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Determination of Water Spray Drop Size and Velocity from a Low Pressure, High Momentum, Water Mist Nozzle

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U.S. DEPARTMENT OF COMMERCE
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
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Abstract

In order to characterize the water spray from a low pressure, high momentum water mist nozzle, measurements were made using an optical array probe droplet analyzer. The water droplet sizes and velocities from the nozzle were measured at varying operating conditions and locations in the spray field. The study resulted in droplet size and velocity ranges for the nozzle, as well as mean droplet velocities and droplet size distributions. The pendent nozzle used in this study is currently being evaluated by listing organizations for fire suppression in residential and light hazard occupancies.

Introduction

The United States Fire Administration is currently investigating methods of lowering the costs of water-based fire suppression systems for use in residential occupancies. One possible method of reducing costs is to reduce the water demand of the suppression system by employing water mist nozzles. Water mist fire suppression systems have been shown to effectively control some types of fires, but have not, as of yet, been approved for use in residential occupancies.

As part of its water mist investigation, the Fire Administration has funded NIST to measure the droplet size range of the water mist produced by a pendent water mist nozzle. The nozzle under study is currently being evaluated by listing organizations for fire suppression systems in residential and light hazard occupancies.

In this study, the droplet size distribution from a water mist nozzle was measured at twenty-nine positions within the water mist pattern. Droplet size and velocity ranges were determined, and mean droplet velocities were calculated.

Droplet Analyzer

The size and velocity measurements were made using a self-contained laser probe operating on the shadowing principle. A laser beam passes from the laser, through the measuring volume, and onto a diode array. 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 and control/data acquisition software record the sizes of individual droplets and information that can be used to calculate droplet velocity.

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 completely within the measuring volume. The probe is capable of measuring droplets with 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 style nozzle 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 nozzle was located 0.030 m ± 0.005 m from the ceiling. The ceiling around the sprinkler was marked to indicate angular positions about the centerline of the nozzle, which acted as the origin. The markings allowed for repeatable rotation of the nozzle in its threaded fitting.

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 straight track, limiting movement to a straight line, and 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 nozzle 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 residential fuels such as beds and other types of furniture.

The water was supplied to the nozzle 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 nozzle was used to monitor water flow conditions. Figure 2 shows a schematic of the experimental configuration.

In regards to the functioning of the water mist nozzle, the spray pattern of this particular nozzle demonstrated a tendency to be seriously affected by water-borne debris. Several times during the experiments, the spray pattern would suddenly undergo a very significant change, with an apparent loss of coverage area, spray momentum, and water flow rate. Upon removal and inspection of the nozzle, small amounts of rust and scale had lodged in the screen of the nozzle. Even though the quantity of debris was small, and blocked a small percentage of the screen, the spray pattern was drastically affected. In order to prevent clogging during the experiments discussed in this report, the piping was flushed daily, and the nozzle cleaned prior to the measurements.

Experiments

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

Movement of the probe was limited to a straight line, therefore the nozzle was rotated in increments of 15 degrees. In order to compare measurements at different pressures, which cause changes in the shape of the nozzle spray envelope, the sampling locations were non-dimensionalized by the distance from the nozzle centerline to the edge of the spray envelope. The outermost measurement point for each pressure was made at the edge of the spray envelope for that pressure. The edge of the spray envelope was determined visually.

The flow rate corresponding to water pressure was measured by collecting and determining the mass of the discharged water over time. The nozzle was operated at 621 kPa ± 14 kPa (90.0 psi ± 2.0 psi) and 448 kPa ± 14 kPa (65.0 psi ± 2.0 psi), which resulted in flow rates of 11.16 lpm ± 0.06 lpm (2.948 gpm ± 0.016 gpm) and 9.48 lpm ± 0.06 lpm (2.507 gpm ± 0.016 gpm) respectively.

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

The droplet size and velocity measurements were based on a minimum of 25000 verified drops for most of the experiments. In some cases, the droplet measurement rate was very low, due to the small number of drops reaching the outer edge of the water spray envelope. In some of these low data rate cases, 25000 verified drops were not measured, but sampling was conducted for a minimum of 600 s.

