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Development of Experimental Pulsed Spray Device for Spot Application

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An experimental pulsed spray device was developed and studies were conducted on targeted spraying and spray application rate. The discharge of carrier fluid and chemical were measured at different set of pressures by using two types of hollow cone nozzles viz BAN nozzle and NMD hollow cone nozzle. Carrier fluid pressure was maintained from 0.05 to 0.2 MPa and the chemical tank pressure was varied from 0.05 to 0.3 MPa. The important characteristics of pulsed spray system were evaluated at different pressures and it was found that, at pressure 1 MPa the VMD was medium spray and at pressure 0.15 to 0.4 MPa VMD was fine spray. It is noticed that the applied volume per unit area is uniform when the pressure is within 0.15 to 0.4 MPa. The results showed that the quantity of chemical applied per pulse varied between 0.4 to 1.2 ml per pulse for different operating pressures and target widths. From the prediction equation, the quantity of chemical applied over the plant was calculated as 2.6 ml when the area of the plant is 78 cm^2. Hence the application rate of chemical was estimated as 0.33 ml/cm ^{2}.

Key words: Spot application; Pulsed spray, Discharge rate.

The successful application of pesticides to field crops result from the proper use of equipment while considering the prevailing field conditions, morphology of the crop, target area, and mobility of the pest (Matthew, 1992). It is estimated that the spray chemical reaching the target area is less than 70 per cent while the remaining 30 per cent is going as drift and misapplication. The selection of suitable sprayer is based on timeliness in operation, uniformity of spray deposition, spray droplet size, coverage, operational cost and safety. In a sprayer, the change in application rate requires an operational adjustment which involves change of spray components and recalibration of the system. Row crop cultivation are increasing every year due to mechanization. In row crops there will be definite spacing between rows and interspacing between plants in a row. Especially, during early stages of row crops plant to plant spacing will be high and gradually it decrease in later stages. Spot application system is the best suited for row crops. For normal continuous sprayers wastage of chemical occurs more in row crops because chemical is sprayed continuously covering the empty space between plant to plant. The sensor guided pulsed spray technique will identify the exact target area and the nozzle will spray only the predetermined quantity of spray chemical in each pulse to the target plant area. Hence pulsed sprayer can be effectively used to spray row crops. Row crops include all fiber crops like cotton, oil seeds like groundnut, sunflower and castor, pulses like green gram, cow pea and red gram and vegetables like brinjal and bendi. The use of this spraying technique enables application of herbicide precisely and accurately on individual plants. This reduces the pesticide consumption and decreases local and global contamination of the environment. With the above techniques and methods there will be more than 30 per cent saving spray chemicals.

Miller and Smith (1992) developed a direct nozzle injection spray boom and evaluated uniformity of spray on a nozzle-to-nozzle basis and across individual nozzle spray patterns. Straight-stream nozzles were used in the study with a metering orifice for direct injection. Brilliant Sulfo Flavine Fluorescent dye was used as tracer. Samples were collected in individual jars and immediately analyzed (within 5 s) using a flurometer.

Brown (2007) developed a commercial target-sensing spray system to spray insecticide in a orchard in order to quantify the resulting reduction in insecticide in surface water runoff from the orchard. The field trials compared ground deposit and resulting runoff from target-sensing spraying versus conventional air-blast spraying. The target-sensing sprayer produced a 40 per cent reduction in the spray application rate and achieved a 41 per cent reduction in ground deposition compared with the conventional air-blast sprayer. Pesticide concentration in surface water runoff was reduced by 44per cent with the target-sensing sprayer versus

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the conventional application. Giles *et al* (2007) established the benefits in target-sensing spraying for reducing pesticide application rates and non-target deposition. In operation, target-sensing sprayers use ultrasonic or optical sensors to continuously detect the presence or absence of target trees; in regions where a sparse target is detected, spray output is modulated; when no target is detected and spraying is ceased.

Materials and Methods

Concept of spot spraying

An experimental model with electronic control system which includes optical sensors and proportional solenoid valves were assembled and mounted on a hydraulic sprayer for a proportional application of chemical to the crop canopy. The sprayer flow rate was adjusted based on the relationship between the actual crop widths measured by the optical sensor. The different canopy shapes and sizes found in row crops, even during the same growing season, makes it necessary to have a continual adjustment of the applied dose to optimize the spray application efficiency. Real-time control systems on sprayers are necessary to achieve a constant spray deposit on the crop canopies and to reduce spray losses. These systems are based on different kinds of physical properties of crop, which may allow monitoring of the canopies.

