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Assessment of Nozzle Spray Characteristics for Agriculture Spraying

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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 studies on the operational parameters of selected nozzles were conducted in the laboratory using a patternator with the operational parameters of four types of nozzles (hollow cone, 3-way discharge nozzle (3D), flood type, and solid cone nozzle), five operating pressures (400, 500, 600, 800, and 1000 kPa), and five nozzle heights (0.2, 0.3, 0.4, 0.5, and 0.6 m). The effects of independent variables on spray discharge, droplet size, uniformity coefficient, droplet density, and spray angle were studied. It was observed that the discharge rate increased by increasing the operating pressure, and discharge varied for different types of nozzles. The Hallow cone nozzle

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exhibited a minimum discharge rate of 0.515 l/min, and the maximum discharge rate recorded was 1.546 l/min for the 3D nozzle. The droplet size decreases with increasing operating pressure. As the operating pressure increased, the size of the droplets formed into fine particles. The maximum droplet size of 251 µm was produced by the 3D nozzle, and the minimum was 117 µm by the Hallow cone nozzle. The spray uniformity increased with an increase in operating pressure. Spray uniformity was minimal in cases of low operating pressure because of the size of the droplets. Droplet density increased with an increase in operating pressure. Spray angle increases with increasing operating pressure. The spray angle is decreased by increasing the nozzle height because of gravity. Spray angles are different for different nozzles.

Keywords: Nozzle; spray discharge; droplet size; droplet density and spray angle.

1. INTRODUCTION

“Crop protection equipment's main goal is to reduce the population of pests in their developmental stages that are directly responsible for damage to particular fields. This goal is achieved most effectively when the chemical is applied sparingly on a scale determined by the pest's occupied area and the urgency with which the pest population needs to be controlled while taking the environment into account” [1]. In order to poison the land, water and air over 99% of the applied chemicals travel into the ecosystem [2]. According to a survey, 80% of all pesticides used on plants may eventually find their way into the soil, where they may have a significant impact on the populations of non-target organisms like earthworms [3].

“The droplet size and velocity distributions within the spray region, wind factors, and the spray volume distribution pattern each have a major effect on how well agricultural spray nozzles work” [4]. Spray testing under realistic pressure conditions is quite challenging. Many obstacles need to be addressed in optimizing the test setup and choosing the right processes for nonintrusive measurement procedures [5,6]. In the event, that the ideal conditions for operation are not maintained, related field issues such as non-uniformity, drift and evaporation through the air are likely to increase and result in poor application of costly pesticides [7]. The multiple variables influencing both the quality and quantity of spraying, which include nozzle pressure, droplet size, spray angle, height, and speed of travel, are responsible for the uniform chemical spray spreading across the field.

“Appropriate pesticide application requires careful consideration of nozzle type and size selection. The nozzle has an important function in deciding the amount of spray applied uniformly, the amount of coverage achieved on the target surface, and how little drift is permitted. Atomization is the process of breaking a liquid into several tiny droplets. The atomization process will be affected by the physical properties of the liquid that is sprayed along with the design and configuration of the nozzle” [8]. Gravitational sedimentation, inertial impact, or both of the two processes can cause spray deposition on the soil's surface, plant canopy, or flying insects [9]. Weather parameters, mainly wind, low humidity, and high temperatures, have an important effect on the spray droplets' transportation to the target. These factors often decrease damage efficiency and increase drift. By choosing nozzles that generate the greatest droplet size while offering sufficient coverage at the specified application rate and pressure, drift can be reduced [10].

The size of the spray particle is important because it influences the pesticide's effectiveness and spray drift, as well as the potential effects of the spraying process on the environment. The amount of chemicals used per unit area, the amount of chemicals deposited, and the percentage of chemicals received in a target region are the major factors influencing the effectiveness of spray particles. Spray angle, spray shape, and volume distribution pattern are other crucial spray parameters that impact the effectiveness of spray particles [11]. Biological efficacy is determined by the extent to which individual droplets cover the target. The spray's effectiveness will increase with the number of droplets per unit area. Low application rates with adequate pressure and high ground speed are the current trend. Low application efficiency is undesirable because it raises the risk of environmental pollution and the death of organisms that are not targets, reduces chemical effectiveness, and increases application costs.