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 for the experiments conducted at 621 kPa ± 14 kPa (90.0 psi ± 2.0 psi), and tables 3a and 3b for the experiments conducted at 448 kPa ± 14 kPa (65.0 psi ± 2.0 psi). The droplet diameters from the experiments were found to range from less than 36 μm to 1230 μm for the experiments conducted at 448 kPa ± 14 kPa (65.0 psi ± 2.0 psi), and range from less than 36 μm to 1155 μm for the experiments conducted at 621 kPa ± 14 kPa (90.0 psi ± 2.0 psi). The droplet diameter range represents 99.9 percent of the droplets measured; that is 0.1 percent of the droplets had diameters greater than the maximum stated value. The 99.9 percent criterion was used to eliminate the possibility of a small number of very large droplets skewing the droplet size range.

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 25 μm for the 448 kPa ± 14 kPa (65.0 psi ± 2.0 psi) experiments and 12 μm for the experiments conducted at 621 kPa ± 14 kPa (90.0 psi ± 2.0 psi).

The velocities of the water droplets were calculated based on the time required for each individual drop to pass through the probe image field. The range of droplet velocities was found to be approximately 0.19 m/s to 1.58 m/s (0.62 ft/s to 5.18 ft/s), with a mean droplet velocity of approximately 0.58 m/s (1.90 ft/s), calculated from the experiments conducted at 448 kPa ± 14 kPa (65.0 psi ± 2.0 psi). For the measurements taken at 621 kPa ± 14 kPa (90.0 psi ± 2.0 psi), the droplet velocities ranged from approximately 0.25 m/s to 1.9 m/s (0.82 ft/s to 6.23 ft/s), with a mean droplet velocity of approximately 0.61 m/s (2.00 ft/s).

Table 1. Radial Positions as a Function of Pressure

Location	Radial Distance (m), (ft)	
	Low Pressure Experiments 448 kPa ± 14 kPa (65.0 psi ± 2.0 psi)	High Pressure Experiments 621 kPa ± 14 kPa (90.0 psi ± 2.0 psi)
A	0.00 (0.00)	0.00 (0.00)
B	0.34 (1.12)	0.29 (0.95)
C	0.68 (2.23)	0.58 (1.90)
D	1.01 (3.31)	0.87 (2.85)
E	1.35 (4.43)	1.17 (3.84)

Table 2a. Droplet Size Distribution for 0-45 Degrees at 621 kPa (90 psi)

Droplet Size	Measurement Position, Angle																
(micrometers)	A, 0	B, 0	C, 0	D, 0	E, 0	B, 15	C, 15	D, 15	E, 15	B, 30	C, 30	D, 30	E, 30	A, 45	B, 45	C, 45	D, 45	E, 45
36	9217	9754	7251	3877	2780	9244	8107	8751	3248	8764	10215	16277	14588	8487	9089	6089	3715	1302
66	4184	4413	3649	2135	1252	4529	4246	4186	1178	4184	5344	6672	7436	4271	4571	3638	1963	411
96	2453	2600	2236	1663	1001	3089	3097	2355	324	2561	3485	1919	2154	2957	2874	2857	1363	87
125	2165	1958	1896	1456	1113	2377	2459	1582	92	2010	2270	684	379	2636	2246	2508	1068	29
155	2288	1634	1873	1546	1371	2302	2163	1213	49	1960	1610	289	53	2772	2138	2655	928	8
185	2430	1493	1921	1761	1283	2006	1659	991	12	1786	1034	151	6	2706	1844	2538	741	12
214	2105	1343	1659	1497	1083	1661	1452	717	17	1611	721	95	1	2593	1522	2371	571	7
243	1603	1339	1629	1596	1005	1445	1368	663	6	1516	558	49	2	2032	1324	2444	543	10
273	909	884	1487	1733	846	813	1327	660	5	922	404	43	1	1022	889	2084	611	10
303	415	389	1085	1632	661	346	914	589	6	394	303	60	1	434	428	1401	741	4
332	152	174	763	1637	561	113	517	641	2	155	157	119	21	216	143	891	1299	3
362	70	65	447	1566	534	40	265	652	1	86	65	79	95	90	74	441	2055	3
391	26	29	261	1368	589	19	217	648	14	29	42	28	131	29	34	282	2356	3
421	16	14	174	1093	750	14	147	620	18	17	28	20	44	26	16	183	2184	13
450	10	7	110	817	898	10	100	504	30	7	9	44	17	11	16	117	1820	33
480	6	1	83	626	984	3	69	410	39	3	8	59	7	6	5	57	1269	51
510	4	2	60	456	1035	1	42	312	52	6	10	39	0	5	2	45	835	88
540	2	1	33	331	979	0	27	257	40	1	4	23	3	8	0	23	594	112
570	2	0	20	262	954	0	9	175	40	2	2	14	1	1	1	10	393	100
600	3	0	14	197	865	0	14	128	29	0	2	14	3	1	1	4	268	79
630	2	0	3	139	811	0	11	109	34	0	0	4	0	1	0	7	156	56
660	0	0	6	86	710	0	3	65	20	1	0	4	0	0	0	6	89	43
690	0	0	2	50	600	0	3	43	20	0	0	1	0	3	0	4	70	34
720	1	0	1	41	568	0	3	23	15	0	0	0	0	0	0	2	53	22
750	0	0	0	43	486	0	0	20	12	0	0	2	0	0	0	0	26	18
780	0	0	0	19	389	0	0	16	5	0	0	1	0	1	0	4	16	10
810	0	0	1	14	347	0	1	10	7	0	0	0	0	0	0	1	8	13
840	0	0	0	9	250	0	1	9	1	0	0	0	0	0	0	0	7	6
870	0	0	0	12	194	0	0	1	1	0	0	0	0	0	0	0	12	4
900-1860	0	0	0	13	632	0	0	5	6	0	0	1	0	0	0	0	9	11
Total	28063	26100	26664	27675	25531	28012	28221	26355	5323	26015	26271	26691	24943	30308	27217	30662	25763	2582