Study of carrier liquid and chemical delivered through same size orifice

Preliminary study was conducted to study the characteristics of mixing two liquids from different tanks maintained at same pressure. To conduct the study a lab set- up was developed which consists of three functional components namely compressor to maintain the pressure, liquid tanks made of brass with proper inlet and outlet facilities and mixing chamber.

Constructional details of experimental set up

Experimental setup consists of a small compressor of capacity 1 MPa operated by 1 hp electric motor was used as the source of pressurized air. The outlet of compressor is connected to two brass tanks of capacity 15 litre for carrier fluid and 4 litre for chemical. Water is used as carrier liquid. For this study, the big tank was filled with carrier liquid and small tank is filled with dye solution. Dye solution was prepared with methylene blue with concentration 10 g l^{-1}. The top of both tanks are connected by a tube so that same pressure is maintained in both chemical tank and carrier liquid tank. Outlets of carrier liquid tank and chemical tank are connected to flow control tubes having 0.8 mm diameter and 70 mm length with the help of flexible tube. The orifice tubes in this were connected to two entry points of mixing chamber (Tomkins *et al.,* 1990). The two inlet tubes are joined to the mixing chamber

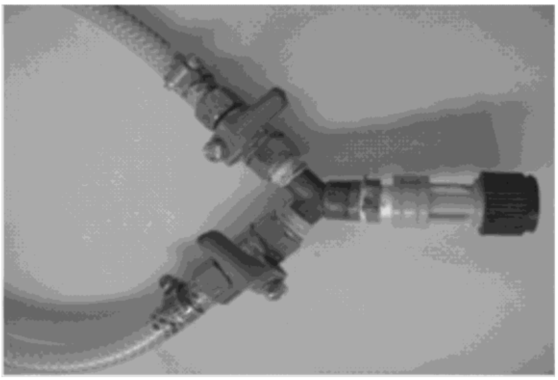

Plate 1. Mixing chamber

in 'Y' shape with two control valves to close and open the liquid flow manually. The mixing chamber is cylindrical in shape with 10 mm diameter and 30 mm length. The delivery end of mixing chamber is connected to a nozzle as shown in (Plate. 1) Carrier liquid and chemical enter into the mixing chamber through orifice tube, control valve and then flows out from nozzle. The discharge was recorded by opening the outlet of each tank separately and together.

Controlling mixing ratio

The compressor supplied pressurized air continuously to both carrier liquid and chemical tank. By means of the control valves the carrier liquid and chemical stream could be opened and closed. Discharge from carrier liquid tank and chemical tank were measured and recorded when the valves are opened separately as well as together.

In this set up, constant pressure was maintained in both carrier liquid and chemical tanks and the outlets of both tanks were connected to mixing chamber. This set up was developed to study the flow of two liquids into mixing chamber and mixing ratio of two liquids in it. The readings were taken by maintaining constant pressure in both carrier liquid and chemical at 0.2 MPa and 0.3 MPa which will give medium droplet size ranging from 101 to 200μ. It was difficult to control manually the flow to mixing chamber. The design of this set up was modified by using pressure regulators and pressure gauges to regulate and maintain constant pressure level.

Study on chemical flow rate with different size of orifices

The outlet of chemical tank is connected to mixing chamber by using nipple and hose pipe. In chemical tank outlet one end of the nipple is sealed and provided with different orifice sizes of 1 mm, 1.5 mm and 2 mm diameter (Plate. 2). For three different sizes of orifice, three separate nipples were selected and fitted in between the outlet of chemical tank and mixing chamber with the help of hose pipe. The flow rate of chemical was measured for different orifice sizes. For this study constant level of pressure was maintained at 0.2 MPa in both carrier liquid and chemical tanks for all sizes of orifices.

