at a 2 km/hr speed on the test rig in this study. The main draw conclusions are as follows. Based on the experiment, the hollow cone nozzle produced the smallest droplets followed by a flat fan nozzle and full cone nozzles at all selected orifice sizes. The Smallest and largest droplet size of the hollow cone, flat fan, and full cone was 130 and 209 µm, 142 and 214 µm, and 279.76 and 492 µm respectively. With an increase of pressure, droplet size was showing a decreasing trend irrespective of orifice size and nozzle. With an increase of orifice size, the droplet spectrum shows an increasing trend irrespective of pressure and nozzle. Relative span data reveals that hollow cone nozzles shows lowest variation on the droplet’s spectrum.

From all the selected types of nozzles, orifice sizes, and operating pressure, hollow cone nozzles were produced the smallest droplet sizes as compared with another selected nozzle at a selected pressure. Hence the hollow cone nozzle was selected for the development of the electrostatic induction nozzle.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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