Table 2b. Droplet Size Distribution for 60-90 Degrees at 621 kPa (90 psi)

	Measurement Position, Angle												
Droplet Size (micrometers)	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
36	7651	7047	5500	3109	10220	10755	11108	13715	8756	10422	11654	19568	930
66	3589	3084	3052	1332	4637	5175	5374	6749	4430	5003	5758	9619	372
96	2597	2118	2535	1028	3014	3329	4190	2871	2886	3140	3467	5505	82
125	2135	1860	2239	860	2289	2245	1887	1019	2492	2106	2186	2682	23
155	2219	1901	2318	926	1942	1721	1104	323	2554	1724	1563	1421	7
185	1992	1963	2230	881	1494	1303	704	106	2563	1330	1001	711	1
214	1974	1766	2150	738	1435	1027	481	25	2266	1296	714	387	1
243	1781	1659	2220	752	1342	882	338	16	1643	1216	654	255	0
273	1257	1513	2232	590	859	687	285	7	912	740	714	210	0
303	569	1129	2008	482	371	462	207	8	390	287	425	306	0
332	231	694	1796	439	168	343	201	6	188	80	159	281	0
362	122	371	1522	399	55	195	181	34	79	24	54	89	1
391	38	245	1058	487	15	81	127	46	38	10	14	32	1
421	17	140	825	644	10	42	134	26	13	9	8	8	0
450	9	85	618	894	4	25	127	12	13	2	3	6	0
480	6	63	500	1165	3	14	126	19	4	0	1	3	0
510	2	40	292	1287	0	11	99	28	4	0	2	4	0
540	1	29	229	1237	1	3	65	25	4	0	0	0	0
570	1	9	138	1281	0	3	53	32	5	0	0	0	0
600	1	6	86	1194	0	0	25	27	0	0	0	0	0
630	0	6	70	1072	0	0	8	12	2	0	0	0	0
660	0	5	46	928	0	0	6	9	2	0	0	0	0
690	0	3	30	772	0	0	6	6	0	0	0	0	0
720	0	4	17	622	0	0	0	5	2	0	0	0	0
750	0	2	21	578	0	1	0	4	1	0	0	0	0
780	0	0	13	436	0	0	1	1	0	0	0	0	0
810	0	0	7	399	0	0	0	0	0	0	0	1	0
840	0	0	4	323	0	0	0	0	0	0	0	0	0
870	0	1	4	248	0	0	0	0	1	0	0	0	0
900-1860	0	0	8	729	0	0	0	0	1	0	0	0	0
Total	26192	25743	33768	25832	27859	28304	26837	25131	29249	27389	28377	41088	1418

Table 3a. Droplet Size Distribution for 0-45 Degrees at 448 kPa (65.0 psi)

