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Determination of Water Spray Drop Size and Speed from a Standard Orifice, Pendent Spray Sprinkler

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Abstract

In order to characterize the water spray from a standard orifice, pendent spray sprinkler, measurements were made using an optical array probe droplet analyzer. The water droplet sizes and speeds from the sprinkler were measured at various locations in the spray field. The study resulted in mean droplet speeds, droplet size distributions, and median droplet sizes based on both the number and volume of the measured drops.

Introduction

The U.S. General Services Administration (GSA) is currently developing an Engineering Fire Hazard Assessment System. Portions of the assessment system relate to sprinkler system effectiveness in open plan office spaces[1], and the use of The Fire Demand Model[2] to predict the water application rate necessary for fire suppression.

As part of the sprinkler effectiveness investigation, GSA has funded NIST to measure the droplet size distribution, and the mean speed of the water spray produced by the pendent sprinkler used in the effectiveness experiments. The droplet size and speed data may be used to predict the fraction of the water discharged from the sprinkler that will penetrate the fire plume and reach the fuel bed.

In this study, the droplet size distribution from a pendent sprinkler was measured at twenty-nine positions within the water spray pattern. Droplet size distributions were determined, and number mean droplet size, volume mean droplet size, and mean droplet speed were calculated.

Droplet Analyzer

The droplet size measurements were made using a Particle Measuring Systems (PMS) Optical Array Probe model OAP-2D-GA2 self-contained laser probe which operates on the shadowing principle.[3] A He-Ne laser beam passing through the measuring volume is directed onto a diode array through a series of optical reflectors and lenses. Particles passing through the measuring volume form a shadow on the diode array, which is detected by the probe. An image is formed by the probe, with the width of the line diode array forming one dimension, and the scanning of the array (time) forming the second dimension of the droplet image. A personal computer with control/data acquisition software records the sizes of individual droplets and information that can be used to calculate droplet speed. The alignment of the probe with the water trajectory resulted in the velocity of the droplets, which could be represented by the product of a magnitude (speed) and a unit vector, oriented approximately parallel to the time dimension of the probe image.

The probe electronics and software contain error correction and droplet verification routines which reject multiple droplets in the measuring volume, and droplets that are not

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[1]Madrzykowski, D. and Vettori, R. L., "Sprinkler Fire Suppression Algorithm." *Journal of Fire Protection Engineering,* Vol. 4, No. 4, pp. 151-164, October/November/December 1992.

[2]Pietrzak, L. M. and Dale, J. J., "User's Guide for the Fire Demand Model; A Physically Based Computer Simulation of the Suppression of Post-Flashover Compartment Fires", NIST-GCR-92-612, Mission Research Corporation, July 1992.

[3]The mention of a particular manufacturer's product does not constitute endorsement by NIST, nor does it indicate that the product is necessarily that best suited for the intended purpose.

completely within the measuring volume. The probe is capable of measuring droplets with nominal diameters from 30 µm to 1860 µm, as configured by the manufacturer.

Experimental Configuration

The experiments were conducted in the NIST Large Fire Research Facility. The pendent spray sprinkler was mounted in the center of a nominally 2.44 m (8 ft) by 2.44 m (8 ft) smooth, flat, horizontal plywood ceiling, which was suspended inside an alcove measuring approximately 4.6 m (15 ft) by 6.0 m (20 ft) by 3.0 m (10 ft) high. A plan view of the alcove is shown in figure 1. The plywood ceiling was located 2.44 m ± 0.03 m (8.0 ft ± 0.1 ft) above the concrete floor of the alcove. In its mounted position, the deflector of the sprinkler was located 0.055 m ± 0.005 m from the ceiling. The ceiling around the sprinkler was marked to indicate angular positions about the centerline of the sprinkler, which acted as the origin. The markings allowed for repeatable rotation of the sprinkler.

Figure 2 shows a schematic of the experimental configuration. The droplet probe was mounted to the top of a cart equipped with a hydraulic lifting mechanism, allowing for adjustments in elevation. The cart travels on a track, limiting movement to a straight line perpendicular to the axis of the sprinkler centerline, thereby reducing possible positioning errors. The elevation of the center of the measuring volume of the droplet probe was 1.50 m ± 0.02 m below the sprinkler deflector for all of the measurements. This distance was chosen as representative of the distance between a nominal 2.44 m (8.0 ft) ceiling and typical office fuels such as desks, chairs, etc.

