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Evaluating the effect of nozzle type, nozzle height and operating pressure on spraying performance using a horizontal spray patternator

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Abstract
Accurate pesticide application from sprayers is essential in modern farming practice as it increased pest control, reduced pesticide costs and wastage, and greater environmental safety. Evenness of lateral distribution of liquid from a sprayer nozzle is one of the requirements of accurate pesticide application. Hence, a study was undertaken to evaluate the lateral distribution of liquid from four different spray nozzles NMD (N1), BCN (N2), Plastic speaker nozzle (N3) and NTM (N4)) on a horizontal spray patternator. The discharge rate, spray distribution pattern, spray angle of all the types of nozzles were measured with a pressure range of 2.5 to 3.5 kg/cm^2 at an interval of 0.5 kg/cm^2 at three different nozzle height (200, 400 and 600 mm). Considerable variations in pattern occurred between successive runs with individual nozzles: the coefficient of variation from four different nozzles ranged from 0.58 to 1.11 for nozzle N1, 0.71 to 1.12 for nozzle N2, 0.75 to 1.02 for nozzle N3 and 0.57 to 1.29 for nozzle N4. The laboratory test results also indicated that spray angle of the nozzles increased with increasing system pressure up to certain limit and then it decreased. Decrease in spray angle and increase in swath width was also observed with increase in nozzle height. It was observed that with the increment of operating pressure, the swath width was found to be increased. Maximum discharge rate of 2.96 l/min was recorded in the plastic speaker nozzle (N3) at the nozzle operating pressure of 3.5 kg/cm^2. Maximum spray angle of 96.7° was observed with BCN nozzle (N2) at 200 mm nozzle height with an operating pressure of 3.5 kg/cm^2. The maximum swath width of 83.4 mm was found with plastic speaker nozzle (N3) at the nozzle operating pressure of 3.5 kg/cm^2 at 600 mm nozzle height.

Keywords: Spray patternator, lateral distribution, nozzles, coefficient of variation

1. Introduction
Pesticide application is one of the major agricultural operation without which a significant percentage of food and fibre crops would be lost, plant diseases would increase and valuable native habitat would be devasted (Rice *et al.*, 2007) [2]. These pesticides, weedicides and herbicides are mainly applied as liquid solutions by using different types of sprayers equipped with hydraulic spray nozzles. A sprayer's main function is to atomize the spray fluid, which may be a suspension, an emulsion, or a solution, into small fine droplets and eject it with some force for distributing it properly. It can also help to regulate the amount of pesticide to avoid an excessive application that might prove wasteful or harmful. The challenge is to reduce spray losses during transport to their target and maximize spray deposition and efficacy and minimize off-target spray deposition by improving the spray application process by selecting and using adequate spray equipment and spray solutions at the right conditions (Dorr *et al.*, 2007) [1]. The nozzle type not only determines the amount of spray applied but also the uniformity of the applied spray, the coverage obtained on the sprayed surfaces and the amount of drift that might occur (Sumner, 2009). In pesticide application, accuracy and uniformity of application is most important to avoid adverse effects of pesticides on environment and crop injury, and reduced pest management. Flow rate, operating pressure and pressure losses, nozzle material, nozzle spray angle, nozzle positioning, spray height, spray width, spray thickness, breakup length, atomization degree or droplet size, impact, spray drift, velocity, spray pattern, etc. are some parameters that affect the nozzle performance. Each nozzle type has specific characteristics and is designed to be used for different applications. Selecting a nozzle based on the spray pattern and other spray characteristics that are required generally yields good results (Lipp, 2012) [4].
Keeping in view of the above discussions, an attempt was made to evaluate the spray characteristics of different nozzles used in agricultural sprayers in a horizontal spray patternator which could help in selecting the appropriate nozzle for plant protection of any agricultural crop.

The data from this study could be used by the nozzle manufactures to recommend spacing of their nozzles on the booms, operating pressure and other spray parameters that farmers use to treat their field crops during spraying using different hydraulic sprayers.

