CHARACTERISTICS OF SPRAY NOZZLES

By

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Introduction

A spray nozzle is the most important mechanism which breaks the spray liquid into the desired size of droplets for application to the surface to be sprayed. Since no nozzle can meet all of the various spray requirement, they are now commonly manufactured with inexpensive replaceable nozzles to give the desired spray characteristics and volume for the specific job.

Though considerable work has been done on the characteristics of spray nozzles in the United States and Europe, there is little published information on the characteristics, design and application of spray nozzles marketed in our country.

For this reason, this investigation was carried out at the Hokkaido University in 1964 to determine the performance of seven Japanese manufacturers' nozzles and two makes of imported nozzles, and to develop standards for the practical operation spray nozzles for spraying crops and for applying herbicides and soil insecticides. This paper discusses some of differences between ordinary spray nozzles and weed control nozzles and gives data useful for the selecting of spray nozzles.

This paper is based upon laboratory experiments, rather than field observations. It describes fundamental tests on the four basic factors that are largely responsible for the performance of spray nozzles, namely, (1) rate of discharge–liters per minute or per 10 ares–, (2) the angle of spray, (3) the size of droplets and (4) the type of spray pattern, with an additional problem of working precision.

Nozzles and Experimental devices

The nozzles used for the tests fall into four classifications from their shapes of orifice. These are (1) flat fan-type, (2) elliptic fan-type, (3) single orifice hollow-cone type and (4) multi orifice cone type.

Plate 1 shows the nozzle assembly and details of disks.

[Journ. Facul. Agr., Hokkaido Univ., Sapporo, Vol. 54, Pt. 2, 1965]

Tee Jet, KYORITSU and YANMAR nozzles; ARIMITSU, HATSUTA, TOKAI and MARUYAMA nozzles; YAMADA A, PLATZ and MIYASHITA nozzles and YAMADA B nozzles are included in (1), (2), (3) and (4) types, respectively.

The flat fan-type nozzles are made in such a way that by means of milled cut or channel across the outside face of the orifice plate and sometimes an elongated orifice in addition to the slot, the liquid is caused to emerge as a flat fan shaped sheet, which is then broken up into droplets. It is reported that nozzles of this type are used extensively for low-pressure weed spraying and in other similar applications.

The elliptic fan-type nozzles consist of punched disks which form an elliptic raised ridge. After forming, the disk is drilled making holes of required size.

In hollow-cone type of nozzles the liquid is fed into a whirl chamber through a tangential side-entry passage, or through a fixed spiral passages, to give it a rotating motion. The orifice is located on the axis of the whirl chamber and the liquid emerges in the form of a hollow conical sheet, which then breaks up into droplets. YAMADA type nozzle has an adjustable plunger and the entire whirl plate can be moved axially by a plunger. Depending on the whirl chamber this results in a coarser spray and narrower discharge angle, extreme conditions being a solid stream.

To obtain data on a controlled rate of delivery, distribution tests of individual nozzles were made.

Plate 2 shows the test apparatus used for this test. It consists of two trays. One is the test tray which contains 120 plastic cups 6 cm in diameter and 9 cm in height. The other is the shutter tray which is provided with a shutter and a by-pass pipe for drainage. The shutter cuts off the apray stream when it is needed and the by-pass pipe drains off excess water. Above the shutter tray, and mounted on a standard which provides height adjustment, is a pipe which carries the nozzles to be tested. MITSUBISHI D–3E, a high speed sprayer pump with pressrue-control, pumps water through the nozzles for testing.

As the size of the spray droplets is an improtant factor in the effectiveness of sprays, studies were made to determine this for the tested nozzles and for different adjustments of a given nozzle. Oil immersion method was used for direct measurment of water droplets as spheres.

Plate 3 shows the special device for catching droplets. The water droplets are caught on microscope slides coated with silicon oil 15000. The water dorplets are collected on these slides by quickly exposing the latter to the spray fog. Since the water has a somewhat greater specific gravity than the oil and is not miscible with it, the droplets go to the bottom of the slides and remain as approximate spheres. In order to determine the size of these droplets, microscopic photography was used for measuring the diameter of the droplet spheres.

Plate 4 shows the microphotograph device used for this test.

Then, for the calibration of the tested nozzles, the nozzles were operated for 1–2 minutes each at different pressures, and the discharge was collected by graduated cylinder.

Another matter that needs consideration in nozzle design is the change in angle of spray stream with increased pressure. To determine spray angle, a synchronous stroboscope (shutter speed: $\frac{1}{10000}$ sec.) and a 35 mm camera were used.

Results and discussion

(1) Calibration

The calibration curves for tested nozzles are shown in Fig. 1. These curves enable one to find the discharge rate of nozzles at any pressure up to 20 kg

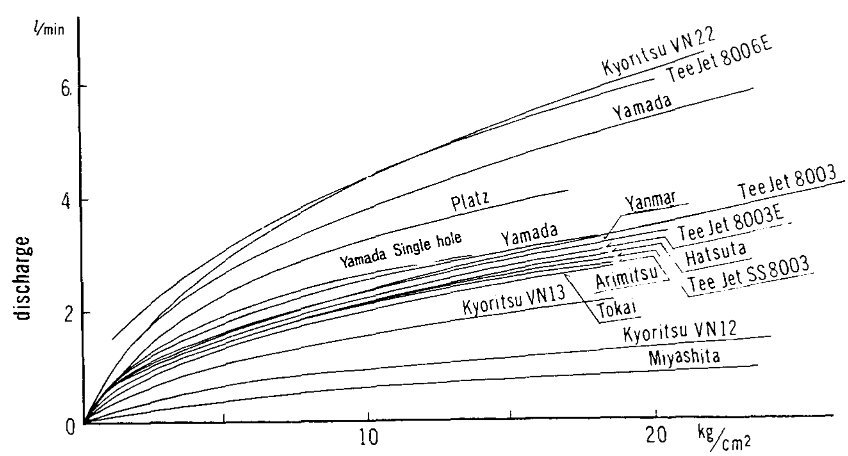


Fig. 1. Calibration curves for various makes of nozzles.

per square cm. In general, the flow rate is aproximately proportional to the pressure, increasing more slowly at a pressure over 4 kg/cm² than at the pressure under that value. While the discharge of KYORITSU VN22 and Tee Jet 8006E nozzles increase largely with the increase of spray pressure, that of KYORITSU VN12 and MIYASHITA nozzles does not increase so much with the pressure increase. Most of the discharge value of the tested nozzles are about 2 liters per minuite at 10 kg/cm² spray pressure.

Since the discharge per unit area is influenced by foward speed of nozzles, calculations were made from the calibration curve of Fig. 1 to determine the discharge per 10 a at the speed of 0.4, 0.8, 1.2, 1.6 m/sec, assuming the spray width to be 50 cm. The results are shown in Table 1. This table indicates that spray discharge decreases with increasing speed. It is reported that usual nozzles, in Germany, can deliver about 47, 94, 140, 187 ℓ/ha.

TABLE 1. Discharge liter per ten ares at various speeds

Type	Tip No. or Symbol	Liquid Pressure in kg/cm²	Liters per 10 a			
			0.4 m/s	0.8 m/s	1.2 m/s	1.6 m/s
Tee Jet (a)	8006 E	4	226	113	75	57
Tee Jet (b)	8003	4	107	54	36	27
Tee Jet (c)	SS 8003	4	109	55	36	28
Tee Jet (d)	8003 E	4	116	58	39	29
ARIMITSU	A	4	109	55	36	28
HATSUTA	H	4	108	54	36	27
TOKAI	O	4	101	51	34	26
YANMAR	Y	5	130	65	43	33
KYORITSU	VN 13	4	108	54	36	27
KYORITSU	VN 12	4	71	36	24	18
KYORITSU	VN 22	4	312	156	104	78
YAMADA	D 1	4	140	70	47	35
YAMADA	D 2	—	—	—	—	—
YAMADA	B 0	5	141	72	47	36
YAMADA	B 1	5	223	112	74	56
YAMADA	B 2	5	225	113	75	57
MIYASHITA	M	4	30	15	10	8

Economical treatment of weeds and vegetable crops requires primarily a uniform coverage of a given area of vegetation with proper penetration of the spray solution. Since the distance from the spray nozzles to the vegetation is relatively short, high pressure is not required. In fact, excessive pressure usually defeats the purpose of the application by highly atomizing and blowing the spray solution from the leaves. Insufficient pressures, however, do not give a satisfactory coverage by resulting flow rate and limited atomizing. O. C. FRENCH and A. S. CRAFTS concluded that a pressure of 75 pounds per square inch (5.2 kg/cm^2) at the nozzles was the most satisfactory for most field work where fan type nozzles are used. And, DENCKER describes that pressure of 5.25–8.75 Atü (kg/cm^2) is generally suited for most of spray nozzles, in special conditions, up to 100 Atü (kg/cm^2). Therefore, the calculation in Table 1 was done at 4 and 5 kg/cm of spray pressure. But this should be determined in future field tests.

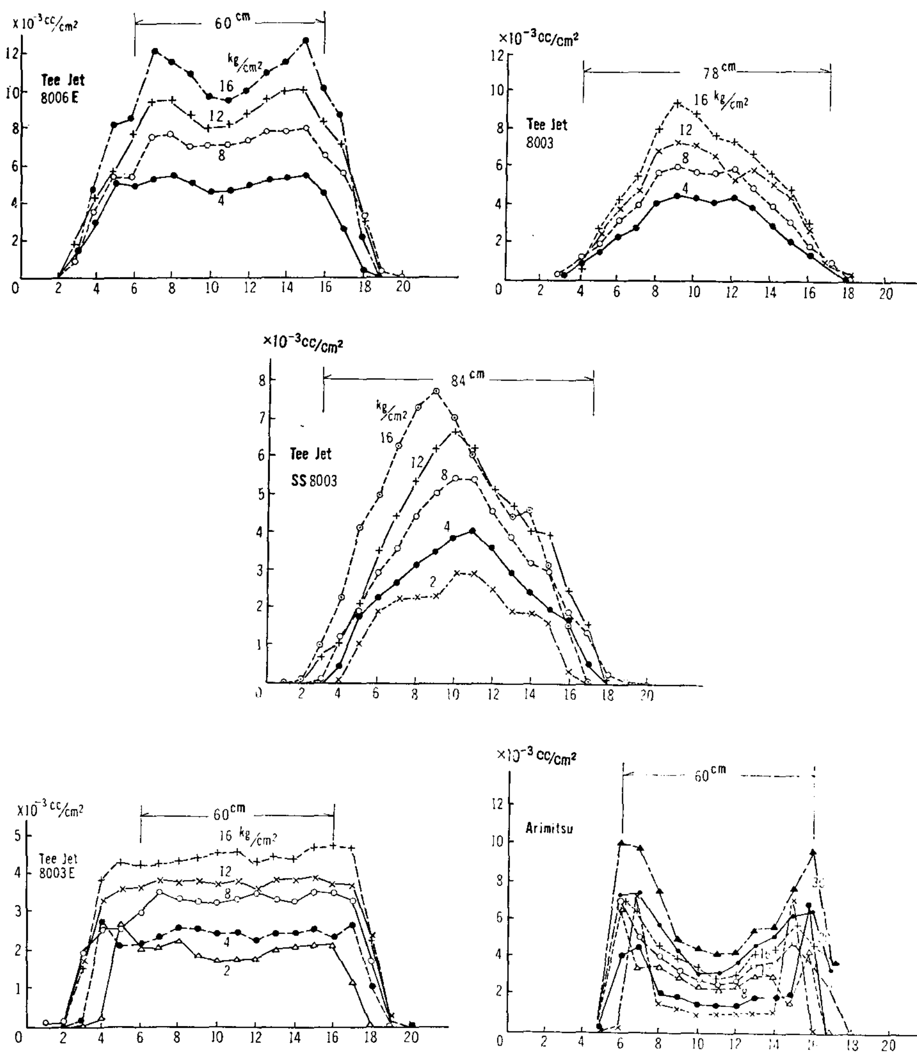


Fig. 2. The relation between discharge of nozzles and forward speed at various spray pressure

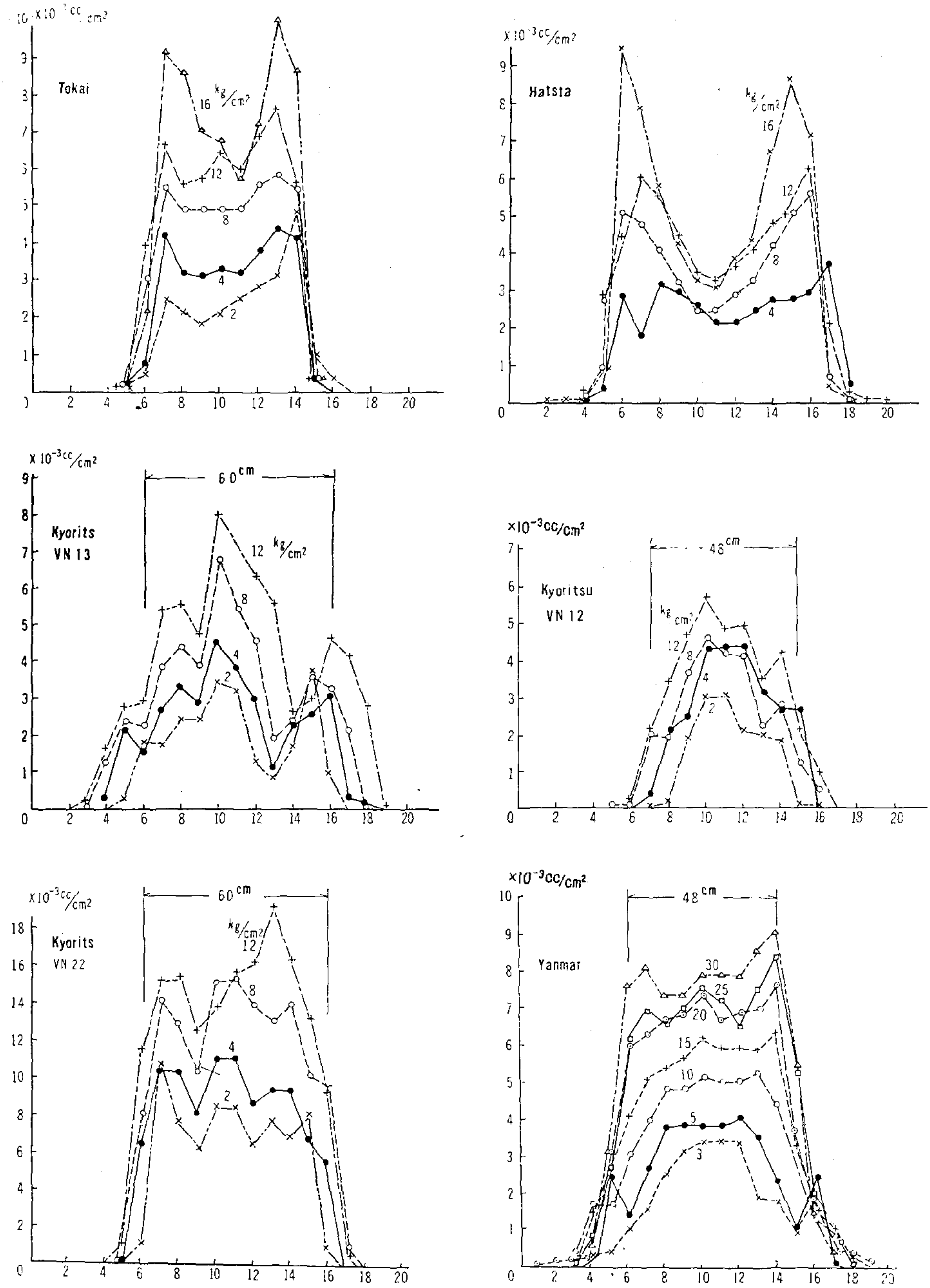


Fig. 2. (continued)

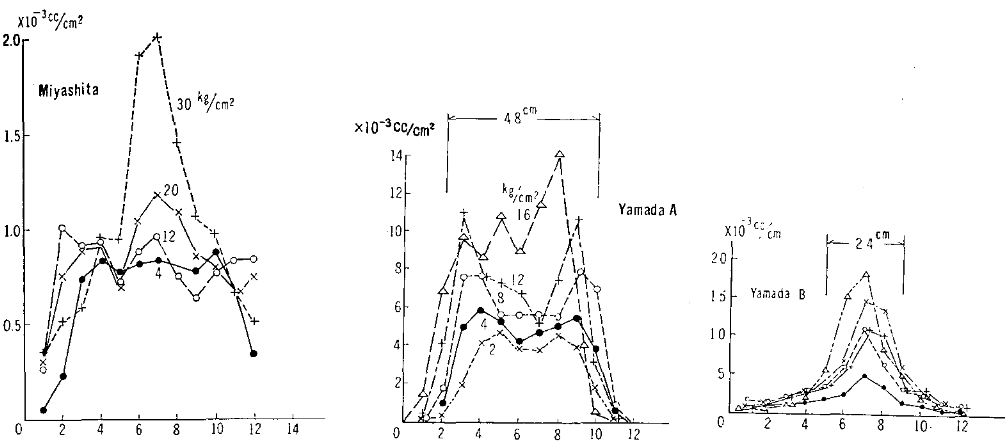


Fig. 2. (continued)

(2) **Distribution Patterns.**

Fig. 2 shows the results of the distribution tests of individual nozzles at various spray pressures. Fig. 3 shows the horizontal distribution at 4 and 5 kg/cm^2 pressure, assuming that the sprayer speed is 1 m/sec.

From these figures, the distribution patterns may be classified into four types. The first type of nozzles, Tee Jet 8003E and 8006E, deliver almost uniform distribution. This is called the uniform type. The second type of nozzles, ARIMITSU, HATSUTA, TOKAI and YAMADA-A, deliver lower volumes at the center than at the outer edges. This is called the 'concave type'. The third type of nozzles, KYŌRITSU VN 13, VN 22, YANMAR and MIYASHITA, deliver higher volumes at three points than at other bands. This is called the 'mountain type'. The last type of nozzles, Tee Jet SS 8003, KYORITSU VN 12, YAMADA-B and Tee Jet 8003, have peak delivery at the center of the band. This is called the 'triangle type'.

Table 2 shows the results of calculation converting the discharge rate of four typical types of nozzles, namely, Tee Jet 8003 E, ARIMITSU, KYORITSU VN 13 and Tee Jet SS 8003, into discharge per 10 ares. This test was done at a nozzle height of 50 cm. In Table 2, it can be seen that ARIMITSU, for instance, delivers 29 liter per 10a as a mean value but the maximum and minimum value of its discharge flow are 70 ℓ/10 a and 14 ℓ/10 a, respectively. This means that if spraying is done at a rate of application close to the maximum amount, it may cause crop damage, and if spraying is done at the minimum rate, little or no effects may be expected. The uniformity of application is essential for spraying nozzles.

