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Design and Experiments on Droplet Charging Device for High-Range Electrostatic Sprayer

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1. Introduction

It presses a solution to apply high-range spray technique for controlling of forest diseases and insect pests. In recent years, there are more and more tall trees in China, as forest covering area becomes wider and wider, including defendable forest, shelter trees in urban areas, fast growth forest, field net forest and shelter trees on highways and etc. To improve the effective spraying range, decrease the droplets drift and enhance the penetration and deposition of droplets, it should be considered such features of sprayer as spraying height, water saving, low pollution and high efficiency. Nowadays, the application of high-range spraying technique mostly is high-pressure shoot gun and big-type spraying vehicle, but the spraying height of these sprayer can not reach 18m.

Electrostatic spray technique has been introduced into agricultural pesticide applications for many years. Law and Cooper (1988) investigated depositions of charged and uncharged droplets from orchard air carrier sprayer They found the deposition charged droplets could increase from 1.5 to 2.4-fold over uncharged droplets from the same air-atomizing, inducting-charging nozzles. Combining Electrostatic spray technique with high-range spray technique, a trailer-mounted ULV sprayer was re-equipped with an electrostatic device (Zhu, 1990). A knapsack electrostatic sprayer was developed with a centrifugal fan driven by a gasoline engine. A rotary-cage electrostatic spraying nozzle was driven by air-stream with contact charging electrode (Zheng and Xian, 1990). A power-carried axial air-assisted electrostatic sprayer for locust control (Xian and Zheng et al, 1992) was developed. With the experiments in a wind tunnel, Almekinders et al (l993) indicated that charged sprays with additional air assistance could provide significantly improved deposition efficiency on targets for small charged droplets. The indoor and outdoor experiments of pest controls (Gao et al., 1994) verified that the electrostatic spray could improve deposition efficiency and coverage uniformity, accelerate the droplet settling speed, reduce the drift loss, and lower the pesticide application rate. A tractor mounted automatic target detecting air-assisted electrostatic orchard sprayer with low spray volume (He et al, 2003) has been developed.

The objectives of this research were to measure the droplet size, the spray breadth and the deposition characteristics with an invented air-assisted electrostatic sprayer so as to meet the forest pest control for tall trees, reduce the application expenses and improve the ecological environment.

2. Equipment and methods

2.1 Air-assisted electrostatic sprayer

Based on the theoretical analysis and practical experiments and the requirements for the forest pest control of tall trees, an axial-flow, air-assisted, ultra-low-volume, electrostatic sprayer was developed (China Patent No ZL03259151.9) as show in figure 1. Because adopting separating design with the sprayer from vehicle, the sprayer can be trailed by four-wheel or other type wheel tractor. A diesel engine mounted on the vehicle produced the power supply to drive axial-flow blower, pump, swing mechanism and generator (Figure 2). The featured parameters of the sprayer (not including vehicle) are listed as follows: configuration dimension of 1900x1400x1100 mm, net weight of 400 kg, and pesticide liquid tank of 400 L. an axial-flow blower (Model of Z50) with the outlet of 500 mm in diameter, 2920 rpm rotation speed and 25m/s maximum air flow rate, spraying height of 20 to 25 m. spraying breadth of 38 to 50m, flow rate of 40 to 460L/h. Droplet size could be regulated by adjusting liquid pressure, from 50 to 150μm. Bellows can swing at range of -15°to 85°in vertical plane.
An electrostatic generator was used to deliver voltage of 24-36V into a high-voltage generator with output voltage of 20 kV in common use and 30 kV in maximum. Both automatic control system and remote control system were used on the sprayer, so only operator was required.

Fig. 1. Electrostatic spray assembly.

