DEVELOPMENT OF ENVIRONMENT FRIENDLY BOOM SPRAYER TEST BENCH

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A 2.7-m long, 1.22-m wide, and 1.73-m high University Boom Sprayer Test Bench had been designed, developed, and fabricated to evaluate different types of nozzles for the measurement of discharge, swath width, cone angle, and spray pattern. Six nozzles had been provided, out of which five were fixed to spray top to bottom onto the corrugated sheet just below the boom pipe like a conventional boom sprayer and the sixth nozzle was directed towards the vertically moveable platform to spray at different angles (0°, 15°, 30°, 45°) with respect to horizontal on the under side of water sensitive papers. The water sensitive papers can be easily inserted in rubber holders mounted on the moving belt for spray uniformity evaluation. The distance between adjacent nozzles on the conventional boom was kept constant as 38.1 cm.
Keywords: Test bench, boom, nozzle, water sensitive paper, swath width

INTRODUCTION

Chemical pesticides have played and will continue to play a major role in the rapid advancement of agricultural production. Farmers are now realizing the use of pesticides. Despite the competition of weed, pathogen, insects and pests, the farmers are continuously applying pesticides to achieve maximum production. It has now become essential to spray the growing crops economically and profitably.

As cotton crop grows, the plant height increases more than plant width, making it almost impossible to penetrate the canopy with overhead spraying. At such stages overhead spraying will not give proper spray distribution (Pandy et al. 1994). Tractor mounted boom sprayers, spray from the top of plants on the upper side of leaves but most of the insects resting on the lower side of leaves have been reported. Mostly the chemicals do not hit the actual target and cause wastage of spray material to the environment. It is necessary to apply pesticide in such a manner that the maximum droplets are deposited at the target.

Insect pest continues to cause losses of yield and quality either directly by feeding, or indirectly as a vector of disease. These losses can be extremely serious and may result in total loss of a crop in some fields. The effectiveness, cost and safety of any pest control program are often greatly influenced by the distribution of the pest control agent. Many pest control applications are made with little knowledge of the variation of the pest control agent on the target. To improve pest control applications, instrumentation is needed to accurately and rapidly determine the distribution of sprays across the swath for various nozzle operation conditions (Mahmood, 2003).

Several different types of equipment and methods have been used for measuring spray distribution patterns. Liljedahl and Strait (1959) and Roth et al., (1979) measured fluorescence of deposits containing a fluorescent tracer on long strips of paper with a photo cell and flourometer respectively. Khdair (2003) developed a system for analyzing nozzle spray distribution for training students and applicators spray distribution patterns across a spray table at various nozzle-operating conditions. Pattern distribution results and coefficient of variation were found very consistent.

Local industry is manufacturing sprayers but yet no scientific effort has been made to test locally made nozzles, which are not technically suitable for use by farmers because of poor workmanship and substandard components. Therefore, this study was designed to develop a test bench and evaluate different nozzles for measuring their discharge, spray pattern, and swath width.

MATERIALS AND METHODS

This section includes: a) Development of University Boom Sprayer Test Bench & b) Testing and evaluation of sprayer nozzles.

a. Development of University Boom Sprayer Test Bench

Different parts of the test bench has been designed & developed as following (Figure 1):

1. Frame: The sprayer test bench frame was made of angle iron (50.8 x 50.8 mm) MS-1025 to decrease the initial cost of the machine. It had sufficient strength to carry the load of corrugated sheet, boom assembly, two electric motors, pump, and other parts. It had two portions; mainframe and vertically moving platform stand. The overall length of the frame is 2.7 m, width 1.22 m, and height 1.73 m. The frame had a provision to adjust the vertical height of boom pipe from the

corrugated sheet and horizontal distance from the moving belt platform.

2. Corrugated sheet: An 18 gauge, grade 308 stainless steel sheet was employed due to anti-corrosive quality. V- channels each 38.1-mm wide and 25.4 mm deep were developed using a hydraulic press along the width of the sheet. The corrugated sheet had 2.7 m length and 1.2 m width. The sheet was fixed on a rectangular angle iron frame, which was bolted with the main frame, in order to mount and remove easily. The corrugated sheet was given a slope of 8° to direct the moving fluid down the slope to 100- ml glass cylinders.

3. Motor and pump assembly: A 3-hp AC motor was employed to drive a gear pump. Motor was operated at 1400 RPM. Motor pulley diameter and pump pulley diameter were 89-mm and 216-mm respectively. A B-type V belt was employed to operate the water pump with motor.

