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MEASUREMENTS OF WATER ENTRAINMENT IN A SQUARE SPRINKLER ARRAY

by

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MINISTRY OF TECHNOLOGY AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

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1. Introduction

This note describes a study of the distribution of water falling on an area of floor beneath an array of four sprinklers mounted below a ceiling, each at the corner of a square of side 11.4 ft. The main object of the study was to compare the distribution obtained by adding the independent contributions of the four individual sprinklers, with the distribution obtained by allowing the water from all four sprinklers to contribute simultaneously to the water pattern at floor level.

The primary object of the work was to compare the rate obtained from the sum of the individual sprinkler contributions with the rate applying when all four sprinklers were contributing to the flow simultaneously, in order to establish whether the individual results were additive.

2. Experimental

Four sprinklers were mounted at the corners of a 3.48 m (11.4 ft) square on a pipe system conforming to the Fire Offices' Committee rules (Figure 1), and suspended symmetrically beneath a 6.10 m (20 ft) square, painted hardboard ceiling. Conventional sprinklers of one make were used, mounted in the pendent position, with the deflection plates at 30.5 cm (12 in) below the ceiling. Measurements of water distribution were made at water pressures of 0.70 kgf/cm^2 (10 lbf/in^2) and 3.52 kgf/cm^2 (50 lbf/in^2, as measured at the point in the main distribution pipe shown in Figure 1.

The water discharged from the sprinklers was collected in plastic buckets arranged at floor level, in a square formed by 64 buckets placed in contact at their rims. The buckets were disposed symmetrically about the centre of the array, forming an approximately 1.83 m (6 ft) square. The internal throat diameter of each bucket was 20.3 cm (8 in), and the plane of the bucket tops was 3.43 m (11 ft 3 in) below the sprinkler deflector plates. The quantity of water falling into each bucket (measured in cm^3) was determined by adjusting the supply pressure to the appropriate value and allowing the sprinklers to discharge for 5 min at a pressure of 0.70 kgf/cm^2 (10 lbf/in^2) and 3 min at 3.52 kgf/cm^2 (50 lbf/in^2).

Five experiments were made at each pressure. In the first of these, the quantity of water collected in the buckets was measured with all four sprinklers discharging simultaneously. In the other four, the contribution of each of the individual sprinklers was measured with the remaining three sprinklers of the array discharging to waste. This was arranged by placing 6 in internal diameter plastic pipes, 9 ft 6 in long, around the sprinklers not required and draining the water well outside the collection area.

3. Results

The results are given in Figures 2, 3, 4, 5 and 6 in terms of the volumes collected in the buckets in cm^3. These values have not been converted to rate of flow per unit area, since only a comparison is required between the four sprinklers operating simultaneously and the sum of the four individual sprinklers. Figure 7 shows the sums of the volumes contributed by the four individual sprinklers, that is, the sum of the rates given in Figures 2, 3, 4 and 5. Figure 8 gives the ratio of the volumes collected under the array to the sum of the four individual sprinklers, i.e. the ratio of the values given in Figure 6 to the corresponding values given in Figure 7.

4. Discussion and conclusions

The important question to be determined in these experiments was whether it was possible to predict the rate of water discharge per unit area and its distribution for an array of four sprinklers from a knowledge of the water discharge from individual sprinklers. In particular, interest was focussed on the central region of the area covered, since it is in this area that the water coverage is expected to be least satisfactory.

The ratios given in Figure 8 show that at a pressure of 0.70 kgf/cm^2 (10 lbf/in^2) there is good agreement between the volumes obtained below the array and those obtained from the sum of the individual sprinkler contributions, with an overall mean value of the ratio of 0.964. This figure means that there was about $3\frac{1}{2}$ per cent less water within the central 6 ft x 6 ft area than would be expected from measurements of the quantities obtained from the individual sprinklers. The discrepancy between the two sets of results is of little practical significance and is likely to be a measure of experimental and computational error. At a pressure of 3.52 kgf/cm^2 (50 lbf/in^2), the quantities of water collected within the 6 ft x 6 ft area were greater than the sum of quantities from the individual sprinklers, with an average increase of 35 per cent over the 6 ft square area. Comparison of quantities collected in individual buckets showed increases up to 90-100 per cent in a few cases. This increase in the quantity of water falling in the centre of the area covered by the sprinklers, over that pertaining to the discharge from individual sprinklers is of considerable practical significance. The effect presumably arises as a result of the entrained air currents associated with the sprinkler sprays, which produce a movement of air towards the centre of the array. The meeting of these currents will result in a strong downdraught in the central area which will cause water drops to fall in the central area which would otherwise have been thrown outside this area. The result will be a concentration of water in the centre of the area covered by the array.