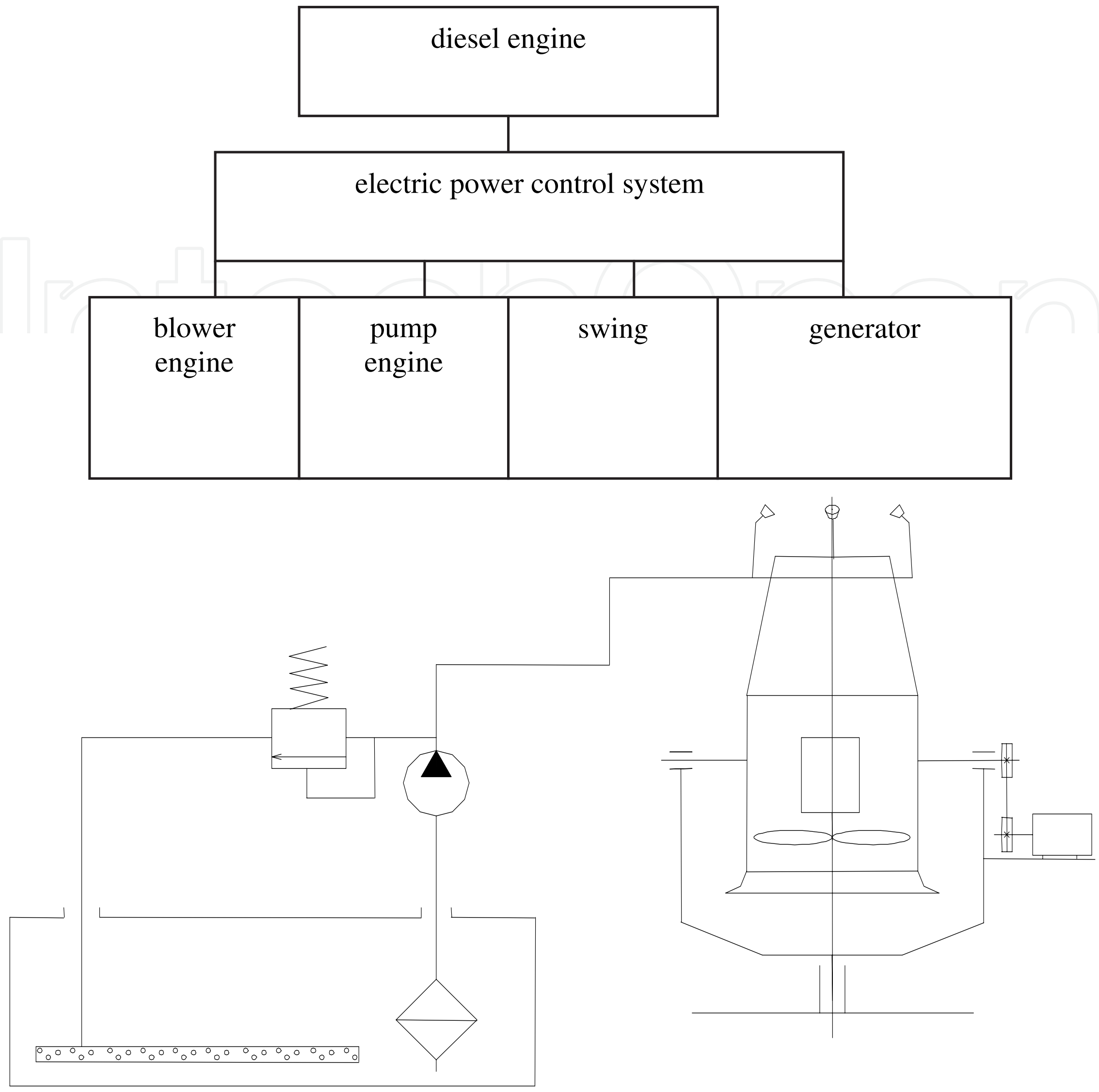
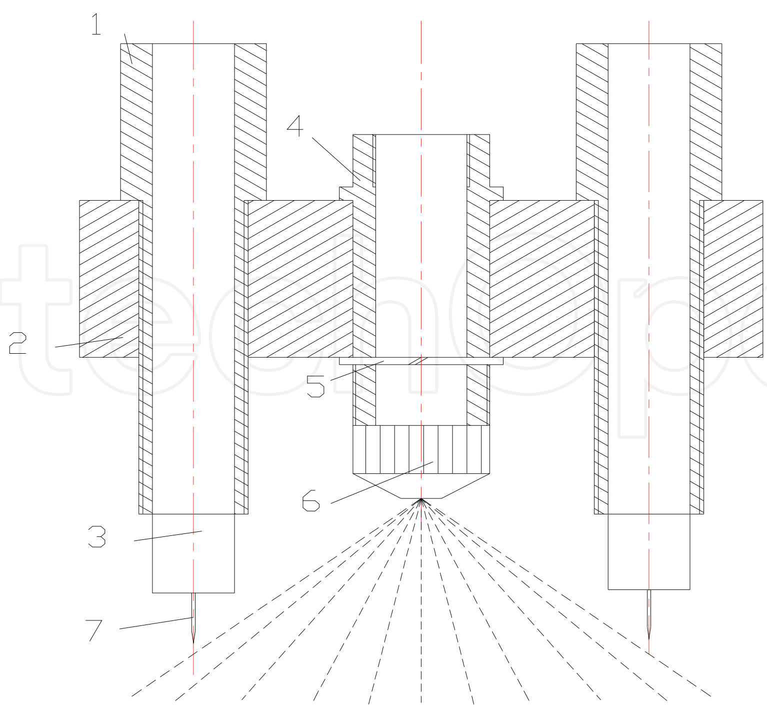


Fig. 2. Power distribution system for sprayer.

2.2 Electrostatic charging device

The charging device was designed using corona charging methods, supplying 20kV high voltage by double acicular electrostatic device (figure 3). Double acicular stainless steel electrodes were mounted on both sides around atomizing area for each nozzle. It charges droplets in the atomizing area, without intervening the droplet transporting and sub-atomization through the air-assisted system. High-voltage wires pass through the fixture and connect with stainless steel electrodes. The fixture is connected with support by screw thread in order to adjust the location between the electrode and the atomizing area. Nozzle passes through support and connects with spraying conduit. For desired charging effect, both fixture and support are made of nylon. The material for nozzles is copper as for better connection and not easy leak. There were six sets of electrostatic charging devices which were mounted around the 6HW-50 air-assisted electrostatic sprayer (Figure 4).