4. Pump: In the design of new boom sprayer test bench, an external gear pump was used due to its simplicity and low cost. It could develop a pressure up to 1000 kPa (10-bar) and its operating speed was 510-540 rpm.

5. Filters: Two filters were provided. A filter of 40-mesh was used in the suction line to prevent the pump from damping. Another imported 52-mesh cylindrical filter was used in each nozzle body with anti-drip system. As the tank was covered with the help of a lid, so no more particles, straw, leaves etc. could go to the tank.

6. Tank: A rectangular stainless steel tank (0.92 m long, 0.47 m wide and 0.29 m high) was designed and fabricated with a capacity of 120 liters of water. The stainless steel 18-gauge sheet (grade-308) was specifically employed due to anti-corrosive quality, durability, and easiness of cleaning.

7. Hoses and Lines: The suction line hoses with 19-mm internal diameter and delivery line hose with 13-mm internal diameter were employed. The main boom pipe was a rigid steel pipe having internal diameter 2-cm. All lines were fitted with a removable end cap to enable flushing.

8. Control valves and Boom pipe: Manual control valves (9.5 mm I.D) were employed to operate each nozzle, which were individually mounted perpendicular to the main boom pipe (25.4 mm I.D). A main control valve (12.7 mm I.D) was installed in the beginning of delivery line hose to regulate the desired flow rate in the main boom pipe and direct the excess water back to tank. The separate control valves facilitated the performance evaluation of each nozzle separately. Horizontal adjustments had been provided to increase or decrease the horizontal distance of main boom pipe from the moving vertical platform. The horizontally placed main boom pipe has also been provided the facility of vertical adjustments above the corrugated sheet.

9. Nozzle: This test bench has been designed, developed, and fabricated to test different types of nozzles for their discharge, swath width, cone angle, and spray pattern. Six nozzle outlets had been provided. Five nozzles were tested for spraying vertically downward onto the corrugated sheet just below the boom pipe like a conventional boom sprayer and the sixth nozzle was installed in the middle of main boom pipe and at 90^0 to other nozzles. The sixth nozzle was designed to direct spray to the bottom surface of WSP inserted in the plastic holders, which were mounted on the belt of vertical moveable platform. An angle adjustment facility was provided on one end of main boom pipe for directing spray at different angles (0°, 15°, 30°, 45°) on the under side of water sensitive paper (WSP). The WSP could be easily inserted in rubber holders mounted on the moving belt for spray uniformity evaluation. The distance between adjacent nozzles spraying from top to bottom on the boom was kept constant as 38.1 cm.

10. Pressure gauge: To measure accurate pressure, glycerin filled pressure gauge was used. This pressure gauge was capable of measuring pressure up to 1000 kPa.

11. Vertically moveable platform: A vertical moveable platform having a length of 2.8 m and height 1.73 m was designed and fabricated. A canvas flat belt having a height of 0.96 m and a length of 6.25 m was driven over two vertically revolving rollers on either side of the stand. Two V- belts (C type) were fixed with flat belt on top and bottom ends. The V-belts were used to move in V- sheaves, which were fixed on lower and upper ends of both the rollers. This arrangement helped in keeping the flat belt in its position at all the desired speeds of belt. Each roller had a length of 1.0 m and a diameter of 0.16 m. A 3-hp variable speed DC motor was used to drive these rollers. The canvas belt could be moved at a speed of 2 Km/hr to 10 Km/hr by varying the speed through variable speed motor. Water sensitive paper (25.4 mm x 31.75 mm) holders were manufactured from flexible rubber sheet and mounted on a canvas belt at different heights from corrugated sheet (30 cm, 50 cm, 70 cm). This mechanism helped in getting spray images on lower side of water sensitive papers (WSP) at different spray pressures, angles, heights and distances from nozzle for evaluating spray uniformity.

12. Nozzle restriction mechanism: A spring loaded nozzle restriction mechanism had been designed to check the nozzle flow towards vertically moving

platform. A 1.2 m long square steel rod (10-mm x 10-mm) with round handle on one end and a stainless steel plate on the other end was designed. This rod was made spring loaded between two brackets and mounted on the inner side of the frame of horizontally placed main boom pipe in such a way that the plate (20-cm x 20- cm) always restricted the flow of the nozzle that is used to spray the undersurface of WSP. For spraying on to the WSP, the handle was pulled against the spring pressure as the WSP on the belt came close the nozzle and released after WSP sprayed. After the WSP were once sprayed, spraying system and moving belt were stopped and WSP were taken out from holders for analysis in the computer lab.