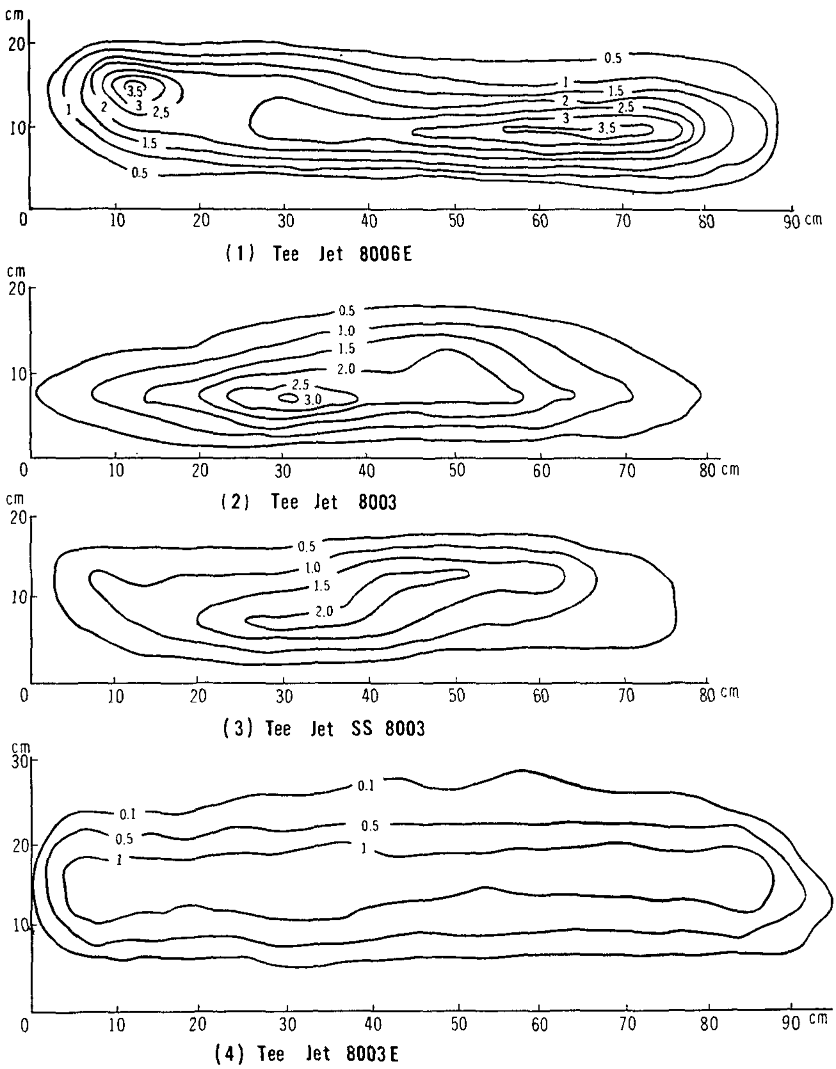


Fig. 3. Horizontal distribution of nozzle discharge in $cc/cm^2 \cdot min$ at 4 and $5 kg/cm^2$ pressure

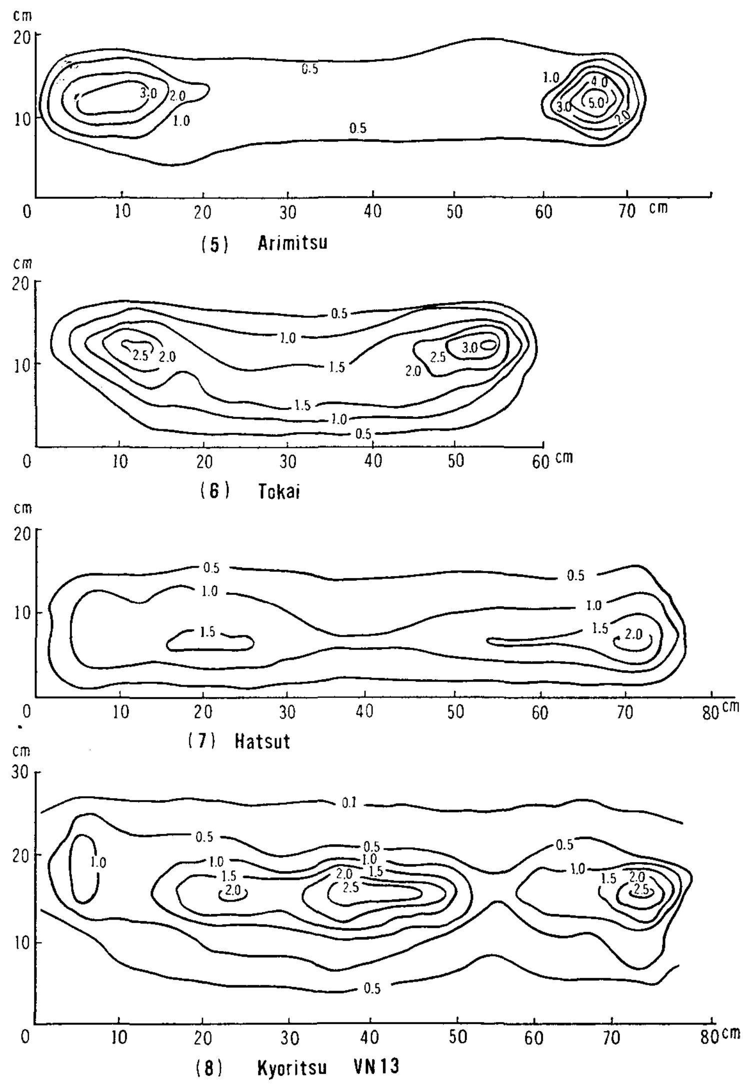
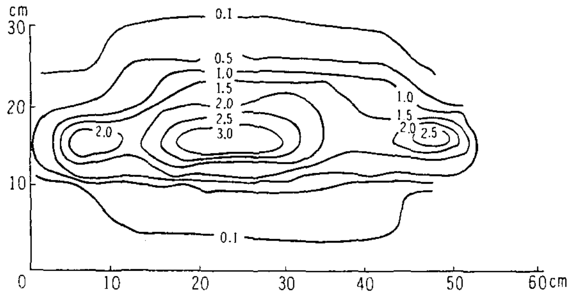
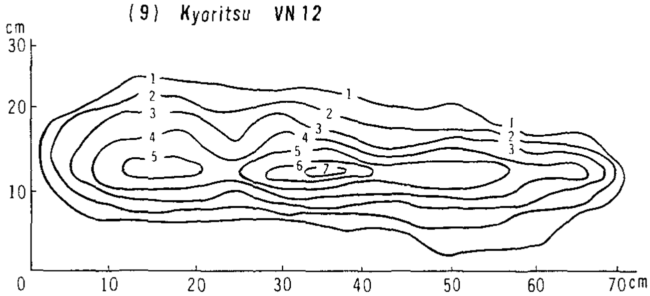


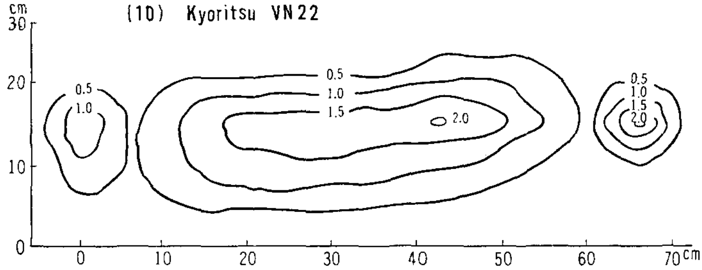
Fig. 3. (continued)



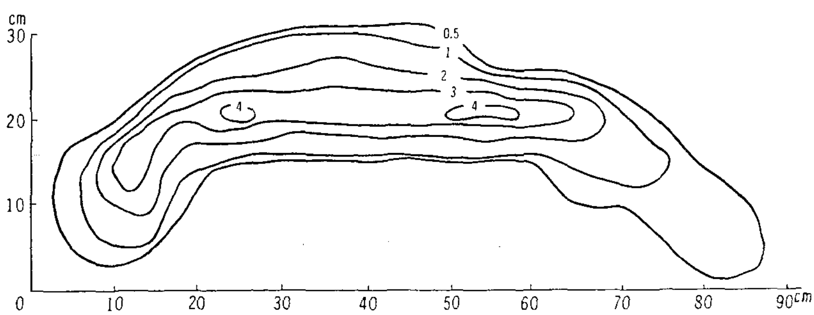
(9) Kyoritsu VN 12



(10) Kyoritsu VN 22

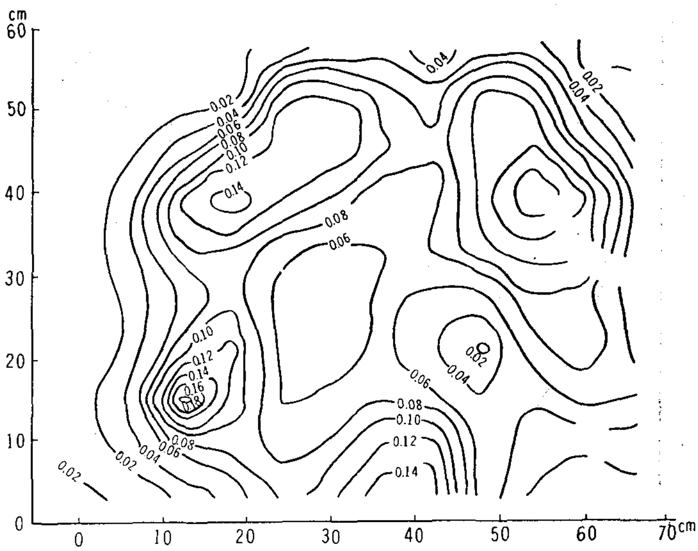


(11) Yanmar

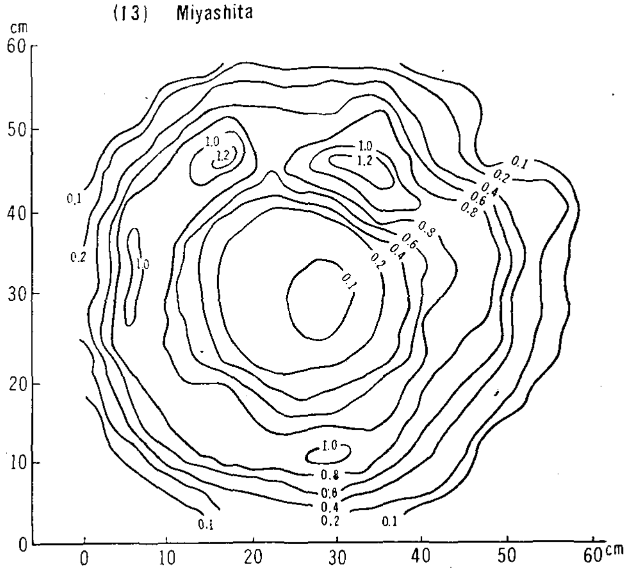


(12) Platz

Fig. 3. (continued)



(13) Miyashita



(14) Yamada A

Fig. 3. (continued)

Therefore, for the control of weeds or insects, the ideal nozzle arrangement should be considered from the distribution patterns. In general, the flat fan-type nozzles are used for weed control and other types of nozzle should be used for other applications.

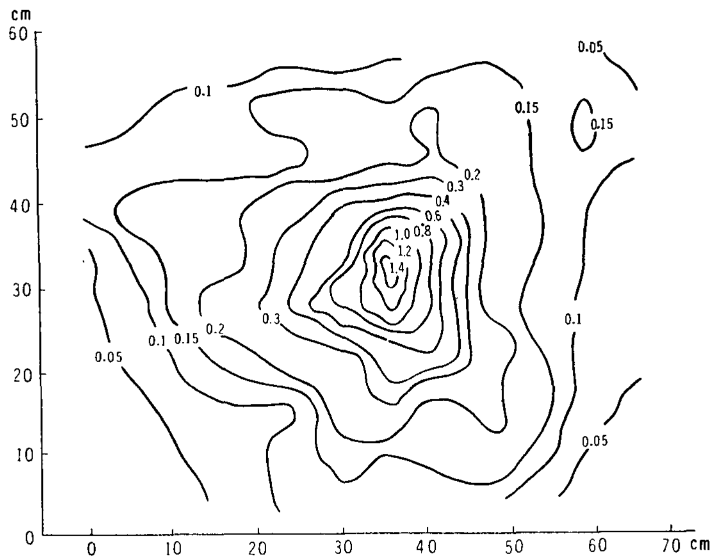


Fig. 3- (continued)

TABLE 2. Distribution of dilivery at four kg/cm² splay pressure

Type	Tip No. or Symbol	Specification	Liters per 10 a 0.4 m/s	0.8 m/s	1.0 m/s	1.2 m/s	0.6 m/s	Distribution pattern
Tee Jet	8003 E DT	max	68	34	27	22	17	
		mean	65	32.5	26	22	16	
		min	62	31	25	21	16	
ARIMITSU	A	max	176	88	70	58	44	
		mean	72	36	29	24	18	
		min	35	17.5	14	12	9	
KYORITSU	K-1	max	112	56	45	38	28	
		mean	80	40	32	27	20	
		min	28	14	11	9	7	
Tee Jet	SS 8003 E CT	max	100	50	40	33	25	
		mean	80	40	32	27	20	
		min	12	6	5	4	3	

(s) Droplet sizes

The data showing the relation between spray pressure and size of spray droplets are summarized in Fig. 4. The ordinate values show frequency

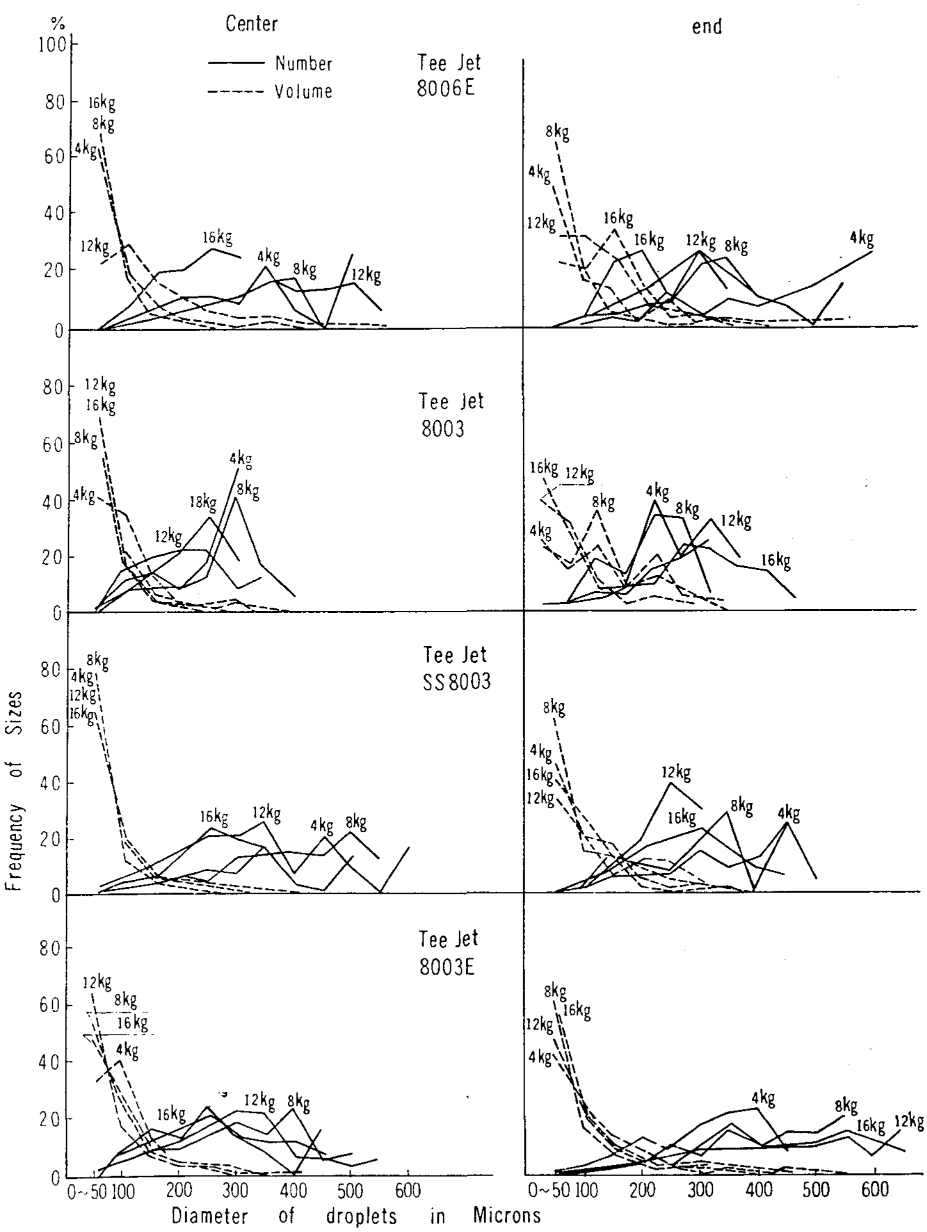


Fig. 4. The relationship bitween spray pressures and droplet sizes

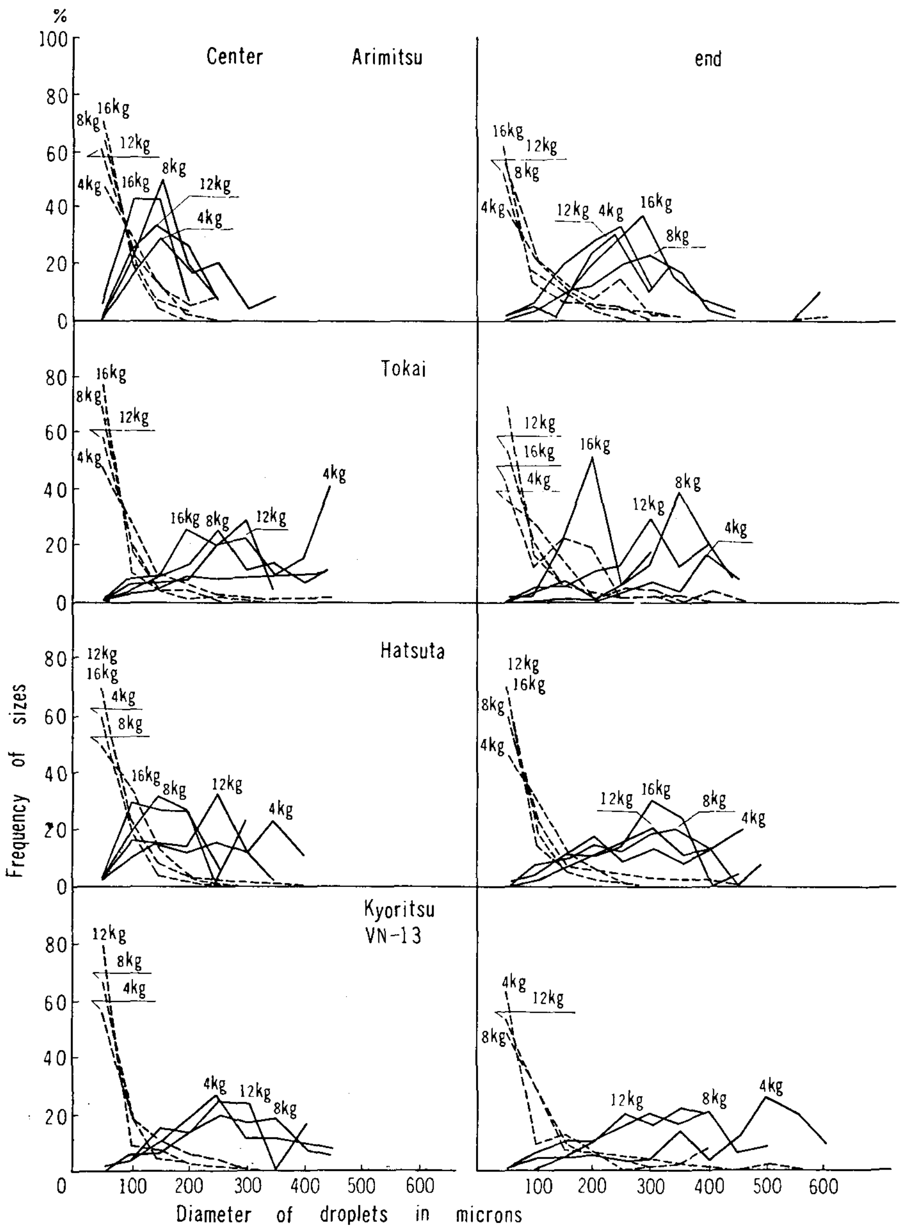


Fig. 4. (continued)