In Figure 9 the ratios given in Figure 8 for a pressure of 3.52 kgf/cm^2 (50 lbf/in^2) are presented graphically in terms of the percentage increase in the volume of water falling at any point in the central 6 ft x 6 ft area. Contour lines have been drawn at intervals of 10 per cent. The pattern of water entrainment is a complex one, with high values towards the sides AB and CD, the greatest entrainment occurring about an approximately central axis parallel to the sides AD and BC. The degree of entrainment at the centre of the area is close to the overall mean value of 35 per cent, and falls off towards the sides AD and BC to values generally well below the mean.

It should be noted that the pattern of entrainment may be affected markedly by other sprinklers operating adjacent to the array, as would be the case in practical situations where more than four sprinklers operate.

5. Conclusions

At an inlet pressure of 0.70 kgf/cm^2 (10 lbf/in^2) there was no significant evidence of entrainment of water at the centre of the area covered by the sprinkler array. At a pressure of 3.52 kgf/cm^2 (50 lbf/in^2) there was an entrainment of water ranging from 0 to 100 per cent, with a mean value over the area of measurement of 35 per cent. The pattern of entrainment is a complex one and suggests that it would be difficult to predict the water distribution beneath a sprinkler array from a knowledge of the water distributions of each individual sprinkler. A number of factors may contribute to the entrainment, such as the area covered by each sprinkler, the depth of the measuring plane below the sprinklers, the type of sprinkler (spray or conventional), the make of sprinkler, water pressure, type of array (i.e. its geometrical configuration), and the sprinkler orientation (upright or pendent). Without a detailed knowledge of the effects which can be produced by each of these factors on the entrainment pattern, it is not possible to predict the water distribution from a knowledge of individual sprinkler distributions with any degree of accuracy.