As nozzle performance ultimately affects how efficiently pesticides are applied, it is important to investigate it. The risk of spray drift, the quantity and distribution of the deposit on the target, and the chemical's absorption or mode of action at the surface of the target are the three main factors that are affected by nozzle performance.

2. MATERIALS AND METHODS

The most important part of spraying pesticides is selecting and employing spray nozzles properly. The nozzle regulates the volume of spray generated over a particular region, the coverage achieved, the uniformity of the spray distribution and the drift losses. As a result, four nozzle types- hollow cone, solid cone, flood type, and three-way discharge (3D) nozzles - that are most often used by local farmers and manufacturers were chosen for the study (Fig. 1).

The experiments were conducted to evaluate the four types of nozzles using a spray patternator (Fig. 2). It is set up with a barrier frame at all sides to cover the nozzle spray, a power-operated motor-driven HTP pump provided to pump the water from the tank, and a pressure regulator to set and maintain the pressure. The variation of pressure in the system could be observed on the digital pressure gauge of the patternator. The patternator consists of 16 channels of discharge outlets for each channel; it also consists of a nozzle holder for adjusting the height of the spray nozzle. The specifications listed in ASTM standard E641-01, standard procedures for testing hydraulic spray nozzles used in agriculture, were followed in the construction of the spray patternator collection system.

The operational parameters selected as independent variables were the type of nozzle, operating pressure and height of spray. The independent variables are evaluated at five levels to determine the spray characteristics (Table 1). The nozzle under test was mounted at the centre of the metallic frame with the help of a nozzle adjustment rod (provided with holes at 5 levels each at 0.1 m intervals) and its tip pointing towards the patternator trough. The height of the nozzle can be adjusted by a height-adjusting mechanism. Spray operation was carried out for a period of 1 minute in the spray patternator. After each experiment, the performance parameters i.e., discharge rate, droplet size, droplet density, uniformity coefficient and spray volumetric distribution were determined.

2.1 Discharge

The discharge of spray nozzles was measured by the volume-time method. For every experiment, the spray volume was collected for one minute from individual patternator channels in a measuring cylinder. Every spray nozzle's discharge was recorded separately at a time (Fig. 3). [12].

2.2 Droplet Size

The size of the spray droplet is represented as volume median diameter (VMD) and number median diameter (NMD). The droplets are captured on the water-sensitive paper (WSP) for each experiment to measure the size of the droplets. These cards were scanned and analysed using DepositScan software to get the droplet size [13].

Table 1. Variables selected for the evaluation

Sl. no.	Parameters	Levels
	Independent variables	
1	Nozzle type	4 (Hallow cone,3D, flood type and solid cone nozzle)
2	Operating pressure (kPa)	5 (400, 500,600,800 and 1000)
3	Nozzle height (m)	5 (0.2, 0.3, 0.4, 0.5 and 0.6)
	Dependent variables	
1	Discharge (l m-1)	
2	Droplet size (µm)	
3	Droplet density (No's cm^{-2})	
4	Spray Uniformity	
5	Spray angle (˚)	

(a) (b) (c) (d)

Fig. 1. Nozzles selected for study (a) Hallow cone (b) 3-way discharge (3D) (c) Flood type (d) Solid cone nozzle

Fig. 2. Spray patternator

Fig. 3. Spray liquid collecting in measuring cylinder

2.3 Droplet Density

Depending on the droplet size, droplet density directly influences the amount of spray that is applied. Droplet density is the quantity of droplets per square centimetre. The number of droplet spots on a one-square centimetre region of WSP was determined using the Deposit Scan software [13].