Droplet Size	Measurement Position, Angle																
(micrometers)	A, 0	B, 0	C, 0	D, 0	E, 0	B, 15	C, 15	D, 15	E, 15	B, 30	C, 30	D, 30	E, 30	A, 45	B, 45	C, 45	D, 45	E, 45
36	8759	7590	6098	5368	4614	4825	5879	6334	2416	9567	9571	906	426	6774	8117	8000	10008	373
66	4362	4358	3865	3250	2110	3124	3611	3831	1249	4634	5045	452	171	3786	4143	4441	5455	122
96	3416	3511	4080	2738	1808	2600	2706	2916	686	3179	4432	82	18	2972	3142	3459	3325	8
125	2785	2668	3310	2541	1654	2501	2661	2333	488	2403	2822	18	0	2909	2368	2668	2047	0
155	2685	2424	3017	2544	1489	2909	2805	2269	315	2191	1851	13	0	3167	2311	2377	1406	0
185	2201	2102	2352	2274	1130	3074	2624	2140	197	1780	1142	4	0	3097	2068	1928	848	0
214	1658	1763	2034	2032	1009	3005	2534	1670	106	1682	858	5	0	2692	1871	1575	552	0
243	1022	1545	1918	2016	835	2411	1867	1593	72	1416	707	1	0	1920	1602	1370	426	0
273	525	811	1500	1729	667	1305	1241	1321	52	843	623	4	0	936	1024	992	291	0
303	191	313	972	1354	480	588	702	967	48	303	522	4	0	416	412	637	272	0
332	79	138	550	1006	428	296	452	746	32	128	245	9	0	177	191	354	289	0
362	37	58	317	768	358	154	265	468	49	53	105	10	1	87	80	181	453	0
391	18	26	149	587	449	72	145	341	59	22	40	1	3	52	54	106	557	0
421	15	17	85	389	456	37	95	226	80	11	26	1	4	19	27	54	603	0
450	12	11	73	284	580	19	54	174	109	6	12	1	0	11	5	29	536	1
480	8	3	45	211	676	11	28	127	116	3	14	3	0	7	3	10	376	0
510	5	0	25	155	762	4	21	81	103	2	5	1	0	7	2	8	305	1
540	1	0	13	122	740	4	14	59	94	0	2	2	0	1	4	3	232	1
570	3	1	12	81	670	1	11	51	64	1	2	0	0	1	0	3	163	1
600	3	0	4	52	595	1	4	38	55	1	0	0	0	0	1	2	108	0
630	1	0	5	44	559	1	0	34	59	0	0	5	0	5	0	1	79	1
660	1	0	1	40	505	0	1	19	38	0	0	0	0	4	1	0	54	0
690	0	0	3	34	447	0	0	15	27	0	1	0	0	1	0	0	42	0
720	1	0	0	23	395	0	3	12	23	0	0	0	0	1	0	0	28	0
750	1	0	0	19	337	0	0	4	16	0	0	0	0	0	1	0	18	0
780	1	0	0	11	320	1	0	8	16	1	0	0	0	2	0	0	21	0
810	1	0	0	5	237	0	0	2	12	1	0	0	0	1	0	0	10	0
840	2	0	0	9	221	0	0	1	6	0	0	0	0	0	0	0	3	0
870	0	0	1	6	172	0	0	2	11	0	0	0	0	0	0	0	3	0
900-1860	0	0	0	11	660	1	0	4	33	1	1	0	0	3	1	0	7	1
Total	27793	27339	30429	29703	25363	26944	27723	27786	6631	28228	28026	1522	623	29048	27428	28198	28517	509

Table 3b. Droplet Size Distribution for 60-90 Degrees at 448 kPa (65.0 psi)