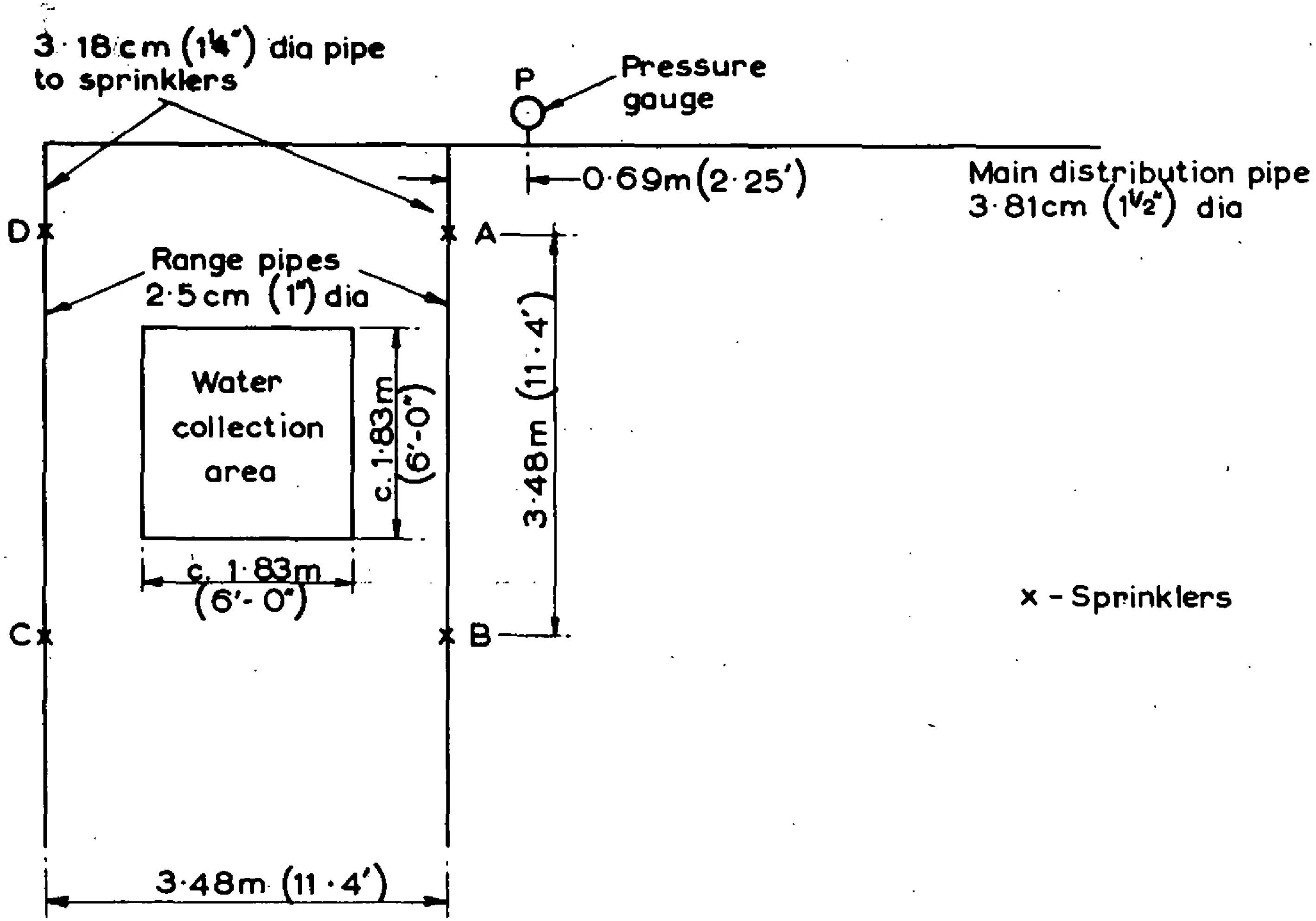

FIG. 1. ARRANGEMENT OF SPRINKLER PIPEWORK

Pressure - 0·70 kgf / cm^2 (10 lbf / in^2)

C D

300	300	290	270	250	270	280	300
300	310	310	290	270	270	270	280
260	320	320	310	280	250	280	280
220	270	280	290	290	270	250	270
180	220	260	270	290	300	270	270
150	180	210	240	270	290	290	270
140	160	180	200	230	260	300	310
140	160	170	140	210	250	290	330

B A

WATER QUANTITY - cm^3

Pressure - 3·52 kgf / cm^2 (50 lbf/in^2)

C D

150	210	260	300	340	450	590	690
110	180	250	320	370	440	550	630
90	140	230	330	400	460	510	570
55	100	180	280	400	480	550	550
40	70	120	200	320	470	560	540
35	50	85	140	260	390	480	480
40	50	80	100	170	290	380	430
50	50	70	90	130	190	270	430

B A

WATER QUANTITY · cm^3

FIG. 2: WATER DISTRIBUTION FOR SPRINKLER 'A'

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Pressure - 0·70 kgf/cm^2 (10 lbf/in^2)

C D

210	220	240	240	220	180	120	100
220	230	230	230	210	180	160	140
220	230	230	230	220	230	240	270
230	220	210	210	230	280	330	390
220	210	200	220	250	310	360	410
210	200	200	230	270	310	340	370
200	200	230	260	280	290	290	300
210	220	240	250	240	240	230	220

B A

WATER QUANTITY - cm^3

Pressure - 3·52 kgf/cm^2 (50 lbf/in^2)

C D

490	440	370	290	210	170	150	150
500	420	360	280	230	200	190	200
470	420	360	300	270	250	250	280
470	440	410	360	340	340	350	360
470	460	480	470	470	470	430	390
390	440	500	540	520	510	440	350
340	370	420	450	450	410	300	230
320	340	370	420	350	270	200	140

B A

WATER QUANTITY - cm^3

FIG. 3. WATER DISTRIBUTION FOR SPRINKLER 'B'

Pressure - 0·70 kgf / cm^2 (10 lbf / in^2)

C D

260	260	250	250	230	230	210	260
240	240	270	280	280	260	260	230
220	230	270	290	330	320	330	300
240	230	250	280	310	350	380	390
250	240	240	250	300	340	400	440
270	250	230	240	250	300	350	420
270	280	260	250	230	240	260	300
260	290	280	250	220	190	180	190

B A

WATER QUANTITY - cm^3

Pressure - 3·52 kgf / cm^2 (50 lbf / in^2)

C D

390	330	280	230	170	140	110	100
410	380	360	310	260	200	150	110
470	460	460	430	370	280	200	150
530	540	520	500	470	400	300	220
530	500	510	500	480	450	370	300
480	430	410	420	380	390	370	330
450	360	310	270	250	260	270	290
430	340	240	190	170	170	180	210

B A

WATER QUANTITY - cm^3

FIG. 4. WATER DISTRIBUTION FOR SPRINKLER 'C'

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Pressure - 0·70 kgf / cm^2 (10 lbf / in^2)

C D

100	140	180	210	250	310	330	370
150	200	260	290	330	370	350	310
250	310	360	400	370	340	270	240
400	450	450	390	330	260	220	220
550	520	430	350	270	220	200	230
520	460	320	250	200	190	210	240
340	270	180	160	150	180	220	250
150	130	100	130	160	200	220	240