The water was supplied to the sprinkler from the building water supply via one inch steel pipe. A ball valve and gate valve were used to turn the water on and off and to control the flow. A pressure gauge approximately 0.35 m (1.1 ft) above the sprinkler was used to monitor water flow conditions.

Experiments

The sprinkler was radially symmetrical about two perpendicular axes. The sizes and speeds of the droplets produced by the sprinkler were measured in various locations within one 90 degree sector of the water spray pattern, reflecting the expected and observed apparent symmetry in the water spray pattern.

As mentioned previously, movement of the probe was limited to a straight radial line, and the sprinkler was rotated in increments of 15 degrees through one quadrant of symmetry. For each of these angular positions, measurements were taken at five radial positions from the sprinkler centerline to the edge of the spray envelope. The edge of the spray envelope was determined visually.

The flow rate dependence on water pressure was measured by collecting and determining the mass of the discharged water over time. The sprinkler was operated at 172 kPa ± 14 kPa (25.0 psi ± 2.0 psi), producing a flow rate of 102 lpm ± 2 lpm

(27.1 gpm ± 0.5 gpm). It is assumed that the trajectories of all drops are always in a vertical plane intersecting the sprinkler centerline. This is consistent with the droplet analyzer orientation and measurement algorithm.

Figure 3 shows the measurement locations, which are identified by an angle and a radial distance from the sprinkler centerline. Table 1 lists the radial distances corresponding to the positions in figure 3. The 0 degree position is defined as perpendicular to the plane containing the sprinkler arms. The standard uncertainty in the distance measurements in figure 3 is ± 0.01 m (± 0.03 ft), and ± 2 degrees.

The duration of each experiment was determined by the quantity and quality of the data. Whenever practical, the droplet size and speed measurements were based on a minimum of 25000 verified drops. For many of the angular positions, the two outermost radial positions exhibited very low droplet concentrations. In such cases, 25000 verified drops were not measured, but sampling was conducted for a minimum of 600 seconds. In some locations, the minimum number of drops could not be measured, due to a collection of water droplets on the optics that direct the laser beam. In such cases, data was combined from several identical experiments, thus increasing the sample size and duration for that location.

Results

The droplet size distribution for the water spray was measured at the twenty-nine locations shown in figure 3. The droplet size distributions for the experiments are shown in tables 2a and 2b. Ninety-nine point nine percent of the droplets measured were found to range from less than 36 µm to 1170 µm; that is 0.1 percent of the measured droplets had diameters greater than the maximum stated value. To eliminate the possibility of a small number of very large droplets skewing the droplet size range, only these 99.9 percent were used in the data analysis. Figures 4a, 4b, and 5 illustrate the percent and cumulative percent distributions of the total number and volume of drops collected in all locations. The median droplet size based on the total number of droplets sampled was 140 µm. However, the median droplet size based on the total volume of droplets was 675 µm. These values correspond to the 50 percent levels shown in figure 5.

The standard uncertainty in the droplet size measurements is ± 15 µm. The repeatability of successive experiments over several days in the same sampling location was evaluated by the use of one standard deviation of the mean droplet size of identical experiments, resulting in a value of 22 µm. One of the angular positions was tested twice for each radial position to determine if the overall shape of the distribution would change if the duration of the experiment was limited to only 300 seconds. When compared to the corresponding experiments regulated by 25000 drops or 600 seconds, the results showed no significant changes to the overall shape of the histograms.

The speeds of the water droplets were calculated based on the time required for each individual drop to pass through the probe image field. The mean droplet speed for the entire spray field was approximately 0.69 m/s (2.3 ft/s).

Table 1. Radial Positions

Location	Radial Distance, m (ft)
A	0.00 (0.00)
B	0.80 (2.6)
C	1.60 (5.25)
D	2.40 (7.87)
E	3.20 (10.5)