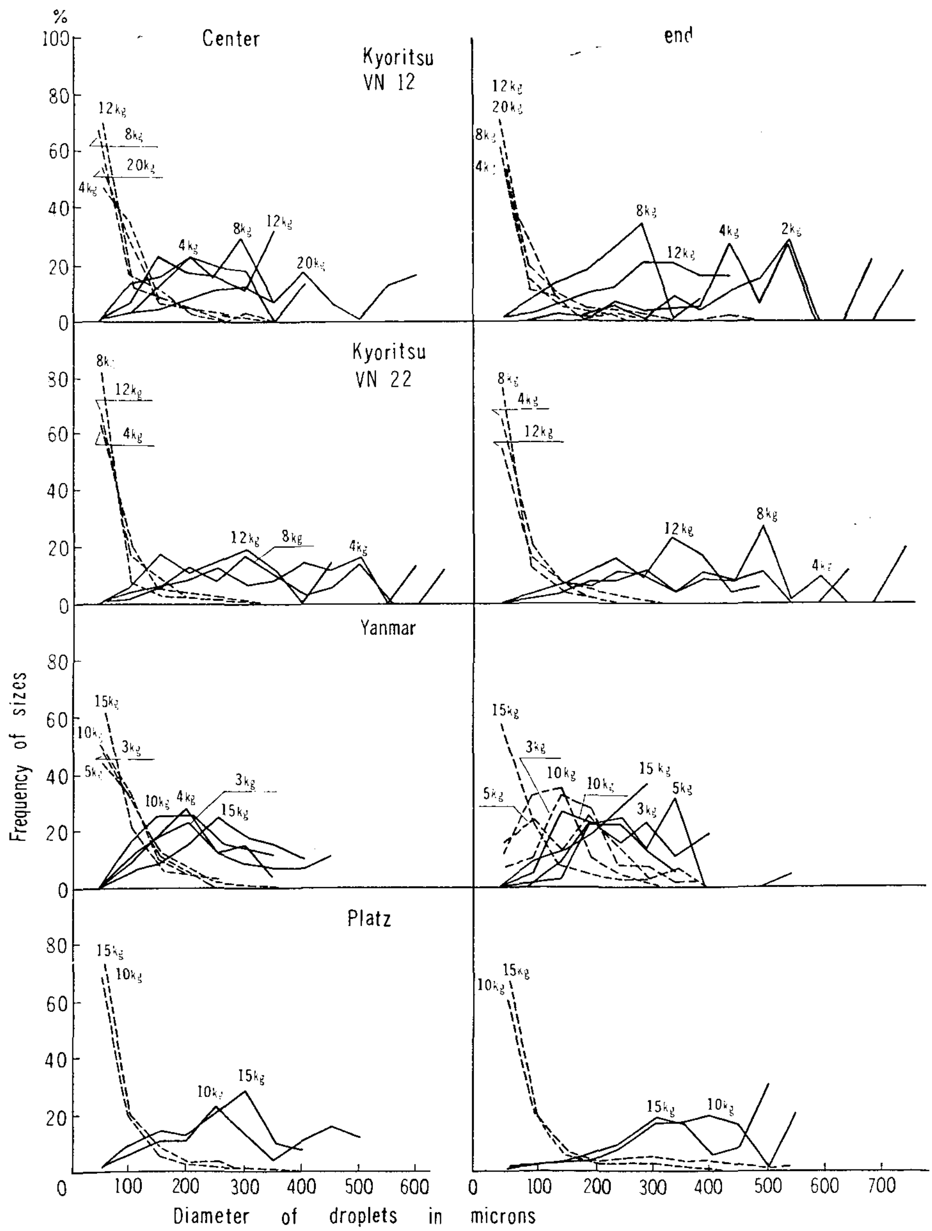


Fig. 4. (continued)

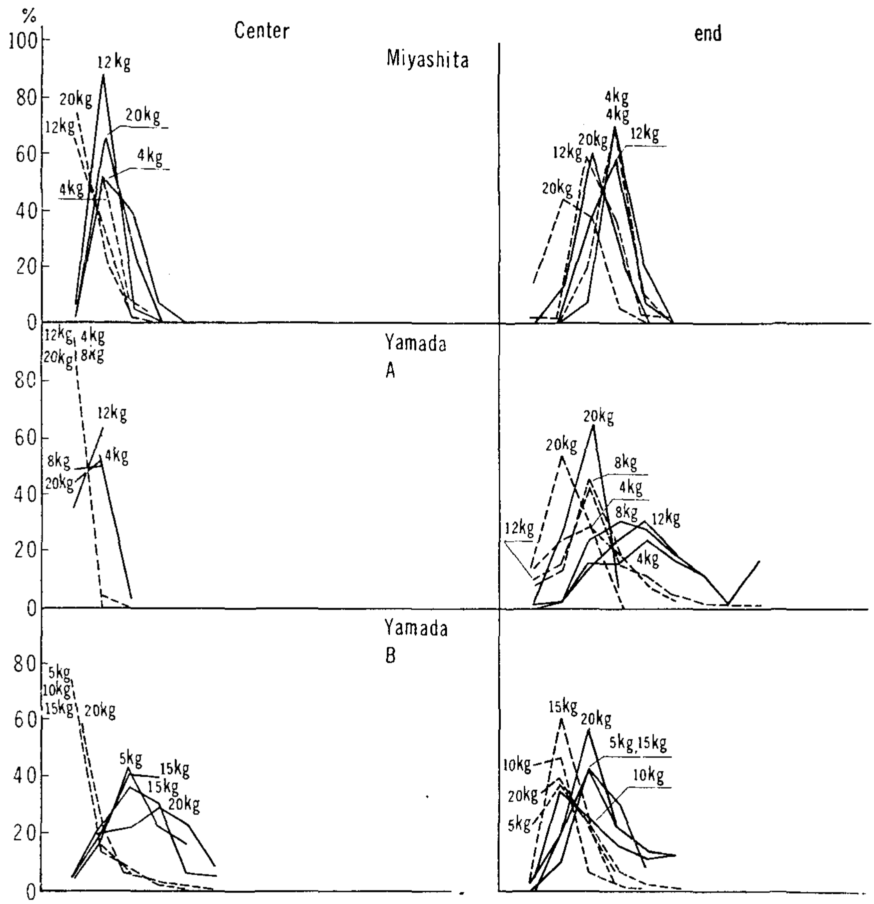


Fig. 4. (continued)

rate of numbers and volume of spray droplets measured from microscopic photographs.

In general, the degree of atomization depends upon the characteristics and operating conditions of the nozzle and upon the characteristics of the liquid being atomized. The average droplet size from a given nozzle is decreased if the pressure is increased. The results obtained in this test (Fig. 4) show that as the spray pressure is increased from 4 to 16 kg per square centimeter the maximum frequency of droplet sizes in number decrease from 350 to 250 microns in most of the tested nozzles. In cone-type nozzles, droplet size is uneven in frequency of sizes ranging from 50 to 700 microns. But, for the fan-type nozzles the droplet size is considerably large and they produce a narrow spectrum of droplet sizes. Most of the droplet size were 100–200 microns.

Since the droplet sizes are influenced by type of nozzles and spray pressures, it should be important for operators to select adequate nozzles for their purpose and to operate them at optimum pressure. For instance, it is difficult to get uniform application for weed control, if the droplet sizes are too large, and if the droplet sizes are too small, droplets are blown away and damage farm crops. 300–400 microns of droplets are recommended for weed control.

From the results mentioned above, the ordinary cone type nozzles are not adequate for weed control, but flat fan-type nozzles should be used. Plate 5 is an example of microscopic photographs showing droplet size of Tee Jet 800 E and YAMADA-A nozzles.

(4) **Spray angle**

Plate 6 shows spray angle of tested nozzles. These photographs were taken from two rectangular directions. The results obtained by the measuring angle on these photographs are shown in Table 3.

From Plate 6 and Table 3, it can be seen that the spray angle of most types of nozzles decreases as the pressure is reduced. At low pressures surface tension tends to draw the edges of the fan together, giving a narrow angle. The nozzles used in the foregoing studies were all tested for change of angle with pressure. From these tests, fan-type nozzles showed spray angles of 60°–85°, and cone-type nozzles showed 50–73 degrees at 4 kg/cm^2 pressure. In Germany, it is reported that most of the spray nozzles show 65–80 degrees of spray angle.

The nozzle fan width and the spacing on the boom will determine how high the boom requires the fans to meet at the tops of the weeds. In boom design, the height from the ground or foliage level is an important factor as related to penetration, rate of delivery, and drift. With a decrease in the spray angle the distance from the nozzle increases proportionaly, causing high atomizing and resulting in poor performance of nozzles.

Thus, 80–85° angle shown in Tee Jet type nozzle is the most optimum value for weed control.

(5) **Working precision of nozzles**

Plate 7 and Plate 8 are close-up photographs of the tested nozzles, showing the shape and size of orifice and revealing the working methods. It can be seen that Tee Jet type nozzles are finished with milling machine resulting in a fine finishing, and YANMAR and KYORITSU nozzles are finished finely at the same degree as Tee Jet nozzles. However, TOKAI, ARIMITSU, HATSUTA and MARUYAMA nozzles are pressed after drill finishing, and these nozzles have

TABLE 3. Spray angle of tested eozzles (degree)

Type	Spray Pressure in kg/cm^2							
	2	4	8	12	16	20	25	30
Tee Jet 8006E	76.5	83.0	86.0	—	87.0	—	—	—
	18.5	16.5	15.0	—	15.5	—	—	—
Tee Jet 8003	71.0	83.0	90.0	—	90.5	93.5	—	90.0
	16.5	19.5	18.0	—	22.0	21.0	—	24.0
Tee Jet SS 8003	74.5	81.0	83.5	—	90.0	—	—	—
	18.5	17.0	17.0	—	16.0	—	—	—
Tee Jet 8003E	74.5	84.0	85.0	—	90.0	—	—	—
	19.0	20.0	18.0	—	18.0	—	—	—
ARIMITSU	51.0	60.5	66.5	—	70.0	72.5	75.0	—
	26.0	24.0	27.5	—	30.0	27.0	28.0	—
HATSUTA	—	65.0	67.0	—	68.0	—	—	—
	—	24.5	28.0	—	26.0	—	—	—
TOKAI	49.5	56.0	54.5	—	54.0	—	—	—
	15.0	16.0	18.5	—	12.0	—	—	—
YANMAR	59.5 (3 kg/cm^2)	64.5 (5 kg/cm^2)	75.5 (10 kg/cm^2)	—	76.0 (15 kg/cm^2)	76.5	—	77.5
	21.0 (3 kg/cm^2)	23.0 (5 kg/cm^2)	23.5 (10 kg/cm^2)	—	24.0 (15 kg/cm^2)	24.0	—	22.5
KYORITSU VN 13	63.5	76.0	80.0	84.0	—	—	—	—
	16.0	18.5	16.0	17.0	—	—	—	—
KYORITSU VN 12	19.5	58.0	63.5	64.0	—	—	—	—
	0	13.5	11.5	20.0	—	—	—	—
KYORITSU VN 22	64.0	68.5	72.5	73.0	—	—	—	—
	22.0	24.0	17.0	17.5	—	—	—	—
MIYASHITA	—	66.5	—	68.5	—	70.7	—	71.0
	—	—	—	—	—	—	—	—
YAMADA A	45.0	52.0	53.0	52.5	—	50.0	—	—
	—	—	—	—	—	—	—	—
YAMADA B	—	73 (5 kg/cm^2)	74 (10 kg/cm^2)	—	80 (15 kg/cm^2)	85.0	76.0	—
	—	—	—	—	—	—	—	—

cracks at the orifice edge. Especially, the working precission of the MARUYAMA nozzle is so poor that it could not be used for the experiment.

Though it seems that working precision of most of the tested nozzles is not different in Plate 7, Plate 8 shows that some orifices does not have true circles.

From these photographs, it is clear that Tee Jet nozzles are finished by the most precise working, revealing excelent characteristics.

(6) Comparison tests of Tee Jet 8003 E nozzles

From the experimental results mentioned above, it was shown that Tee Jet nozzles have the best characteristics in discharge distribution, droplet sizes and spray angle and they are finished most finely. Thus, an experiment on the same items above was carried out to compare the characteristics of the same types of nozzles, namely, five Tee Jet 8003 E nozzles.

The results are given here.

(a) Discharge in cubic centimeter per minutes.

Table 4 shows experimental data. It can be seen that the difference in discharge among five nozzles are very slight, with a 4.5% error.

(b) Relation between discharge and speed.

Fig. 5 shows the results of the distribution tests of five nozzles at 4 kg/cm² pressure. Spray width of these nozzles are 84 and 78 cm, assuming the nozzle height as 50 cm. And the distribution pattern of individual nozzles were almost identical.

TABLE 4. Discharge of five Tee Jet 8003 E nozzles

Nozzle No. / Pressure kg/cm²	1	2	3	4	5
4	1400	1340	1330	1335	1340
8	1965	1875	1890	1915	1890

(c) Spray angle.

Plate 9 and Table 5 show the spray angle of individual nozzles at 4 kg/cm². These angles differ very little from each other.

TABLE 5. Spray angle of fiive Tee Jed 8003 E nozzles

Nozzle No.	1	2	3	4	5
Spray Angle	84°	83°	78°	79°	77°

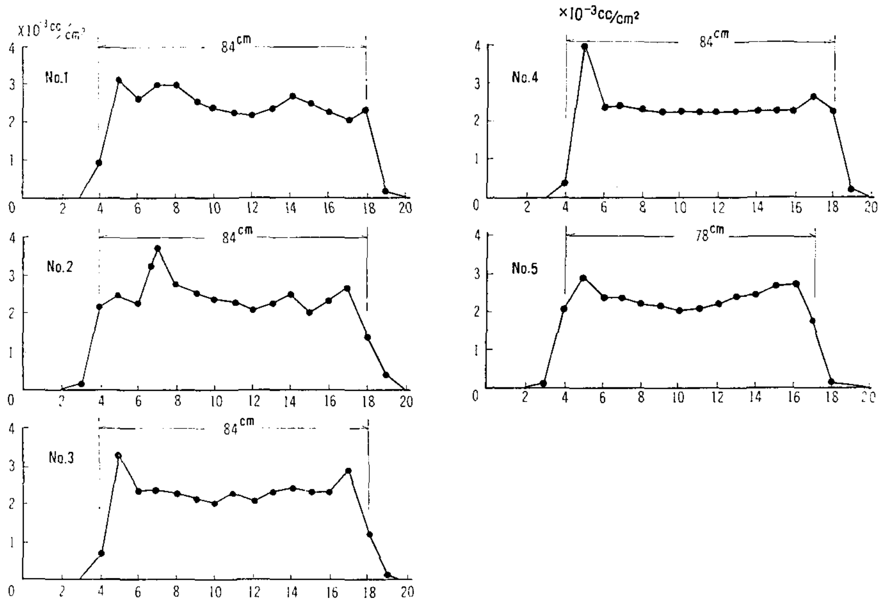


Fig. 5. The relation between discharge of nozzles and foward speed at 4 kg/cm^2 spray pressure (Tee Jet 8003 E)

Conclusion

In order to contribute to the designing good spray nozzles and their proper operating, the fundamental experiments on characteristics of sixteen makes of spray nozzles were carried out. The results were as follows:

(1) All nozzles should be operated at adequate pressures for different purposes. Because, it was found that the flow rate was proportional to the pressure and its proportional rate was different for individual nozzles.

The discharge patterns of tested nozzles were classified into four typical shapes.

(2) Tee Jet nozzles showed the most uniform distribution pattern.

(3) When spray pressure rises higher, spray droplets showed a tendency to atomize more finely. Tee Jet nozzles seemed to have the best droplet sizes for weed control application.

(4) Tee Jet nozzles showed 80～85° of spray angle at 4 kg/cm^2, and this angle is most suitable for spray application. This is because the most effective spray application is obtained at such angles, resulting in good penetration and delivery rate.

It was surmized that the most excellent performance of Tee Jet nozzles are due to their working precision. And this was shown by tests of five individual Tee Jet 8003 E nozzles on its characteristics.