13. Pattern meter: At the lower end of corrugated sheet, nozzle pattern-measuring system was designed, fabricated, and mounted horizontally on a rectangular hollow shaft (25.4-mm x 25.4-mm) and bolted under the main frame. The pattern meter consisted of vertically adjusted 72-glass cylinders (2.54 cm I.D., 100-ml volume). The reaching fluid to the v-channels of the corrugated sheet and flowing down the slope was collected in its respective cylinder at the lower end of each v-channel. Each cylinder was held in position in an individually mounted spring-loaded holder on the shaft. A vertical angle adjustment assembly (0-100°) was designed in order to revolve the pattern meter for emptying the cylinders after measurements. A water collecting stainless steel tray equal in length to corrugated sheet with semicircle end was designed and mounted below the pattern meter. Water flowed down the slope in tray to water tank mounted under the main frame.

b) Testing and Evaluation of Sprayer Nozzles

1. Nozzle discharge: The spray boom was installed on the test bench. After setting desired pressure, nozzle discharge of each nozzle was measured in the graduated cylinder for a period of 60 seconds (1 minute). Hollow cone (HC) nozzles tested were as following:

- HC, Punjab Engineering Co. FSD. (Local)
- HC / 0.8 / 3.00 (International Ltd. UK) Yellow
- HC / 0.4 / 3.00 (International Ltd. UK) Orange

2. Swath width and spray angle: Swath width and spray angles (angle between the outer surfaces of the sprayed liquid with respect to nozzle orifice) are the important parameters of spray nozzle performance. Wider angles of spray will require high pressure of application. Spray angle increases with the increase in pressure. Spray angle of each nozzle was calculated by measuring the effective swath width. The distance between extreme graduated cylinders collecting water was measured and the angle was calculated with the help of following formula (Mahmood, 2003):

$$\theta / 2 = \tan^{-1} (b / H)$$

Where, θ = Cone angle, b = ½ of swath width, and, H = Nozzle height (Fig. 2).

3. Spray pattern: Spray pattern is generally the spraying trend of a specific nozzle. It helps to evaluate the fluid proportion sprayed along the swath width of a nozzle. In determining spray pattern, nozzle was operated at a specific pressure and height above the corrugated sheet. The fluid from nozzle hitting the corrugated sheet moved into the V-channels (38.1-mm wide and 25.4 mm deep) on the corrugated sheet and collected in the graduated cylinders. From these cylinders, volume of fluid collected was measured. A histogram between discharge of each nozzle & cylinder distance was plotted to see the spray pattern of nozzle.

RESULTS AND DISCUSSION

The performance of a sprayer and ultimate environmentally effective chemical use depends mainly on the performance of a sprayer nozzle, which is an important part of a sprayer. To evaluate the performance of spray nozzle, a sprayer test bench was developed in the Department of Farm Machinery and Power, Faculty of Agricultural Engineering and Technology. Imported and locally developed nozzle, were tested for nozzle discharge, spray angle, and spray pattern at different pressures.

1. Imported and locally made nozzles: Locally manufactured hollow cone type nozzles performed irregularly and inconsistently. Spray pattern and discharge of the nozzles manufactured by Punjab Engineering Co. Faisalabad were found to perform unreliably. It was found difficult to record precise data with the locally manufactured nozzles. Spray pattern had been conical shaped but its dimensions like swath width and cone angle were found inconsistent at different trials of the same pressure setting as shown in Table 1. However, the other two imported nozzles (HC/0.8/3 Yellow and HC/0.4/3 Orange) performed very well at all the pressure levels (Table 2 & 3). The discharge and spray pattern (swath width and cone angle) data were found very consistent for all the pressure settings. This indicates good workman ship of the imported nozzles.

2. Effect of Pressure on Nozzle Discharge: The discharge of different nozzles like, Yellow (HC/0.8/3), Orange (HC/0.4/3) and King (HC) were measured at different pressures and tabulated in Tables 1 to 3. The pressure was changed from 250 kPa to 500 kPa. It appeared that the discharge of each type of nozzle increased with the increase in pressure. Higher the pressure, higher the discharge. To double the discharge, the pressure must be roughly increased by four times. The discharge was greater for pressure 500

KPa than other two pressure levels (250 kPa & 350 kPa). It is also clear, that with the increase of nozzle orifice diameter, the discharge also increased. Therefore, nozzle King (HC) having orifice diameter 0.0016 m had greater discharge than Yellow (HC/0.8/3) with 0.0013 m diameter and Orange (HC/0.4/3) with 0.0007 m diameter at all the six pressure levels.