1. fixture, 2. Support, 3. high-voltage wire, 4. Conduit, 5. Gasket, 6. nozzle, 7. electrode

Fig. 3. Eectrostatic Equipment Structure

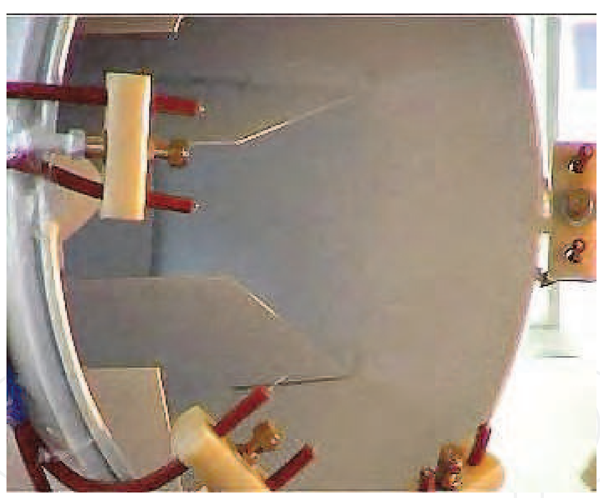
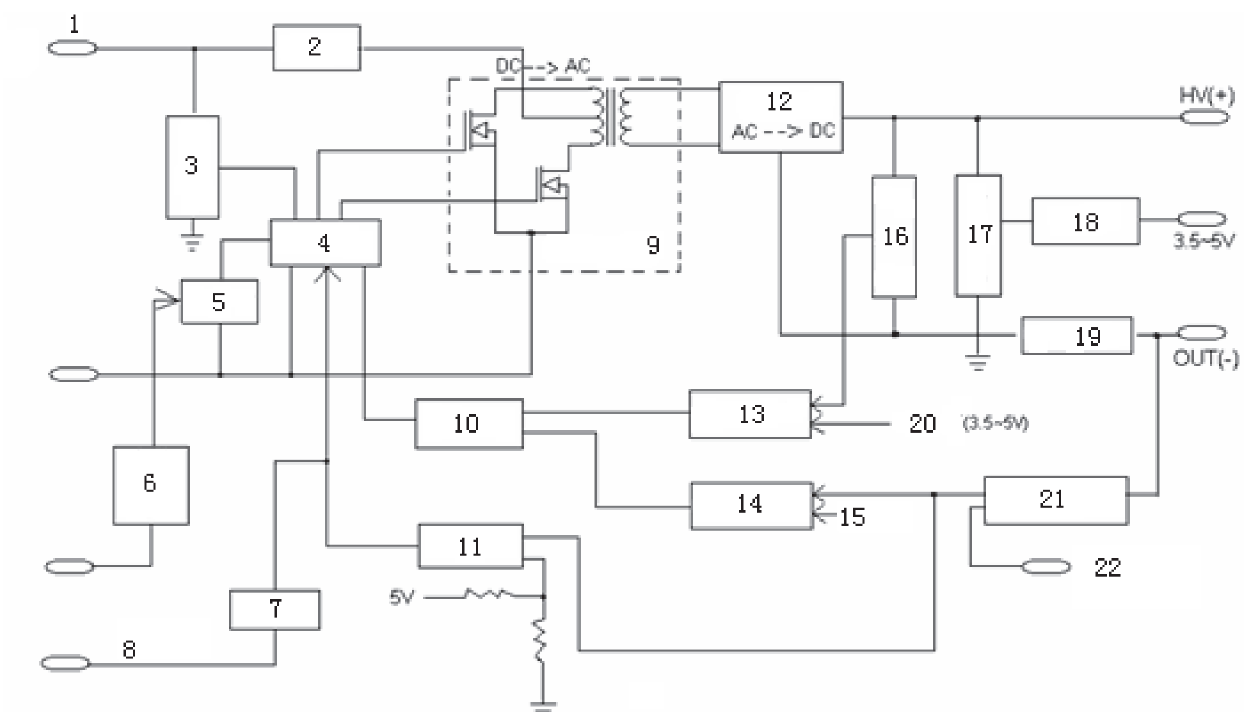


Fig. 4. Fixing of electrodes for sprayer

2.3 High-voltage generator

High-voltage electrode mounted on the nozzle produces high voltage corona which makes droplets charged. In order to ensure the formation of corona field, the high-voltage generator should be supplied with limited voltage and steady current. The highest voltage can be set by a regulating knob. Under steady power supply, stabilized current will decide current density of corona field. Voltage amplitude can be adjusted according to conditions of corona field. In this manner, output current keeps steady and charging equipment can work normally under wider variation range of corona field.