2.4 Uniformity Coefficient

Uniformity Coefficient is the ratio of VMD and NMD, which gives the uniformity of the spray. The uniformity coefficient of spray droplets was determined by using the following formula. The more uniform the size of droplets the nearer the ratio to 1 [14].

$$\mathrm{UC} = \frac{\mathrm{VMD}}{\mathrm{NMD}}$$

2.5 Spray Angle

The spray angle of each nozzle at 5 pressure levels is measured by the Image processing method with the help of Python programming language, using the libraries OpenCV and scikit-image [15].

3. RESULTS AND DISCUSSION

The operational parameters *viz*. discharge rate, droplet size, droplet density, spray uniformity and spray angle were determined and analysed at different levels of the operating parameters. The observations obtained from the study were statistically analysed using design expert software using factorial CRD.

3.1 Discharge Rate

The maximum discharge of 0.89, 1.55, 0.98 and 1.40 l min^{-1} was obtained with Hallow cone, 3D, Flood type and Solid cone nozzle, respectively at 1000 kPa operating pressure and 0.4 m nozzle height. The minimum discharge rate of 0.58, 1.25, 0.85 and 0.98 l min^{-1} was recorded by hallow cone, 3D, flood type and solid cone nozzles, respectively, at 400 kPa operating pressure and 0.4 m nozzle height. The variation of discharge rate with operational parameters was shown in Fig. 4, which indicated that as the operating pressure was increased, the discharge rate was also increased for all selected nozzles. This was observed because the operating pressure was directly proportional to the square root of the discharge rate [16]. The discharge rate is independent of the nozzle height. These outcomes confirmed the statements made by Iqbal et al. [17]; Kathirvel et al. [18].

Only the nozzle type and operating pressure, out of the three independent variables, significantly affect the discharge rate at the one per cent significance level, whereas the height of the nozzle shows no significant effect on the discharge rate. The average discharge rates produced by the hallow cone, 3D, flood type and solid cone nozzle were 0.74, 1.36, 0.91 and 1.18 l min^{-1} with a standard deviation of .115, 0.106, 0.045 and 0.164. The values of the coefficient of variation and coefficient of determination (R^2) were 3.63 and 0.93 respectively.

3.2 Droplet Size

The volume median diameter (VMD) and number median diameter (NMD) for the hollow cone nozzle, 3D nozzle, flood type and solid cone nozzles were calculated at five different operating pressures 400 kPa, 500 kPa, 600 kPa, 800 kPa and 1000 kPa. It was observed that as the operating pressure increases, the droplet size decreases. The value of the VMD decreases with increases in the pressure. The lowest VMD is 117 µm attained at an operating pressure of 1000 kPa and 0.6 m height for the Hallow cone nozzle and the highest of 251 µm at an operating pressure of 400 kPa and 0.2 m height for the 3D nozzle. The same trend is being followed by the NMD. It is observed that the value of the VMD is always greater than the NMD (Fig. 5).

For the same operating pressure, hollow cone nozzles were producing smaller droplets than 3D action, flood type and solid cone nozzles. This may be because of the higher discharge rate from these nozzles and in the case of 3D action, it has three orifices, therefore, overlapping of the droplets might have occurred. The operating pressure of the hydraulic nozzle determined the size of the droplets in the spray spectrum. High nozzle pressure breaks up the liquid into small droplets. Jain et al. [19]; Dahab and Eltahir [20] both made the same observations. In terms of spray height, in all four of the chosen nozzles, droplet size decreased as nozzle height increased. However, when considering the operating pressure and nozzle type, the nozzle height had very little of an effect. This was noted because, as the spray's height increased, the droplets travelled a greater distance. However, during this motion, the droplets disintegrated before they reached the surface.

Azizpanah et al. [21] observed the smaller diameters of droplets with increasing the height of the spray nozzle above the ground surface.

The mean droplet size obtained from the hallow cone, 3D, flood type and solid cone nozzle at five different levels of operational parameters were 129.2, 229.8, 148.4 and 178.6 µm with a standard deviation of 9.94, 13.37, 10.95 and 11.89 respectively. By statistical analysis, it was found that all three parameters (*Viz*, nozzle type, operating pressure and nozzle height) significantly affected the droplet size at the 1 per cent level of significance. The values of coefficient of variation and coefficient of determination (R^2) were 3.63 and 0.9788, respectively.