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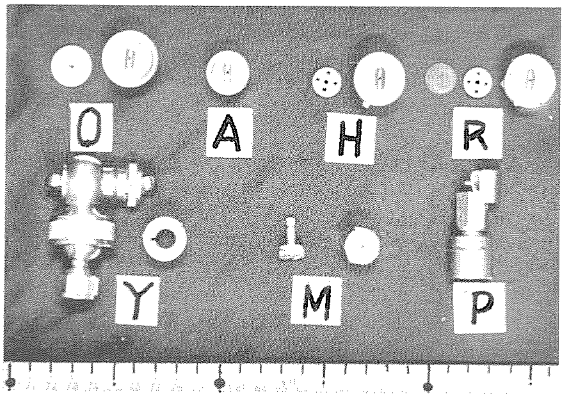
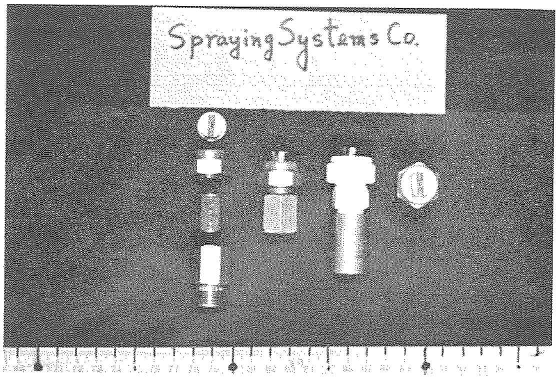
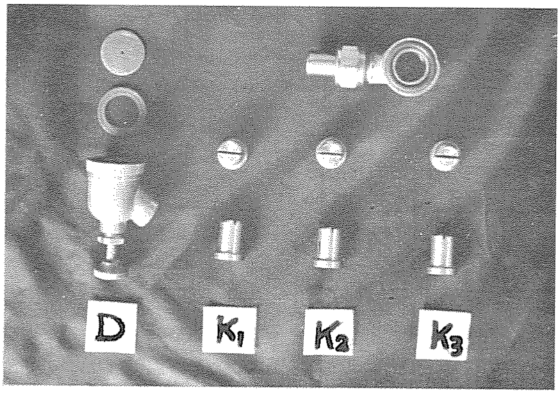
Plate 1. Tested Nozzles



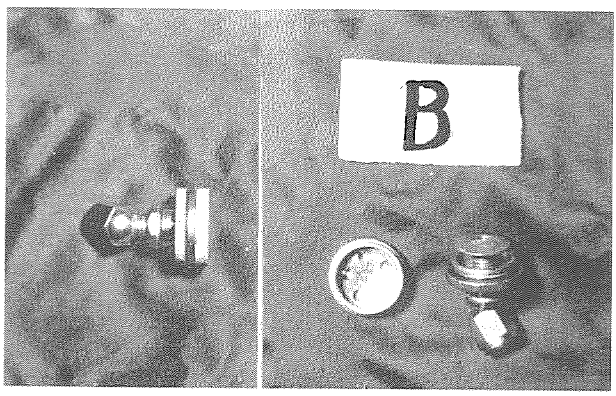
O : TOKAI
A : ARIMITSU
H : HATSUTA
R : MARUYAMA
Y : YANMAR
M : MIYASHITA
P : PLATZ



Tee Jet



K_1 : KYORITSU
K_2 : 〃
K_3 : 〃
D : YAMADA A



B : YAMADA B

Plate 2. Distribution test apparatus

Plate 3. Device for collecting droplets

Plate 4. Device of microscopic photograph

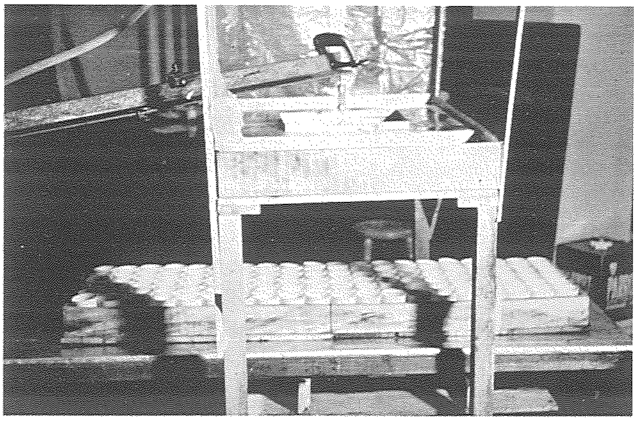


Plate 2

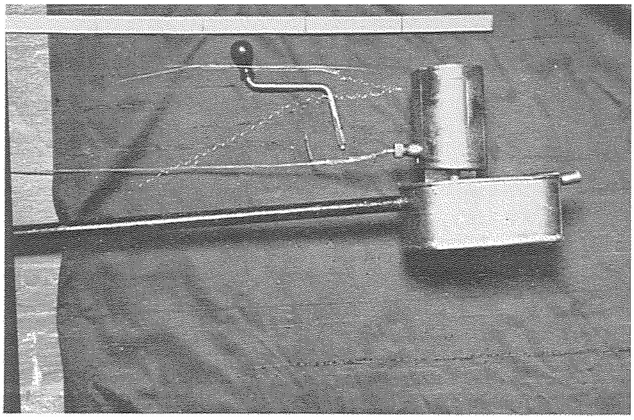


Plate 3

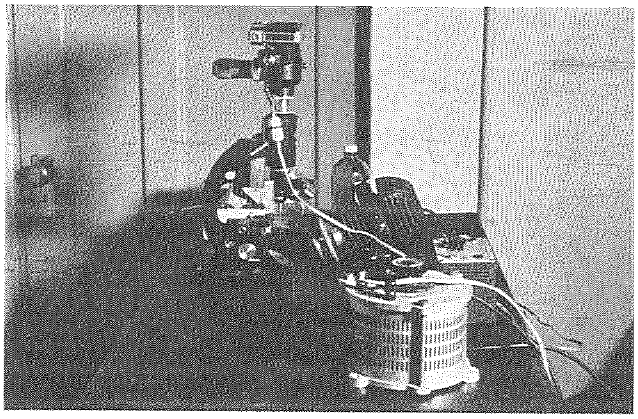
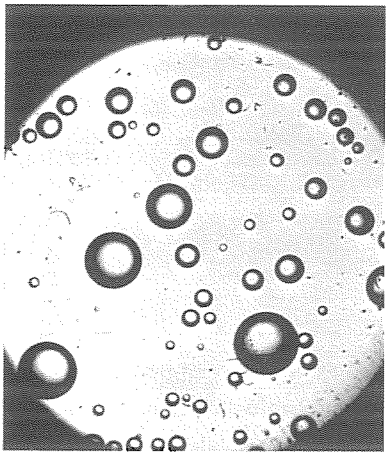


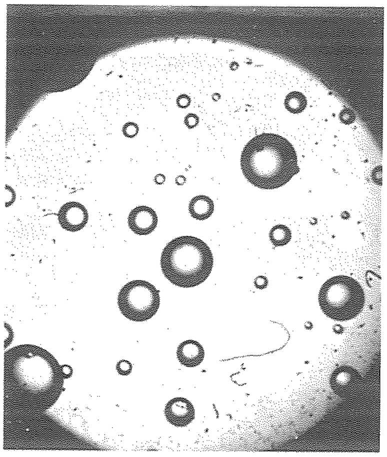
Plate 4

Plate 5-1. Microscopic photographs of droplets caught at the center (left photos) and at the end (right photos) of the stream from Tee Jet 8003E nozzle. Spray pressures are (a) 2 (b) 4 and (c) 8 kg/cm^2.

DTa 2

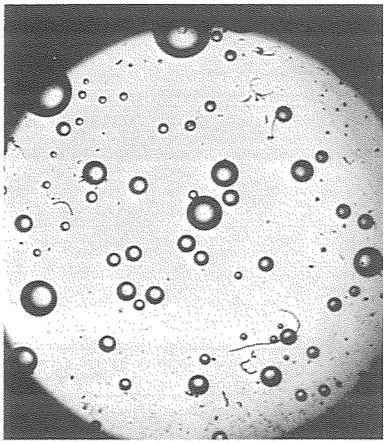


DTa′ 2

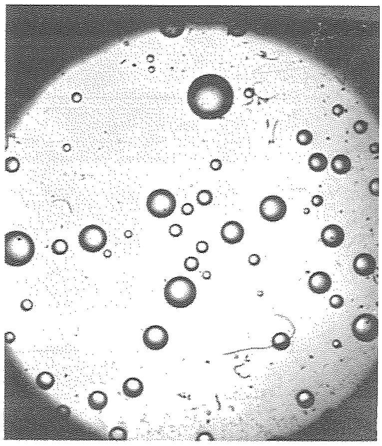


(a)

DTa 4

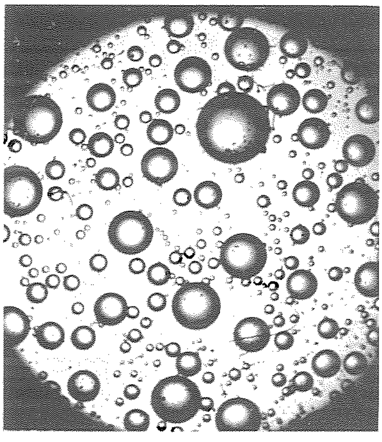


DTa′ 4

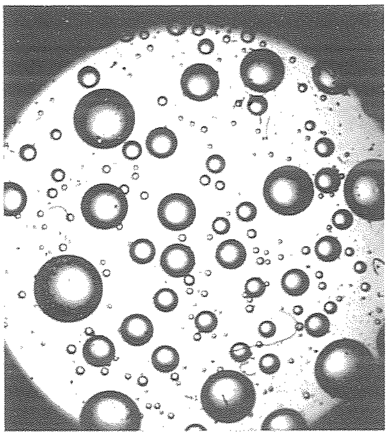


(b)

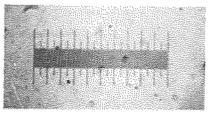
DTa 8



DTa′ 8



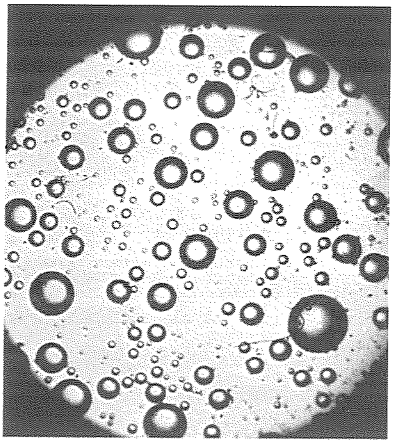
(c)



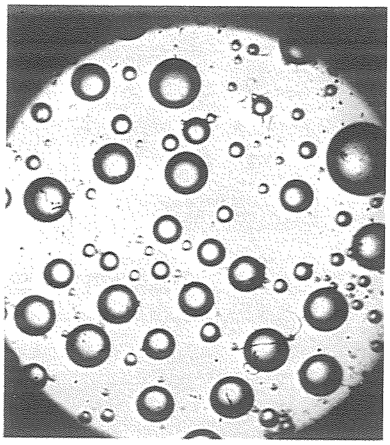
Full length of this scale is 1 mm.

Plate 5–2. Microscopic photographs of droplets caught at the center (left) and at the end (right) of the stream from Tee Jet 8003 E nozzle. (continued)
Spray pressures are (d) 12 and (e) 16 kg/cm^2.

DTa 12

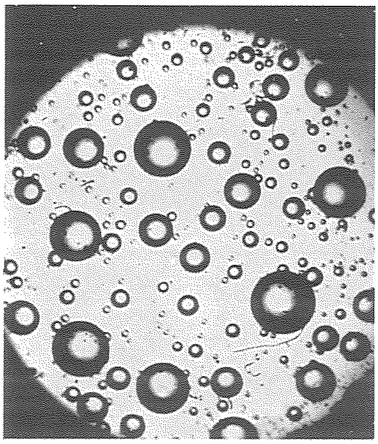


DTa′ 12

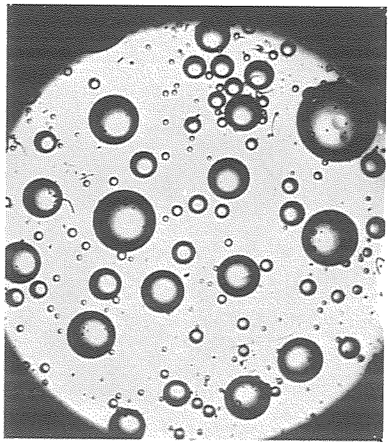


(d)

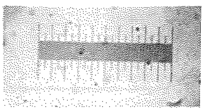
DTa 16



DTa′ 16



(e)

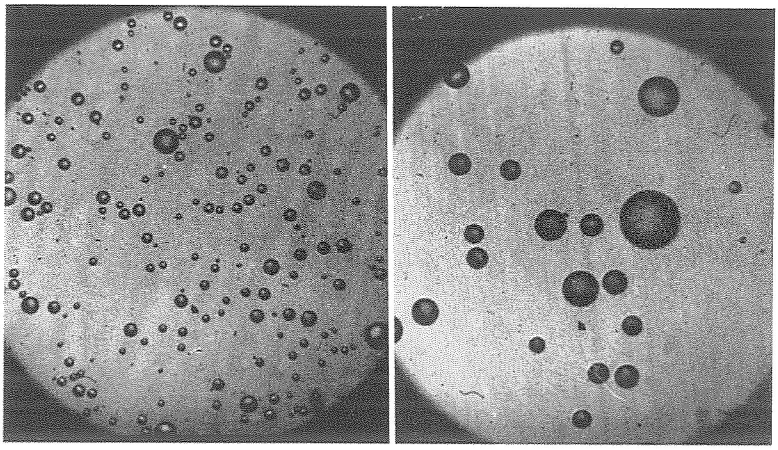


Full length of this scale is 1 mm.

Plate 5–3. Microscopic photographs of droplets caught at the center (left) and at the end (right) of the stream from YAMADA A nozzle.

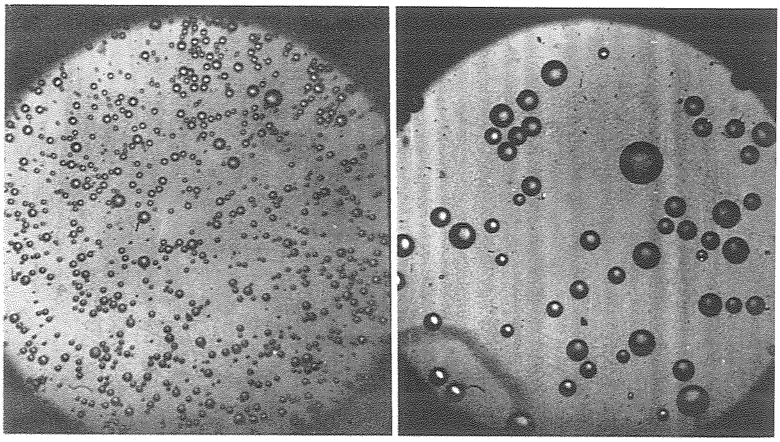
Spray pressures are (f), 2 (g) 4 and (h) 8 kg/cm^2.

a D_1 2 a D_1' 2



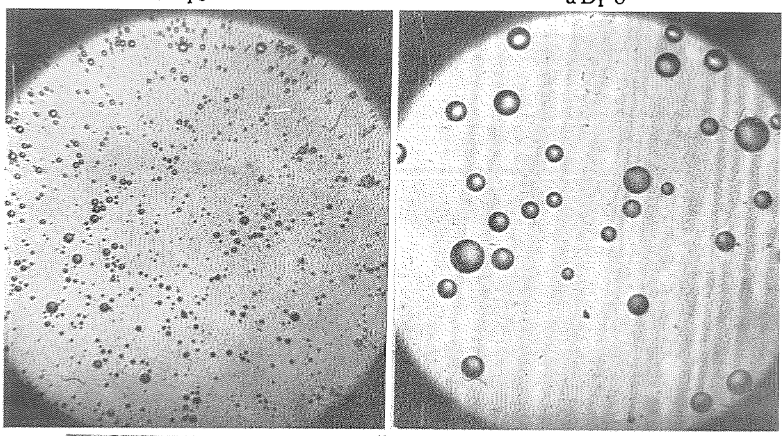
(f)

a D_1 4 a D_1' 4

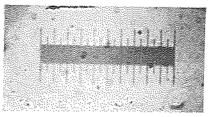


(g)

a D_1 8 a D_1' 8



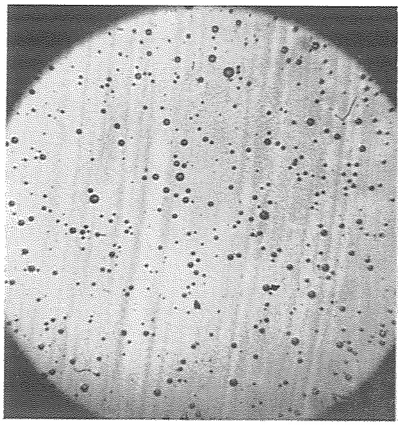
(h)



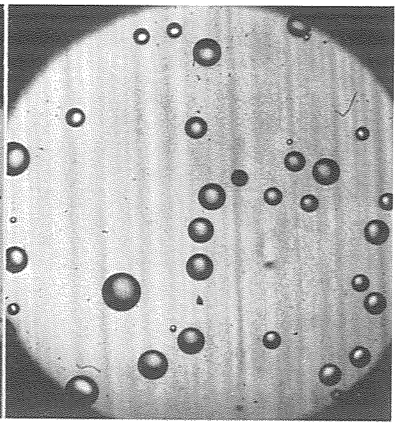
Eull length of this scale is 1mm

Plate 5-4. Microscopic photographs of droplets caught at the center (left) and at the end (right) of the stream from YAMADA A nozzle. (continued)
Spray pressures are (i) 12 and (j) 29 kg/cm^2.

a D_1 12

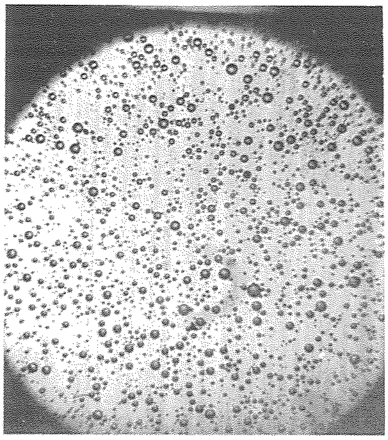


a D_1' 12

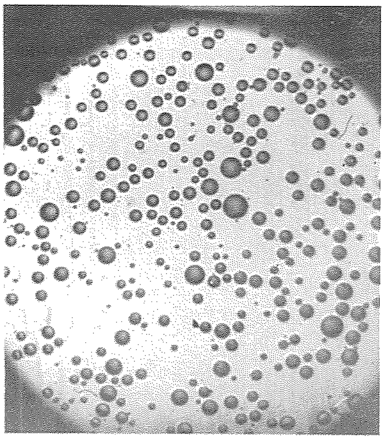


(i)