The nonlinear DC high-voltage power supply technique was introduced in the high-voltage power supply equipment, i.e. the typical DC high-voltage switch power supply technique in DC-DC mode (figure 5). The MOSFET, IGBT, quasi-resonant frequency conversion technique (the frequency of power supply can be 2500Hz) and the silicon voltage multiplier technique were introduced. Compared with the linear power supply, it has outstanding characteristics of high efficiency, small volume, low weight, fast reaction, low power storage and short period of designing and manufacturing.
The ±10～±30kV/5mA DC high-voltage power was generated by the high voltage generator, the regulation and display systems were combined fixed in the same control box. The regulation switch、shunt supply insurance、trimmer pot、fault display LED、two ±HV digital display and the power supply of the digital display were included in the control box. The control box has the significant advantage of small volume(only 15cm×10cm×10cm), low weight(only 250g), convenient moved and installed for monitoring and manual adjusting by driver.



1. power, 2. LC decoupling, 3. auxiliary power, 4. PWM, 5. slow starting, 6. starting control 7. monostable circuit, 8. fault signal, 9. power converter, 10. control conversion, 11. short circuit protection, 12. double voltage rectification, 13. voltage comparator, 14. current comparator, 15. user setting, 16. voltage feedback network, 17. voltage divider, 18. voltage follower, 19. current sampling, 20. user setting, 21. Amplifier, 22. display the output current

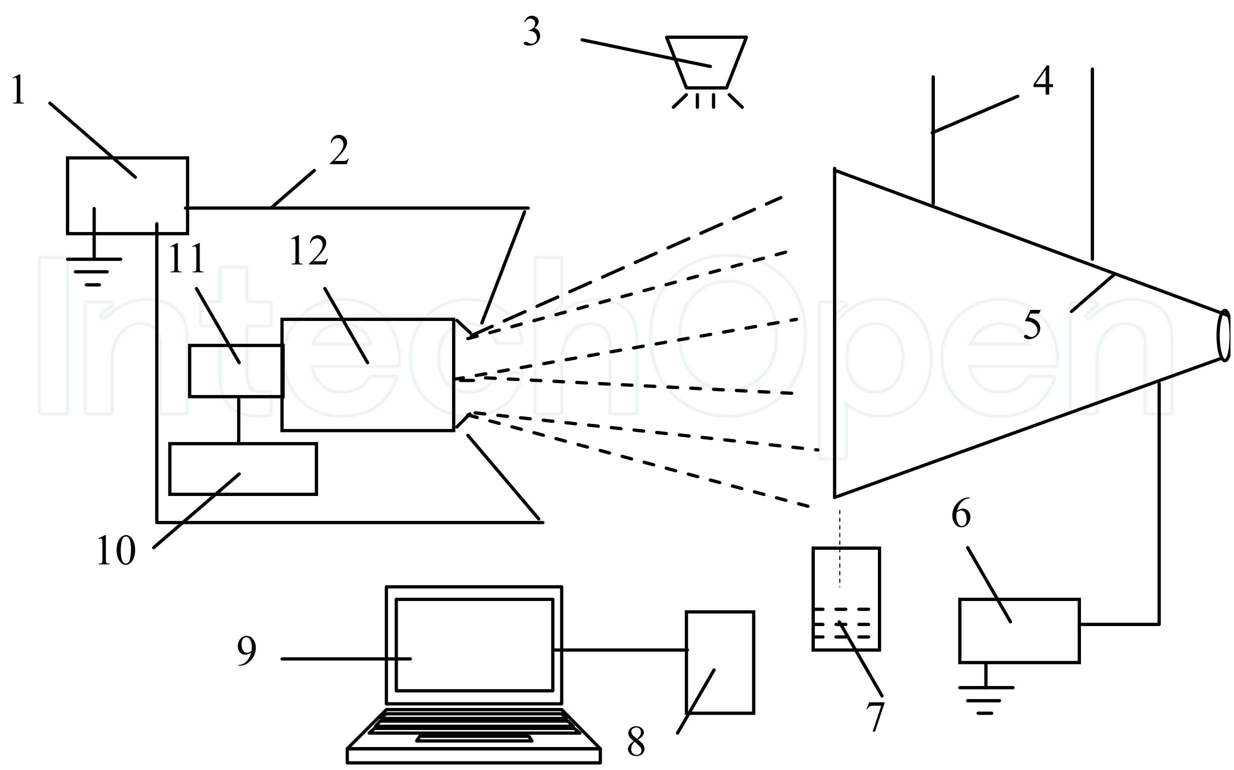
Fig. 5. Work Principle of High-voltage Generator

Between August 10-12, 2009, a long trade tree of a fast growing poplar in Jiangsu Province were sprayed by high range sprayer with electrostatic spraying system to control *micromelalopha troglodyte*, a length of 10Km had been sprayed (figure 6). 10 kg raw pesticide was mixed with 200kg water for spraying. The vehicle speed was 8 km / h, each side lasted 1 hours. Totally 1000L working liquids had been carried out. Before the spraying, the mixed pesticide was added an appropriate amount of liquid fluorescent sodium till the light-green color appeared. After the forestry targets receive the color droplets, the light-green color was useful for observing and stating droplet deposition distribution and deposition density. After three days, the pest mortality or the viability of the pre-arranged standard plants (gauze was setup for observation) was investigated till the seventh day.