The effect of pressure on discharge studied for each type of nozzle was plotted in figures 3 to 5. The functional relationships representing the data for imported and locally made nozzle are given as following:

$Q = 7x10^{-6} + 3x10^{-8} P - 2x10^{-11}P^2$ $R^2 = 0.981$ (King)

$Q = 1x10^{-5} - 1x10^{-8} P + 5x10^{-11}P^2$ $R^2 = 0.983$ (Yellow)

$Q = 1x10^{-6} + 1x10^{-9} P + 1x10^{-11}P^2$ $R^2 = 0.985$ (Orange)

Where: Q = Discharge (m^3/s), P = Pressure (kPa)

The R^2 value for HC King was 0.981, for Yellow (HC/0.8/3) 0.983 and for Orange (HC/O.4/3) was 0.985 respectively. The high values of R^2 under all the nozzle data recorded indicated that the predicted models were appropriate to explain the relation between pressure and discharge and were fitting well to their respective data set.

3. Spray pattern (Spray angle and Swath width): Spray angle is an important parameter of nozzle performance that establishes the correct nozzle spacing, overlapping and height of application. Spray angle is dependent on type of nozzle, orifice size and operating pressure. Table 1, 2 and 3 depict that as the pressure was increased 2 times (250 kPa to 500 kPa), the cone angles in King (local), Yellow and Orange (imported) nozzles were increased 1.1 times, 1.07 times and 1.05 times respectively. It indicates that increase in nozzle diameter resulted in the increase of cone angle, which was more prominent at the largest size nozzle. It is also clear from each of the above tables, that the increase in pressure directly increased the cone angle. The increase in swath width was 1.17 times in King nozzle (local), where as in case of both the imported nozzles the increase in swath width was 1.1 times as the pressure was increased 2 times (250 to 500 KPa) for the same height of nozzle from the corrugated sheet (42.1 cm).

With the increase in pressure from 250 to 500 KPa, the variations in nozzle cone angle and swath width among different replications ranged 7.5% to 14 %and 16% to 20 % respectively for locally manufactured nozzle. Where as for imported nozzles negligible variations were observed among different replications in the same parameters for the same range of pressures. This could be due to better workman ship involved for the manufacture of imported nozzles.

Figure-6 presents the spray pattern of locally made and imported nozzles. From Figure-6 it is clear that locally made nozzle had greater variations in spray pattern than the imported along the swath of nozzle at all the levels of pressure.

Table 1. Discharge and Spray pattern at different pressures for spray nozzle(HC/King) manufactured by Punjab Engineering Co. FSD. at 42.1cm boom height.

Pressure psi (Kpa)	Parameters *	Replications					Mean
		1	2	3	4	5	
36.25	Q (l/min)	00.80	00.78	00.76	00.76	00.70	0.76 l/min (1.3 x 10^{-5} m^3/s)
	θ°	82	80	78	78	72	78
(250 Kpa)	B (cm)	73.58	71.08	68.58	68.58	61.08	68.58
43.50	Q (l/min)	00.80	00.82	00.88	00.96	00.94	0.88 l/min (1.5 x 10^{-5} m^3/s)
	θ°	84	82	80	74	80	80
(300 Kpa)	B (cm)	77.39	74.89	72.39	64.89	72.39	72.39
50.75	Q (l/min)	00.97	00.87	00.93	00.93	00.95	0.93 l/min (1.6 x 10^{-5} m^3/s)
	θ°	84	74	80	80	82	80
(350 Kpa)	B (cm)	77.39	64.89	72.39	72.39	74.89	72.39
58.00	Q (l/min)	01.08	01.03	01.03	01.05	00.96	1.03 l/min (1.7 x 10^{-5} m^3/s)
	θ°	88	84	84	86	78	84
(400 Kpa)	B (cm)	80.2	76.2	76.2	78.2	70.2	76.2
65.25	Q (l/min)	01.00	01.10	01.08	01.06	01.06	1.06 l/min (1.8 x 10^{-5} m^3/s)
	θ°	80	84	82	86	86	86
(450 Kpa)	B (cm)	71.00	85.00	84.00	80.01	80.01	80.01
72.50	Q (l/min)	01.19	01.19	01.15	01.18	01.13	1.19 l/min (2x 10^{-5} m^3/s)
	θ°	86	86	80	90	88	86
(500 kpa)	B (cm)	75.01	74.01	80.01	85.00	86.00	80.01

*Q = Discharge, l/min; θ°= Cone angle, degree; B = Swath width, cm

Table 2. Discharge and Spray pattern at different pressures for spray nozzle (HC/0.8 Yellow) manufactured by International Ltd. UK. at 42.1cm boom height.