Table 2a. Droplet Size Distribution for 0-45 Degrees

Droplet Size Range (micrometers)	Radial Position, Angle (Degrees)																		
	A, 0	B, 0	C, 0	D, 0	E, 0	B, 15	C, 15	D, 15	E, 15	A, 30	B, 30	C, 30	D, 30	E, 30	A, 45	B, 45	C, 45	D, 45	E, 45
21-51	4074	3463	3641	1046	602	4545	5492	1586	1026	6428	5195	5197	1586	947	1496	2625	5123	1651	1504
51-81	2419	1968	2195	510	385	2662	3903	1063	648	3937	3113	2692	753	495	671	1784	3883	1161	997
81-110	2757	1723	1741	247	123	1927	3012	487	274	3610	2330	1982	301	182	415	1681	2899	485	533
110-140	2894	1855	1560	202	33	1941	2085	190	96	3307	2094	1652	156	48	399	1722	2009	153	145
140-170	3696	2208	1535	230	6	2146	1504	92	38	2981	2222	1392	154	11	480	1944	1559	55	66
170-200	3686	2431	1390	254	4	2258	1039	63	28	2863	2210	1232	171	4	477	2134	1268	51	74
200-229	2794	2378	1326	245	2	2267	780	78	18	2133	2333	1197	236	3	548	2570	941	74	55
229-258	2353	2712	1211	249	2	2291	577	62	28	1397	2308	1132	202	3	610	2691	795	54	36
258-288	1611	2333	1004	184	3	2166	438	60	20	986	1951	910	203	1	528	2431	677	43	33
288-318	975	1742	802	145	0	1767	335	40	19	530	1473	650	116	1	408	1821	491	36	25
318-347	642	1420	666	77	3	1415	261	31	10	246	1167	598	92	4	286	1332	419	31	12
347-377	412	965	567	58	2	1049	232	22	15	112	870	528	64	2	208	988	355	28	11
377-406	270	688	530	40	1	698	209	17	9	74	663	577	44	0	141	651	425	28	1
406-436	178	522	532	25	2	592	212	19	11	50	513	624	22	1	100	499	484	19	4
436-465	127	392	688	15	0	452	254	13	6	35	363	819	21	0	59	418	713	20	2
465-495	71	315	770	12	1	410	429	9	3	22	328	985	15	0	29	295	1024	21	0
495-525	39	265	929	9	1	323	753	10	4	10	273	1153	5	1	21	234	1202	14	2
525-555	25	200	1035	7	0	292	888	10	8	4	218	1062	9	0	11	196	923	16	1
555-585	13	171	1006	9	1	212	880	7	5	4	176	1017	7	0	8	181	798	17	1
585-615	6	145	935	7	1	174	761	8	3	1	168	805	2	1	4	155	610	9	1
615-645	1	111	773	5	0	141	553	6	2	2	106	631	7	0	3	134	437	15	0
645-675	3	92	576	3	1	123	431	4	1	0	105	473	9	0	0	97	328	26	1
675-705	2	63	477	3	0	100	310	13	0	1	91	403	6	0	1	88	232	60	1
705-735	1	64	409	4	0	80	231	13	4	0	61	354	10	0	0	58	222	78	0
735-765	0	46	307	2	0	56	218	30	1	0	52	289	12	0	0	44	160	126	2
765-795	1	40	248	5	0	52	143	48	2	0	47	240	20	0	0	44	134	172	1
795-825	0	19	197	5	0	47	112	75	1	0	32	203	49	0	0	30	113	168	0
825-855	0	19	163	12	0	25	82	85	0	0	25	174	63	0	0	16	81	168	0
855-885	0	16	171	11	0	22	56	87	2	0	23	131	92	0	0	13	56	149	0
885-1875	0	50	613	387	1	47	179	433	5	0	47	536	754	1	0	33	211	509	35
Total	29050	28416	27997	4008	1174	30280	26359	4661	2287	28733	30557	29638	5181	1705	6903	26909	28572	5437	3543