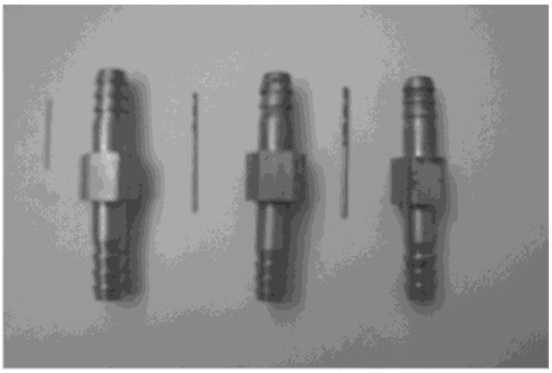

Plate 2. Metering nipple with orifice of sizes 1mm, 1.5 mm and 2mm

Pressure control and flow control mechanism

To maintain desired level of pressure in the tanks, pressure regulators are mounted along with pressure gauges to control the pressure level. Timely opening and closing of both carrier liquid tank and chemical tank outlet flow mixing is achieved by using pneumatic solenoid valves.

Measurement of discharge rate

The discharge through nozzles (flat fan nozzles namely BAN nozzle and NMD hollow cone nozzle shown in Plate 3. is collected in measuring cylinder and the quantity collected was recorded for specific interval of time. These values were expressed in terms of discharge per minute. Each discharge was tested at operating pressure ranging from 0.05 to 0.35 MPa by varying the pressures in both the tanks at 0.05 MPa intervals and test was replicated thrice (Ayers *et al.*, 1990, Juste *et al*., 1990). The discharge of carrier liquid and chemical were measured as separate and combined streams. The discharge measured was recorded in milliliter per minute.

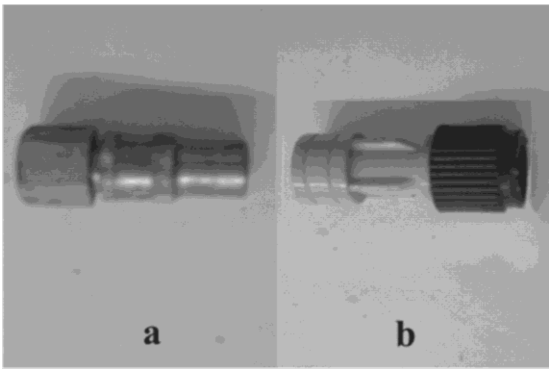

Plate 3. (a) BAN nozzle (b) NMD hollow cone nozzle

Study of pulsed spray characteristics

Experiments were conducted to study the spray characteristics of the pulsed spray in terms of discharge rate and droplet size parameters namely droplet diameter, Numeric Mean Diameter (NMD), Volume Mean Diameter (VMD), VMD/NMD ratio, applied volume in micro l cm^{-2} and area covered.

Suitable mechanism to maintain constant pressure level was used here. The pneumatic solenoid valves were replaced with liquid solenoid valves. Outlet chamber of pressure control mechanism unit along with liquid solenoid valves were fixed on a plate of size 60 mm width and 100 mm length. This set up consists of carrier liquid and chemical tanks, pair of liquid solenoid valves, 12 V DC battery to operate solenoid valves and control box.

The outlets of carrier liquid tank and chemical tank were connected to inlet of liquid valve with the help of female connector and PU tube. Outlet of liquid solenoid valves were connected to two ends of brass ‘T’ joint and outlet of ‘T’ joint was connected to spray nozzle.

Test rig for simulation of pulsed spray with artificial target

The trolly unit was designed to move the nozzle across the target. The injection chamber is mounted to the end of L shaped frame which was fitted on the carriage of trolly unit. Provision was made to change the height of frame. The device consists of pair of rails mounted at a height of 700mm from ground level. The carriage was guided on tubular rails and moved back and forth through a chain and sprocket mechanism. The drive was obtained from 12 V DC motor. The motor drove the carriage unit through chain drive. The drive was designed to move the carriage at a speed of 0.6 m s^{-1}. The nozzle along with liquid solenoid valve was mounted on a vertical post and was aligned so that the centre of the nozzle was in line with the horizontal plane.

Working of pulsed spray device

The experimental model of pulsed sprayer was developed (Fig. 1 & Plate. 4) Compressor is used to maintain pressure in chemical and carrier liquid tank. Liquid solenoid valves control the flow of chemical according to the signal received from sensor when trolly carriage is allowed to move forward and backward across the artificial target along with the injection chamber and optical sensor and the valves were operated with the help of a 12V DC battery and 2V DC supply. Carrier liquid allowed to spray continuously and the chemical (NaCl solution) will be injected into the nozzle when the optical sensor senses the simulated model of target. When sensor moves away from the target, immediately the solenoid valve will stop the chemical injection. The Pico log data logger is connected to a personnel computer to record the voltage with the help of circuit. The Pico data logger records the data in computer due to the variation in voltage when carrier liquid alone is flowing through the nozzle and both chemical and carrier liquid is spraying.