B A

WATER QUANTITY - cm^3

Pressure - 3·52 kgf / cm^2 (50 lbf / in^2)

C D

40	50	80	120	170	280	410	640
50	70	110	180	270	440	600	750
80	120	180	300	430	590	700	850
120	180	270	360	470	500	550	640
170	240	310	350	370	350	390	430
210	260	280	270	260	270	330	400
200	220	210	200	200	240	320	420
160	160	140	140	160	220	300	340

B A

WATER QUANTITY - cm^3

FIG. 5. WATER DISTRIBUTION FOR SPRINKLER 'D'

Pressure - 0·70 kgf / cm^2 (10 lbf / in^2)

C D

840	900	950	960	920	960	900	880
890	970	1030	1050	1050	1020	970	910
960	1100	1140	1190	1140	1060	1030	1040
1050	1090	1120	1120	1120	1080	1120	1190
1120	1140	1100	1050	1020	1060	1140	1230
1150	1100	990	920	920	970	1120	1220
1030	980	870	840	850	900	1000	1060
860	810	800	790	800	800	850	890

B A

WATER QUANTITY - cm^3

Pressure - 3·52 kgf / cm^2 (50 lbf / in^2)

C D

940	1100	1100	1320	1400	1560	1620	1880
1000	1140	1400	1640	1800	1840	1760	1680
1220	1360	1620	2050	2150	2090	1960	1880
1320	1500	1760	2120	2250	2210	2120	2050
1380	1580	1820	2050	2140	2110	2170	2050
1340	1640	1880	1940	1920	1900	2000	2010
1300	1580	1700	1780	1740	1660	1700	1840
1220	1520	1660	1600	1600	1480	1440	1580

B A

WATER QUANTITY - cm^3

FIG. 6. WATER DISTRIBUTION FOR SPRINKLERS A, B, C AND D, DISCHARGING SIMULTANEOUSLY

Pressure - 0·70 kgf / cm^2 (10 lbf / in^2)

C D

870	920	960	970	950	990	940	970
910	980	1070	1090	1090	1080	1040	960
950	1090	1180	1230	1200	1140	1090	1090
1090	1170	1190	1170	1160	1160	1180	1270
1200	1190	1130	1090	1110	1170	1230	1350
1150	1090	960	960	990	1090	1190	1300
950	910	850	870	890	970	1070	1160
760	800	790	770	830	880	920	980

B A

WATER QUANTITY - cm^3

Pressure - 3·52 kgf / cm^2 (50 lbf / in^2)

C D

1070	1030	990	940	890	1040	1260	1580
1070	1050	1080	1090	1130	1280	1490	1690
1110	1140	1230	1360	1470	1580	1660	1850
1175	1260	1380	1500	1680	1720	1750	1770
1210	1270	1420	1520	1640	1740	1750	1660
1115	1180	1275	1370	1420	1560	1620	1560
1030	1000	1020	1020	1070	1200	1270	1370
960	890	820	840	810	850	950	1120

B A

WATER QUANTITY - cm^3

FIG. 7. SUM OF QUANTITIES OF WATER FOR INDIVIDUAL SPRINKLERS A, B, C AND D

Pressure -0·70 kgf / cm^2 (10 lbf / in^2)

C D

0·97	0·98	0·99	0·99	0·97	0·97	0·96	0·91
0·98	0·99	0·96	0·96	0·96	0·95	0·93	0·95
1·01	1·01	0·96	0·97	0·95	0·93	0·95	0·96
0·96	0·93	0·94	0·96	0·97	0·93	0·95	0·94
0·93	0·96	0·97	0·96	0·92	0·91	0·93	0·91
1·00	1·01	1·03	0·96	0·93	0·89	0·94	0·94
1·08	1·08	1·02	0·97	0·96	0·93	0·93	0·91
1·13	1·01	1·01	1·03	0·96	0·91	0·92	0·91

B A

Overall mean = 0·964

Pressure - 3·52 kgf / cm^2 (50 lbf / in^2)

C D

0·87	1·07	1·11	1·40	1·57	1·50	1·29	1·19
0·83	1·09	1·30	1·50	1·59	1·44	1·18	1·00
1·10	1·19	1·32	1·51	1·46	1·32	1·18	1·02
1·12	1·19	1·28	1·41	1·34	1·28	1·21	1·16
1·14	1·24	1·28	1·35	1·30	1·21	1·24	1·23
1·17	1·39	1·48	1·42	1·35	1·22	1·23	1·29
1·26	1·58	1·67	1·75	1·63	1·38	1·34	1·34
1·27	1·71	2·02	1·91	1·98	1·74	1·53	1·41

