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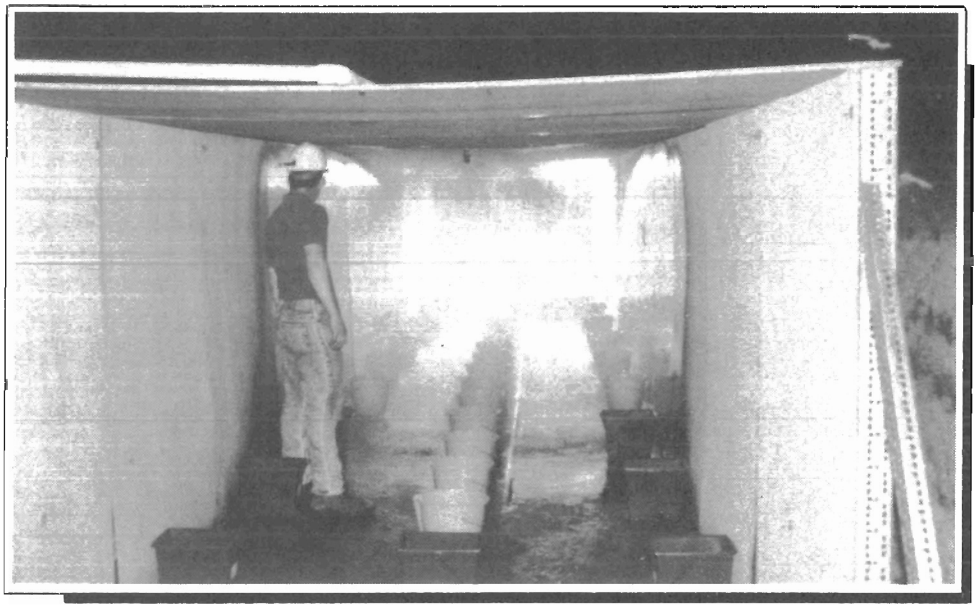

United States Department of the Interior

Bureau of Mines

Cover Photograph: Experiment in progress in simulated underground mine entry to evaluate the effect of ventilation on water spray patterns of automatic sprinkler heads.

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UNITED STATES DEPARTMENT OF THE INTERIOR
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BUREAU OF MINES

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cfm	cubic foot per minute	gpm/ft^2	gallon per minute per square foot
ft	foot	in	inch
ft^2	square foot	min	minute
ft/min	foot per minute	pct	percent
gal	gallon	psig	pound per square inch gauge
gpm	gallon per minute		

THE EFFECT OF VENTILATION ON THE WATER SPRAY PATTERN OF AUTOMATIC SPRINKLER HEADS

By A. C. Smith,[1] M. W. Ryan,[2] R. W. Pro,[3] and C. P. Lazzara[4]

ABSTRACT

The U.S. Bureau of Mines conducted a study to evaluate the effect of ventilation on the water spray patterns of automatic sprinkler heads. Experiments were performed in a rectangular tunnel with pendent, upright, pendent sidewall, and horizontal sidewall sprinkler heads at air velocities of 0, 150, 300, 500, and 800 ft/min. As the air velocities were increased, there were significant shifts in the total coverage areas, density distribution patterns, and the maximum coverage densities for all types of heads. The pendent and upright heads exhibited upstream shifts in total coverage in the direction of the airflow ranging from 4 to 6 ft, while the downstream coverage distances were extended up to 14 ft at the 800 ft/min airflow. The shift in upstream coverage distance for the sidewall heads ranged from 6 to 12 ft, while the downstream coverage was extended up to 22 ft at 800 ft/min. The results showed that airflow can have a significant effect on the coverage characteristics of automatic sprinkler heads and needs to be considered in the design of effective sprinkler fire suppression systems for ventilated areas.

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INTRODUCTION

The U.S. Bureau of Mines conducted experiments to evaluate the effect of ventilation on the water spray pattern of commercially available automatic sprinkler heads. This study is part of a larger program to evaluate the performance of automatic sprinkler systems in underground coal mines, and supports the Bureau's goal to improve safety in the mining industry.

Underground mine fires are a serious threat to life, property, and the Nation's mineral resources. From 1980 to 1990, the Mine Safety and Health Administration (MSHA) investigated 149 coal mine fires (*1*).[5] In 1984, a fire in the Wilberg Mine, UT, resulted in 27 fatalities (*2*). In 1988, a conveyor belt fire spread rapidly through the Marianna No. 58 Mine, PA, and the entire mine had to be sealed and abandoned (*3*). Research on the development and evaluation of improved and novel fire control and suppression systems is required to reduce the risk of severe coal mine fires, and to enhance fire safety. Recent advances in aboveground fire-extinguishing technology, especially in the area of automatic sprinkler systems, need to be realistically evaluated and adapted to combat underground mine fires.

Automatic sprinkler systems are the primary method of protecting lives and property from fire in aboveground facilities. The National Fire Protection Association (NFPA) has no record of a multiple-death fire (more than 2 fatalities) in a completely sprinklered building where the system was operating properly. This does not include explosions or flash fires where fire fighters have been killed during fire suppression operations (*4*). A recent high-rise fire in Philadelphia, PA, that started on the 22d floor burned out of control until reaching the sprinklered 30th floor. There a sprinkler system designed for light hazard occupancy, with water supplied by a fire department pumper, stopped the vertical spread of the fire and eventually extinguished it (*5*). The demonstrated effectiveness of these systems in aboveground applications, along with their reliability and low maintenance, has led to their increased use in underground mines.

Federal regulations for underground coal mines require that either automatic sprinkler systems (wet pipe or dry pipe), deluge-type water spray systems, foam generators, or dry powder chemical systems be installed at all main and secondary conveyor belt drive areas. When water sprinkler systems are used, they are required to provide protection for motor drive belt takeups, electrical controls, gear reducing units, and for the first 50 ft of fire-resistant or 150 ft of non-fire-resistant belts, at 8-ft intervals. Fire suppression devices are also required on unattended underground equipment (*6-7*).

Federal regulations (*8*) state that if water sprinkler systems are installed in underground mines, the components shall be installed, as far as practical, in accordance with the NFPA-13 standard (*9*). The fundamental design principle of NFPA-13 is to leave no area unprotected. Automatic sprinkler systems are designed to apply water to a burning area to control or extinguish fires. Each type of sprinkler head has design parameters that specify its coverage area, minimum water flow rate, orifice size, and discharge coefficient. Sprinkler head spacing is based on the required delivery density, defined as the minimum rate of water application, which if delivered to the top of the fuel package is capable of suppressing a fire.

The water discharge requirement for underground coal mine sprinkler installations on conveyor belt systems is a minimum rate of at least 0.25 gpm/ft^2 on the top surface of the top belt. In addition, the discharge shall be directed at both the upper and bottom surfaces of the top belt and to the upper surface of the bottom belt. The supply of water shall be adequate to provide constant flow of water for 10 min with all sprinklers functioning. These requirements address only the amount of water to be discharged by a sprinkler head, and do not address the water distribution characteristics of the head. Along the conveyor belt, the actual water density covering the belt may be more than or less than 0.25 gpm/ft^2, as long as the average over the entire belt is 0.25 gpm/ft^2.