Fig. 6. Worksite of sprayer

2.4 Experiments

The experiment was performed in a void workshop with the area of 150m×80m. As measured, the ambient wind speed was 0.8m/s, the atmosphere temperature was 28°C, relative humidity was 60% and the wind speed at the outlet of the sprayer was 25m/s. An electrostatic spray experimental system was built for atomization tests, charge-mass ratio measurements and droplets deposit investigations. A charge-mass ratio measurement device was designed and applied to measure the charge attenuation of charged droplets along the spraying swath. A laser granularity-measuring system was used to evaluate distribution of droplets granularity on sectional planes along the spray jet (figure 7). Three stainless steel balls, mounted on metal pole for simulating tree, were well-distributed on metal pole from spray boundary to spray center from anywhere within the distance of 25m apart from sprayer, (figure 8). Away from 25m, stainless steel balls were distributed at the space out 0.8m on metal pole. To collect droplets, a number of white papers were attached to the balls. Red dye was filled in reagent for test so that red droplets can be seen distinctly on the paper. In practical operation, the spray vehicle moved at speed of 10km/h and collecting set was fixed on a wheelbarrow pushed through spray area at equal speed.



1. high-voltage generator, 2. high-voltage wire, 3. Emitter, 4. insulative hang frame, 5. cone-shaped cage 6. Amperemeter, 7. calculation bucket, 8. Sink, 9. Computer, 10. liquid trunk, 11. Pump, 12. sprayer