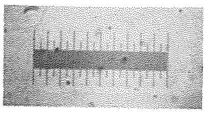
a D_1 20



a D_1' 20

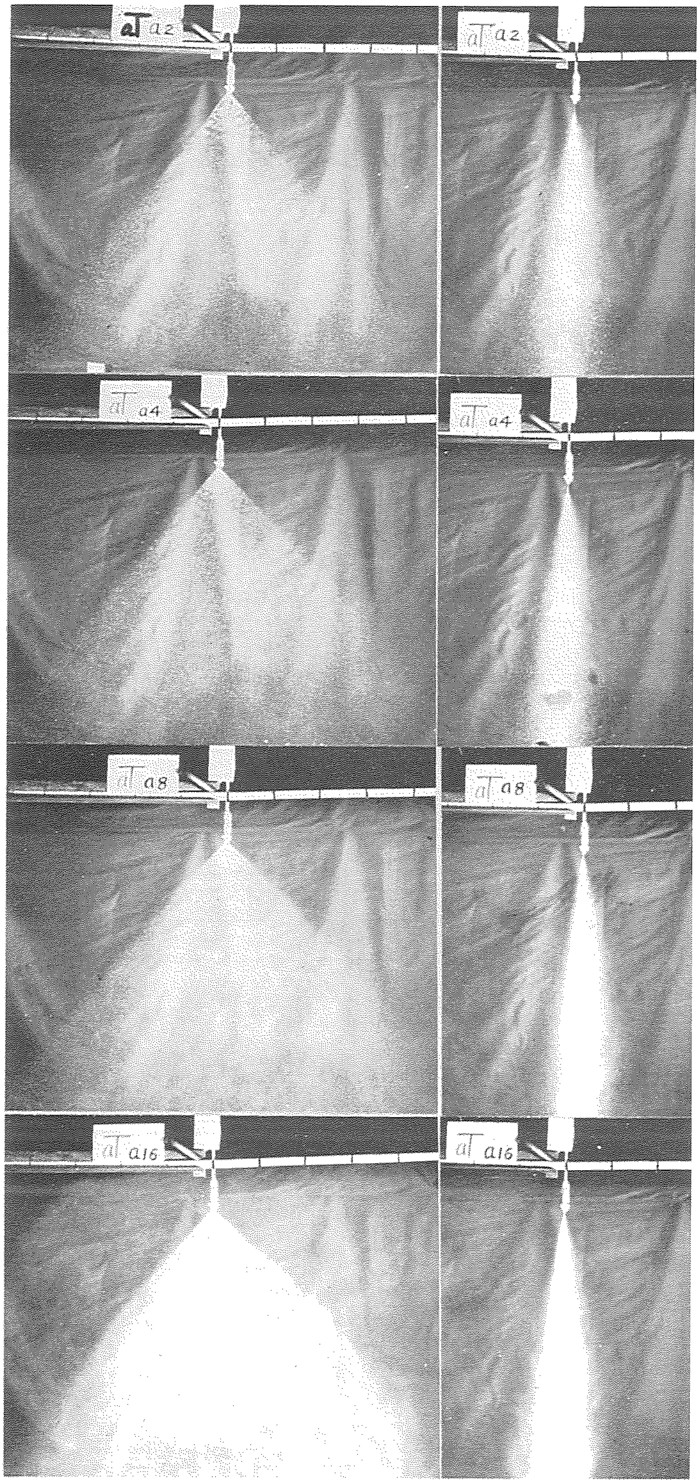


(j)



Full length of this scale is 1 mm

Plate 6-1. Spray angle of Tee Jet 8006 E nozzle at (a) 2 kg/cm^2, (b) 4 kg/cm^2, (c) 8 kg/cm^2 and (d) 16 kg/cm^2 of spray pressures.



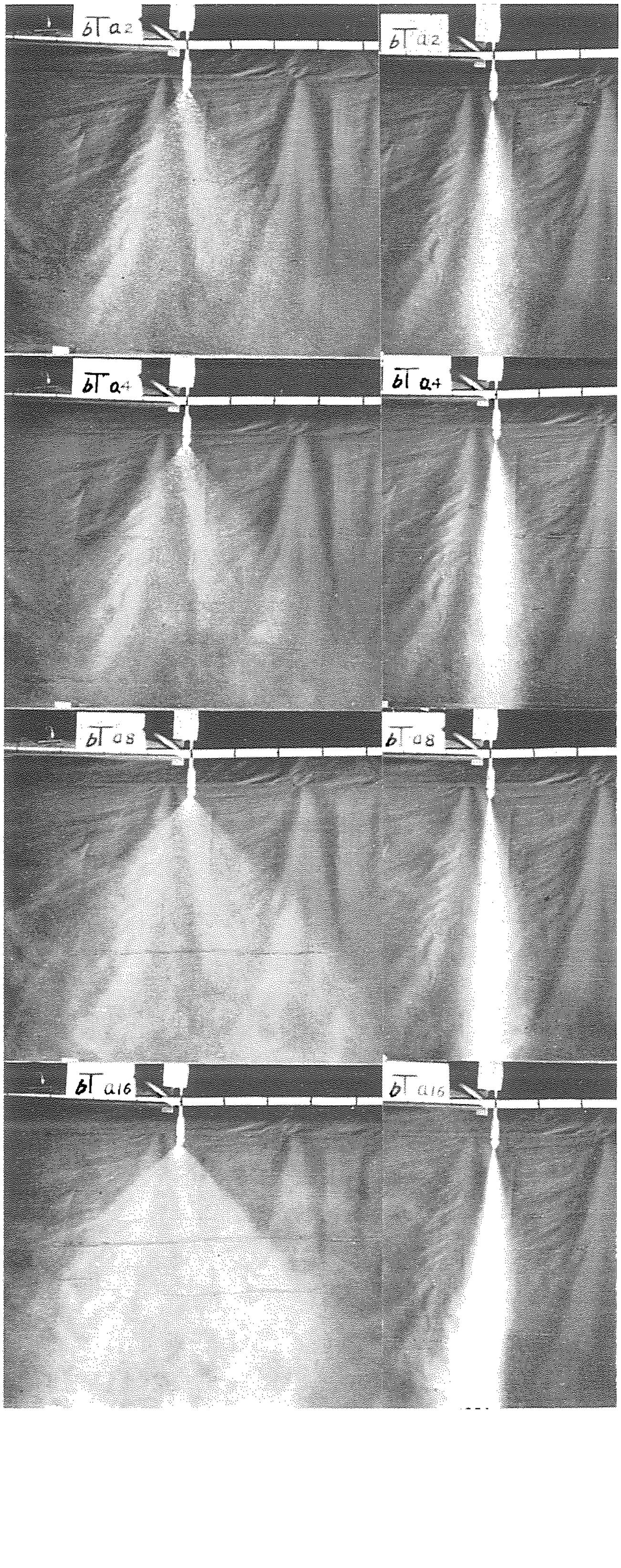
(a)

(b)

(c)

(d)

Plate 6–2. Spray angle of Tee Jet 8003 nozzle at (a) 2 kg/cm^2, (b) 4 kg/cm^2, (c) 8 kg/cm^2 and (d) 16 kg/cm^2 of spray pressures.



(a)

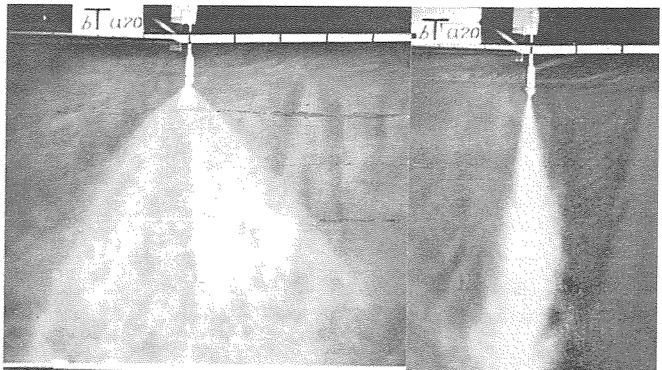
(b)

(c)

(d)

Plate 6-3. Spray Angle of Tee Jet 8003 nozzle at (e) 20 kg/cm^2 and (f) 30 kg/cm^2 of spray pressures.

(e)



(f)

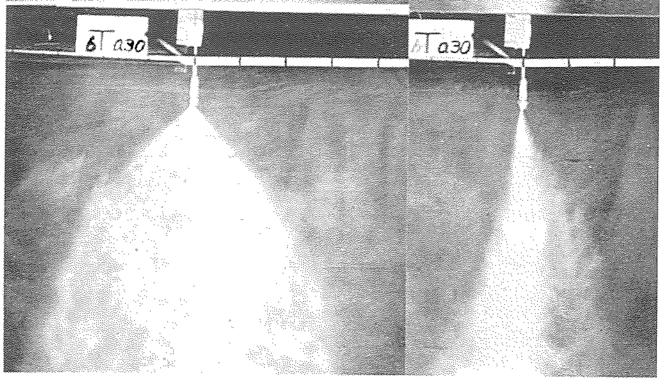
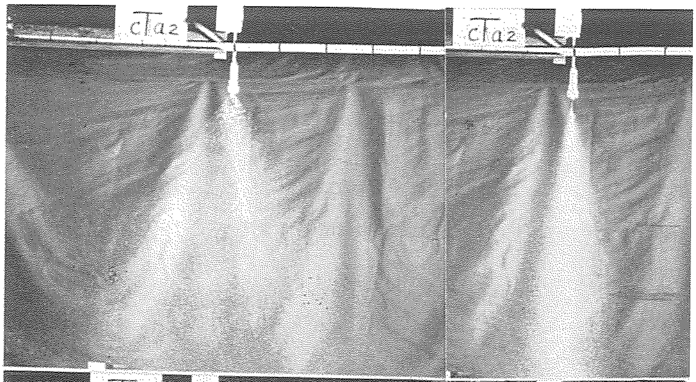
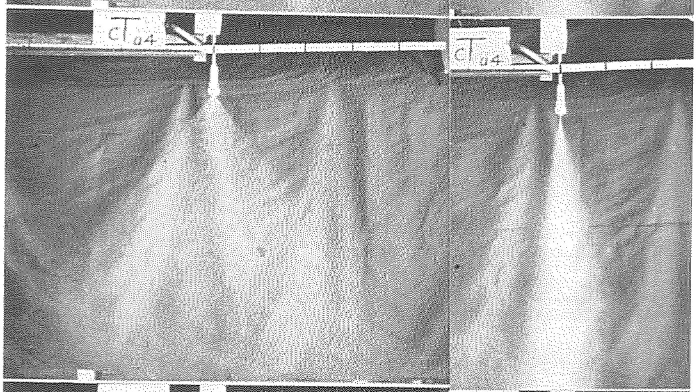


Plate 6-4. Spray angle of Tee Jet SS 8003 nozzle at (a) 2 kg/cm^2, (b) 4 kg/cm^2, (c) 8 kg/cm^2 and (d) 16 kg/cm^2 of spray pressures.

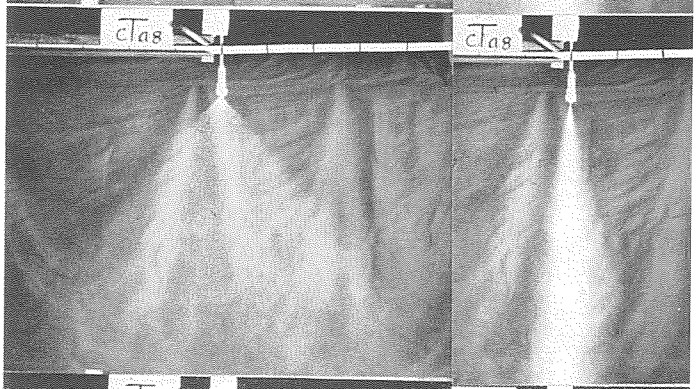
(a)



(b)



(c)



(d)

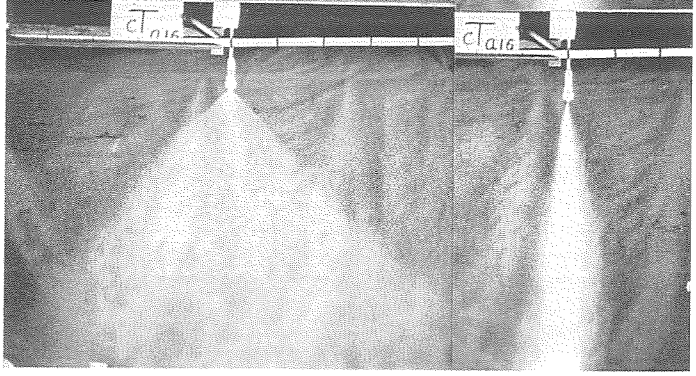


Plate 6–5. Spray angle of Tee Jet 8003 E nozzle at (a) 2 kg/cm^2, (b) 4 kg/cm^2, (c) 8 kg/cm^2 and (d) 16 kg/cm^2 of spray pressures.

(a)

(b)

(c)

(d)

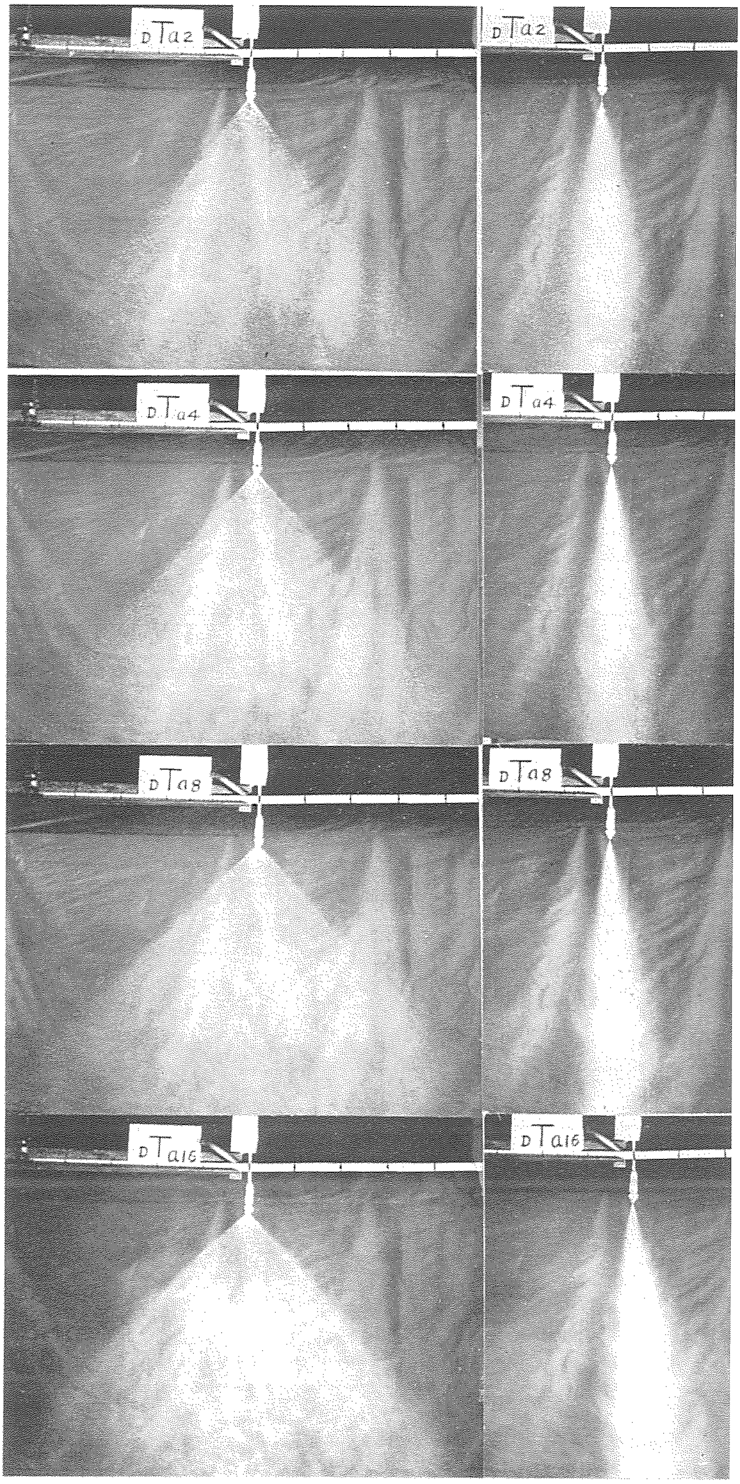


Plate 6–6. Spray angle of ARIMITSU nozzle at (a) 2 kg/cm^2, (b) 4 kg/cm^2, (c) 8 kg/cm^2 and (d) 16 kg/cm^2 of spray pressures.

(a)

(b)

(c)

(d)

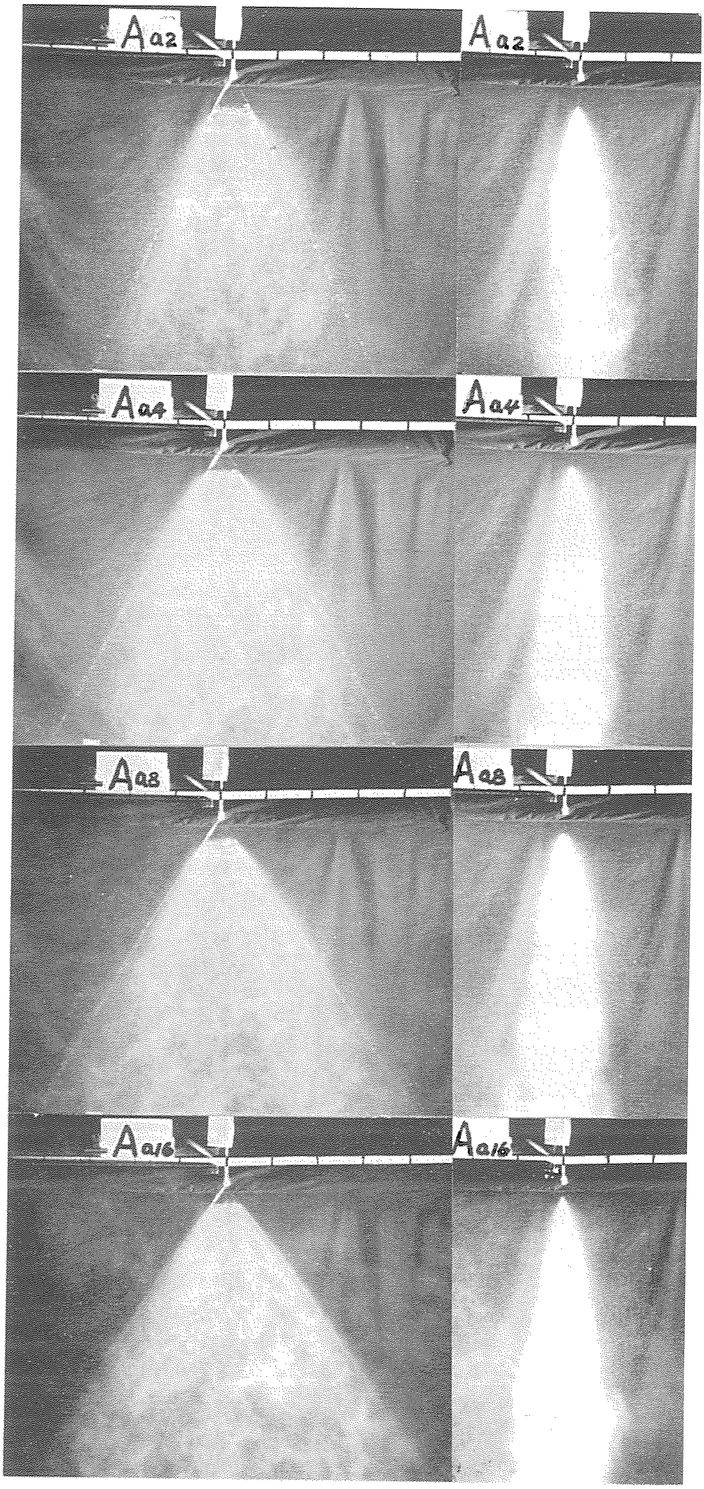


Plate 6-7. Spray angle of ARIMITSU nozzle at (e) 20 kg/cm^2 and (f) 30 kg/cm^2 of spray pressures.