2. Materials and Methods

2.1 Overview of the experimental setup

A laboratory test set up containing a horizontal spray patternator with arrangement of fitting different spray nozzle was developed as shown in the Fig. 1. The different components of the spray patternator includes supply tank, power transmission system, pump, pressure gauge, pressure regulator, on-off valve, pipes for transmitting liquid solutions, nozzle stand and corrugated sheets and glass tubes for collecting liquid solution. Except the front side, all other sides of the test set up were covered with GI sheets to minimize the effect of surrounding air velocity. For this study, four types of nozzle were selected namely NMD nozzle (N1), small BCN nozzle (N2), plastic speaker nozzle (N3) and NTM brass nozzle (N4). To evaluate the effects of operating pressure and nozzle height on uniformity of spray distribution pattern in laboratory using different types of nozzles, three different nozzle heights (200, 400 and 600 mm) and three operating pressures (2.5, 3.0 and 3.5 kg/cm^2) were selected. The number of channels may be increased or decreased so that the whole of the spray falls within the patternator. The inclination of the spray channel section was made adjustable. The nozzles were mounted at the centre of a metallic frame and its axis was kept perpendicular to the horizontal. The nozzles were connected to a constant water supply through a pump and a pressure gauge was mounted to check the pressure. Liquid collected at each channel were allowed to collected in the glass tubes fitted at the end of each channel from where the volume of liquid was noted. The data from spray tests were collected to analyze the variation of nozzle height and operating pressure on spray angle, swath width, uniformity in volume distribution and discharge rate for all the four types of nozzles used in the study.

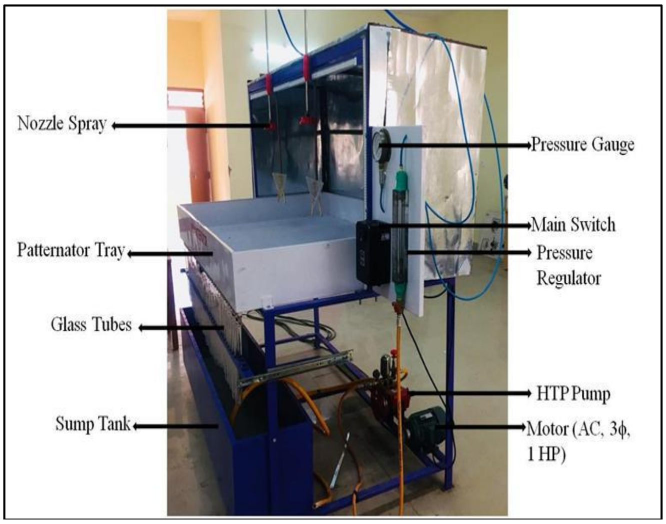

Fig 1: Horizontal spray patternator with different components

2.2 Methods of Measurement

A set procedure was followed for the measurement of different parameters like spray angle, swath width, discharge rate of nozzles, measurement of spray pattern etc. All the measurements were taken as per the guidelines of Indian Standard, IS: 8548-1977.

2.2.1 Spray angle and swath width

As per standard, the working width (the distance between the outer edges of the outermost channels which at the working pressure received 50% or more of the largest quantity of liquid collected from any one channel) in millimeters shall be measured for each of the nozzle height. The spray angle for each nozzle was calculated on the basis of working width and nozzle height as shown in the Fig. 2 and using the formula Equation 1.