Table 2b. Droplet Size Distribution for 60-90 Degrees

Droplet Size Range (micrometers)	Radial Position, Angle (Degrees)												
	B, 60	C, 60	D, 60	E, 60	B, 75	C, 75	D, 75	E, 75	A, 90	B, 90	C, 90	D, 90	E, 90
21-51	4961	3140	819	675	11051	1629	1684	901	6012	11323	7784	1063	989
51-81	2150	1962	418	335	5672	859	922	447	2526	6271	4259	474	395
81-110	1363	1253	142	127	3155	363	336	114	1762	3911	2017	181	198
110-140	1303	748	46	55	2124	182	119	30	1649	3074	966	114	214
140-170	1411	692	28	22	1466	111	53	16	1857	2644	602	111	258
170-200	1548	788	38	26	1117	65	59	18	1978	2409	494	125	313
200-229	1663	781	29	24	899	62	71	9	1798	2181	437	128	344
229-258	1754	849	33	14	714	64	71	17	1758	2012	540	168	375
258-288	1692	750	27	19	624	62	71	21	1619	2011	633	147	317
288-318	1430	667	33	14	439	45	67	13	984	1591	614	165	224
318-347	1081	638	16	11	285	51	38	3	595	1180	648	110	180
347-377	847	516	21	7	177	37	26	4	326	668	711	69	120
377-406	781	645	13	11	110	38	23	1	192	403	846	41	68
406-436	711	827	13	7	61	33	17	6	126	221	820	31	58
436-465	585	1015	10	2	52	32	14	1	70	113	779	25	38
465-495	523	1167	8	4	68	59	9	2	34	93	723	20	29
495-525	455	1371	5	3	73	111	9	4	18	71	611	14	20
525-555	381	1329	6	0	98	123	4	4	14	68	484	11	11
555-585	343	1226	5	0	105	112	4	0	13	69	383	11	10
585-615	337	1028	10	1	110	115	3	2	2	56	323	20	8
615-645	274	906	6	1	104	120	4	1	2	67	218	18	8
645-675	220	812	16	0	112	91	5	0	0	62	173	32	2
675-705	184	701	38	1	87	70	10	0	0	36	141	60	5
705-735	153	591	85	0	86	66	23	2	0	50	96	61	3
735-765	156	487	90	3	63	66	27	0	2	31	83	79	1
765-795	106	408	105	0	47	42	43	1	0	14	40	73	0
795-825	96	370	119	1	39	39	43	1	0	17	45	74	6
825-855	60	258	108	0	23	25	44	0	0	8	22	89	2
855-885	43	219	88	1	21	30	45	0	0	10	27	92	1
885-1875	110	752	338	24	26	62	201	25	0	13	32	343	30
Total	26721	26896	2713	1388	29008	4764	4045	1643	23337	40677	25551	3949	4227

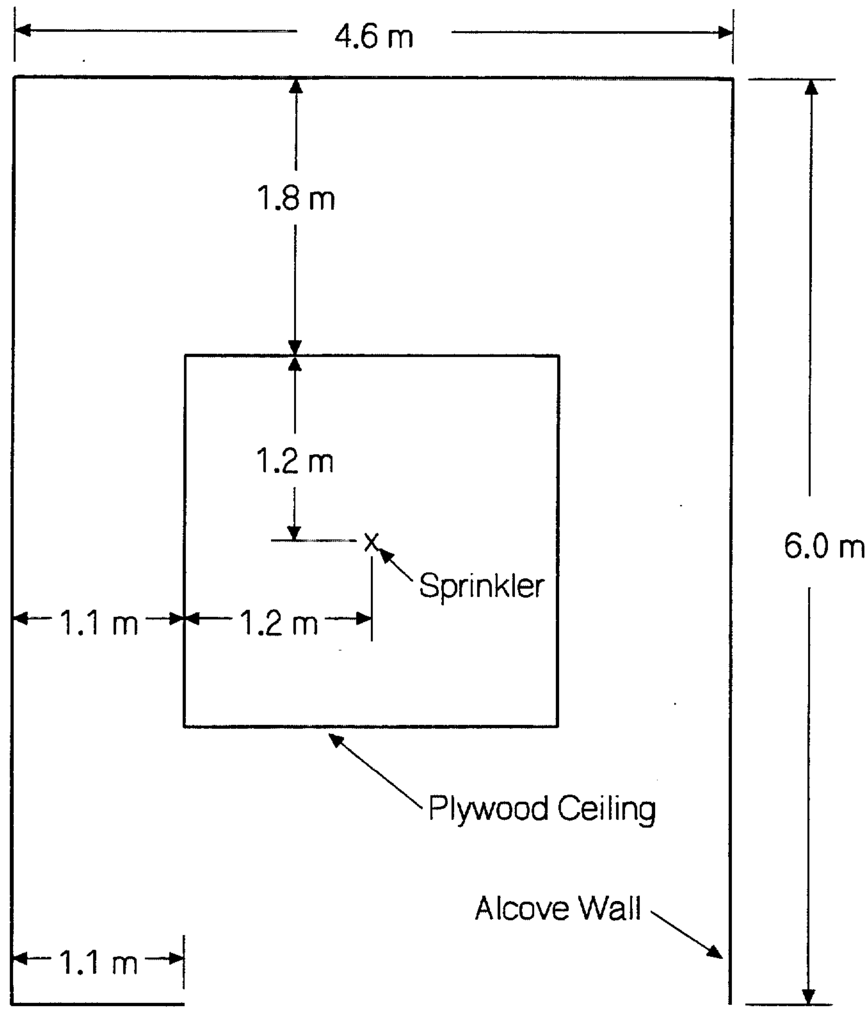

Figure 1. Plan view of the sprinkler alcove.