The standards governing the listing of automatic sprinkler heads have broad requirements concerning coverage area (*9*). The distribution patterns of most commercially available sprinklers have been tested only for overall coverage under specific geometric conditions. The distribution patterns are not expected to be axisymmetric, since the frame arms of most sprinklers obstruct the pattern, and the edges of the deflector create a fingering effect. Also, the distribution patterns vary with water pressure.

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[5] Italicized numbers in parentheses refer to items in the list of references at the end of this report.

As pressures increase, the coverage patterns expand outward and become elliptical in shape.

The standards do not consider the effect of ventilation on the coverage areas or distribution patterns of the sprinkler heads. In aboveground buildings, this is usually not a concern, and is probably the basis for the exclusion of this parameter. However, in an underground coal mine, automatic sprinkler systems are installed in an environment where ventilation flows are necessary. Data on the performance of sprinkler heads under ventilated conditions, however, are lacking. Suppression tests of conveyor belt drive fires in ventilated flows using automatic sprinklers, multipurpose dry powder, and high expansion foam were conducted by Warner in 1974 (*10*). However, that study, funded by the U.S. Bureau of Mines, concentrated on comparing the effectiveness of the different types of suppression systems to extinguish conveyor belt fires and did not focus on the performance of individual components of the sprinkler system.

Information on how ventilation will affect the water coverage patterns of sprinkler heads is of utmost importance in the design of automatic sprinkler suppression systems to maximize their effectiveness in extinguishing a mine fire. Also, this information should be helpful in evaluating the potential for more extensive use of automatic sprinkler systems in other ventilated mine areas, such as on a longwall face or in haulageways.

ACKNOWLEDGMENTS

The authors acknowledge Steven J. Luzik, supervisory chemical engineer, and Thomas M. Fircak, engineering technician, of the Department of Labor, MSHA, for their input in the design of the experiments and for their cooperation in the use of the MSHA fire gallery; and Robert A. Cortese, electronics engineer, U.S. Bureau of Mines, for his assistance in the analysis and graphical presentation of the data.

SPRINKLER HEADS

The spray patterns of six different commercially available sprinkler heads were examined in this study. The sprinkler heads included pendent heads from two manufacturers, designated as A and B, horizontal sidewall heads from the same two manufacturers, a pendent sidewall head from manufacturer B, and an upright head from manufacturer A. To conduct a spray pattern experiment, the fusible links were removed from the sprinkler heads prior to installation in the tunnel. Examples of the four types of sprinkler heads, with the fusible links in place, are shown in figure 1. These examples are not the sprinkler heads used in these experiments.

The pendent and pendent sidewall sprinkler heads are designed to be installed with the deflector down, while the upright head is installed with the deflector up, and the horizontal sidewall sprinkler is installed horizontally, as shown. The flow patterns for the pendent and upright heads are typically circular, while the sidewall heads are designed to direct their water sprays in a particular direction. The actual spray patterns depend on the head's deflector design, as well as other factors such as water pressure and flow rate.

EXPERIMENTAL FACILITY

The water spray pattern experiments were conducted in the MSHA fire gallery at the Bureau's Pittsburgh Research Center. The gallery, shown in figure 2, is a modified X-shaped structure constructed of 4-ft-high concrete-filled cement-block walls, and an arch-shaped corrugated steel roof. To simulate the rectangular geometry of an underground mine entry for the experiments, a 32-ft-long, 7-1/2-ft-wide, 6-ft-high tunnel was constructed using 1/2-in plywood on a steel frame in the interior of the north section of the gallery.

The water supply for these experiments was provided by a 48-in water main approximately 3,500 ft to the north,

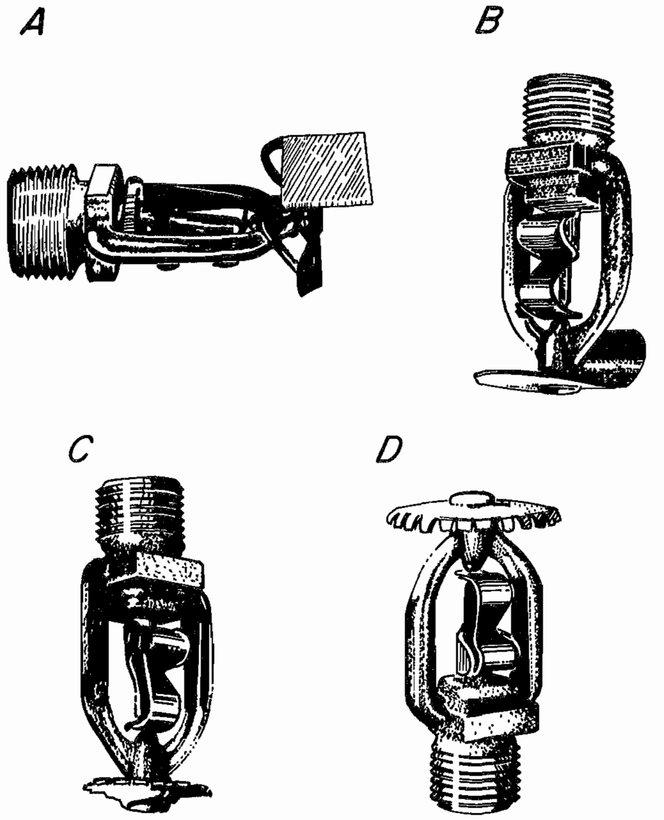

Figure 1.—Sprinkler heads. ***A*****, Horizontal sidewall;** ***B*****, pendent sidewall;** ***C*****, pendent; and** ***D*****, upright sprinkler heads.**

that fed a hydrant located next to the fire gallery, as shown in figure 2. A 50-ft section of 2-1/2-in rubber-lined fire hose was run from the hydrant to the west wall of the north section of the fire gallery. The water was then fed through a 2-in plastic pipe and a 1-1/2-in pipe nipple that extended through the wall of the gallery to a 1-in-diam plastic pipe inside the tunnel. The 1-in pipe was run above the plywood roof down the length of the tunnel. A ball valve, located where the pipe reduced from 1-1/2 to 1 in, was used to control the flow of water.

The water system maintained a static pressure of approximately 80 psig and a constant residual pressure of about 47 psig, while flowing 38 gpm from the sprinkler. The water pressure was measured by a diaphragm-type pressure transducer attached to the supply line near the end of the tunnel. The water flow was measured by a paddle-wheel-type flowmeter located in the 2-in section of plastic pipe. The flowmeter operated by generating a frequency that was converted to voltage and measured by a strip chart recorder. Junction boxes on the exterior walls of the gallery provided interfacing cable for linking the pressure and water flow sensors to a control room adjacent to the fire gallery.