Pressure psi (kPa)	Parameters *	*Replications* 1	2	3	4	5	Mean
36.25	Q (l/min)	00.71	00.72	00.72	00.72	00.73	0.72 l/min (1.2 x 10^{-5} m^3/s)
	θ°	86	86	86	86	86	86
(250 Kpa)	B (cm)	80.01	80.01	80.01	80.01	80.01	80.01
43.50	Q (l/min)	00.79	00.79	00.78	00.79	00.80	0.79 l/min (1.32 x 10^{-5} m^3/s)
	θ°	88	88	88	88	88	88
(300 Kpa)	B (cm)	83.82	83.82	83.82	83.82	83.82	83.82
50.75	Q (l/min)	00.84	00.85	00.85	00.85	00.86	0.85 l/min (1.42 x 10^{-5} m^3/s)
	θ°	88	88	88	88	88	88
(350 Kpa)	B (cm)	83.82	83.82	83.82	83.82	83.82	83.82
58.00	Q (l/min)	00.90	00.91	00.92	00.91	00.91	0.91 l/min (1.52 x 10^{-5} m^3/s)
	θ°	88	88	88	88	88	88
(400 Kpa)	B (cm)	83.82	83.82	83.82	83.82	83.82	83.82
65.25	Q (l/min)	00.95	00.90	00.96	00.95	00.99	0.95 l/min (1.62 x 10^{-5} m^3/s)
	θ°	92	92	92	92	92	92
(450 Kpa)	B (cm)	87.63	87.63	87.63	87.63	87.63	87.63
72.50	Q (l/min)	01.11	01.12	01.10	01.12	01.15	1.12 l/min (1.87 x 10^{-5} m^3/s)
	θ°	92	92	92	92	92	92
(500 kpa)	B (cm)	87.63	87.63	87.63	87.63	87.63	87.63

*Q = Discharge, l/min; θ°= Cone angle, degree; B = Swath width, cm

Table 3. Discharge and Spray pattern at different pressures for spray nozzle(HC/0.4/3 Orange) manufactured by International Ltd. UK. at 42.1cm boom height.

Pressure (Kpa)	Parameters *	*Replications* 1	2	3	4	5	Mean
36.25 psi	Q (l/min)	00.34	00.35	00.35	00.35	00.36	0.35 l/min (5.8 x 10^{-6} m^3/s)
	θ°	84	84	84	84	84	84
(250)	B (cm)	76.2	76.2	76.2	76.2	76.2	76.02
43.50 psi	Q (l/min)	00.37	00.37	00.38	00.38	00.40	0.38 l/min (6.3 x 10^{-6} m^3/s)
	θ°	86	86	86	86	86	86
(300)	B (cm)	80.01	80.01	80.01	80.01	80.01	80.01
50.75 psi	Q (l/min)	00.39	00.40	00.40	00.40	00.41	0.40 l/min (6.7 x 10^{-6} m^3/s)
	θ°	86	86	86	86	86	86
(350)	B (cm)	80.01	80.01	80.01	80.01	80.01	80.01
58.00 psi	Q (l/min)	0.425	0.425	0.43	0.43	0.44	0.43 l/min (7.2 x 10^{-6} m^3/s)
	θ°	86	86	86	86	86	86
(400)	B (cm)	80.01	80.01	80.01	80.01	80.01	80.01
65.25 psi	Q (l/min)	0.445	0.45	0.45	0.45	0.455	0.45 l/min (7.5 x 10^{-6} m^3/s)
	θ°	88	88	88	88	88	88
(450)	B (cm)	83.82	83.82	83.82	83.82	83.82	83.82
72.50 psi	Q (l/min)	0.52	0.49	0.50	0.50	0.49	0.50 l/min (8.4 x 10^{-6} m^3/s)
	θ°	88	88	88	88	88	88
(500)	B (cm)	83.82	83.82	83.82	83.82	83.82	83.82