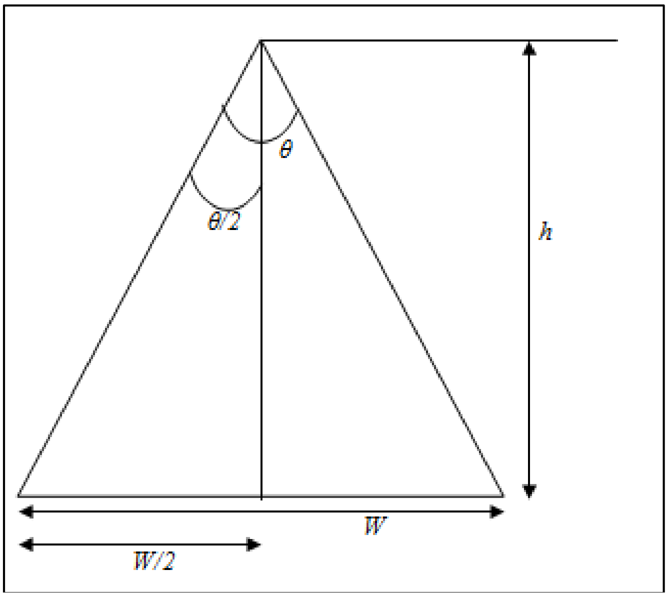

Fig 2: Spray angle measurement

$$W = 2 \times h \times \tan\frac{\theta}{2}$$

Where, W is the width of spray cone, mm ….1
h is the height of the spray, mm and θ is the spray angle in degrees

2.2.2 Measurement of nozzle discharge

The nozzle discharge refers to the amount of liquid sprayed in a unit time. In order to measure discharge the motor was started was allowed to stabilize for some period of time. The motor operated the HTP pump. Initially the overflow valve of the pump and the overflow valve at the delivery line were kept fully open. The discharge from the pump was allowed to go back to the water storage tank. Once the reciprocating pump obtained the desired speed, the opening of the overflow valve in the delivery line was gradually reduced and the inlet gate valve was slowly opened. This allowed the liquid to go to the nozzle and the pressure of the liquid was indicated by pressure gauge provided in the delivery line. The discharge of the nozzles N1, N2, N3 and N4 were measured at 2.5, 3.0 and 3.5 kg/cm^2 pressures. The desired pressure was obtained by regulating the flow through the inlet and overflow gate valves. Each nozzle was operated for 30 seconds and the discharge of each nozzle was allowed to drop in different channels on the corrugated sheet below the nozzle and finally collected in the graduated tubes. The volumes of liquid collected in tubes were noted down. This procedure was repeated for all the above mentioned pressures for different nozzles and data were collected by taking three repetitions. The average data was calculated and the relationship between pressure and discharge was studied.

2.2.3 Measurement of lateral spray distribution
In order to measure the lateral spray distribution, the liquid was sprayed from three different heights such as 200 mm, 400 mm and 600 mm and at four different operating pressure such as 2.5, 3.0 and 3.5 kg/cm^2 as discussed earlier. The spray was then allowed to made fall on corrugated sheet having top width of each section equal to 40 mm. The discharge from each corrugation was collected in 100 ml size measuring test tubes. The spray through nozzle was then allowed to flow through different 100 ml size measuring test tubes for a period of 30 seconds. The amount of liquid collected in each measuring cylinder was then recorded. This uniformity of spray distribution was measured in terms of coefficient of variations (C.V.) and was estimated by using the standard equation

$$CV = \frac{SD}{X} \times 100$$

Where, SD is the standard deviation and X is the mean data …………..2

Statistical Analysis
The analysis of variance (ANOVA) was performed on coefficient of variation to determine the effects of nozzle types, pressures and nozzle heights and their interactions at the confidence interval was set at α = 0.05 using Design Expert 6.0.11. The detail of the statistical model performed was presented below.

Table 1: Statistical design summary

Study Type	Response Surface	Experiments	52
Initial Design	Central Composite	Blocks	No Blocks
Design Model	Quadratic		

Response	Name	Obs	Minimum	Maximum	Trans	Model
Y1	CV	52	0.55	1.29	None	Quadratic
Factor	**Name**	**Type**	**Low Actual**	**High Actual**	**Low Coded**	**High Coded**
A	Pressure	Numeric	-1.00	1.00	-1.000	1.000
B	Height	Numeric	-1.00	1.00	-1.000	1.000
C	Nozzle	Categorical	N1	N4		Levels: 4

3. Results and Discussion
3.1 Effect of nozzle type, height and pressure on uniformity of distribution
According to results of coefficient of variation in the Table 1 and analysis of variance Table 2 indicated that nozzle type, pressure and nozzle height affect significantly on the spray uniformity distribution. Nozzle height was most significant factor influencing variation of CV followed by interaction of pressure-height, pressure and nozzle type at 5% level of significance. The increasing nozzle height tends to decrease the coefficient of variation of spray. As well as, increasing of nozzle pressure tend to give a good uniformity of dose. We can observe from Table 1 that the best value of coefficient of variation 54.7% was achieved by using NTM brass nozzle (N4) at a height of 600 mm and at pressure 3.5 kg/cm^2.