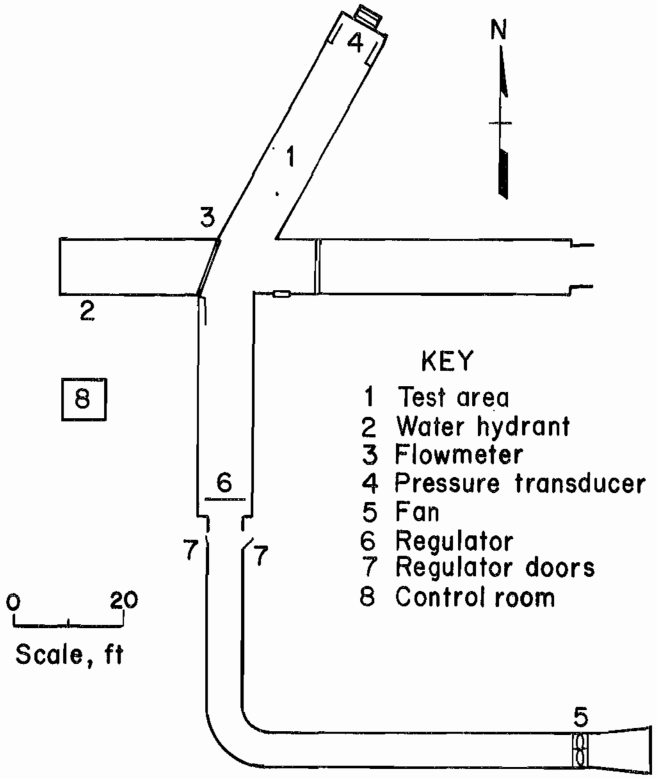

Figure 2.—Fire gallery facility.

The sprinkler heads were located along the centerline of the tunnel, either 12 or 20 ft from the south end of the plywood enclosure, depending on the type of sprinkler head being evaluated. To install the sprinklers, a 3/4-in opening was made in the center of the plywood roof, and a 2-in-long, 1/2-in-diam pipe nipple was extended from a tee in the supply line through the opening. A coupler connected the pipe nipple to the sprinkler head. For the horizontal sidewall sprinkler heads, an elbow was used in place of the coupler. In the experiments using an upright sprinkler head, a 4-in-long, 1/2-in-diam nipple was extended from the elbow, with another elbow on the end of the nipple. The sprinkler head was then attached to that elbow, in the form of a U-shape. In all the experiments, including the experiments with the horizontal sidewall heads, the sprinkler head deflector was 4-7/8 in from the plywood roof. For the experiments with the pendent and upright heads, the frame arm of the sprinkler was oriented perpendicularly to the direction of the airflow.

Ventilation was provided by a high-capacity fan, capable of producing up to 100,000 cfm at a pressure drop of 8.0 in water gauge, located in the south section of the gallery. The airflow was controlled with the regulator and regulator doors, shown in figure 2.

EXPERIMENTAL PROCEDURE

To conduct an experiment, the sprinkler head was installed in the tunnel, and the activation mechanism was removed from the head. The air velocity was then set to within 10 pct of the desired value, by adjusting the regulator and regulator doors. The airflow was measured using a vane anemometer at the nine locations, shown in figure 3, in the tunnel cross section where the sprinkler head was located.

Experiments were conducted in triplicate for each sprinkler head at air velocities of 0, 150, 300, 500, and 800 ft/min. The water supply was turned on using the ball valve inside the tunnel, and left open for 4 min. Water discharged from the sprinkler was collected in 2.5-gal containers placed at 2-ft intervals down the center of the tunnel and at 4-ft intervals along the walls of the tunnel. The lips of the containers were 10 in above the floor, and each container had a cross-sectional opening of 0.6 ft^2. The center of the containers along the walls were 3 ft from the centerline of the tunnel, and offset 2 in from the wall to prevent water runoff from the wall from being measured at that location. Upon completion of an experiment, the water collected in each container was measured using a graduated cylinder. A water spray pattern experiment in progress is shown in figure 4.

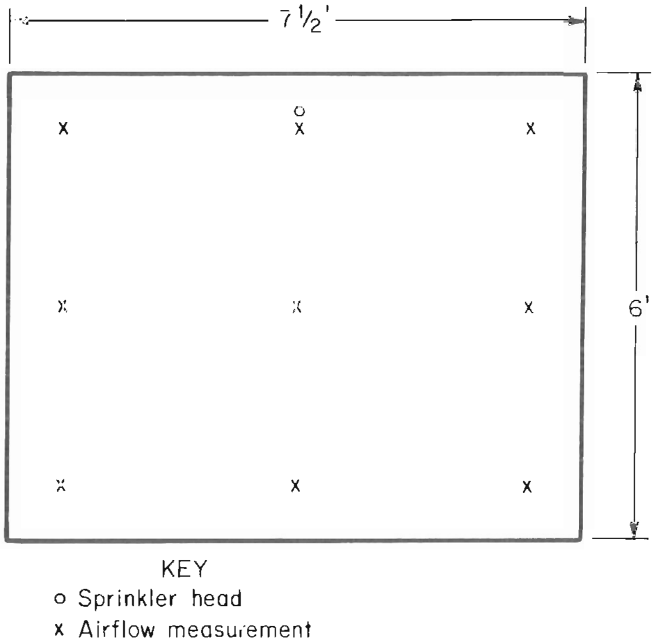

Figure 3.—Locations of air velocity measurements (x's are 6 in from walls, floor, and ceiling).