(e)

(f)

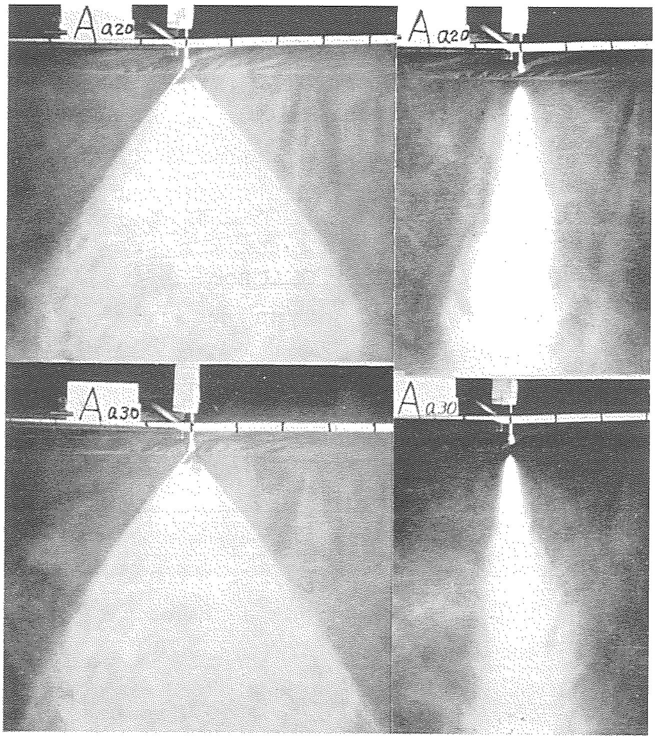


Plate 6–8. Spray angle of TOKAI nozzle at (a) 2 kg/cm^2, (b) 4 kg/cm^2, (c) kg/cm^2 and (d) 16 kg/cm^2 of spray pressures.

(a)

(b)

(c)

(d)

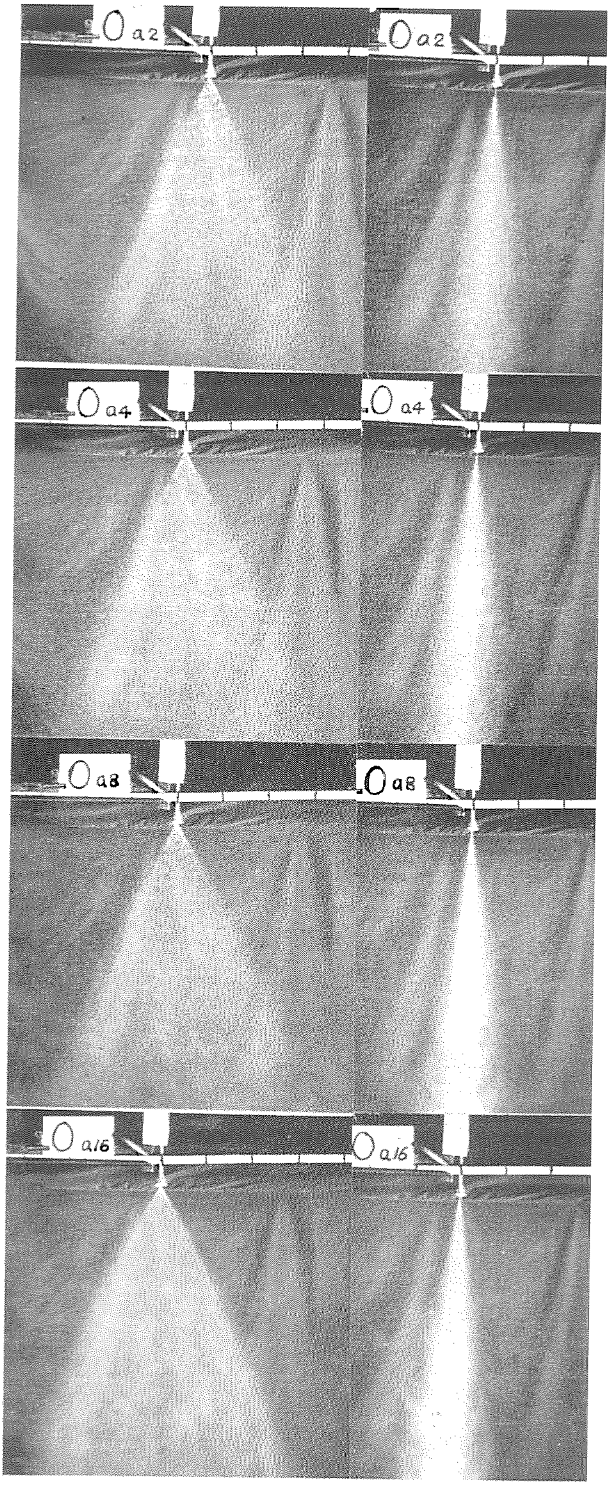
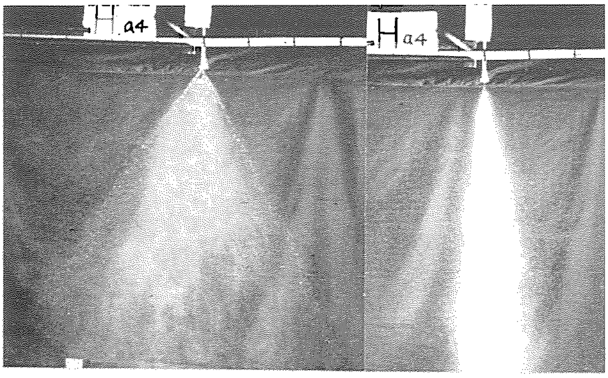
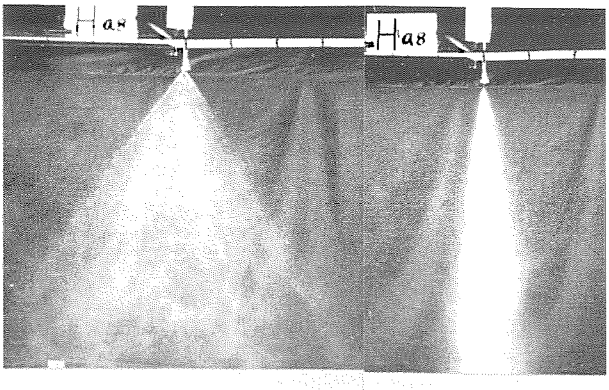


Plate 6–9. Spray angle of HATSUTA nozzle at (a) 4 kg/cm^2, (b) 8 kg/cm^2 and (c) 16 kg/cm^2 of spray pressures.

(a)



(b)



(c)

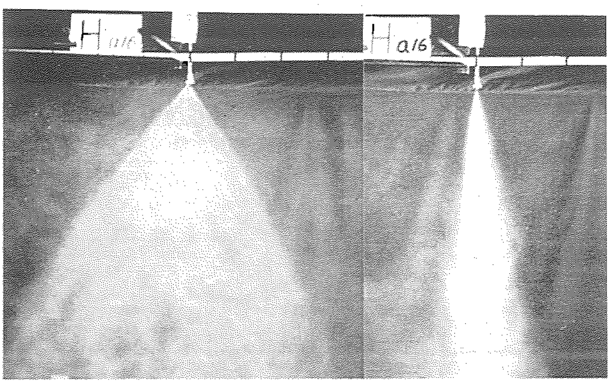


Plate 6–10. Spray angle of KYORITSU VN–13 at (a) 2 kg/cm^2, (b) 4 kg/cm^2, (c) 8 kg/cm^2 and (d) 16 kg/cm^2 of spray pressures.

(a)

(b)

(c)

(d)

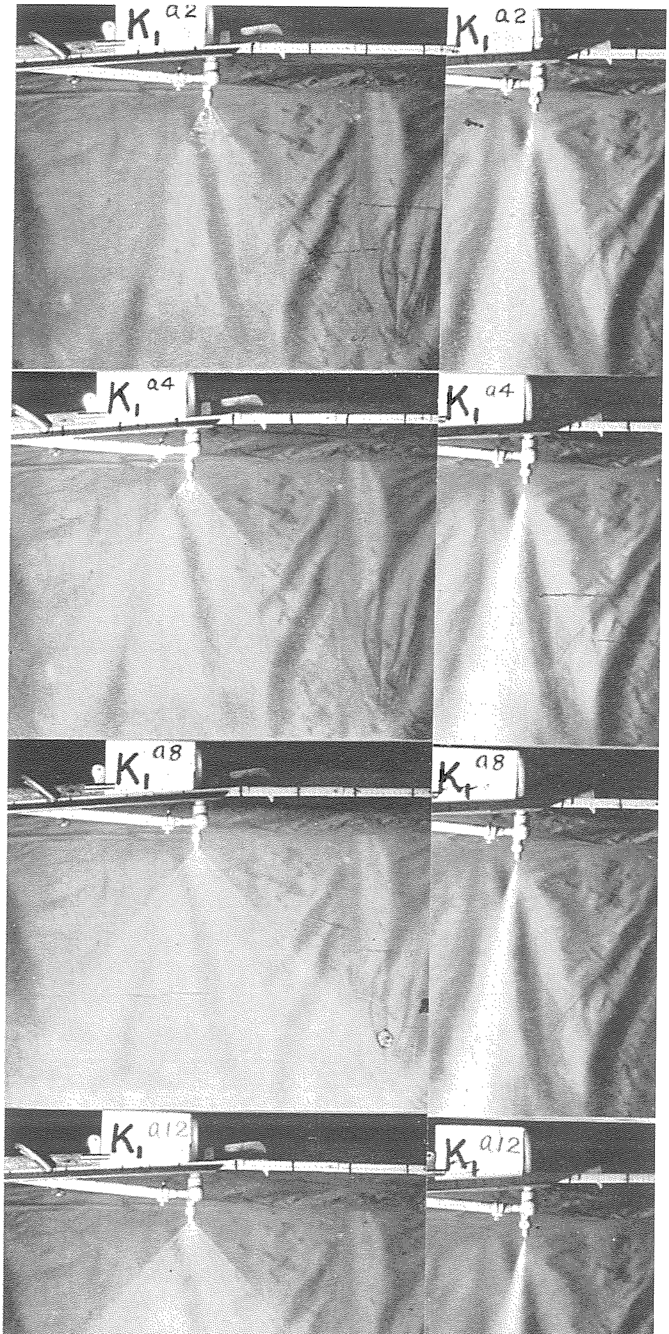


Plate 6–11. Spray angle of KYORITSU VN–12 nozzle at (a) 2 kg/cm^2, (b) 4 kg/cm^2, (c) 8 kg/cm^2 and (d) 16 kg/cm^2 of spray pressures.

(a)

(b)

(c)

(d)

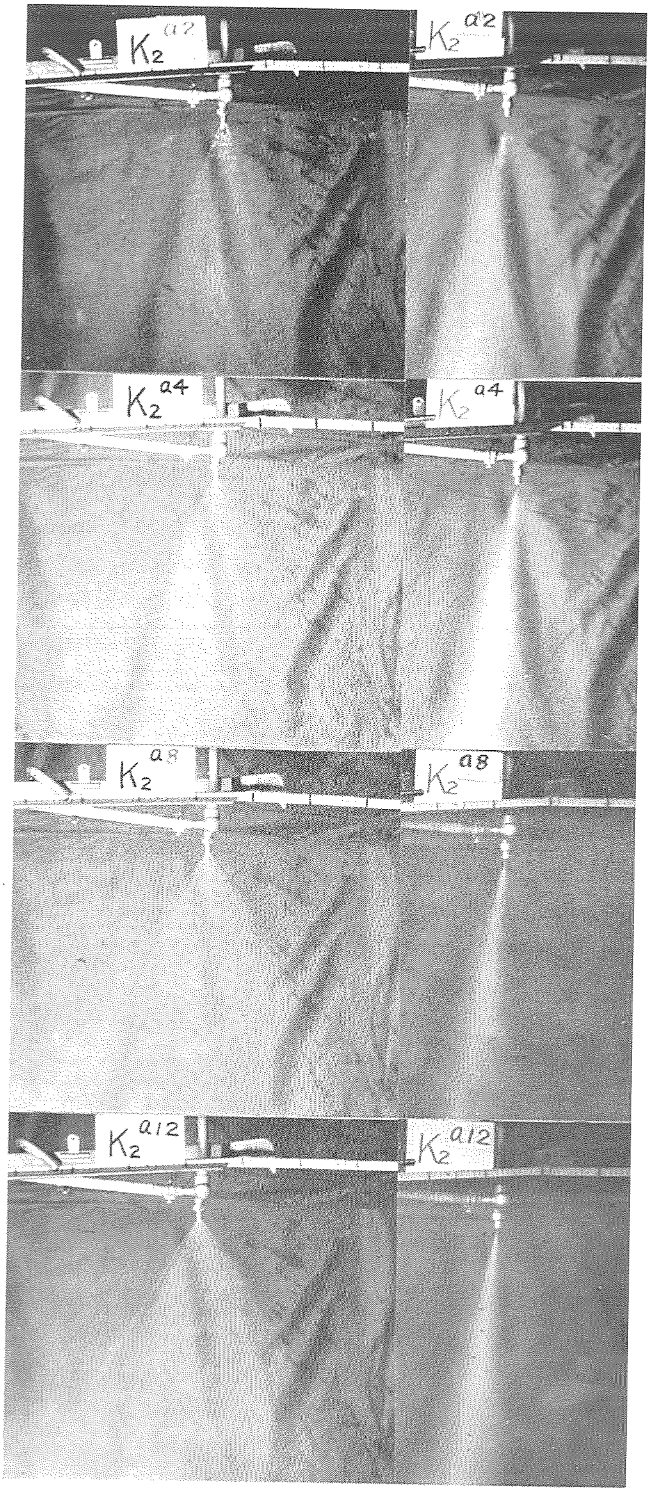
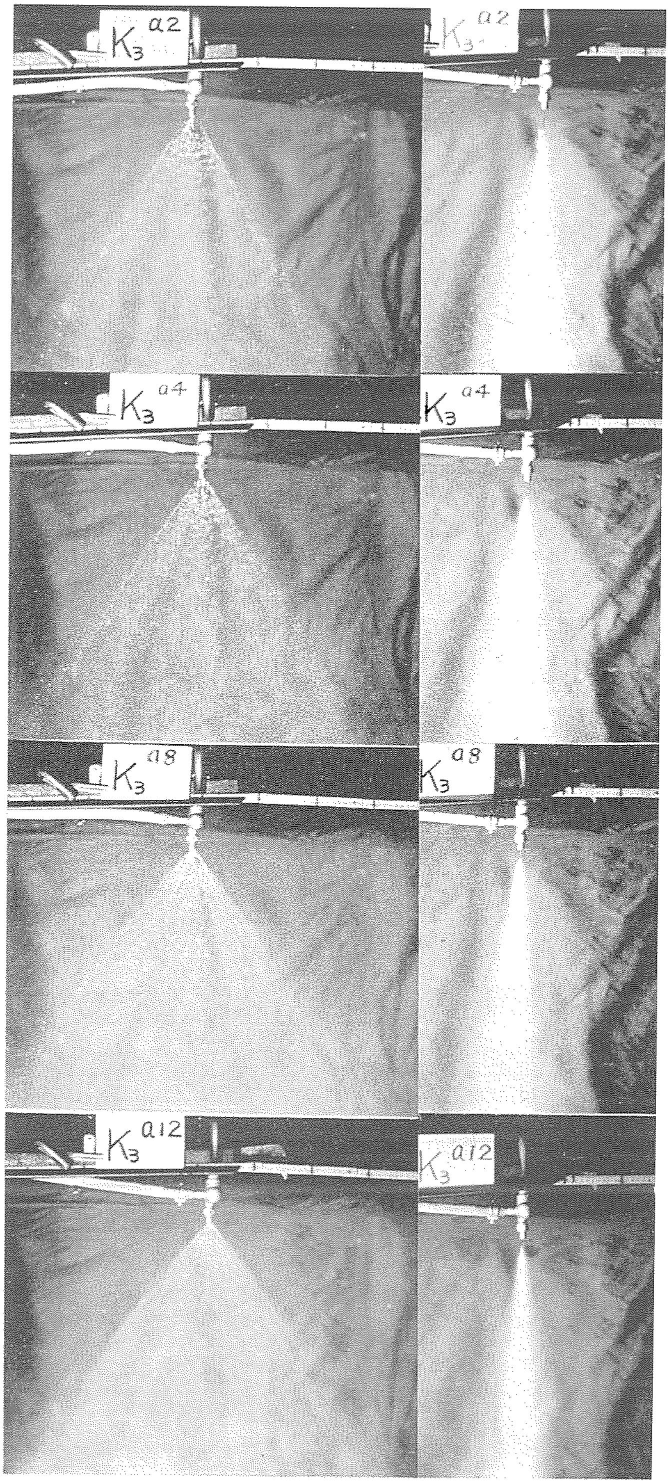


Plate 6-12. Spray angle of KYORITSU VN-22 nozzle at (a) 2 kg/cm^2, (b) 3 kg/cm^2, (c) 8 kg/cm^2 and (d) 16 kg/cm^2 of spray pressures.