Table 1: Effect of nozzle types, nozzle heights and pressures on uniformity in volume distribution

Nozzle type	Operating pressure, kg/cm^2 ↓ Nozzle height, cm →	Coefficient of variation 200 mm	400 mm	600 mm
N1	2.5	1.110	0.731	0.706
	3	0.999	0.730	0.700
	3.5	0.990	0.713	0.581
N2	2.5	1.119	0.886	0.802
	3	1.067	0.735	0.760
	3.5	1.019	0.712	0.756
N3	2.5	1.008	1.020	1.007
	3	0.762	0.938	0.895
	3.5	0.750	0.932	0.892
N4	2.5	1.291	0.820	0.595
	3	1.252	0.701	0.567
	3.5	1.103	0.626	0.547

Table 3: Variance analysis of the effect of two nozzle types, angles and pressures on coefficient variation (CV)

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F
Model	1.03	14	0.074	5.30	< 0.0001 significant
A	0.042	1	0.042	3.04	0.0897
B	0.28	1	0.28	20.03	< 0.0001
C	0.15	3	0.049	3.53	0.0240
A2	0.027	1	0.027	1.95	0.1713
B2	0.025	1	0.025	1.77	0.1911
AB	1.051E-004	1	1.051E-004	7.565E-003	0.9312
AC	5.532E-003	3	1.844E-003	0.13	0.9399
BC	0.47	3	0.16	11.37	< 0.0001
Residual	0.51	37	0.014		
Lack of Fit	0.38	21	0.018	2.27	0.0492 significant
Pure Error	0.13	16	8.062E-003		
Cor Total	1.54	51			

3.2 Effect of nozzle height and pressure on volumetric discharge of nozzles
The volumetric distributions of the nozzles obtained from the patternator test were presented through trend lines (Fig. 3a to 3d) and the effect of height and pressure on the volumetric distribution was studied. Each trend line represents the average discharge collected from the channels of the patternator at a particular height and pressure. It was found from the figures that, with increase in the nozzle height the curves became more flat and wide, as the height was increased the number of channels collecting the spray increased while the peak discharge value in the channels decreased. This confirms height has some influence on the swath. From the figures, it was also observed that as the pressure increased from 2.5 kg/cm^2 to 3.5 kg/cm^2, the number of channels receiving liquid were increased and hence the discharge. This inferred that increasing the pressure increases the swath as well as the volumetric discharge. The channels present in the centre received more discharge as compared to the channels to both the ends. Similar results were reported by Yadav H K, 2012. Figure 4 shows that for all the nozzle types, the maximum peak discharge was obtained from the channels at 200 mm nozzle height and at 3.5 kg/cm^2 operating pressure and it was found 225, 155, 175 and 190 ml for nozzle N1, N2, N3 and N4, respectively.