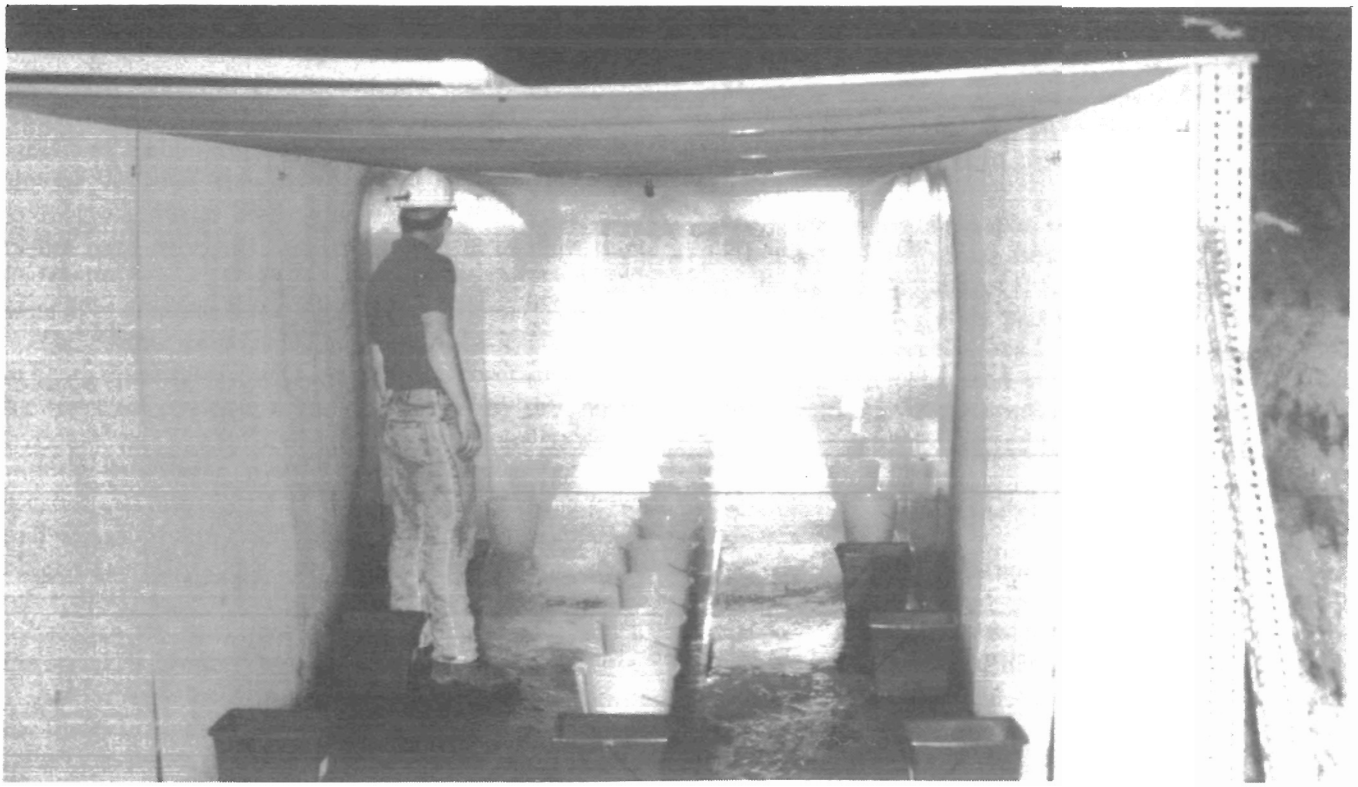

Figure 4.—Typical spray pattern experiment.

RESULTS AND DISCUSSION

In order to evaluate the effect of ventilation on the water spray patterns of the sprinkler heads, the maximum upstream and downstream coverage distances of each sprinkler head, as well as the maximum water density in gallons per minute per square foot (gpm/ft^2) observed for each head, were determined at each airflow. These values are shown in table 1.

In addition, bar graphs showing the average water densities, in gallons per minute per square foot, collected in the containers located at 4-ft intervals along the length of the tunnel were constructed for each sprinkler head at each airflow. These are shown in figure 5. The sprinkler head was located at the 0-ft center point in the graphs, with the airflow moving from left to right. Therefore, the negative numbers on the x-axis indicate the distance upstream from the sprinkler head. The values denoted by the legend "left" were calculated from the water collected in the containers along the left side of the tunnel with respect to the airflow, while the values denoted by the legend "right" were calculated from the water collected along the right side of the tunnel with respect to the airflow. It should be noted that collection containers were located along the center axis at 2-ft intervals, so some data were not shown in the bar graphs. Thus, the maximum coverage distances and water densities shown in table 1 may not be evident in the bar graphs.

Table 1.—Maximum upstream and downstream coverage distances and maximum water density and location relative to sprinkler head

Type of sprinkler head	Air velocity, ft/min	Maximum coverage distance, ft		Maximum water density, gpm/ft^2	Location,[1] ft
		Upstream	Downstream		
Pendent A	0	12	12	1.15	0 R
	150	12	14	.81	0 L,R
	300	10	16	1.23	0 L
	500	10	20	.78	0 L
	800	8	22	.46	0 L
Horizontal sidewall A ..	0	24	22	.51	-14
	150	24	4	.54	-14
	300	20	12	.47	-22
	500	18	16	.45	-8
	800	12	24	.41	-6
Upright A	0	12	10	.62	0 L
	150	8	10	.49	0 R
	300	8	14	.44	0 L
	500	6	20	.50	0 L
	800	6	24	.51	-4
Pendent B	0	14	14	.82	0
	150	12	14	1.04	0
	300	12	18	.84	0
	500	12	20	.46	0
	800	8	22	.55	0
Horizontal sidewall B ..	0	24	2	.45	0
	150	24	4	.76	0
	300	20	12	.65	0
	500	20	16	.37	0
	800	12	24	.24	0 L
Pendent sidewall B	0	20	14	.50	-4 R
	150	18	14	.45	-4 L
	300	16	16	.61	-4 R
	500	16	20	.58	-4 R
	800	14	24	.24	0 L

[1] All locations are along center of tunnel unless otherwise noted. L = left side of tunnel with respect to airflow; R = right side of tunnel with respect to airflow. Negative numbers denote upstream location with respect to sprinkler head.

In order to extrapolate the effect of ventilation on water spray patterns to wider entries or open ventilated areas, which was not possible to measure directly owing to the experimental setup, contour plots were generated using the data with unfixed boundary conditions. These plots are shown in figure 6. The plots were generated by a personal computer-based graphics program, and based on a biharmonic spline interpolation of the data matrix. In each plot the sprinkler head is located at the (0,0) axis point and the airflow is from left to right, with the negative numbers along the x-axis depicting the position upstream of the sprinkler head. The contour lines are in increments of 0.1 gpm/ft^2, with the outer contour line showing the extent or boundary of the water coverage area.

PENDENT HEADS

The results of the spray pattern experiments using the pendent heads from manufacturers A and B are shown in the bar graphs in figure 5, and the contour plots for these heads are shown in figure 6. From table 1, the head from manufacturer A had maximum coverage distances of 12 ft both upstream and downstream from the head at 0-ft/min air velocity, while the coverage distances for the head from manufacturer B at 0 ft/min was 14 ft upstream and downstream. At 0-ft/min air velocity, the maximum water densities for both heads were observed at the 0-ft position in the tunnel with respect to the sprinkler head, with measured values of 1.15 and 0.82 gpm/ft^2 observed for the heads from manufacturer A and B, respectively. The bar graphs indicate that the maximum water density occurred to the right side of the sprinkler head from manufacturer A, while the maximum water density for the head from manufacturer B occurred directly under the sprinkler head. This is attributed to the design of the head deflectors since water pressures, flow rates, and the experimental configurations of the sprinkler heads were kept constant throughout the experiments.

The contour plots for the two heads at 0 ft/min, shown in figure 6, indicate circular, symmetrical coverage patterns for the total coverage areas represented by the outside contour line. The total coverage distances are consistent with the data shown in table 1. Both sprinklers exhibited symmetrical discharge patterns with respect to the longitudinal axis, with a small area of relatively high densities observed directly under the sprinkler head from manufacturer B. These water distribution characteristics are attributed to the frame arm and deflector configuration of the sprinkler head.