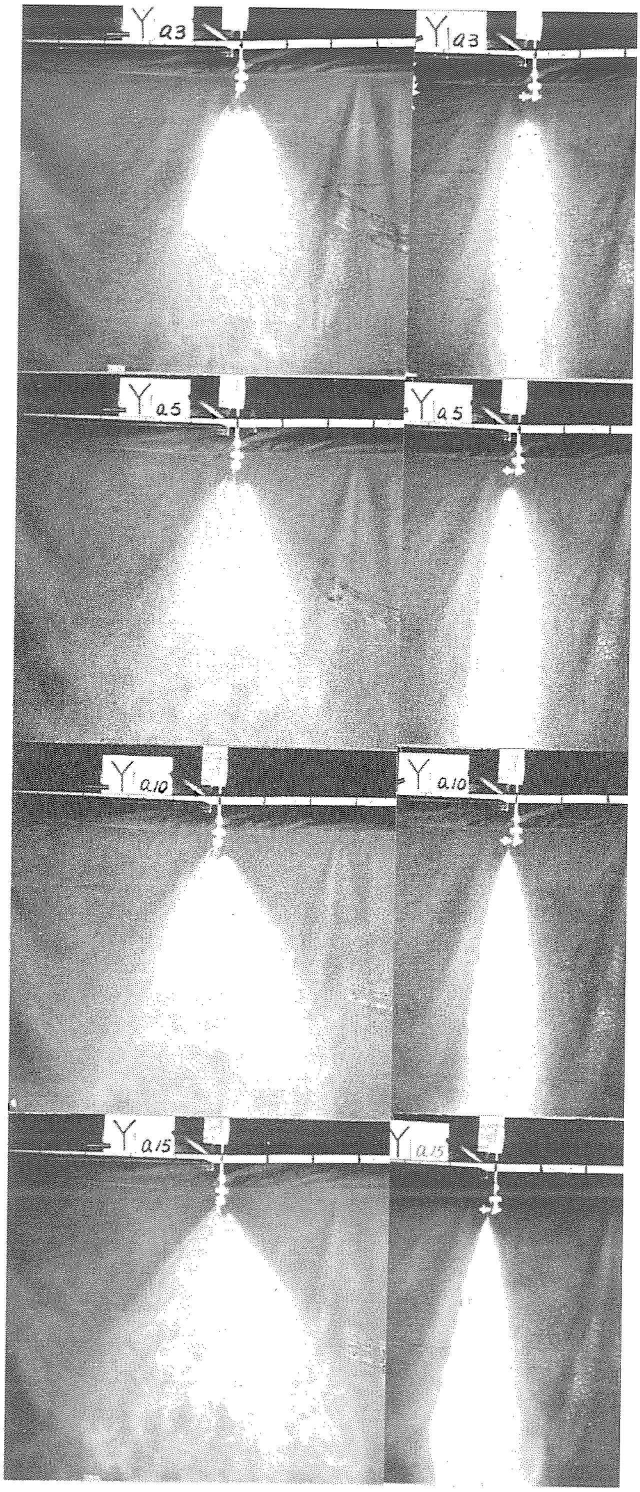
(a)

(b)

(c)

(d)

Plate 6–13. Spray angle of YAMADA nozzle at (a) 2 kg/cm², (b) 4 kg/cm², (c) kg/cm² and (d) 16 kg/cm² of spray pressures.



(a)

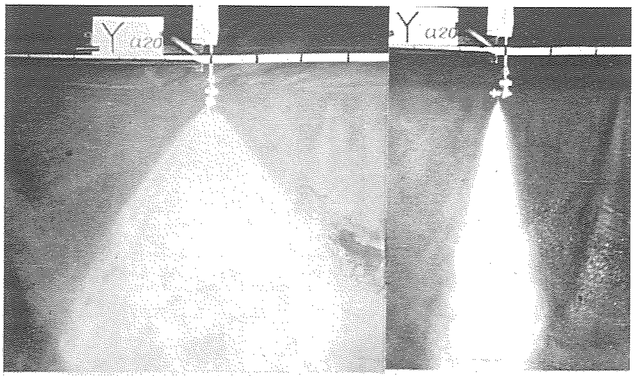
(b)

(c)

(d)

Plate 6–14. Spray angle of YAMADA nozzle at (e) 20 kg/cm^2 and (f) 30 kg/cm^2 of spray pressures.

(e)



(f)

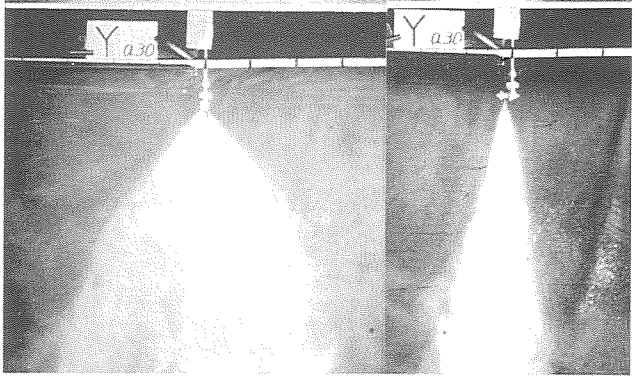
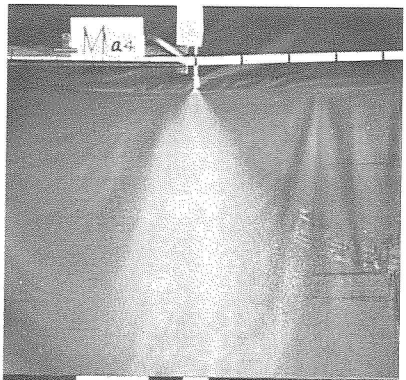


Plate 6–15. Spray angle of MIYASHITA nozzle at (a) 4 kg/cm^2, (b) 12 kg/cm^2, (c) 20 kg/cm^2 and (d) 30 kg/cm^2 of spray pressures.

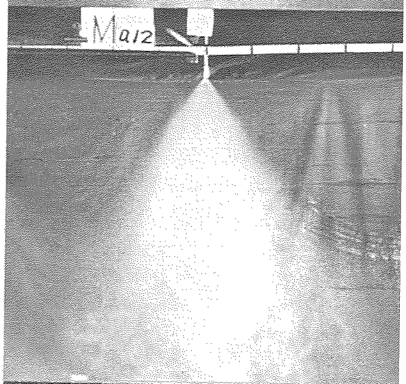
Plate 6–16. Spray angle of YAMADA A nozzle at (a) 2 kg/cm^2, (b) 4 kg/cm^2, (c) 8 kg/cm^2 and (d) 12 kg/cm^2 of spray pressures.
Plungere was scrwed up by one turn.

Pl. 6–15

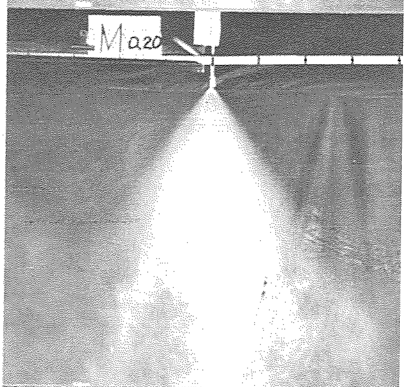
(a)



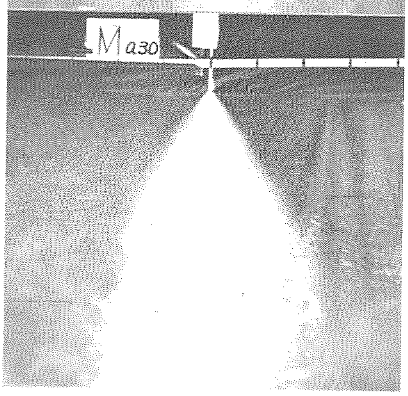
(b)



(c)

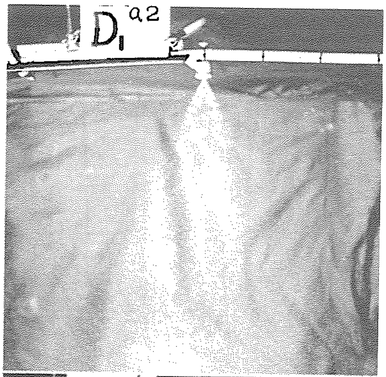


(d)

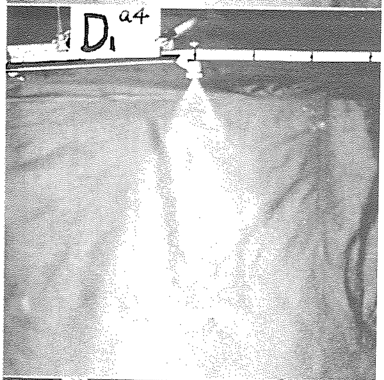


Pl. 6–16

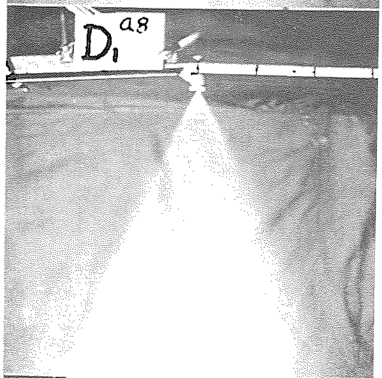
(a)



(b)



(c)



(d)

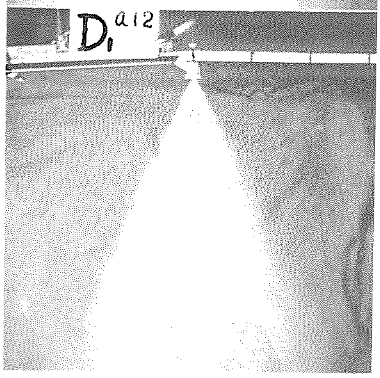


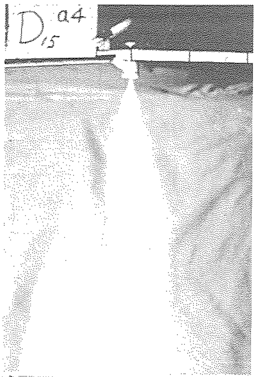
Plate 6–17. Spray angle of YAMADA A nozzle at (a) 4 kg/cm^2, and (b) 12 kg/cm^2 of spray pressures.
Plunger was screwed up by one and half turns.

Plate 6–17′. Spray angle of YAMADA A nozzle at (a) 4 kg/cm^2 and (b) 12 kg/cm^2 of spray pressures.
Plunger was screwed up by two turns.

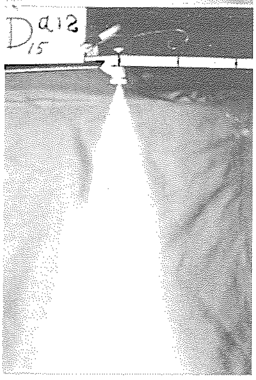
Plate 6–18. Spray angle of YAMADA B nozzle at (a) 5 kg/cm^2, (b) 10 kg/cm^2, (c) 15 kg/cm^2 and (d) 20 kg/cm^2 of spray pressures. Plunger was full down.

Pl. 6-17

(a)

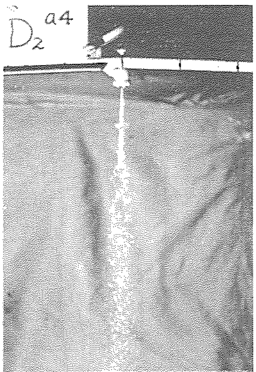


(b)

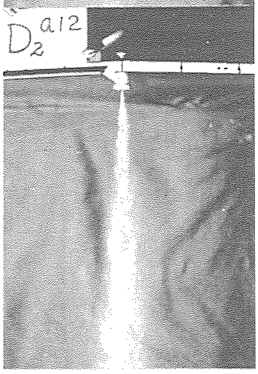


Pl. 6-17′

(a)

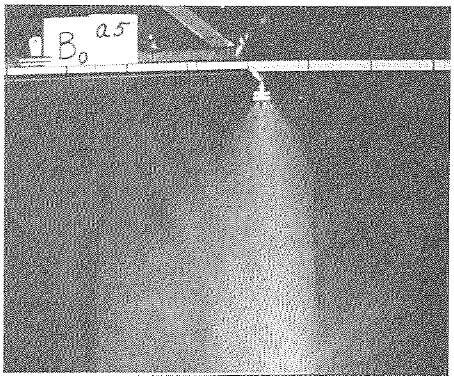


(b)

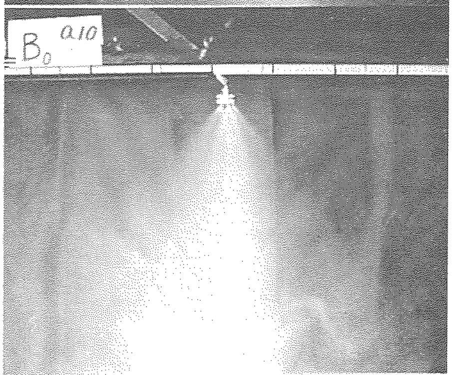


Pl. 6-18

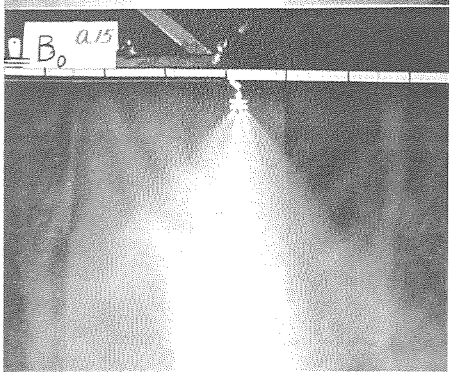
(a)



(b)



(c)



(d)

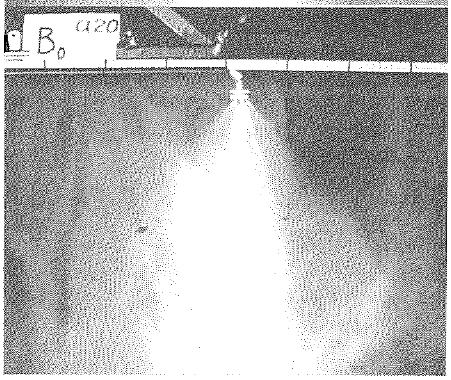
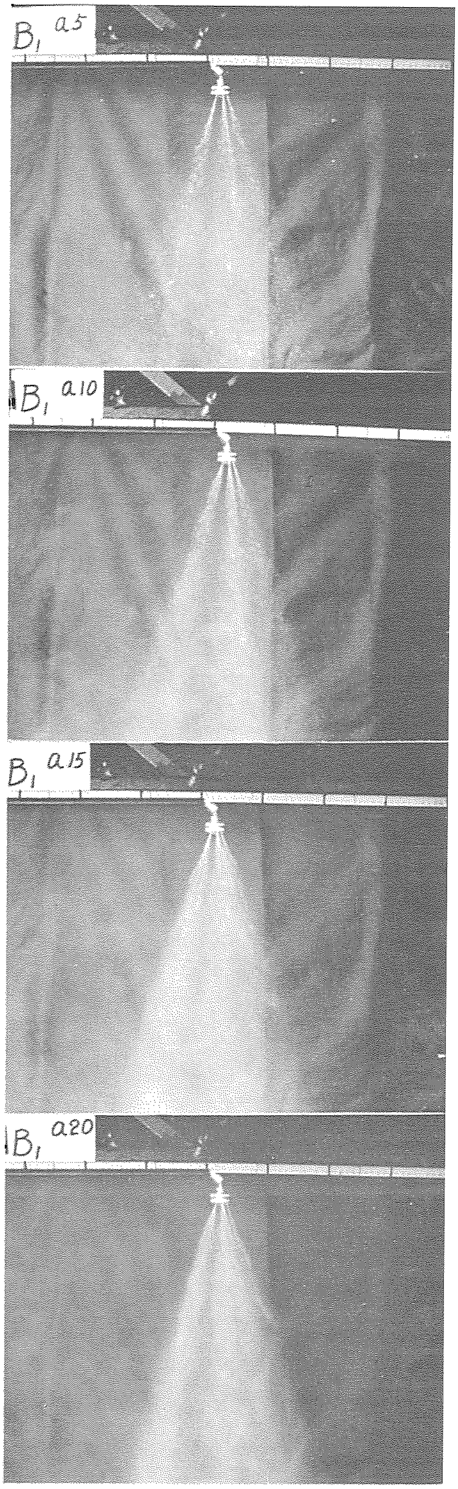


Plate 6–19. Spray angle of YAMADA B nozzle at (a) 5 kg/cm^2, (b) 10 kg/cm^2, (c) 15 kg/cm^2 and (d) 20 kg/cm^2 of spray pressures. Plunger was screwed up by one turn.

Plate 6–20. Spray angle of YAMADA B nozzle at (a) 5 kg/cm^2, (b) 10 kg/cm^2, (c) 15 kg/cm^2 and (d) 20 kg/cm^2 of spray pressures. Plunger was scrwed up by two turns.

Pl. 6–19



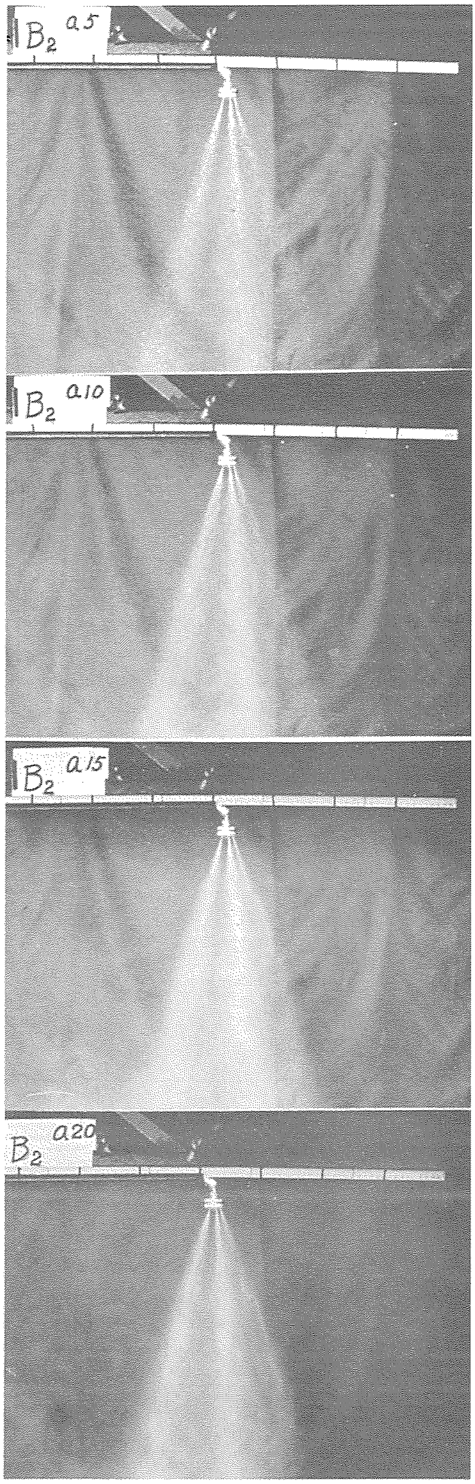
(a)

(b)

(c)

(d)

Pl. 6–20



(a)

(b)

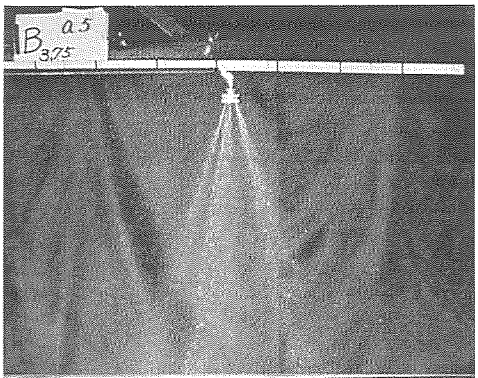
(c)

(d)

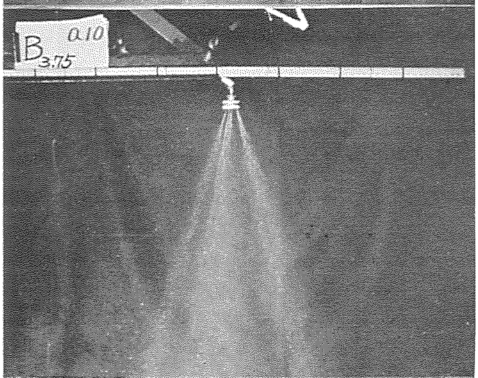
Plate 6–21. Spray angle of YAMADA B nozzle at (a) 5 kg/cm^2, (b) 10 kg/cm^2, (c) 15 kg/cm^2 and (d) 20 kg/cm^2 of spray pressures. Plunger was screwed up by three and three quarter turns.