Fig. 7. Electrostatic spray experimental system

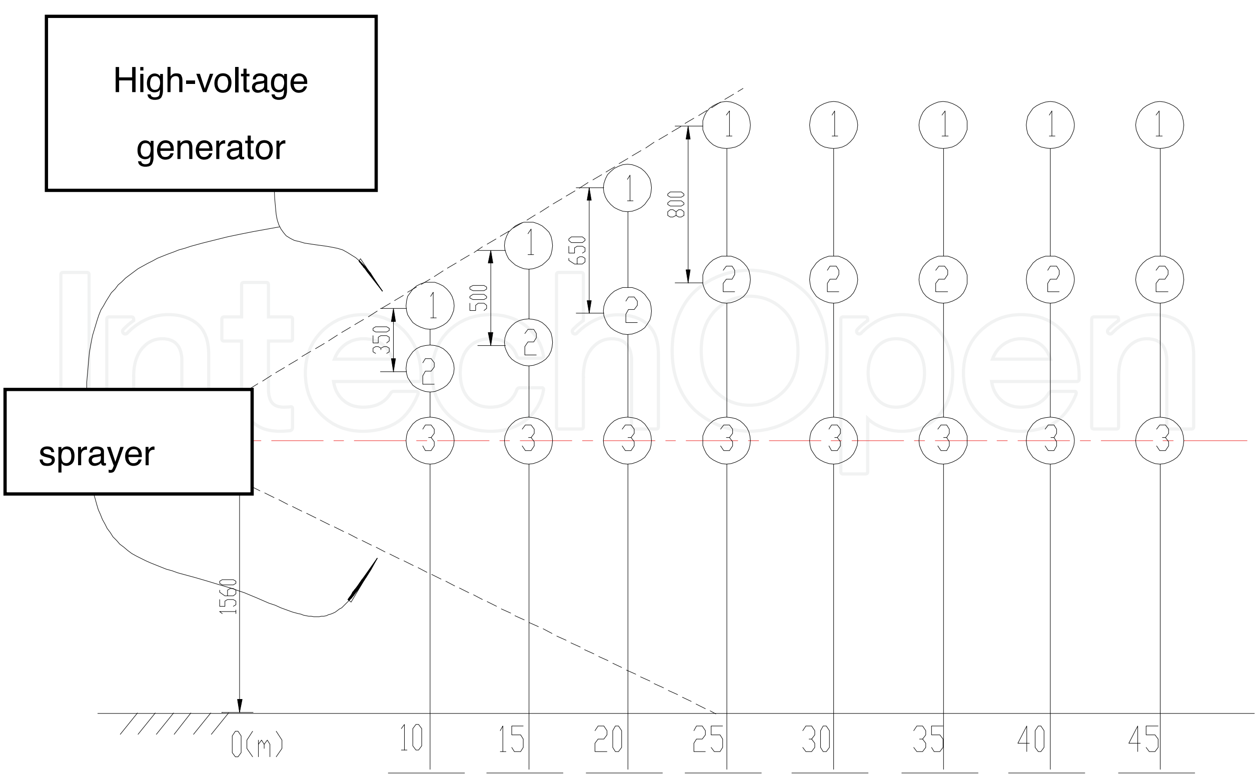


Fig. 8. Electrostatic spray simulation test system

3. Results and discussion

3.1 Droplet size measurement

Droplet size can be measured in different positions and heights with different spraying condition and different charging voltages. The chart in figure 8 shows droplet size is measured in different charging voltages (15kV and 20kV) at the same positions (15m apart from sprayer) and in the same spraying condition. VMD is 108.4μm for non-electrostatic spraying, while it is 96.7μm at 15kV charging voltage and 80.6μm at 20kV charging voltage for electrostatic spraying. Comparing a with b in figure 9, curve of b was extend to small size direction, which showed more small size droplets were distinctly generated. So electrostatic spraying can make the droplets atomization better. Comparing b with c, curve of c was offset to small size direction, droplet were atomized deeply. Curve of c was steeper than curve of b which shows that droplet size was more uniformity when charging voltages increased.

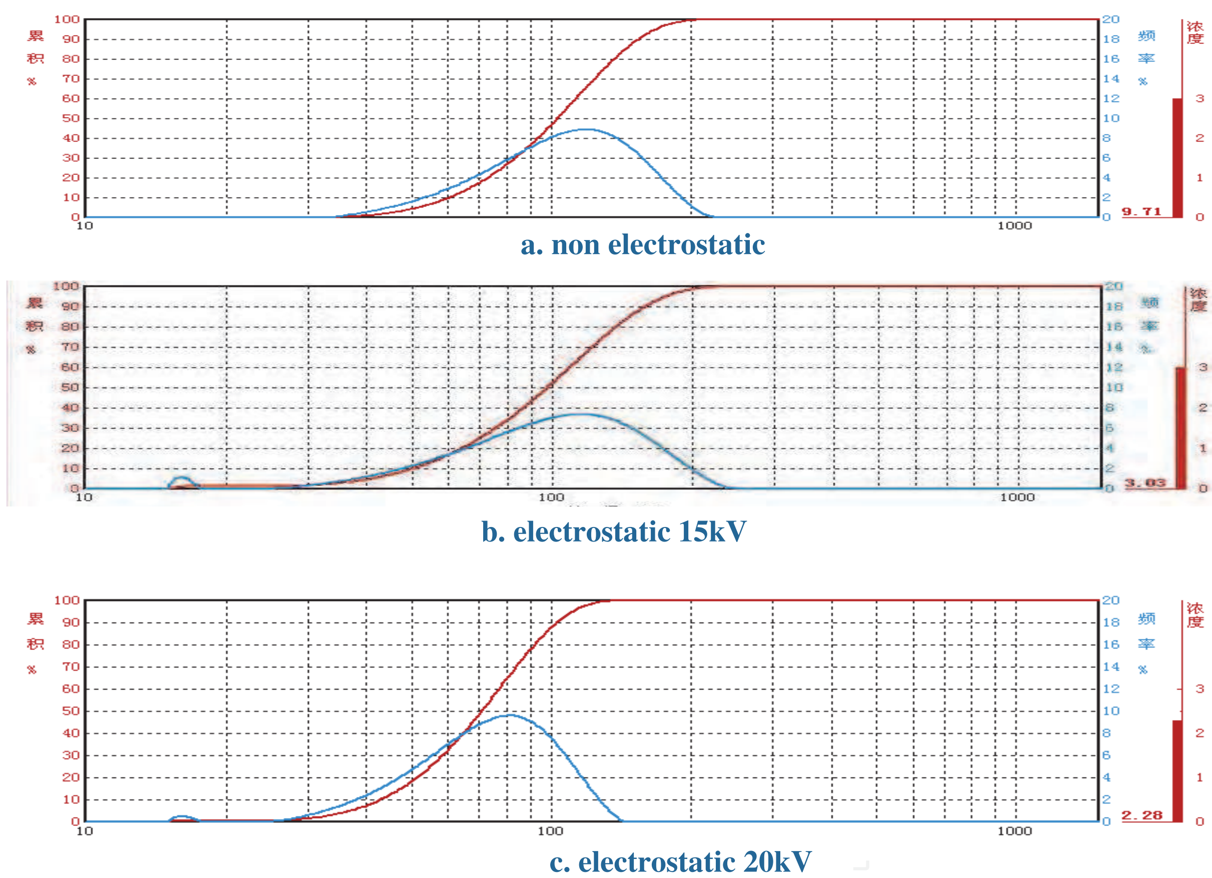


Fig. 9. Droplets granularity chart

3.2 Charge-to-mass ratio test

One of the most important indexes to evaluate the effectiveness of electrostatic spraying is the charge-to-mass ratio. Generally speaking, the higher the charge-to-mass ratio, the more effective the electrostatic spraying should be. The test facility involves a bucket for collecting droplets, a micro-amperemeter for measuring the electric current and an insulated frame.

The charge could be determined by measuring the current with the micro-amperemeter and the mass rate was determined by collecting spray liquid for a specified time. The charge-to-mass ratio q_{cm} was calculated by dividing the current by the mass rate.
Charge-to-mass ratio was measured in three different position (10m, 20m, 30m) and different voltages (15kV to 25kV) with a certain spraying parameters. The figure.10 showed that the q_{cm} rises as the charging voltage increases and the droplet diameter decreases, and the q_{cm} goes down in a lower descent rate as the distance increases. This means that the charged droplet still carry charge at distant spots.