As the air velocity was increased, there was a shift in the upstream and downstream coverage distances. These values are shown in table 1, and the shifts can be seen in the bar graphs. The airflow appeared to have more of an effect on the downstream coverage distance than on the upstream coverage distance. Comparing the distances at 0 and 800 ft/min, the A pendent head's upstream coverage distance was reduced 4 ft, from 12 to 8 ft, while the downstream coverage was extended from 12 to 22 ft, an increase of 10 ft. This effect was also seen for the B pendent head. The upstream coverage distance was reduced from 14 to 8 ft, a reduction of 6 ft, while the downstream distance was extended from 14 to 22 ft, an increase of 8 ft.

In addition to showing the effect of the airflow on the upstream and downstream coverage distances, the contour plots indicate that the coverage distances in the radial direction were also extended. This effect was most pronounced at 500 and 800 ft/min, as seen in the bar graphs for the A pendent head, and to a lesser degree for the B pendent heads at these airflows. The ventilation effect on coverage distances away from the sprinkler head may be attributed to the higher air velocities carrying the smaller water droplets in the direction of the airflow.

In addition to the greater coverage distance as the air velocity was increased, there was a discernible trend in the maximum water densities, as shown in table 1. For the A pendent head, the maximum measured value decreased at 150 ft/min, and rose again at 300 ft/min, after which there was a substantial drop at 500 and 800 ft/min. Similar results were seen for the B pendent head since the maximum value occurred at 150 ft/min. It is not possible to determine if the increase or decrease in water densities at 0, 150, and 300 ft/min was due to the airflows, or if the maximum water density occurred at a point where no measurement was made. However, at 500 and 800 ft/min, the contour plots show that there was a decrease in the water densities. This indicated that air velocities of 500 ft/min or greater were capable of physically affecting the water droplet size.

As shown in the bar graphs, the A pendent head's spray pattern in the longitudinal direction changed from a normal distribution pattern at 0 ft/min, to a more uniform water density distribution pattern from 0 to 12 ft downstream of the sprinkler head. At air velocities of 500 ft/min or greater, the head would not be effective in delivering sufficient water upstream to a fire beyond 4 ft. This effect was also observed for the B pendent head.

UPRIGHT HEAD

The spray patterns observed for the upright head were similar to those observed for the pendent heads. At 0 ft/min airflow, the upstream and downstream coverage distances were 12 and 10 ft, respectively. However, the amount of water collected 12 ft upstream was too little to be discernible in the bar graphs. The contour plots at 0 ft/min show symmetrical, circular spray patterns, although the radial coverage distances appear to be slightly higher than the longitudinal coverage distances.

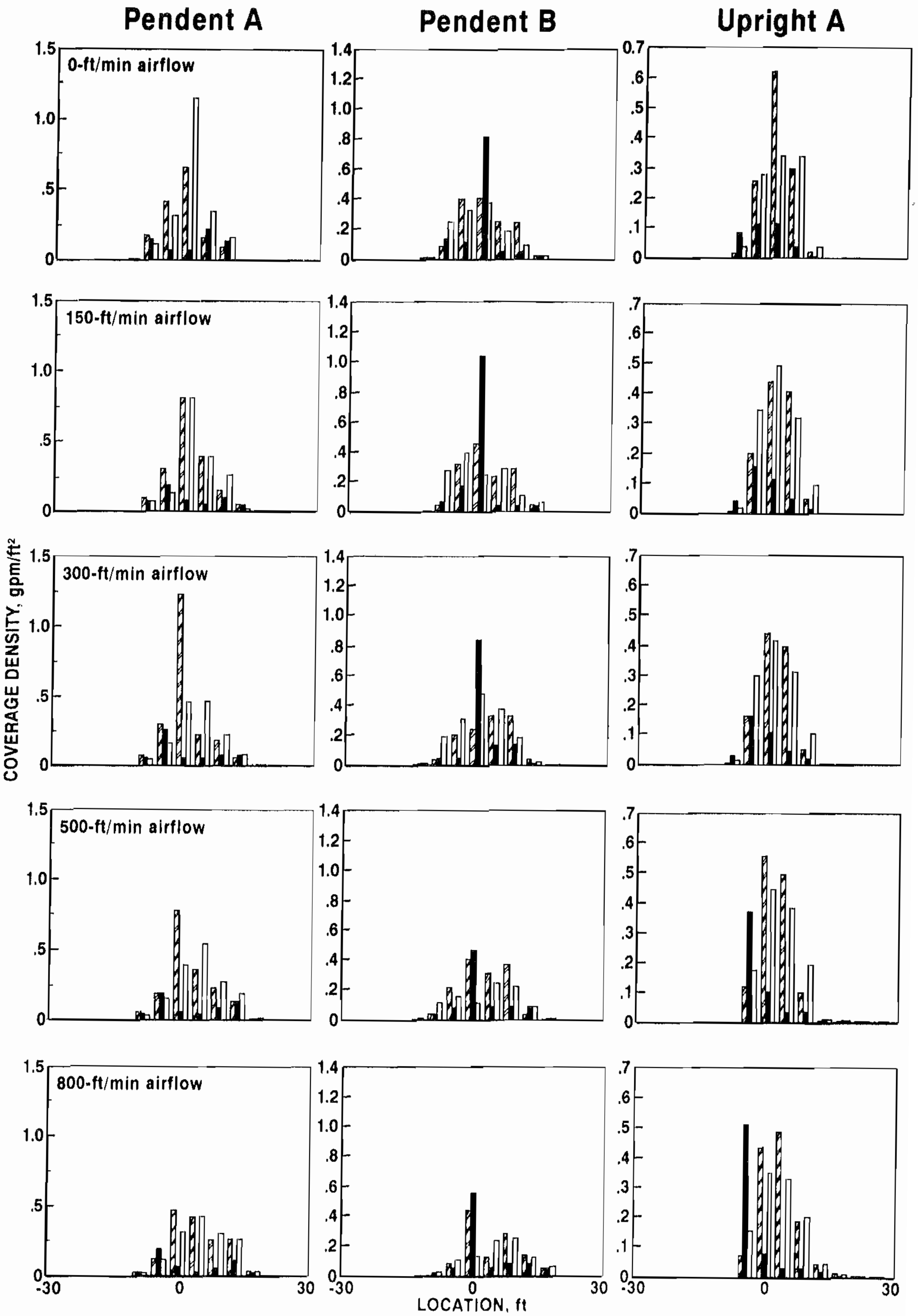

Figure 5.—Water distribution graphs.