3.3 Spray Uniformity Co-efficient

The value of the spray uniformity should be near to one for better results. The minimum uniformity coefficient of 1.5, 1.1, 1.7 and 1.3 was noted for hallow cone, 3D, flood type and solid cone nozzles respectively, at 1000 kPa and 0.6 m nozzle height. The maximum uniformity coefficients of 1.9, 1.4, 2.5 and 1.6 were recorded for hallow cone, 3D, flood type and solid cone nozzles respectively at 400 kPa and 0.2 m nozzle height. The effect of operational parameters on spray uniformity is shown in Fig. 6.

The spray uniformity value for hollow cone, 3D, fold type, and solid cone nozzles decreased as operating pressure increased. This was noted because the droplet size decreased with increasing pressure [21,22]. As the nozzle height was increased, the spray uniformity was decreased but the effect was less compared to the operating pressure. As the height of the nozzle increases, the spray droplet disintegrates and smaller droplets are formed. If the VMD is reduced, this will decrease the spray uniformity value.

The average uniformity coefficient values obtained by hallow cone, 3D, flood type and solid cone nozzles were 1.72, 1.27, 2.04 and 1.46 with a standard deviation of 0.133, 0.102, 0.261 and 0.120 respectively. It is observed these types of nozzles. Operating pressure and nozzle height significantly affect the uniformity co-efficient values at a 1 per cent level of significance. The values of the co-efficient of variation and coefficient of determination (R^2) were 5.86 and 0.9277 respectively.

3.4 Droplet Density

The maximum droplet density (118 numbers per cm^{-2}) was recorded by the hollow cone nozzle.

The maximum droplet density of 118,78, 100 and 90 numbers per cm^{-2} was obtained for hallow cone, 3D, flood type and solid cone nozzles respectively at 1000 kPa and 0.6 m nozzle height. The minimum values of 86, 47, 62 and 59 were noted for hallow cone, 3D, flood type and solid cone nozzles respectively, at 400 kPa and 0.2 m nozzle height.

For each of the three selected nozzles, increasing the operating pressure also increased the droplet density on the surface (Fig. 7). The observed phenomenon might be due to a greater reduction in droplet size at higher operating pressures as compared to lower operating pressures [23,24,13]. Although operating pressure had a greater impact on droplet density than nozzle height, it was still noted that increasing nozzle height also resulted in an increase in droplet density. As the nozzle height was increased, a consistent dispersion of the spray spectrum was observed. For each of the four chosen nozzles, the same pattern was noted. These results concur with what was reported by Gupta et al. [25]; Dahab and Eltahir [19]; Ferguson et al. [5]; Azizpanah et al. [21].

The mean droplet density values produced by the hallow cone, 3D, flood type and solid cone nozzles were 102, 63, 81 and 73 No's cm^{-2} with a standard deviation of 9.37, 9.51, 11.94 and 8.94 respectively. All the operational parameters, *viz.* type of nozzle, operating pressure and nozzle height significantly affect the uniformity co-efficient values at a 1 per cent level of significance. The values of the co-efficient of variation and coefficient of determination (R^2) were 4.01 and 0.9683 respectively.

3.5 Spray Angle

Maximum spray angles of 93°, 91°, 123° and 93° were obtained by hallow cone, 3D, flood type and solid cone nozzle respectively, at 1000 kPa. Minimum spray angles of 74°, 65°, 101° and 71° were noted by the hallow cone, 3D, flood type and solid cone nozzle respectively at 400 kPa. The spray angle increases with an increase in operating pressure and decreases negligibly with an increase in nozzle height due to the effect of gravity. A Similar trend was observed in Padhee et al. [26].