The carrier liquid solenoid valve will be opened and injects carrier liquid continuously. Whereas the chemical will be injected only when the sensor

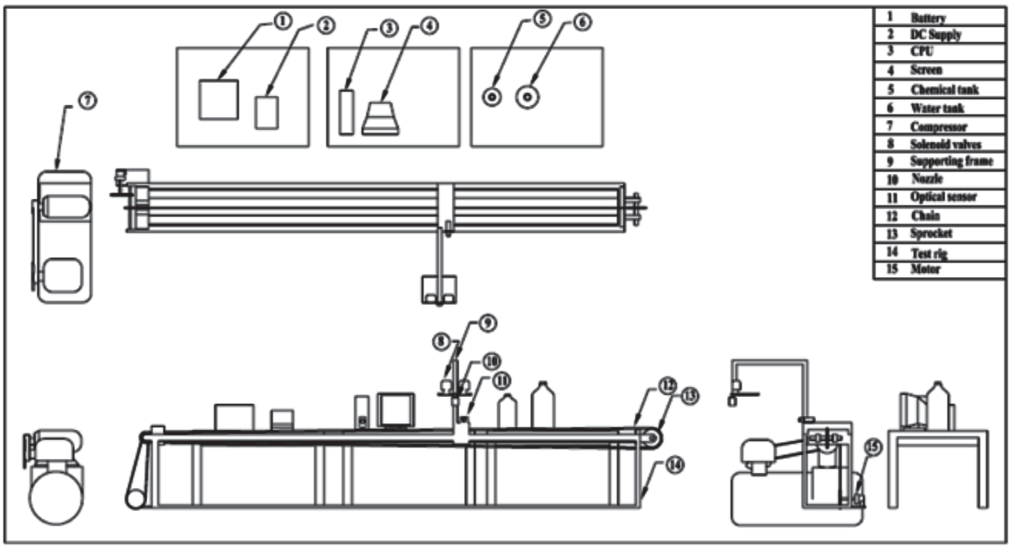

Fig.1. Schematic view of the pulsed spray device

senses any object. Immediately after crossing the object, the sensor will close the solenoid valve and injection of chemical will be stopped.

Results and Discussion

In the present study the lab scale model was proposed to build the pressure using manual hand

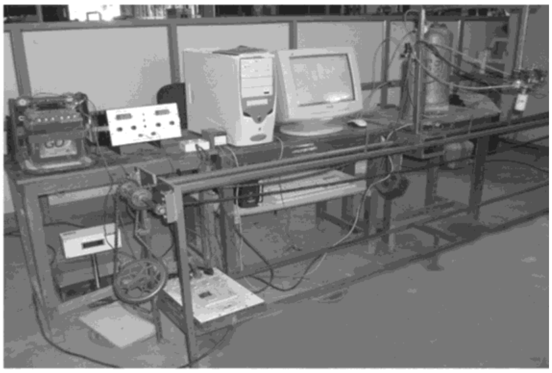

Plate 4. Pulsed spray device simulation set up

compression sprayer. Two models of commonly used nozzles namely BAN nozzle and hollow cone nozzle were selected for this study. This ensured good atomization at low operating pressures.

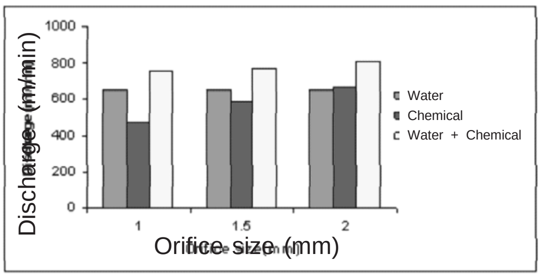

Fig. 2 Pressure Vs Discharge at 0.2 MPa with varying orifice sizes

The main objective of this experiment is to access how the carrier liquid and chemical flows from different streams can be controlled by using 'Y' mixing chamber, single nozzle and shut off valves. The experiment was repeated for two pressures viz 0.2 MPa and 0.3 MPa. The difference in total discharge of liquid collected through the nozzle from two tanks was 150 ml min^{-1}at pressure of 0.2 MPa and 0.3 MPa. There is no significant difference between the discharge of carrier liquid and chemical between single stream and combined stream at 0.2 MPa and 0.3 MPa.