*Q = Discharge, l/min; θ°= Cone angle, degree; B = Swath width, cm

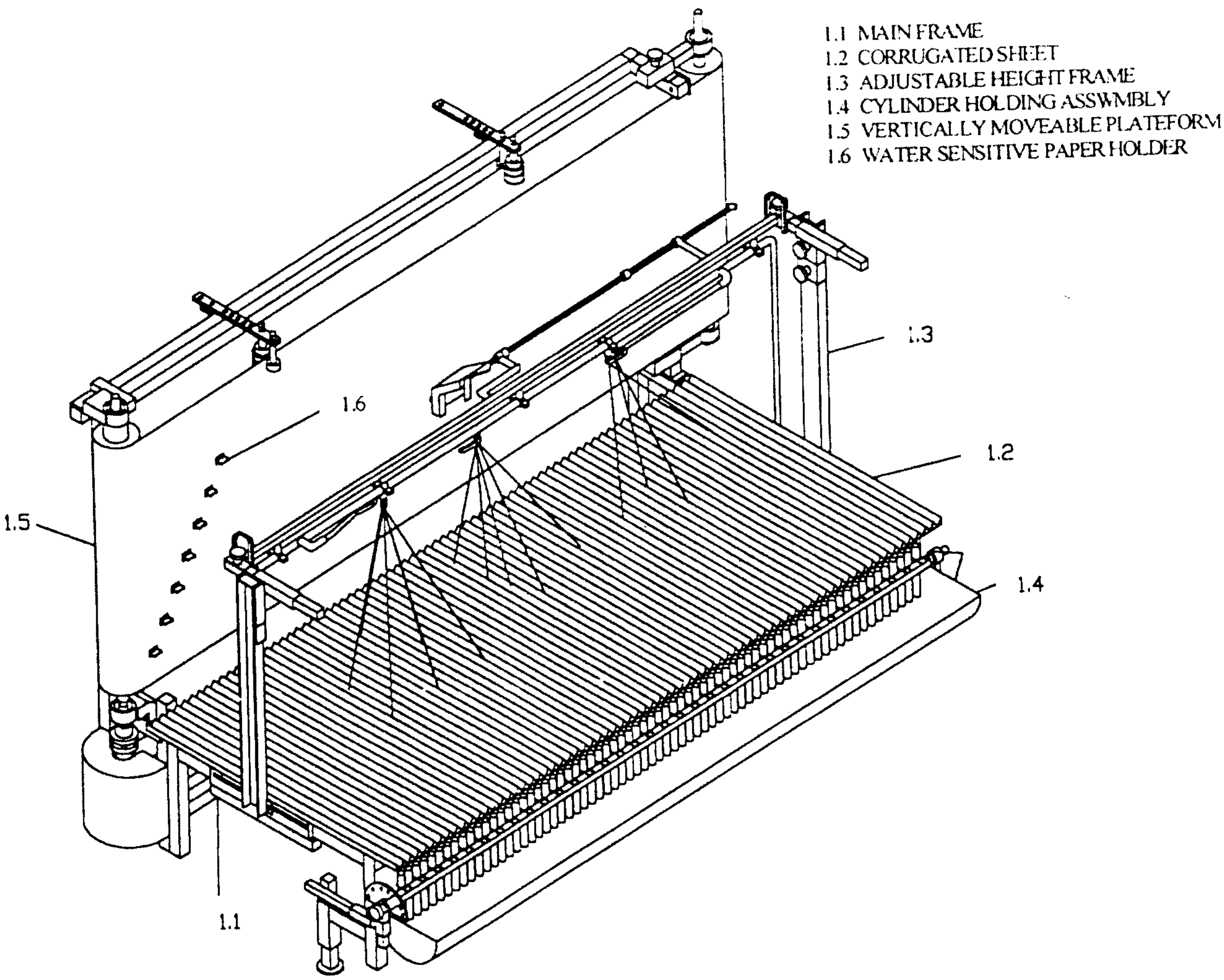

Figure 1. University Boom Sprayer Test Bench

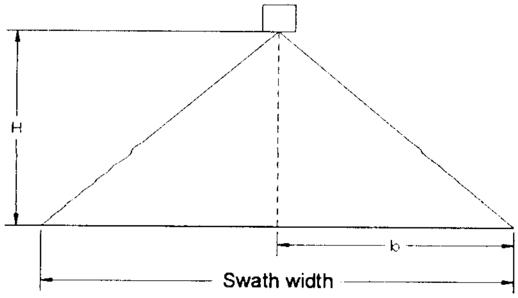

Figure 2. Cone angle measurement of a nozzle