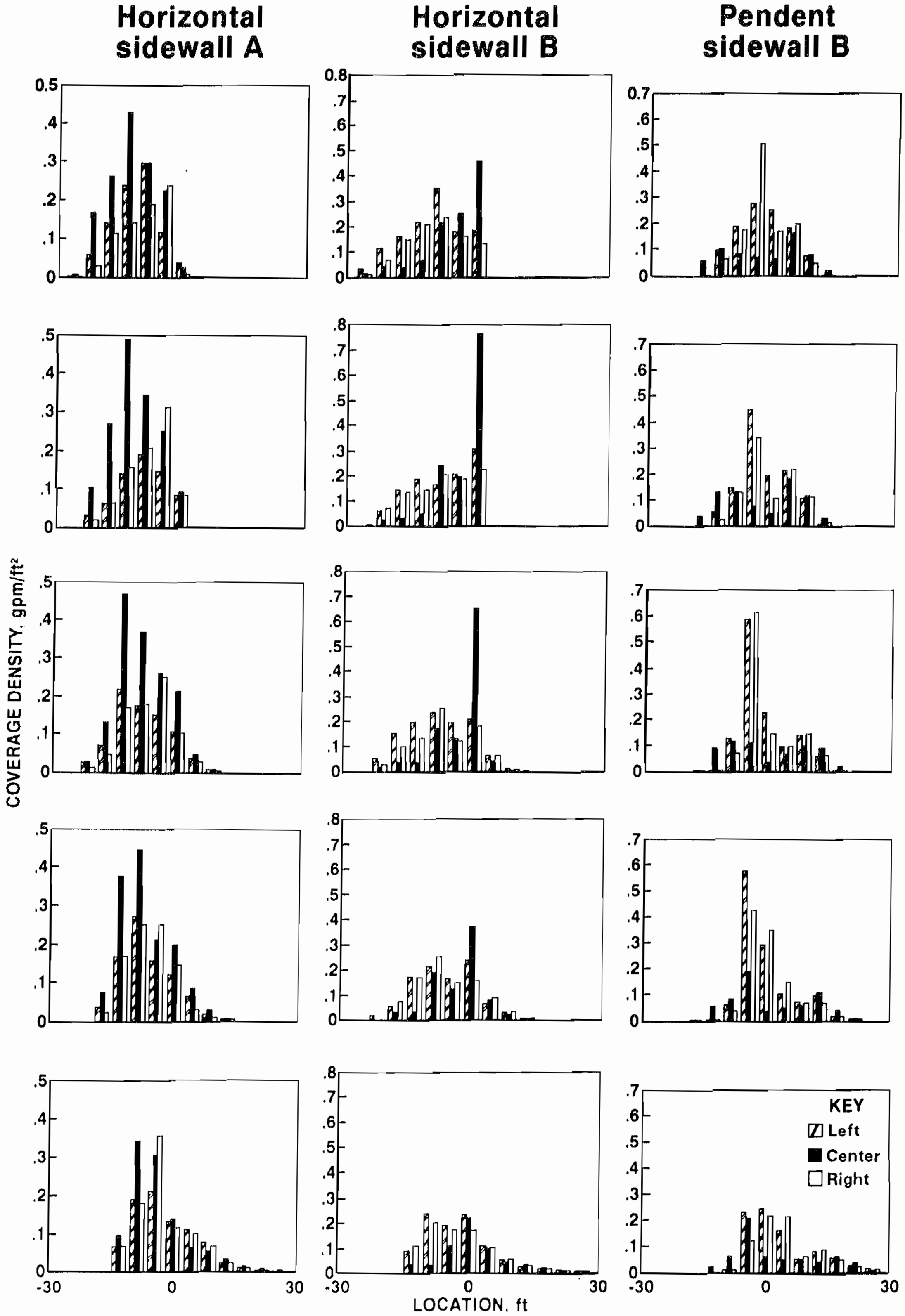

Figure 5.—Water distribution graphs—Continued.

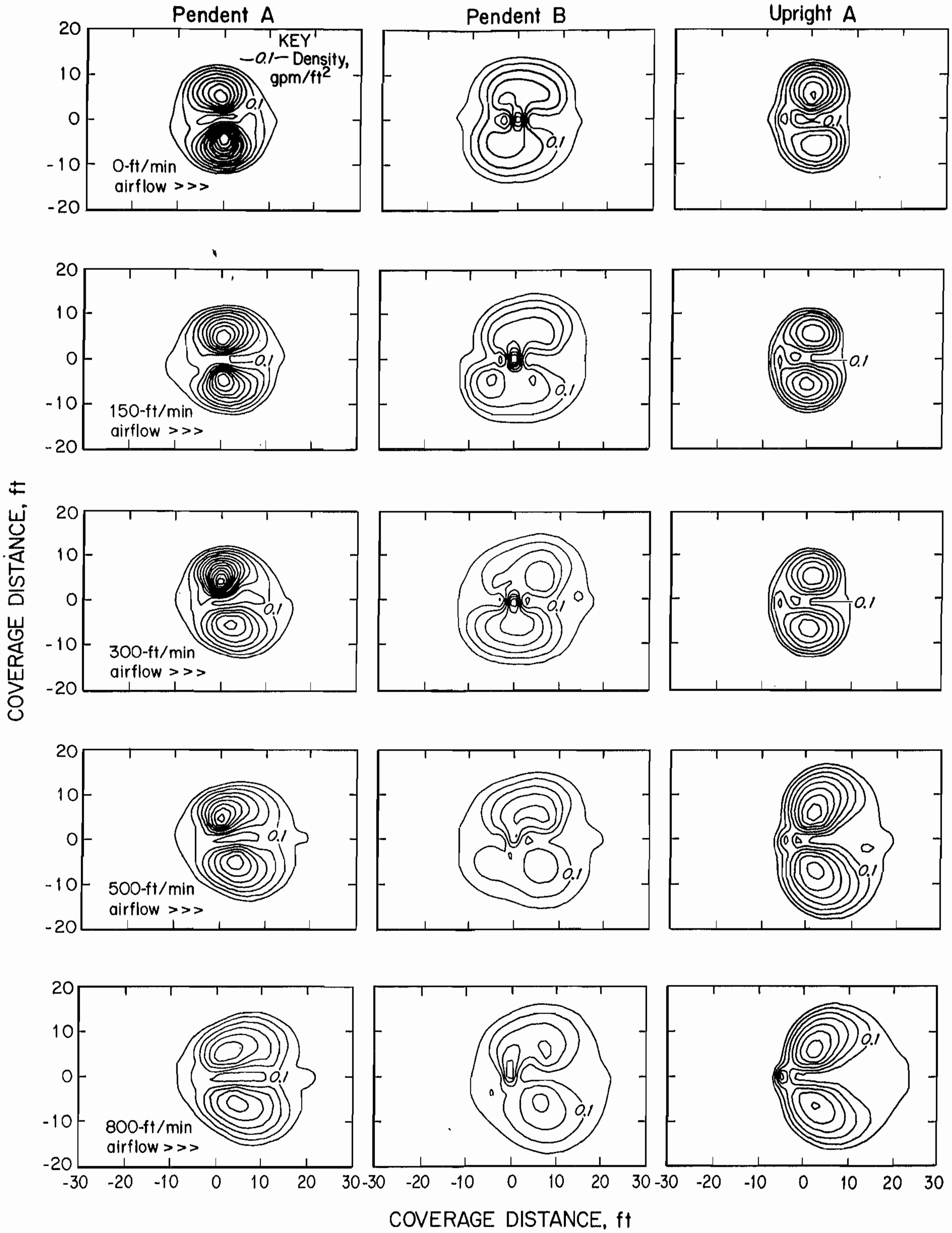

Figure 6.—Water distribution plots.