The average spray angle produced by different nozzles at different levels of operating parameters was 86, 79, 113 and 82 for the hallow cone, 3D, flood type and solid cone nozzle respectively with a standard deviation of 6.77, 8.98, 8.49 and 7.73 respectively. In the statistical analysis type of nozzle and operating pressure show a significant effect on the

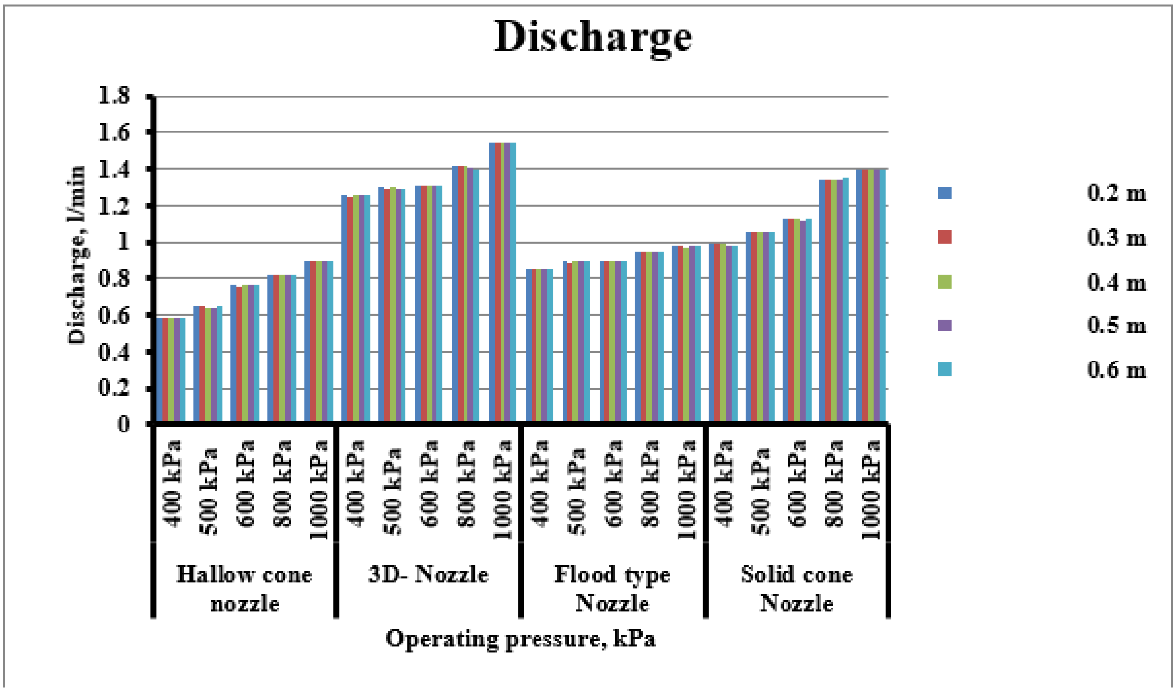

Fig. 4. Effect of nozzle type, operating pressure and nozzle height on spray discharge