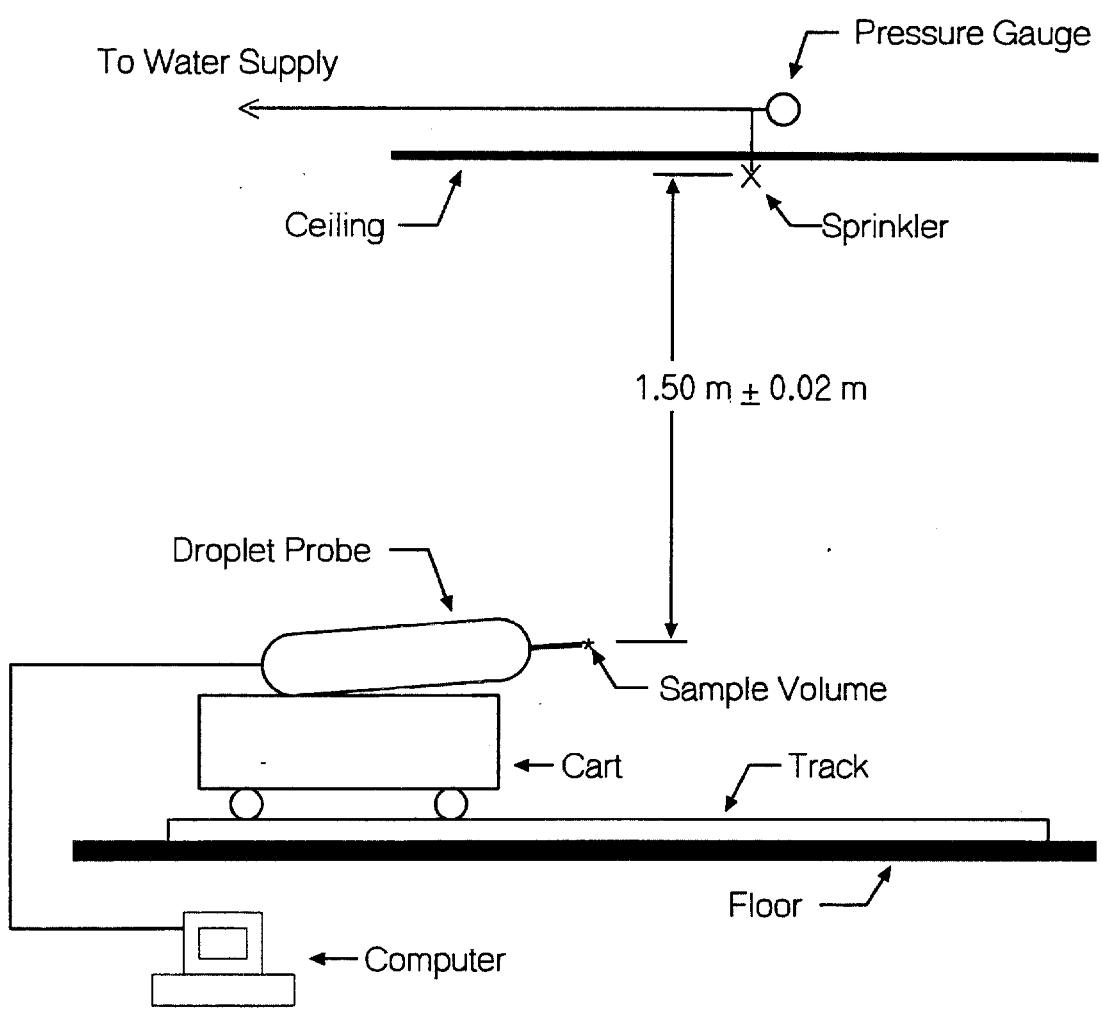

Figure 2. Elevation view of the experimental configuration.