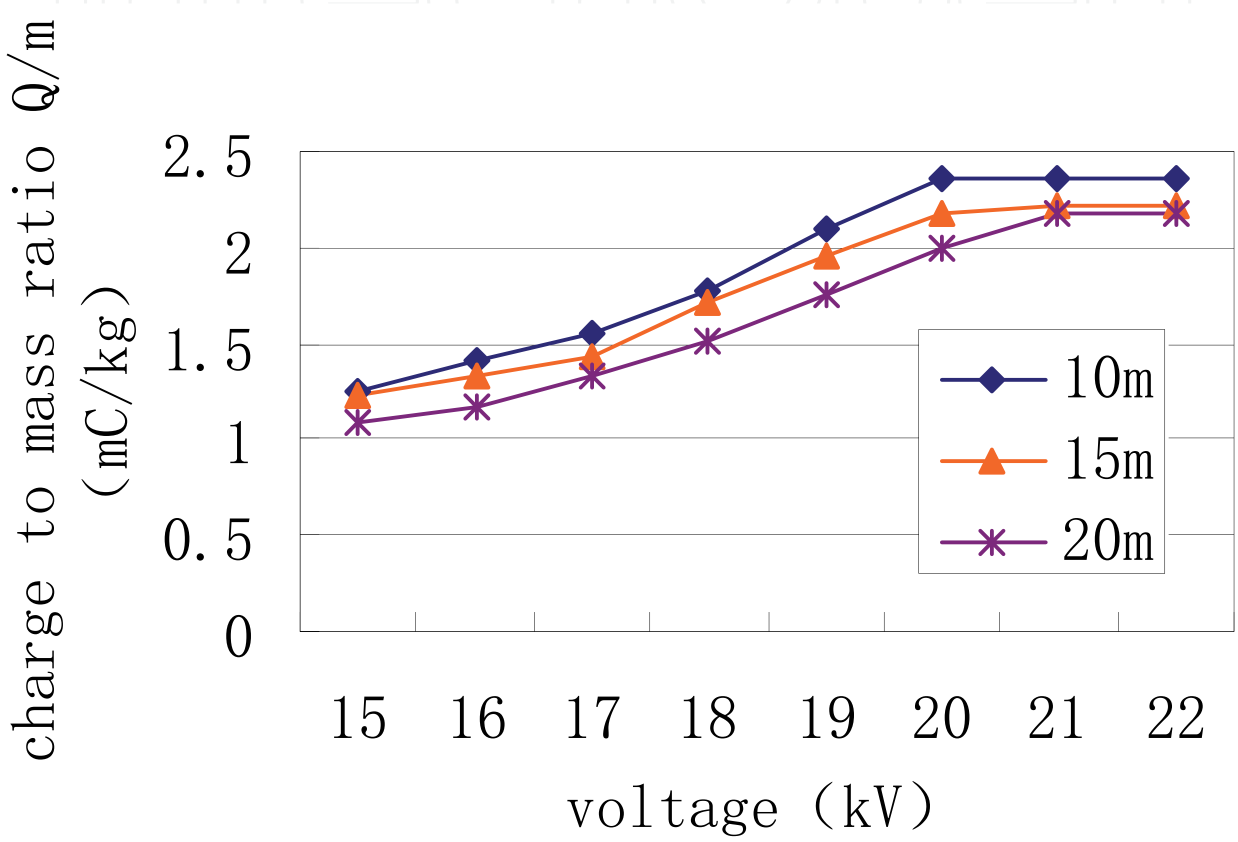


Fig. 10. Relation between charging voltage and charge-to-mass ratio

3.3 Droplet coverage rate

After collecting droplets, droplets volumes were estimated by a square window with area of 1×1cm². The test results were listed in table 1. As just as figure 7, number 1, number 2, number 3 display position of collecting ball. Table 1 shows test result for two mode of spraying such as non electrostatic spraying and electrostatic spraying. Because paper on front of collecting ball had been fully dyed into red within 15m, coverage rate had not been counted. Droplets volumes on the bottom collecting ball were more than others at the same location. Compared with non-electrostatic spraying, more droplets from electrostatic spraying deposited on the targets as far as 45m and fewer droplets drifted away. The electrostatic spraying can make coverage rate of target front increase 21 droplets per cm². Therefore, it can obviously decrease the probability of pesticide poisoning in other surface and the wastage of pesticide.