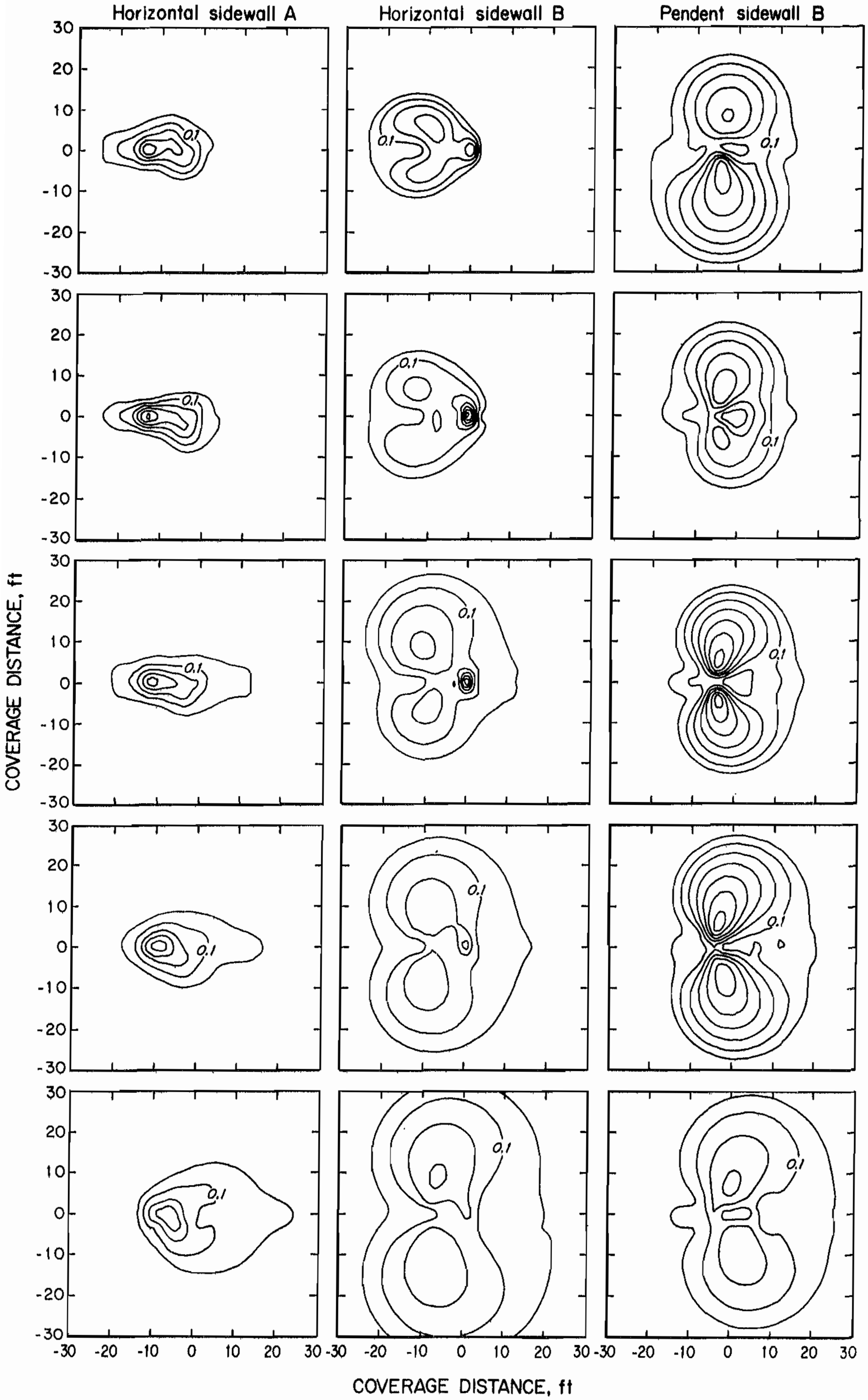

Figure 6.—Water distribution plots—Continued.

Again, the most water at 0 ft/min was delivered in the cross-sectional area of the tunnel where the sprinkler head was located, with the highest water densities measured in the collection containers to the left and right of the sprinkler head. The maximum coverage density observed at this airflow, 0.62 gpm/ft^2, was considerably less than was observed for the pendent heads. Also, the amounts of water collected at the 8 ft positions upstream and downstream of the sprinkler head were considerably less than for the pendent heads, less than 0.1 gpm/ft^2 compared with 0.2 gpm/ft^2, for at least one collection container at the 8-ft positions for the pendent heads.

At air velocities of 150 and 300 ft/min, there was little change in the coverage patterns, although table 1 indicates a 4-ft decrease in coverage distance upstream at 150 ft/min and an extension of 4 ft downstream at 300 ft/min. Again, the amounts of water collected at these locations, 8 ft upstream and 14 ft downstream, were less than 0.02 gpm/ft^2, and are not discernible in the bar graphs.

At 500 and 800 ft/min, the coverage distances were extended downstream to 20 and 24 ft, respectively, while the upstream distance was reduced to 6 ft, as shown in table 1. The contour plots show a substantial increase in the radial coverage distances at these air velocities, from about 12 ft at 300 ft/min to about 18 ft at 500 and 800 ft/min.

The decrease in the maximum water density with increased airflow observed for the pendent heads was not observed with the upright head. The maximum water density remained fairly constant at approximately 0.5 gpm/ft^2. This indicates that the sprinkler and deflector design produced a more even distribution of water droplet sizes. A noticeable effect was the change in the location of the highest water density to the 4-ft upstream location and to the center collection container at 800 ft/min.

HORIZONTAL SIDEWALL HEADS

The bar graphs showing the measured water densities for the horizontal sidewall heads from manufacturers A and B are shown in figure 5, and the contour plots for these heads are shown in figure 6. The water spray was directed upstream, or into the airflow. At 0 ft/min, the measured water distribution pattern for the head from manufacturer A indicated a normal distribution pattern centered around the 12-ft position upstream from the head where the highest density occurred. The pattern extended to about 24 ft upstream, and 0 ft, or directly under the head, in the downstream direction. The water distribution pattern for the head from manufacturer B differed significantly, with the highest density measured directly under the sprinkler head. The density distribution decreased with distance away from the head in the upstream direction. The data in table 1 indicate that some water was collected in the center containers located 2 ft downstream from the head, but these amounts were both less than 0.1 gpm/ft^2.