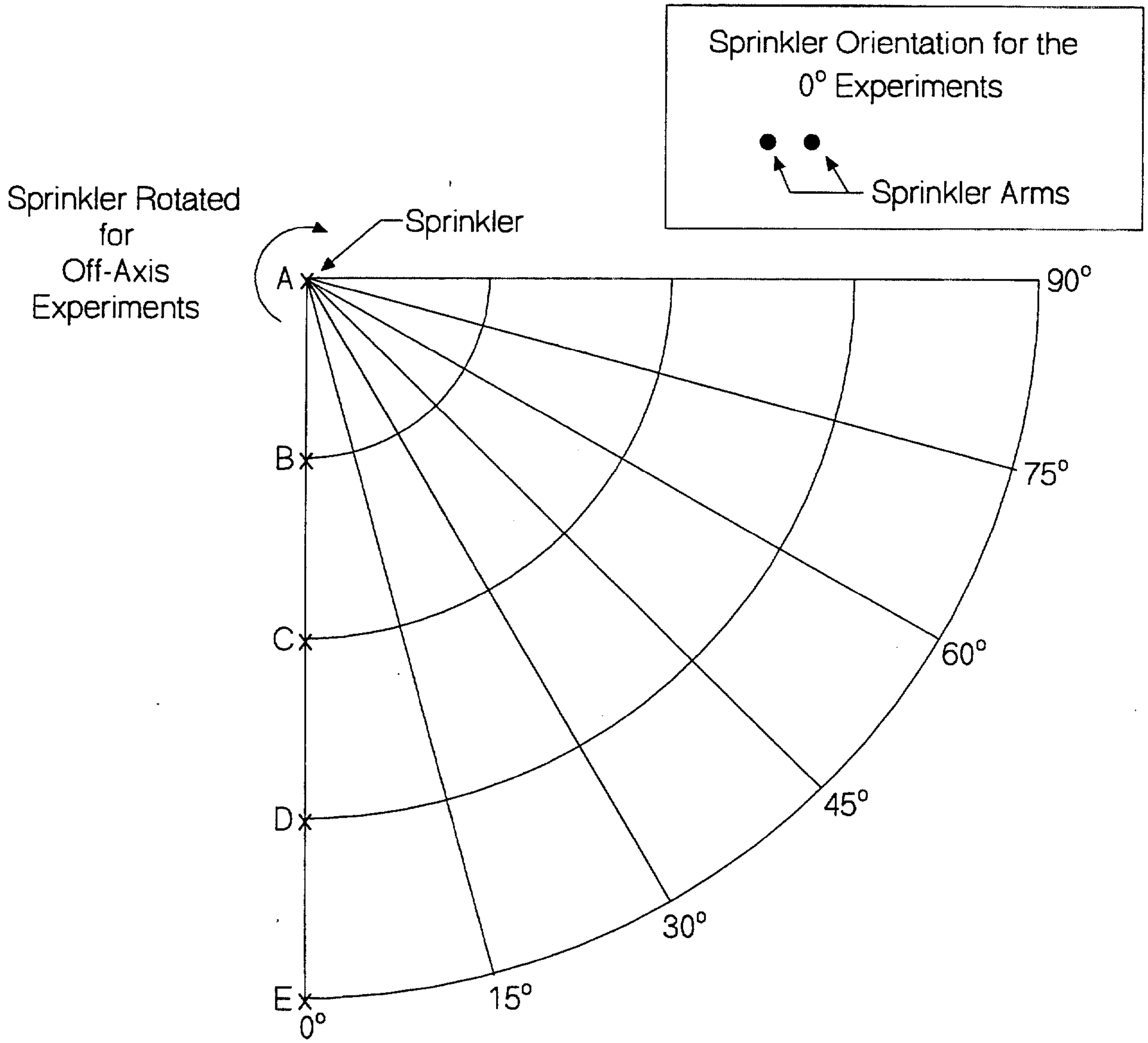

Figure 3. Plan view of the measurement locations.