Plate 6–22. Spray angle of YAMADA B nozzle at (e) 25 kg/cm^2 of spray pressure. Plunger was screwed up by three and three quarter turns.

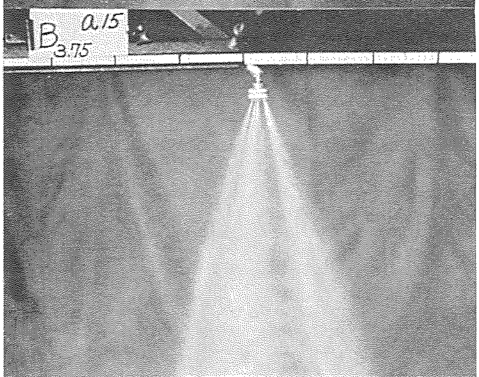
(a)



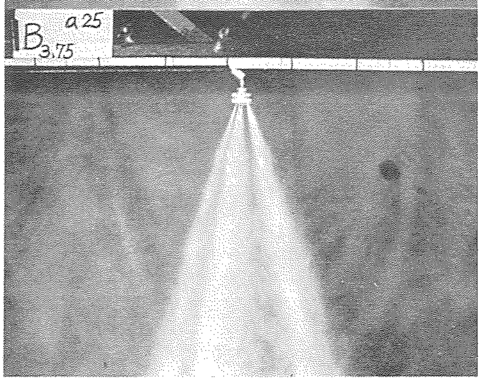
(b)



(c)



(d)



(e)

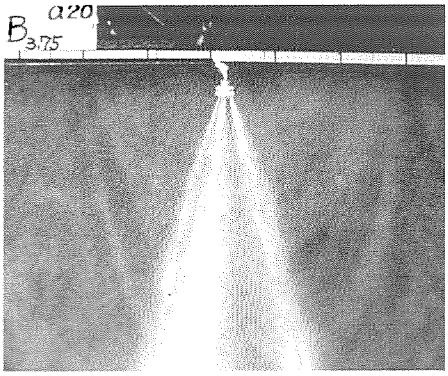
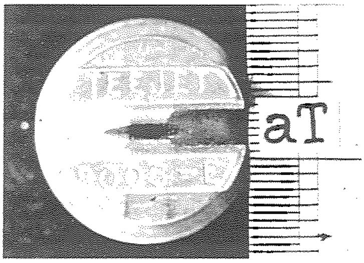
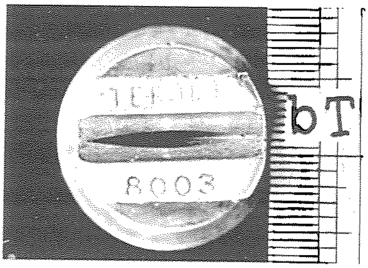


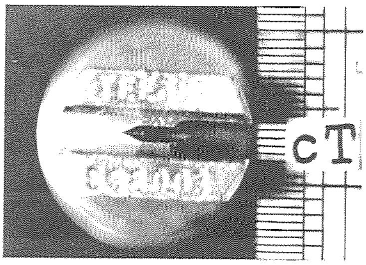
Plate 7-1. Enlarged photographs of tested nozzles



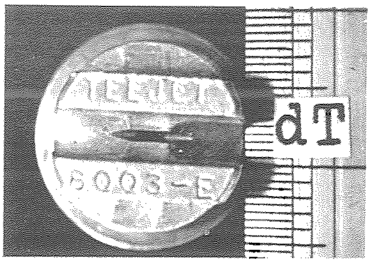
(a) Tee Jet 8006-E



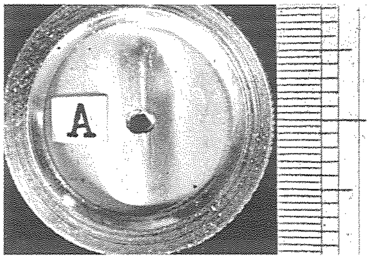
(b) Tee Jet 8003



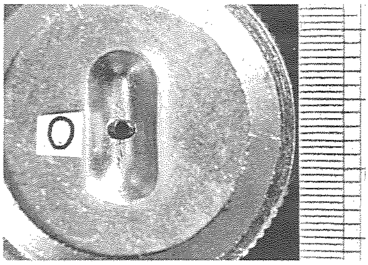
(c) Tee Jet SS 8003



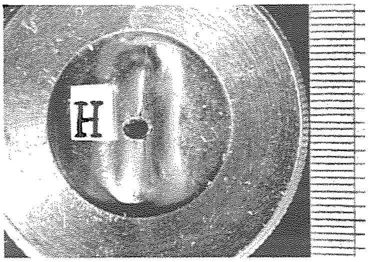
(d) Tee Jet 8003-E



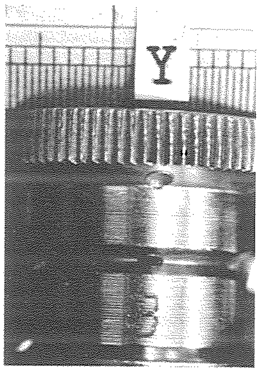
(e) ARIMITSU



(f) TOKAI

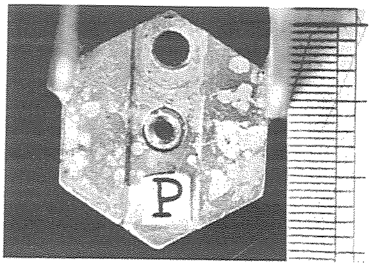


(g) HATSUTA

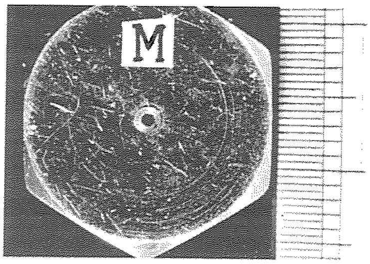


(h) YANMAR

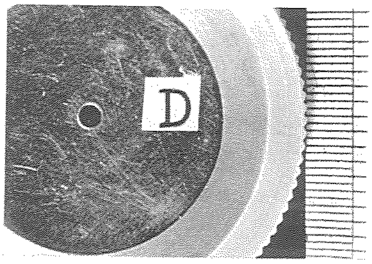
Plate 7–2. Enlarged photograph of tested nozzles. (continued)



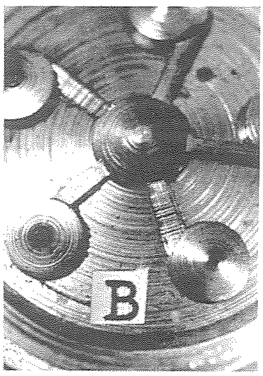
(i) PLATZ



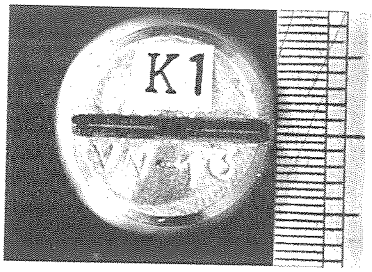
(j) MIYASHITA



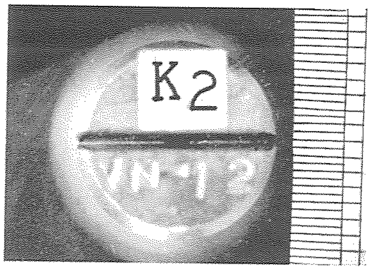
(k) YAMADA A



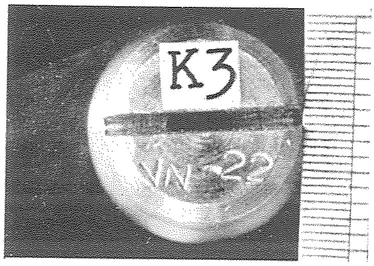
(l) YAMADA B



(m) KYORITSU VN-13

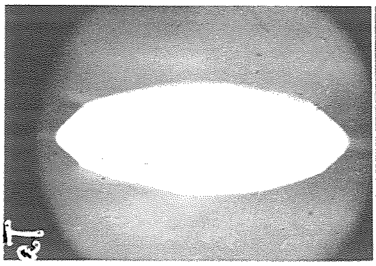


(n) KYORITSU VN-12

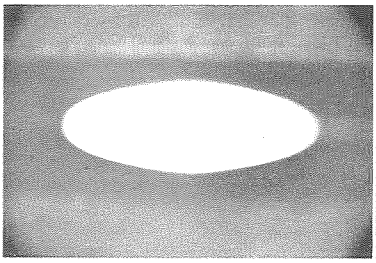


(o) KYORITSU VN-22

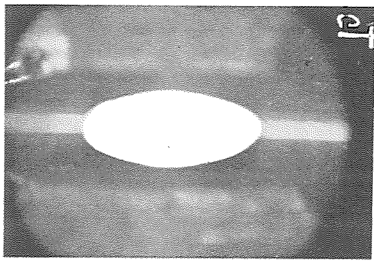
Plate 8-1. Microscopic photographs of nozzle orifices.



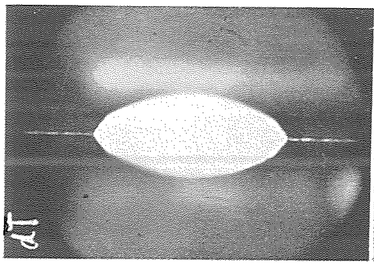
(a) Tee Jet 8006-E



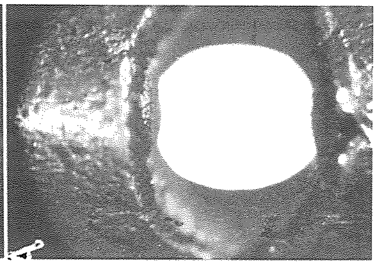
(b) Tee Jet 8003



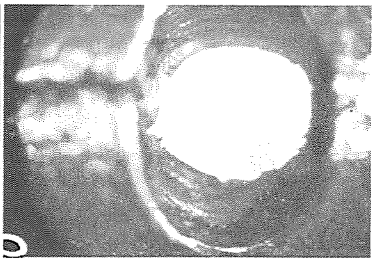
(c) Tee Jet SS-8003



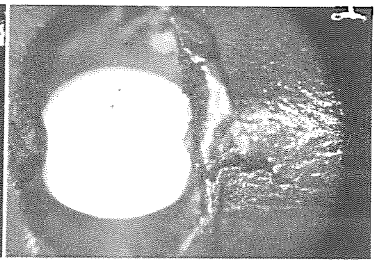
(d) Tee Jet 8003-E



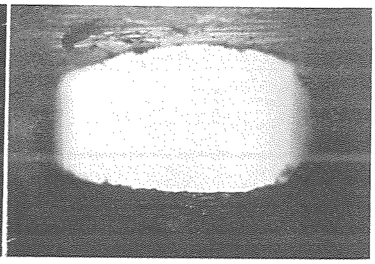
(e) ARIMITSU



(f) TOKAI

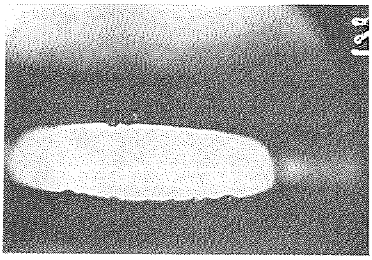


(g) HATSUTA

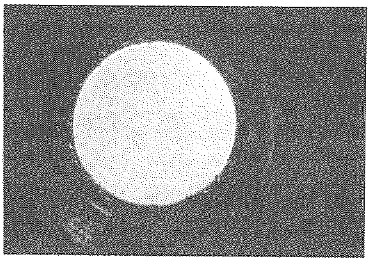


(h) YANMAR

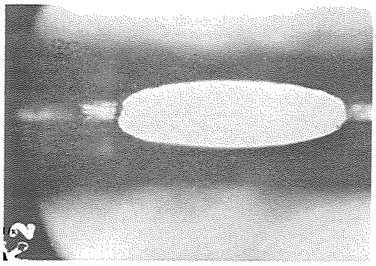
Plate 8–2. Microscopic photographs of nozzle orifices. (continued)



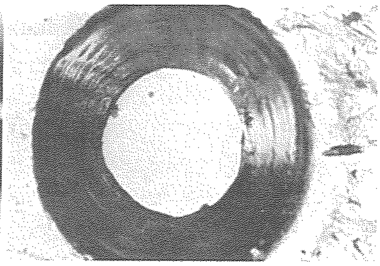
(i) KYORITSU VN- 13



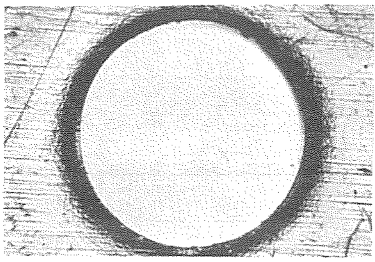
(l) PLATZ



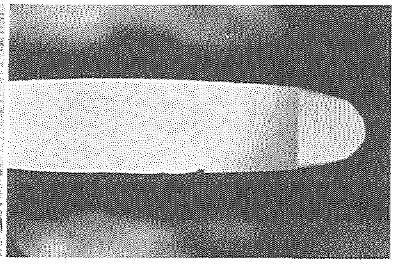
(j) KYORITSU VN-12



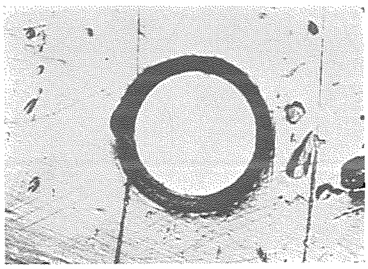
(m) MIYASHITA



(k) KYORITSU VN-22



(n) YAMADA A



(o) YAMADA B

Plate 9–1. Spray angle of individual nozzle of Tee Jet 8003 E at 4 kg/cm^2 of spray pressure.

(1)

(2)

(3)

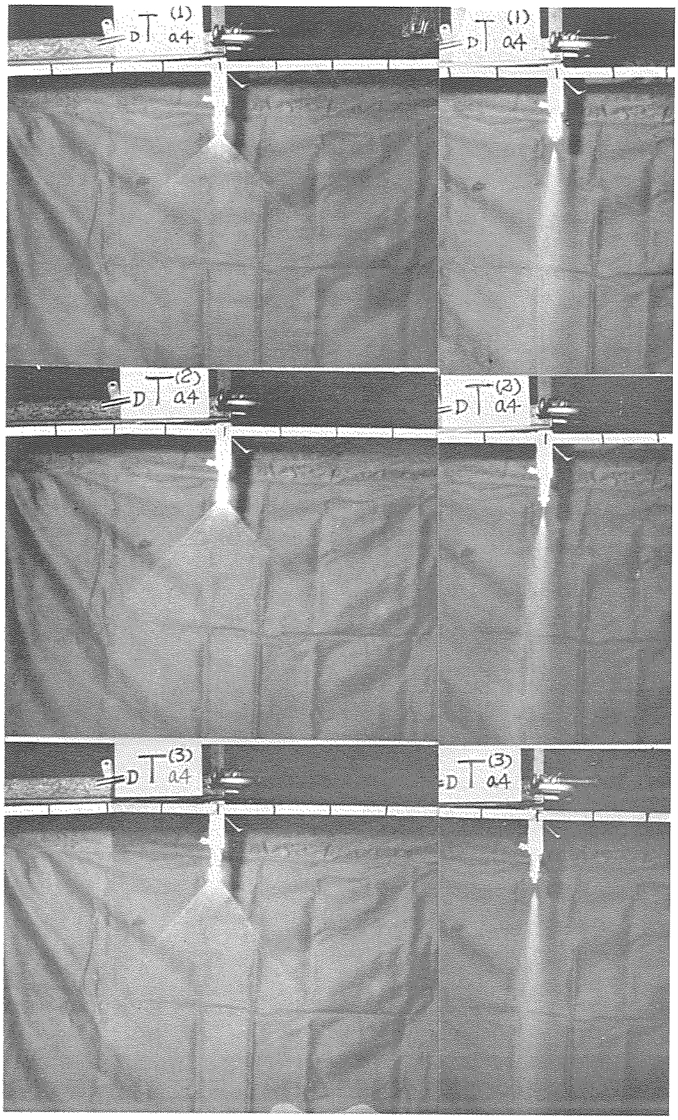
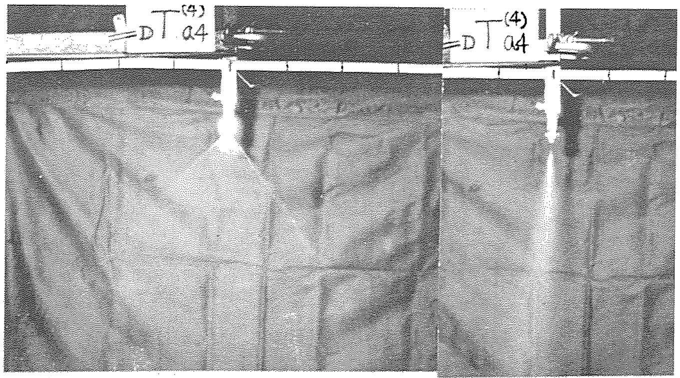


Plate 9–2. Spray angle of individual nozzle of Tee Jet 8003 E at 4 kg/cm^2 of spary pressure. (continued)

(4)



(5)