B A

Overall mean = 1·35

FIG. 8. RATIO OF QUANTITY OF WATER COLLECTED UNDER ARRAY TO SUM OF QUANTITIES OF THE FOUR INDIVIDUAL SPRINKLERS

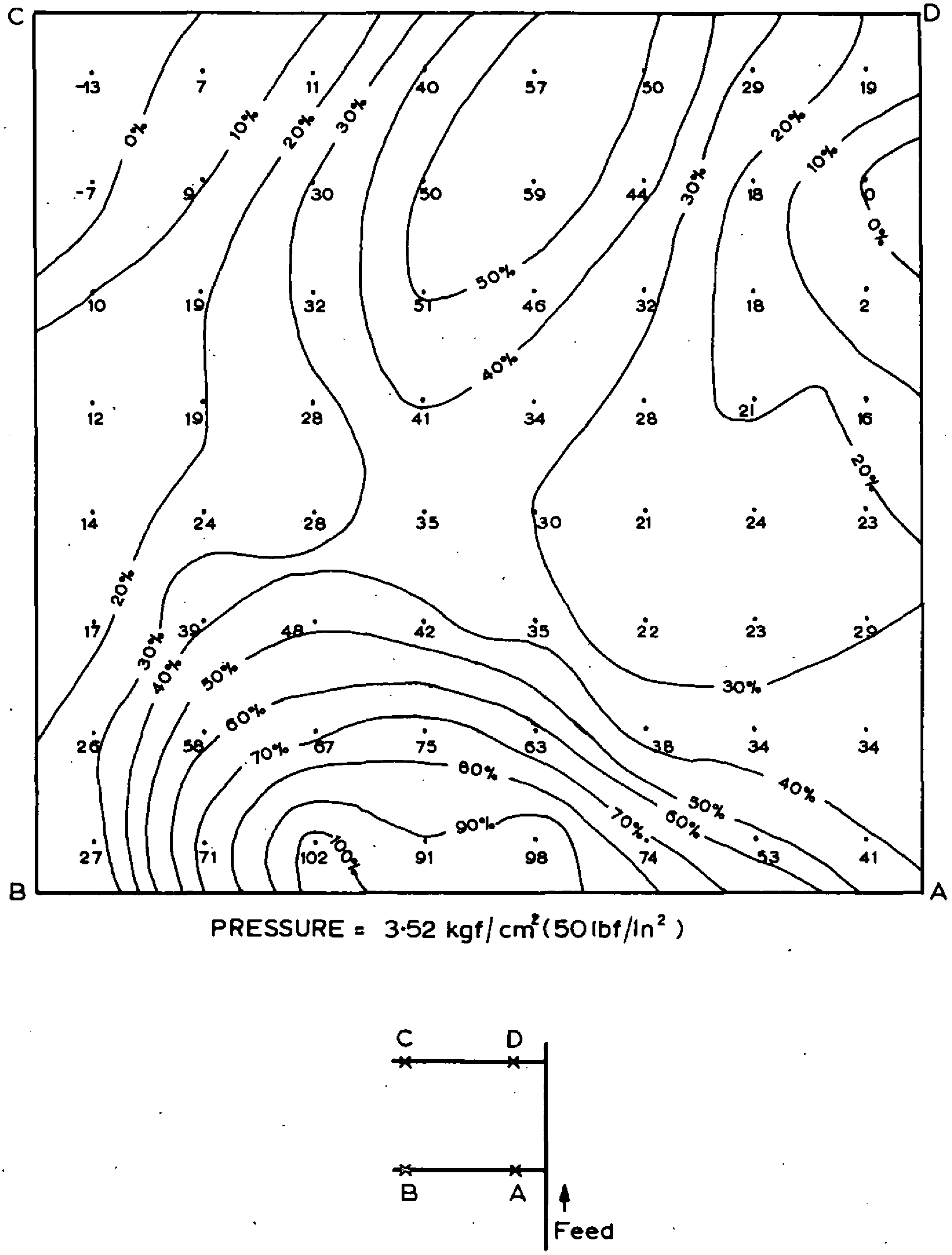

FIG. 9. CONTOUR DIAGRAM OF PERCENTAGE INCREASE IN WATER QUANTITY UNDER ARRAY COMPARED WITH SUM OF QUANTITIES OF INDIVIDUAL SPRINKLERS