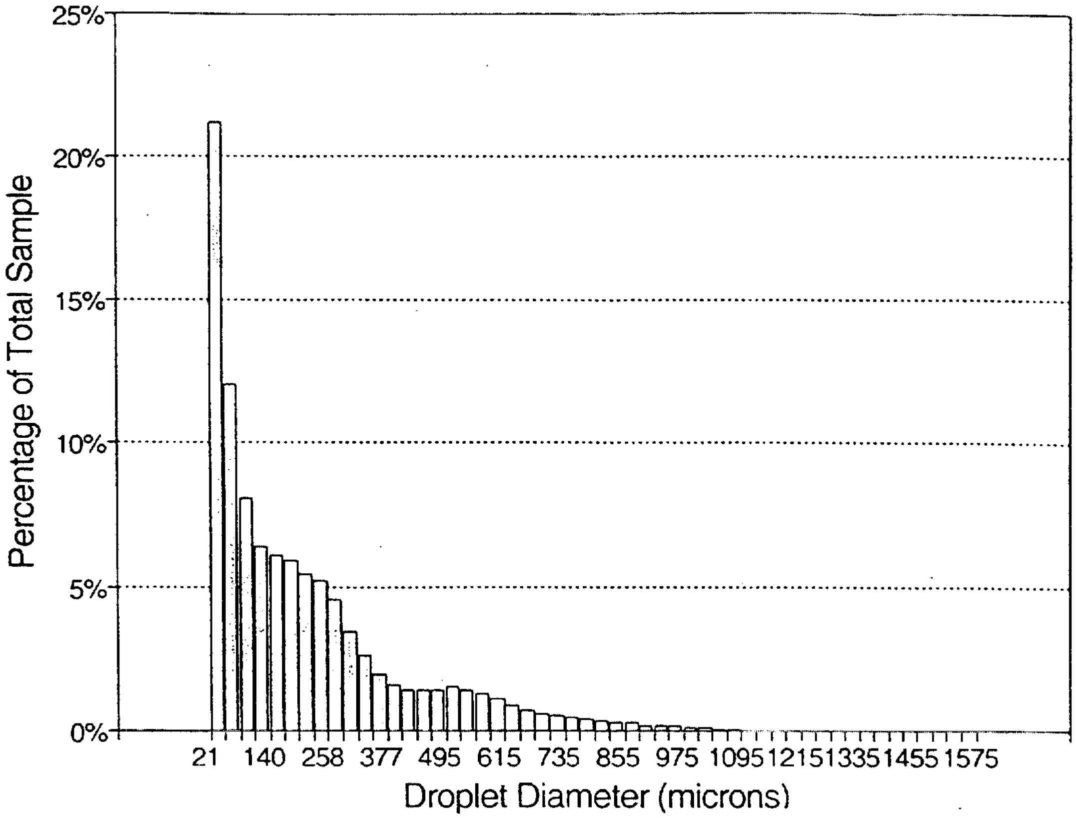

Figure 4a. Percent distribution based on number of drops.

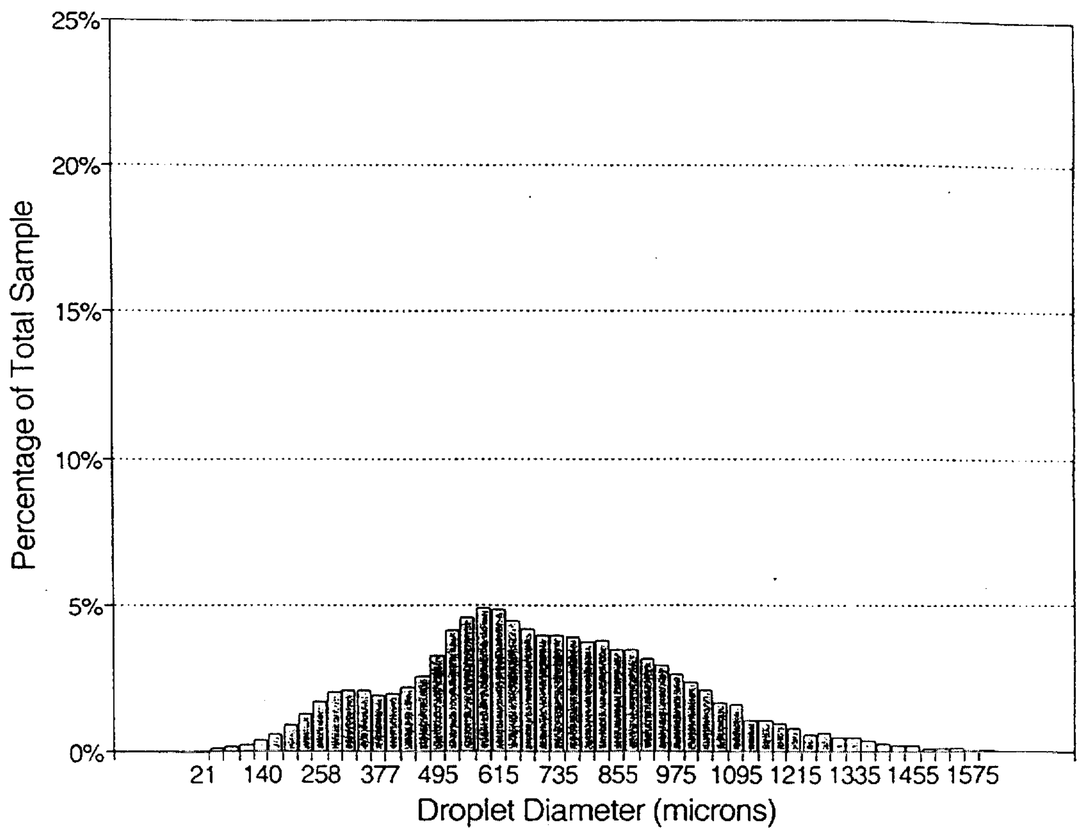

Figure 4b. Percent distribution based on water volume.