Droplet Size	Measurement Position, Angle												
(micrometers)	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
36	7665	6867	2948	980	9558	9485	9872	1484	6128	15355	7766	3043	332
66	4023	3696	1631	336	4522	4782	5530	830	3268	8390	4243	1561	139
96	3660	3049	1396	142	2872	2957	3708	297	2646	8177	4837	935	18
125	2679	2565	1295	99	2122	2110	2188	71	2818	6636	3775	528	3
155	2171	2470	1377	130	1915	1524	1299	14	3398	5661	2411	276	1
185	1814	2130	1323	119	1628	1135	825	2	3487	4439	1542	114	0
214	1559	2007	1238	89	1394	853	536	2	3260	3993	1037	42	1
243	1597	1849	1422	103	1077	820	376	0	2486	3169	833	21	0
273	957	1485	1510	86	549	827	295	2	1262	1547	817	16	0
303	477	992	1518	65	247	658	220	1	576	604	520	33	0
332	188	610	1552	45	92	381	305	1	261	208	184	78	0
362	76	399	1599	43	37	223	373	2	126	90	63	54	5
391	49	214	1461	37	15	172	275	14	53	39	23	27	2
421	24	109	1355	21	5	103	182	16	27	14	17	10	1
450	6	86	1108	38	0	64	218	7	17	4	7	2	0
480	5	49	878	51	3	53	214	5	14	3	2	1	0
510	2	33	752	77	1	39	238	0	4	2	0	0	0
540	1	25	532	65	2	15	191	1	3	4	0	0	0
570	1	14	434	101	0	12	152	2	5	0	0	0	0
600	0	13	311	106	0	9	118	1	6	1	0	0	0
630	0	9	274	93	0	3	97	1	3	0	0	0	0
660	0	4	228	77	0	1	60	0	6	0	0	0	0
690	0	3	180	79	0	2	49	1	2	0	0	0	0
720	0	0	114	87	0	0	32	0	1	1	0	0	0
750	0	0	77	82	0	0	30	1	2	0	0	0	0
780	0	0	58	55	0	0	20	0	0	0	0	0	0
810	0	0	46	50	0	0	18	0	0	0	0	0	0
840	0	0	26	50	0	0	10	0	1	0	0	0	0
870	0	0	23	37	0	0	7	0	0	0	0	0	0
900-1860	0	0	48	134	0	0	12	0	7	0	0	0	0
Total	26954	28678	26714	3477	26039	26228	27450	2755	29867	58337	28077	6741	502

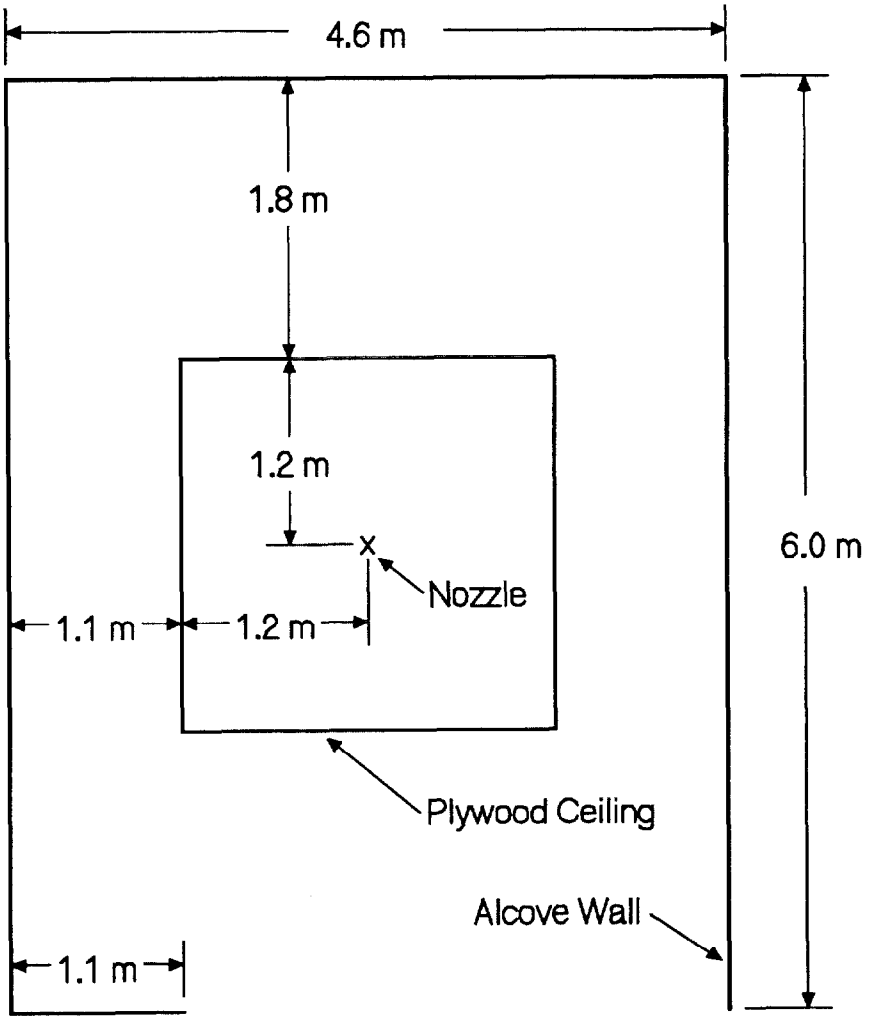

Figure 1. Plan view of the nozzle alcove.