The quantity of liquid delivered was measured with different orifice was separately for carrier liquid and chemical as well as together and are presented in Table 1.

Table 1. Discharge rates (ml min^{-1}) for different orifice sizes at 0.2 MPa

	Different orifice sizes		
	1mm	1.5mm	2mm
Carrier liquid	653	653	653
Chemical	473	586	670
Carrier liquid + chemical	756	773.	806

There is gradual increase in chemical discharge with orifice size as shown in Fig.2. The combined discharge of carrier liquid and chemical increased from 473 ml min^{-1} to 670 ml min^{-1} as orifice size increased from 1 mm to 2 mm. Gradual increase was observed in combined discharge of carrier liquid and chemical together as orifice size increased from 1mm to 2 mm at pressure of 0.2 MPa.

Studies were conducted to evaluate discharge rates in BAN nozzle and NMD hollow cone nozzle in different sets of pressure are presented in Table 2. Carrier pressure was maintained at 0.05, 0.1, 0.15 and 0.2 MPa.

For the BAN nozzle it was observed that the combined discharge of chemical and carrier liquid was less than the discharge of carrier liquid and chemical measured separately when same pressure was maintained at carrier liquid tank and chemical tank (Table 2). Discharge of carrier liquid

Table 2. Discharge of carrier liquid and chemical

Carrier liquid tank pressure (MPa)	Chemical tank pressure (MPa)	Discharge (ml/min)					
		BAN nozzle			NMD hollow cone nozzle		
		Carrier liquid	Chemical	Carrier liquid + chemical	Carrier liquid	Chemical	Carrier liquid + chemical
0.05	0.05	483	466	336	253	203	246
	0.1	483	613	636	253	280	300
	0.15	483	716	470	253	353	343
0.1	0.15	596	590	516	336	280	313
	0.1	596	716	753	336	356	350
	0.2	596	853	730	336	436	400
0.15	0.15	723	710	656	450	353	423
	0.2	723	853	900	450	436	446
	0.25	723	953	1000	450	486	480
0.2	0.2	870	853	753	506	420	493
	0.25	870	966	1076	506	483	506
	0.3	870	1060	1153	506	556	540

was 483, 596, 723 and 870 ml min^{-1} at pressure of 0.05, 0.1, 0.15 and 0.2 MPa respectively. As pressure was increased in the chemical tank by 0.05 MPa discharge of chemical was higher than carrier liquid by 120, 120 130 and 90 ml min^{-1} .When pressure of chemical tank increased by 0.1 MPa than carrier liquid tank pressure, the discharge of chemical was increased by 223, 257, 230 and 190 ml min^{-1} respectively

For the NMD hollow cone it was observed that discharge of carrier liquid was 253 ml min^{-1}, 336 ml min^{-1}, 450 ml min^{-1} and 506 ml min^{-1} respectively at pressure 0.05, 0.1, 0.15 and 0.2 MPa. As pressure increased in the chemical tank by 0.05, 0.1, 0.15 and 0.2 MPa, discharge of chemical was higher than carrier liquid by 27, 20, 24 and 23 ml min^{-1}. When pressure of chemical tank was increased by 0.5,0.1, 0.15and 0.2 MPa than carrier liquid pressure, the discharge of chemical was increased by 100, 100,36 and 50 ml min^{-1}.

Table 3. Effect of pressure on VMD, VMD/NMD ratio, applied volume & Area covered

Pressure (MPa)	Volume Mean Diameter (VMD)	VMD/ NMD ratio	Applied volume (micro litre/cm^2)	Area covered (per cent)
0.1	288.13	1.92	0.2	4.67
0.15	165.65	1.21	0.16	5.32
0.2	161.85	1.2	0.18	5.36
0.25	158.89	1.2	0.18	6.34
0.3	149.79	1.22	0.18	6.6
0.35	134.98	1.15	0.18	7.13
0.4	131.4	1.24	0.19	8.13

The resulted VMD is presented in Table 3. At pressure of 0.1 MPa the VMD is greater than 200 µm and considered as medium spray. For pressure from 0.15 to 0.4 MPa the VMD is between 100-200 µm and observed as fine spray.