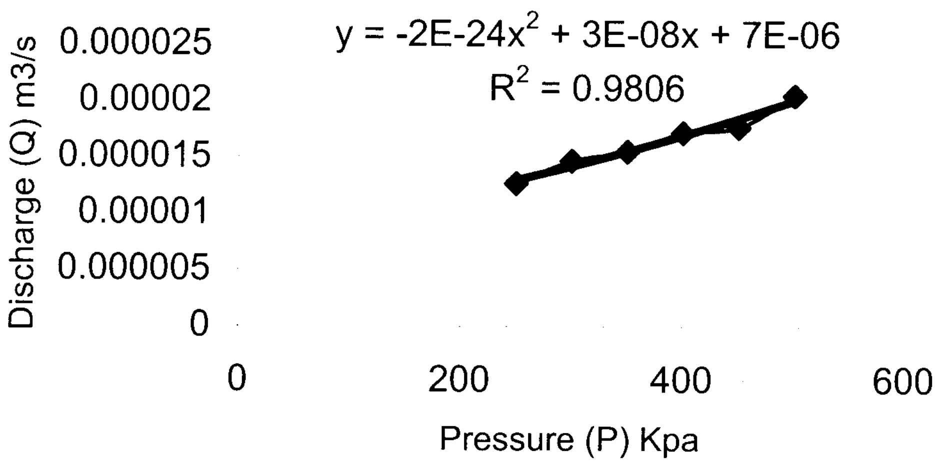

Figure 3. Effect of pressure on nozzle discharge (locally manufactured HC / King).

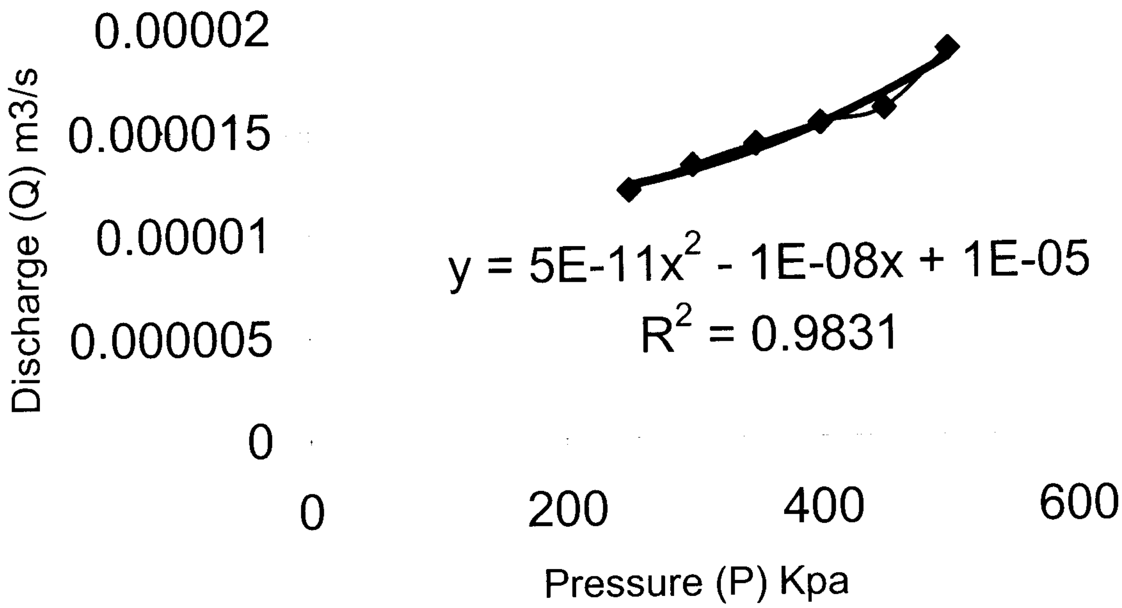

Figure 4. Effect of pressure on nozzle discharge (imported HC/ 0.8 / 3, Yellow).