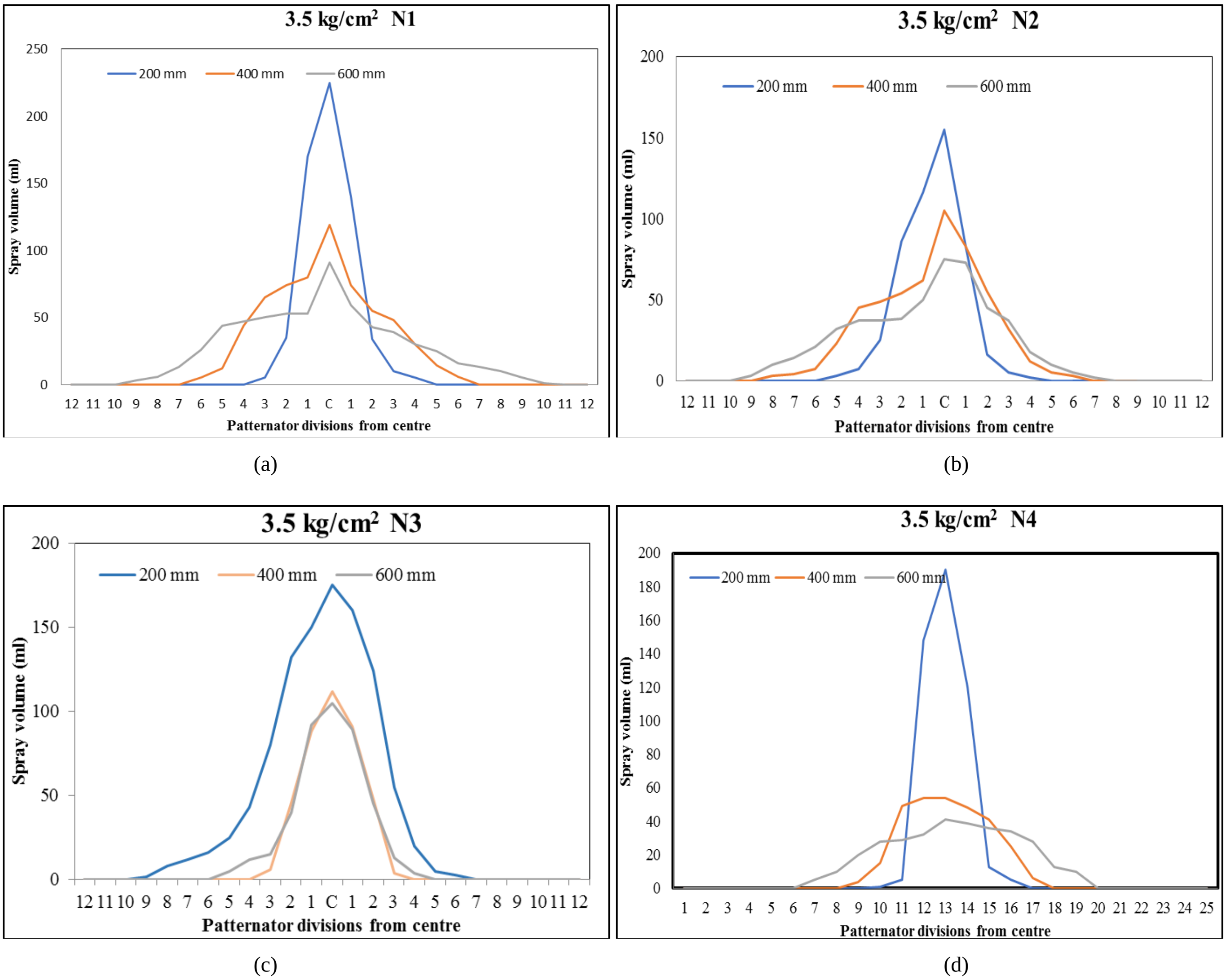

Fig 3: Effect of nozzle height on spray volumetric distribution of different nozzles at 3.5 kg/cm^2

The distribution of liquid solutions in different channels of the spray patternator was presented in Fig. 4.

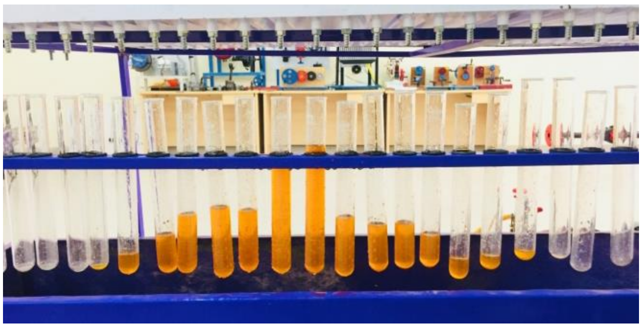

Fig 4: Spray distribution pattern

3.3 Effect of nozzle height and operating pressure on spray angle of nozzles

The spray angle for all nozzle types were measured using Equation 1 as discussed earlier. From the data measured, it was found that as the operating pressure was increased from 2.5 kg/cm^2 to 3.5 kg/cm^2, the maximum spray angle for nozzle N1, N2, N3 and N4 increased from 82.56˚ to 89.89˚; 89.86˚ to 96.7˚; 73.96˚ to 96.36˚; 82.56˚ to 96.36˚, respectively. This increment may be due to gradual increase in operating pressure. In case of nozzle height a reverse trend was observed, i.e. with increment in the nozzle height from 200 mm to 600 mm, decrease in maximum spray angle from 89.86˚ to 78.0˚; 96.7˚ to 68.68˚; 96.36˚ to 68.68˚; 96.36˚ to 59.3˚,was observed for nozzle N1, N2, N3 and N4, respectively.