It was observed that as the pressure increased the VMD is decreased. At pressure 1 MPa the VMD is high and observed as medium spray. At pressure 0.15 to 0.4 MPa VMD is maintained in a significant range and classified as fine spray. At pressure 0.1 MPa VMD/NMD ratios is 1.92. For the pressure range of 0.15 MPa to 0.4 MPa the droplet spectrum was uniform. The VMD/NMD ratio arrived at pressure range 0.15 to 0.4 MPa pressures are nearly 1 which is classified as ideal (Senthil Kumar, 1995). It is also observed that applied volume is less in lower pressures and uniformity is maintained in all pressures except at 0.1 MPa. It is found that as pressure increases the coverage area is also increased due to reduction in droplet size .When droplet size decreased the cover area covered increased. Hence, setting of pressure requirement depends on the area covered by sprayers.

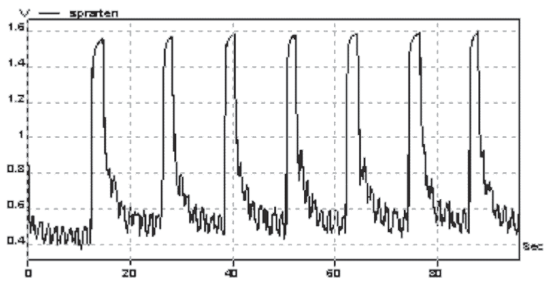

Fig. 3 Train of pulse for chemical

The quantity of chemical sprayed per pulse is proportional to the area under the time voltage curve. A train of observations recorded is given in Fig.3

The quantity of chemical applied by triggering pulses of different width using artificial target is depicted in Fig. 4 (for different operating pressures).

From fig 4 it is observed that the quantity of chemical applied per pulse varied between 0.4 to 1.2 ml per pulse for different operating pressures and target widths. Except for the low pressure of 0.1 MPa, the quantity of chemical applied per pulse does not vary significantly with respect to operating pressure for different pulse duration.

Voltage (mv) = - 2.577 + 914.11XC + 20.10XP - 186.85XC^2

A mathematical prediction equation has been developed correlating the voltage of triggering pulse and the concentration of chemical (C) and operating pressure (P).

It can be inferred that, for pulse duration less than 80 milliseconds (4 cm target) the pulse is composed of a rising edge and a falling edge without any plate in between, that is triggering of the pulse makes the concentration to increase and before the peak is reached the pulse is switched off and concentration drops. However, when the pulse duration is 100 millisecond there is sufficient time for the chemical flow to reach its peak value and stays at the peak value for a short duration before being switched off. Hence the above discussion shows that when the duration of pulse is more than 100 milliseconds the chemical applied per plant will be dependent on pressure.

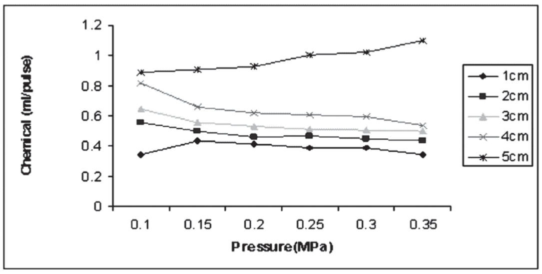

Fig. 4 Pressure Vs discharge per pulse

Theoretically the plant can be modeled as circular or cylindrical object which has to be sprayed at the top. The diameter of the plant will vary from zero to maximum intra row spacing of the plants at which point the plant will touch each other. Taking a typical plant of 10 cm diameter and operating speed of 1.8 kmh^{-1} (0.5 cm/s) the time for traversing the plant diametrically is 200 milliseconds. Based on the prediction equation, the quantity of chemical applied over the plant duration is calculated as 2.6 ml when the area of the plant is 78 cm^2. Hence the application rate will be 0.33ml/cm^2.

Conclusion

In the pulsed spray device, the chemical applied pressure should be maintained at 0.15 to 0.4 MPa to get a fire spray at which the applied volume per unit area will be uniform throughout the spraying operation. The application rate of chemical was estimated at that pressure was 0.33ml/cm^2.

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