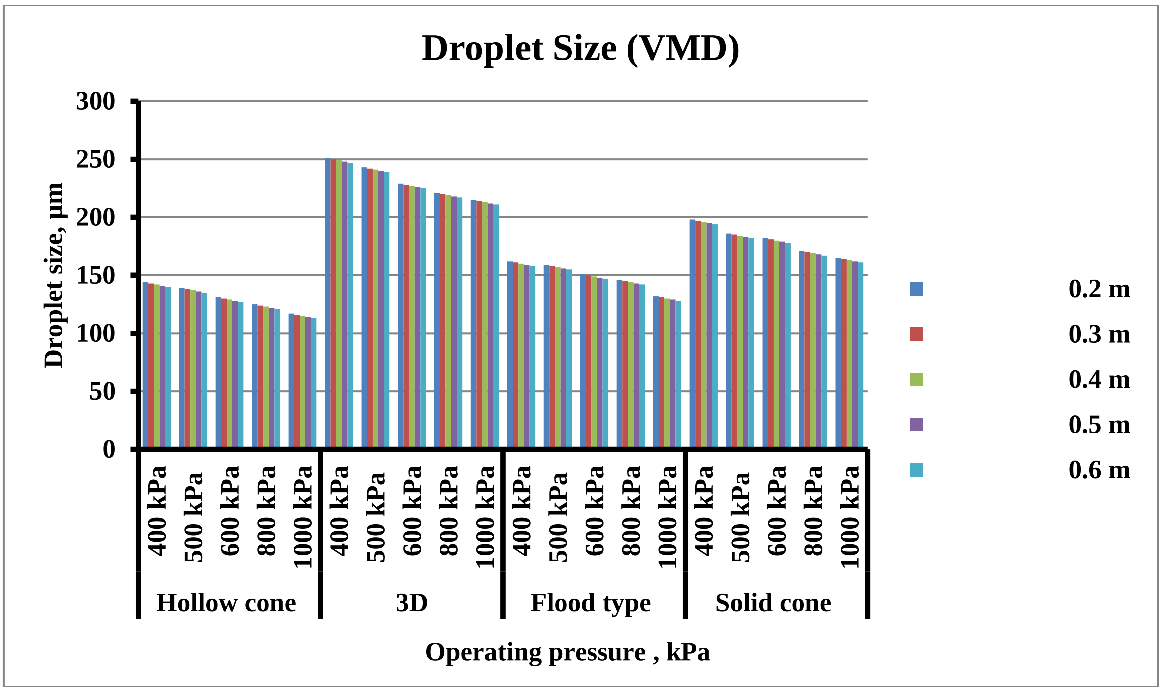

Fig. 5. Effect of nozzle type, operating pressure and nozzle height on droplet size