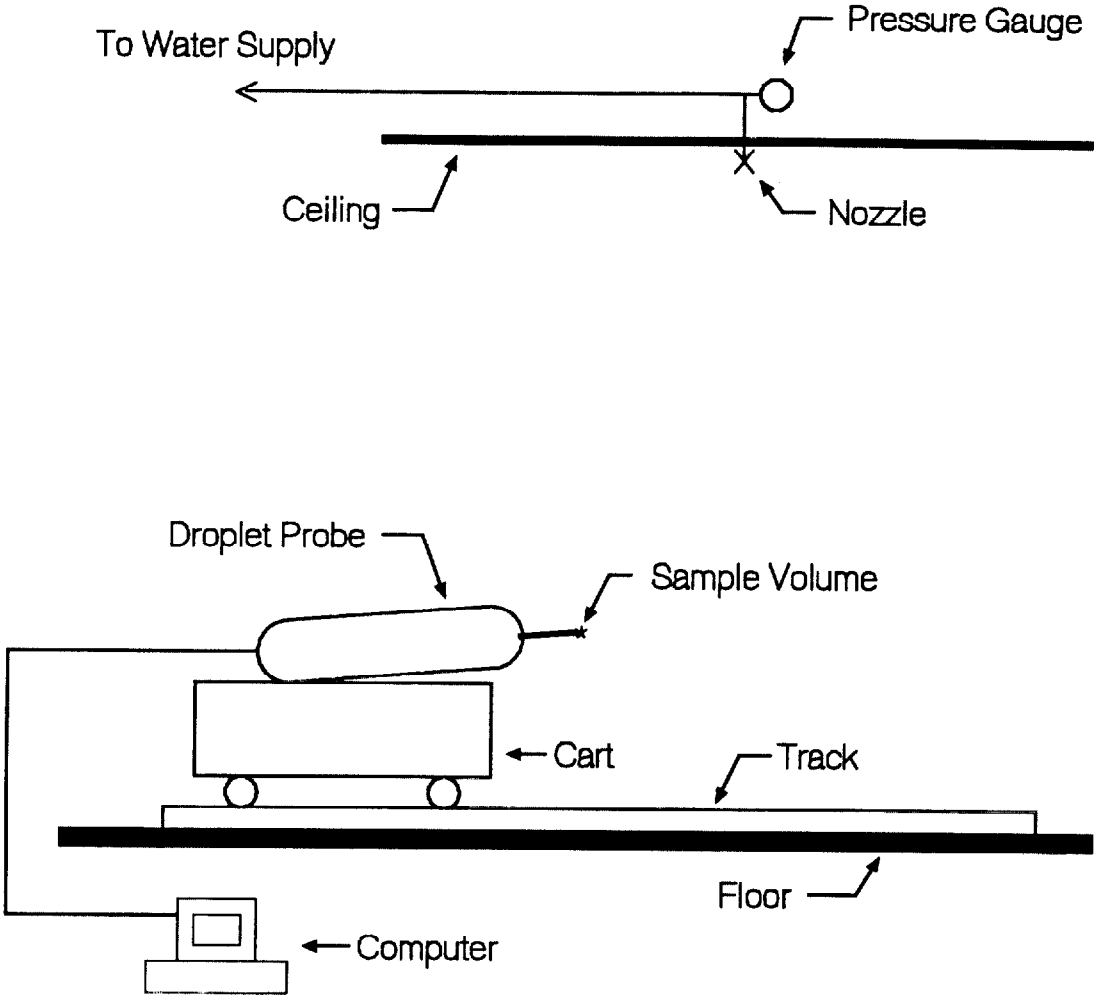

Figure 2. Elevation view of the experimental configuration.