Mode of spraying	Ball number	Coverage ratio(droplets/ cm²)							
		10m	15m	20m	25m	30m	35m	40m	45m
Non electrostatic	1 front*			124	109	76	65	22	16
	2 front			177	128	87	71	41	19
	3 front			193	132	93	77	54	23
Electrostatic	1 front			158	136	102	81	63	34
	2 front			194	148	110	92	74	37
	3 front			208	165	115	97	79	41
Electrostatic	1 back*	72	67	58	49	39	31	19	7
	2 back	87	61	52	43	43	28	13	9
	3 back	90	76	72	52	47	35	17	11

*front is the side face to sprayer on collecting ball, back is the side far away sprayer on collecting ball. Blank shows paper on front of collecting ball had been fully dyed into red within 15m, coverage rate had not been counted.

Table 1. Comparison with coverage rate in deferent conditions

3.4 Spraying breadth

The spraying breadth experimental results showed that electrostatic spraying could increase spraying breadth and averagely increase spraying breadth to 0.84m (Table 2). The reason is that charged droplets will repel each other exerted by the like charges.

Mode of spraying	Spray breadth(m)							
	2m	4m	6m	8m	10m	15m	20m	25m
Non electrostatic	1.04	1.53	1.92	2.32	2.77	4.26	6.15	7.65
Electrostatic	1.82	2.41	2.87	3.03	3.54	5.09	7.04	8.56

Table 2. Comparison with spray breadth in different conditions

3.5 Field test result

After field test, some result were received. with the electrostatic spraying, the average cumulative mortality of pest was 95.4% and with the non-electrostatic spraying, the average cumulative mortality of pest was 74.8%. The highest mortality of pest appeared on the fourth and the fifth day after spraying and the total number of dead pest reached up to 75% of total deaths. There was a sharp decline in deaths after the seventh day. It was shown in the tests that with the electrostatic spraying, the mortality of pest was significantly higher than that of the non-electrostatic spraying. It was positively correlated with the fact that the droplet deposition effect with electrostatic spraying was obviously better than that of non-electrostatic spraying. The reason was that with the electrostatic spraying, the droplet deposition density was larger, the distribution was more uniform and the larval had more chance to contact pesticide, so higher mortality; on the contrary, the droplet deposition density was smaller, less even distribution and the larvae had less chance to contact pesticide, so lower mortality. with the high-range electrostatic spraying for controlling *Micromelalopha troglodyte*, to achieve the desired effect, the dosage of raw pesticide was only 300g/mu. If controlling *Micromelalopha troglodyte* for 20,000ha, fund can be saved $90,000，wood loss can be reduced 30,000m³,economical loss can be retrieved $6,600,000，utilization ratio of patricide can be improved 60%.

It was shown that the effect of high-range electrostatic spraying was superior to conventional aerial spraying. It was beneficial for reducing spraying drift losses, improving the density of droplet deposition. Therefore, it had the outstanding advantages of high spraying efficiency and low spraying cost.

4. Conclusions

Nanjing forestry University has started the research work on basic theory, testing, measurement and practical applications in electrostatic spray since 1990s. The test research result shows superiority for electrostatic spraying. The electrostatic spraying can make the front target coverage rate increase 21droplets / cm^2. Droplet can be found on front and back of target at far as 45m. When charging voltage is 20kV, electrostatic spray can averagely increase the spray breadth for 0.84m, improve the droplet distributing uniformity with the average volume medium diameter (VMD) of 80.8μm and obtain the maximum charge-to-mass ratio of 2.35mC/kg. The electrostatic spray could produce uniform and fine droplets with better droplet adhesion and spread, higher deposit efficiency, lower environmental contamination, lower application rate, less application expenses and longer residual action than conventional sprays.

On the bases of the experimental results and practical production examinations in the laboratory and field, it showed that combining high-range spray technique with electrostatic spray technique, the invented air-assisted high-range electrostatic sprayer was provided with scientific design, rational structure, convenient operation, high productivity and high efficiency. There was not droplet backward phenomenon during the electrostatic spray, and thus the possibility, of pesticide contamination by the sprayer was greatly reduced.

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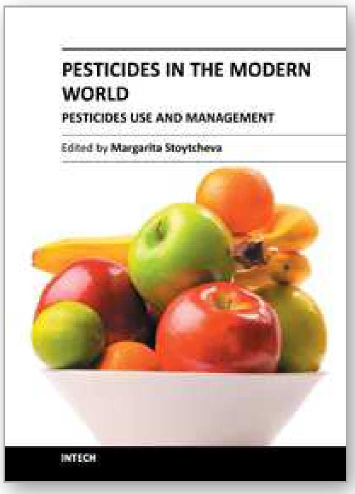

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This book brings together issues on pesticides and biopesticides use with the related subjects of pesticides management and sustainable development. It contains 24 chapters organized in three sections. The first book section supplies an overview on the current use of pesticides, on the regulatory status, on the levels of contamination, on the pesticides management options, and on some techniques of pesticides application, reporting data collected from all over the world. Second section is devoted to the advances in the evolving field of biopesticides, providing actual information on the regulation of the plant protection products from natural origin in the European Union. It reports data associated with the application of neem pesticides, wood pyrolysis liquids and bacillus-based products. The third book section covers various aspects of pesticides management practices in concert with pesticides degradation and contaminated sites remediation technologies, supporting the environmental sustainability.