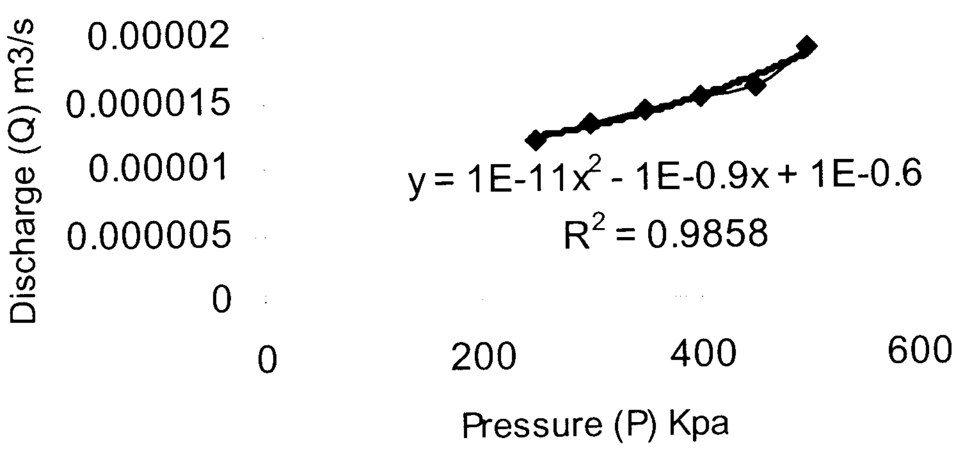

Figure 5. Effect of pressure on nozzle discharge (imported HC/ 0.4 / 3, orange).

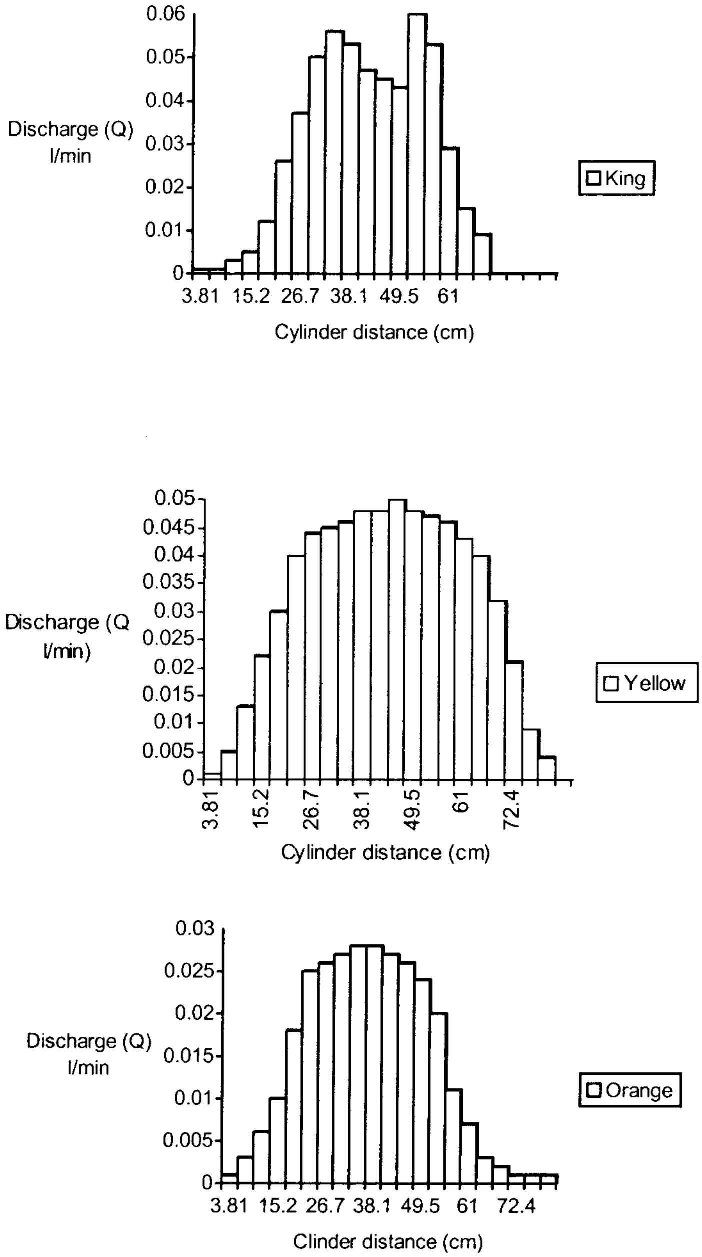

Figure 6. Spray pattern of local (King) and imported (Yellow & Orange) nozzles at 350 kPa

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