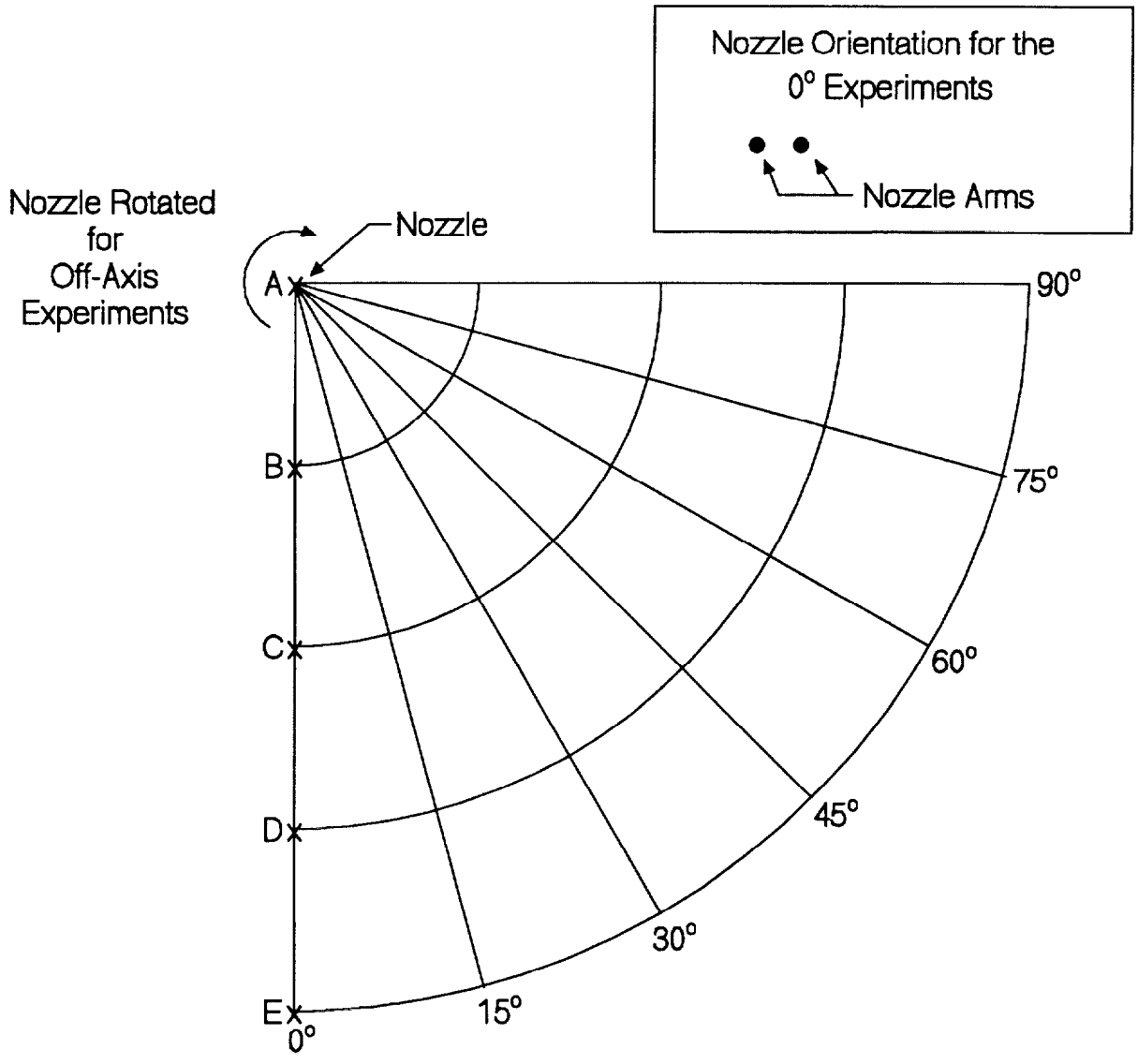

Figure 3. Plan view of the measurement locations.

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Determination of Water Spray Drop Size and Velocity from a Low Pressure, High Momentum, Water Mist Nozzle.

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In order to characterize the water spray from a low pressure, high momentum water mist nozzle, measurements were made using an optical array probe droplet analyzer. The water droplet sizes and velocities from the nozzle were measured at varying operating conditions and locations in the spray field. The study resulted in droplet size and velocity ranges for the nozzle, as well as mean droplet velocities and droplet size distributions. The pendent nozzle used in this study is currently being evaluated by listing organizations for fire suppression in residential and light hazard occupancies.

KEY WORDS (MAXIMUM OF 9; 28 CHARACTERS AND SPACES EACH; SEPARATE WITH SEMICOLONS; ALPHABETIC ORDER; CAPITALIZE ONLY PROPER NAMES)
drop size measurements; drop sizes; sprays; velocity measurements; water mist

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