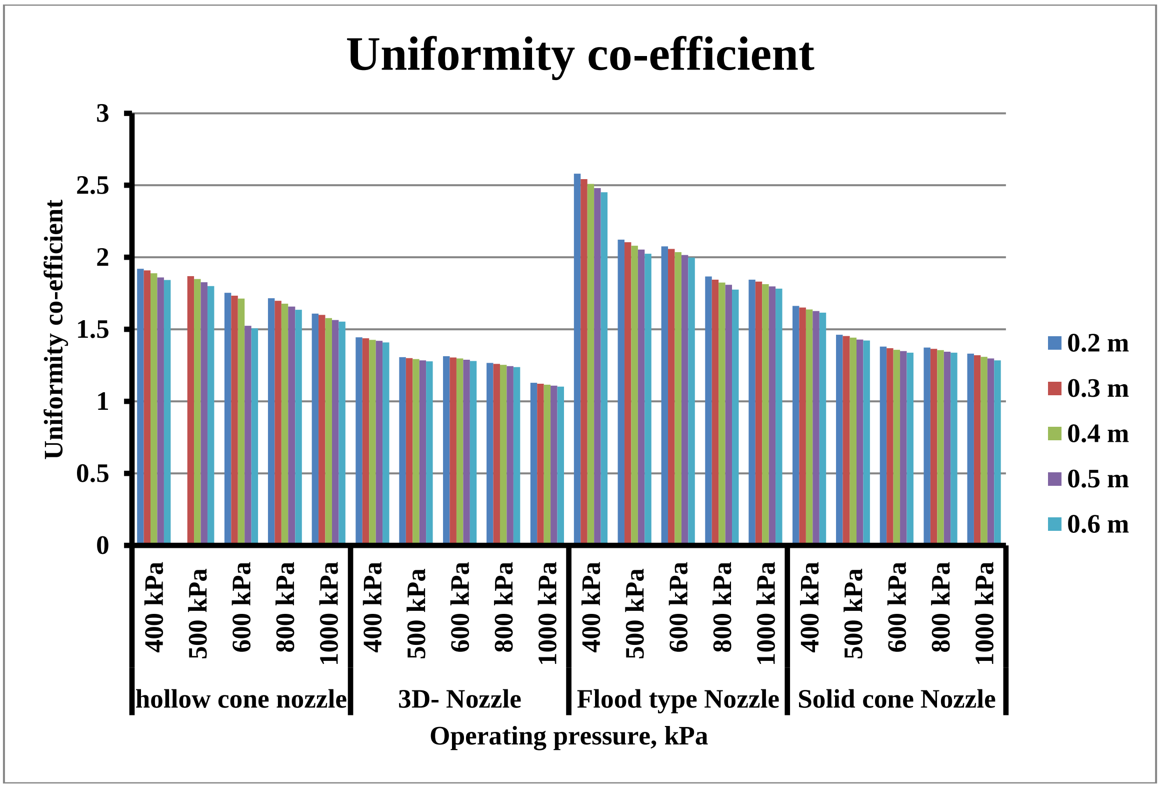

Fig. 6. Effect of nozzle type, operating pressure and nozzle height on uniformity coefficient

spray nozzle at 1 percent of significance effect and nozzle height shows no significance on spray angle. The values of the co-efficient of variation and co-efficient of determination (R^2) were 5.13 and 0.8283 respectively.