For the head from manufacturer A, at 150 ft/min, there were slight increases in the water densities observed 12, 8, 4, and 0 ft upstream from the head, and a small decrease in the amount observed 16, 20, and 24 ft upstream from the head. At 300 ft/min, this effect was still evident, with small quantities of water measured at the positions 4 and 8 ft downstream from the head. The largest effects of the airflow were seen at 500 and 800 ft/min. At 500 ft/min, the largest water density was measured at the 8-ft position upstream from the head, while at 800 ft/min, the largest density was found 4 ft upstream from the head. At 800 ft/min, water was measured as far as 24 ft downstream from the head at the center position. Overall, there was a shift in the coverage pattern from 24 to 12 ft upstream of the head, and from 0 to 24 ft in the downstream direction. This is seen in the contour plots in figure 6, as well as a smaller increase in the radial coverage distances, from about 10 ft at 0 ft/min to about 14 ft at 800 ft/min. The decrease in the maximum measured water densities seen for the pendent heads was not evident for this head, with only a slight decrease, 0.51 to 0.41, observed. However, the maximum values at the lower airflows were considerably less than those observed for the pendent head from the same manufacturer.

At 150 ft/min, the airflow appeared to have had little effect on the spray distribution pattern for the horizontal sidewall head from manufacturer B, with the exception of an increase in the maximum observed density from 0.45 to 0.76 gpm/ft^2 at the center position at 0 ft. At 300 ft/min, the maximum density was again observed at the center position at 0 ft, with little effect on the observed densities 4, 8, 12, and 16 ft upstream of the sprinkler head. The small amounts of water collected at the 24-ft positions upstream at 0 and 150 ft/min were no longer observed, while small quantities were measured 4, 8, and 12 ft downstream of the head. At 500 ft/min, the amount collected at the 0-ft position decreased significantly, with little change in the measured quantities 12, 8, and 4 ft upstream, and 4 ft downstream from the head. Finally, at 800 ft/min, a relatively even density distribution of about 0.2 gpm/ft^2 was observed from 8 ft upstream to 0 ft, with a smaller amount collected 12 ft upstream, and small amounts, ranging from 0.1 to 0.005 gpm/ft^2 observed out to 24 ft downstream from the head.

A much larger effect of airflow on the radial discharge distances was observed for the horizontal sidewall head from manufacturer B, with the contour model indicating that coverage exceeded 30 ft from the head radially at 800 ft/min. While the actual predicted distances may be overstated by the model's calculations, it is obvious that the spray pattern for this head was affected greatly by the ventilation flow, and to a much larger extent than the spray pattern for the horizontal sidewall head from manufacturer A.

There was a marked trend in the maximum observed water densities for this head similar to those observed for the pendent heads. The maximum increased from 0 to 150 ft/min, and then decreased as the air velocity was increased, with the amount measured at 800 ft/min being significantly less. This evidence, combined with the much wider spray pattern, indicated that the head and deflector design created much smaller water droplets that were more easily influenced by the airflow.

PENDENT SIDEWALL HEAD

The bar graphs for the pendent sidewall head from manufacturer B (fig. 5) show that the directional nature of the head is not as evident as was seen for the horizontal sidewall heads. The maximum measured values at 0 ft/min airflow were measured 4 ft upstream from the head, and the maximum upstream and downstream coverage distances were 20 and 14 ft, respectively. In comparison, the downstream coverage distance for the horizontal sidewall heads was just 2 ft, while the upstream coverage distance for these heads was 24 ft. The distribution pattern appeared to be normally distributed about the 4-ft position upstream. The contour plot indicates a much wider radial distribution occurred at 0 ft/min, extending between 20 and 30 ft, than for any of the other heads.

As the air velocity was increased, the maximum measured water density remained relatively stable at the upstream 4-ft position until the air velocity reached 800 ft/min. At that airflow, the maximum was reduced significantly at the 0-ft left position, although the distribution densities were essentially the same at the upstream 4-, 0-, and downstream 4-ft positions in the longitudinal directions.

At 800 ft/min, the distribution pattern was shifted in the direction of the airflow, with the coverage distance extended 14 ft upstream and 24 ft downstream from the head. The contour plots show the radial coverage distances decreased at 150 and 300 ft/min, and then increased to nearly 30 ft at 500 and 800 ft/min. For the water distribution densities of 0.1 gpm/ft^2 or greater, the contour plots at 500 and 800 ft/min resemble the contour plots for the pendent and upright heads at 0 ft/min.

IMPLICATIONS OF RESULTS

In applying the results of this study to illustrate the effect of ventilation on the performance of automatic sprinkler systems, assume that a small or incipient fire occurs between sprinkler heads spaced at 8-ft intervals. The data on the water discharge patterns of the standard pendent, pendent sidewall, and upright heads at 800-ft/min airflow indicate that if the fire occurs just downstream of a sprinkler head, activating the next head downstream, a significant water density would not reach the fire. At 800 ft/min, the 0.1-gpm/ft^2 upstream coverage areas for these heads extends only 4 ft. If the activation of this head does not immediately control the fire, given the unlimited fuel supply present in a coal mine, the fire may grow, eventually activating additional sprinkler heads downstream. For a suppression system with a limited water supply, this may deplete the water at the site of the fire, possibly allowing it to overpower the system.

With the exception of the pendent head from manufacturer B, this scenario may be extended to airflows of 500 ft/min for the standard and upright heads. In fact, even at airflows as low as 150 ft/min, the coverage area of the pendent and upright heads from manufacturer A extends upstream to just 6 ft at the 0.1-gpm/ft^2 coverage density. If the ventilation is high enough to prevent the heads nearest the fire from activating, the potential for the spread of the fire grows.

These examples illustrate the potential for ventilation to affect adversely the design performance and operation of automatic sprinkler systems under ventilated conditions. The data presented in this report were obtained under specific experimental conditions and may not reflect the performance of automatic sprinklers under actual in-mine conditions. In addition, data on the effect of ventilation on the activation and extinguishment characteristics of automatic sprinkler heads are necessary to further evaluate and refine the performance criteria for the control and extinguishment of mine fires using water sprinkler systems.

SUMMARY

This study was conducted to evaluate the effect of ventilation on the water spray patterns of automatic sprinkler heads. Experiments were conducted on two types of pendent and horizontal sprinklers, and on an upright and a pendent sidewall type sprinkler. The sprinklers were mounted in a rectangular tunnel to simulate installation in a mine entry, and exposed to ventilation flows of 0, 150, 300, 500, and 800 ft/min. Residual pressure and flow were kept constant.

At 0-ft/min airflow, the pendent and upright heads exhibited circular coverage patterns, extending from 10 to 14 ft upstream and downstream of the sprinkler. The horizontal sidewall heads covered areas ranging from 2 ft downstream to 24 ft upstream, while the pendent sidewall

head covered an area from 14 ft downstream to 24 ft upstream. As the flows were increased, there was a marked shift in the coverage areas as well as a decrease in the coverage densities.

The results indicate that ventilation can have a significant effect on the coverage characteristics of automatic sprinkler heads. This information, combined with the effect of ventilation on the activation characteristics, is of utmost importance in the design of automatic sprinkler systems to maximize their effectiveness in the control and extinguishment of fires in ventilated areas.

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