3.4 Effect of nozzle height and operating pressure on swath width of nozzles

From the measured swath width data, it was observed that as the operating pressure was increased from 2.5 kg/cm^2 to 3.5 kg/cm^2, the maximum swath width for nozzle N1, N2, N3 and N4 increased from 39.9 to 77.1 mm; 44.7 to 82.0 mm; 35.1 to 83.4 mm; 35.1 to 68.5 mm, respectively. This increment may be due to gradual increase in operating pressure. In case of nozzle height, same increasing trend was observed, i.e. with increment in the nozzle height from 200 mm to 600 mm, increase in swath width was reported with maximum swath width of 77.1, 82.0, 83.4 and 68.5 mm with nozzle N1, N2, N3 and N4, respectively was observed at 600 mm nozzle height.

3.5 Effect of operating pressure on discharge rate of nozzles

The effect of operating pressure on discharge rate of nozzles was presented in Fig. 5. From the figure, it was observed that for all the nozzle types, the discharge rate increased with increase in operating pressure. This was because, as there was increase in operating pressure, more amount of liquid was sprayed and hence the rate of discharge. From the results, it was also found that the maximum discharge rate of 2.96 lpm (litre per minute) was obtained with nozzle N3 at 3.5 kg/cm^2 operating pressure followed by 1.36 lpm, 1.19 lpm and 0.95 lpm with nozzle N4, N1 and N2, respectively.

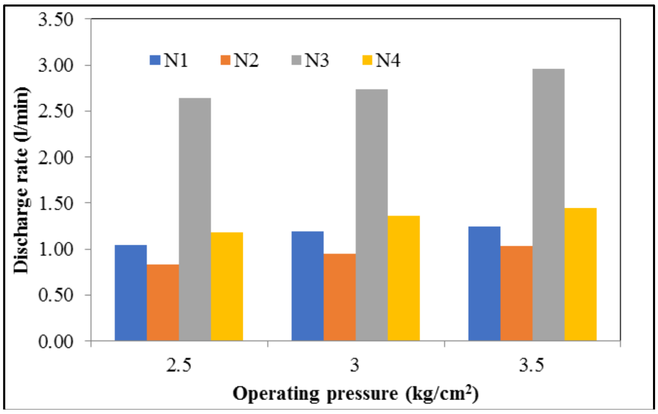

Fig 5: Effect of operating pressure on discharge rate of nozzles

4. Conclusion

The results indicated that the nozzle operating pressure and height of nozzles affect the spray uniformity distribution. The NTM nozzle gave the lowest values of the spray uniformity coefficient in terms of coefficient of variation (C.V.) values compared to the other nozzles used in this study. No much effect of the interactions of nozzle height and nozzle pressure on the spray pattern was observed as evident from the ANOVA. The increasing of nozzle height tends to increase the uniformity of spray and the coverage of spray dose. As well as, the increasing of nozzle pressure tend to give the good uniformity of spray solutions. These data generated from this study could be used for selection of proper sprayer type for specific crop.

The following specific conclusions were drawn from the study:

- The most uniform volumetric distribution of N4 nozzle was obtained at 600 mm height on 3.5 kg/cm^2 operational pressure and C.V. value of the distribution was 0.567.
- At 200 mm nozzle height, maximum spray angle of 96.7^o was observed with BCN (N2) nozzle followed by Small speaker (N3), NTM (N4) and NMD (N1) at 3.5 kg/cm^2 operating pressure.
- Maximum discharge rate of 2.96 lpm was recorded with plastic speaker nozzle at the operating pressure of 3.5 kg/cm^2 followed by NTM nozzle (1.36 lpm), NMD nozzle (1.19 lpm) and BCN nozzle (0.95 lpm).

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