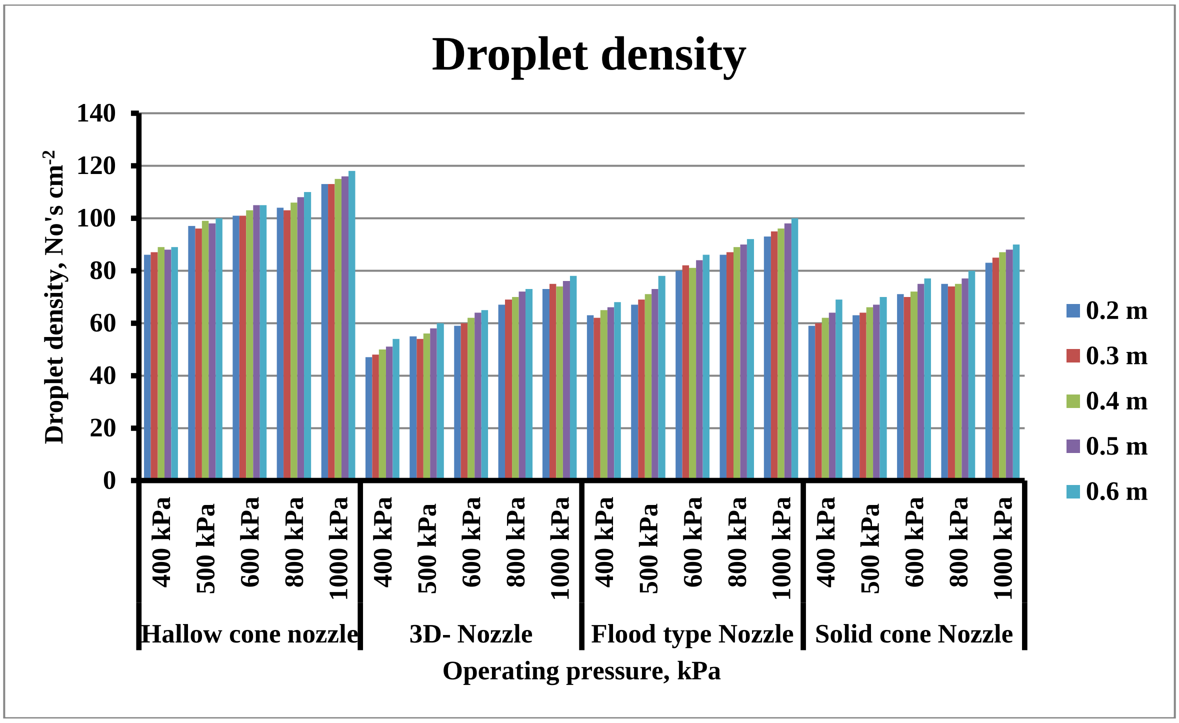

Fig. 7. Effect of nozzle type and operating pressure on droplet density

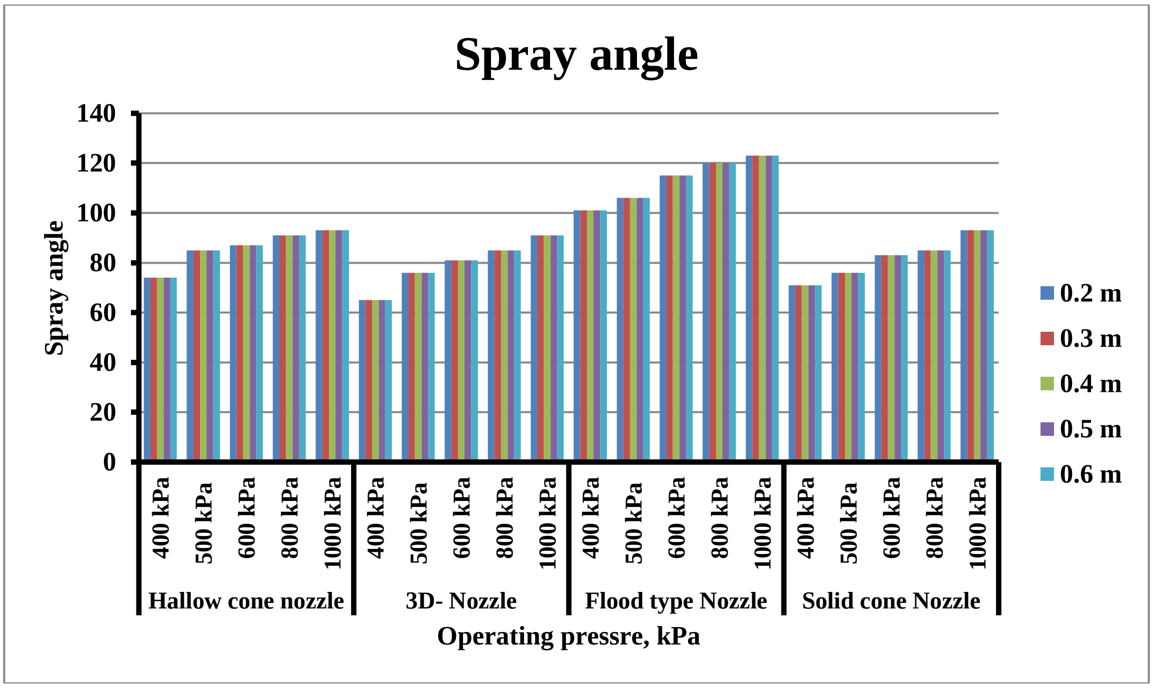

Fig. 8. Effect of nozzle type and operating pressure on spray angle

4. CONCLUSION

In this study on effect of operational parameters on different nozzles was evaluated under laboratory conditions at different nozzles i.e., hollow cone nozzle, 3D nozzle, flood type nozzle and solid cone nozzle at different operating pressures and nozzle heights. The discharge rate increased by increasing the operating pressures and discharge was varied for different types of nozzles. The hallow cone nozzle exhibited a minimum discharge rate of 515 ml min^{-1} and the maximum discharge rate was recorded at 1546 ml min^{-1} by 3D nozzle. The discharge rate was high in the case of the 3D nozzle due to its orifice size and three openings. Droplet size decreases with increasing operating pressure. The droplet size is greater in the 3D nozzle and less in the hollow cone nozzle. The maximum droplet size was 251 µm by 3D nozzle and the minimum was 117 µm by hollow cone nozzle. The uniformity coefficient increased with increasing operating pressure. The maximum uniformity co-efficient was 1.13 by the 3D nozzle and the minimum uniformity co-efficient was 2.58 by flood type nozzle. Droplet density increased with an increase in operating pressure. The droplet density varied for different operating pressures ranging from 47 to 113 No's cm^{-2} for four different nozzles. Spray angle increased with operating pressure. The spray angle is decreased by increasing the nozzle height because of gravity. Spray angles are different for different nozzles.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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