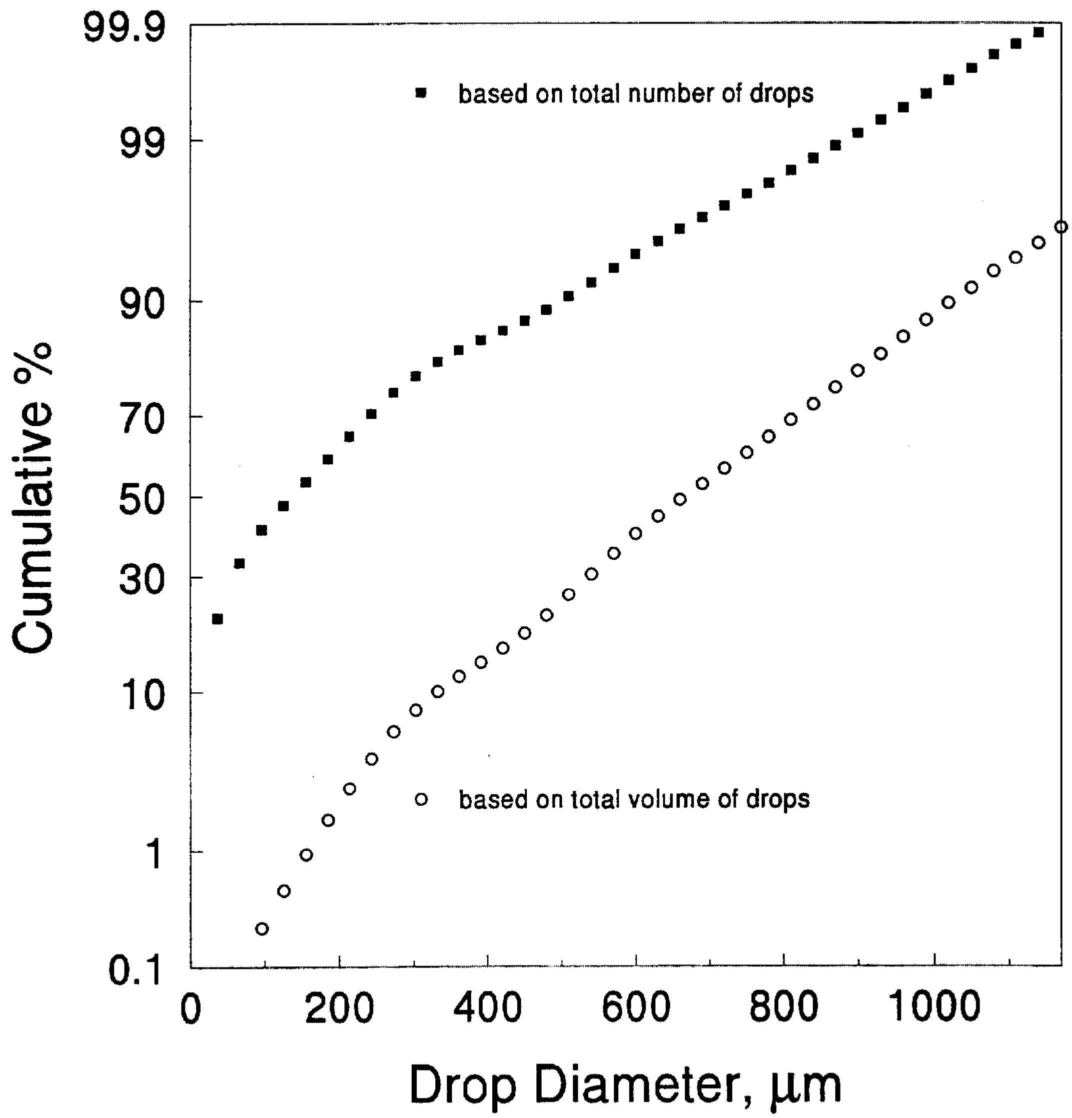

Figure 5. Drop size distributions based on number of drops and water volume.

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