Effect of air velocity on conveyor belt fire suppression systems

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Abstract

Four different types of fire suppression systems were evaluated in large-scale fire experiments to study the effect of air velocity on their effectiveness in extinguishing conveyor belt fires. The four different types of suppression system were water sprinkler, deluge-type water spray and two different dry chemical fire suppression systems. The large-scale fire tests were conducted with 1.8-m- (72-in.)-wide fire-resistant rubber belt that met the Mine Safety and Health Administration flame resistant requirement specified in Title 30, Code of Federal Regulations, Part 18, section 18.65 (also known as the 2G Flame Test). Each fire suppression system was tested at air velocities of 152 - 168 m (500–550 ft) per minute (mpm) and 411 - 457 mpm (1,350 - 1,500 fpm). Two tests were conducted at both air velocities for each fire suppression system. Both of the water-based fire suppression systems were able to suppress the fire to the point that a miner could extinguish it with a fire extinguisher. However, the amount of water needed to suppress the fire to the point where a miner could walk up to and extinguish any smoldering belting was greater than the current MSHA regulations required. MSHA regulations only require 10 minutes of water supply for a suppression system. In the test setup, neither of these systems would have suppressed the fire had the water been turned off to the system after 10 minutes. The dry chemical suppression systems produced mixed results. Dry chemical suppression system A did not suppress the conveyor belt fire at either air velocity. Dry chemical system B suppressed the fire at 152 mpm (500 fpm) air velocity, but produced mixed results at the higher air velocity. Details are presented on the large-scale fire test setup, arrangement of the fire suppression systems and conclusions regarding the effect of air velocity on fire suppression system design and performance.

Key words: Health and safety, Fire control, Conveyor belt systems

Introduction

On June 1, 2004, the underground coal mine ventilation safety standards Code of Federal Regulations, Title 30, Part 75, became effective for the use of a conveyor belt entry as an intake air course to ventilate working sections. These standards, also known as the "Belt Air Rule," contained a section which limited the air velocity in the conveyor belt entry to no greater than 152.4 meters per minute (mpm) (500 ft per minute, fpm), unless otherwise approved by the Mine Safety and Health Administration (MSHA) in the mine ventilation plan with respect to fire suppression systems. The "Belt Air Rule" included the requirement that air velocity be compatible with fire suppression systems. This requirement was due to the findings of the MSHA report on the VP 8 mine fire that occurred on July 15, 2003 (MSHA, 2003). It was determined that the air velocity at the belt drive where the fire started was in excess of 335 mpm (1,100 fpm) and that the air velocity adversely affected the dispersion of the dry powder chemical fire suppressant during the fire. A mine operator challenged the final rule of limiting the air velocity in the belt entry in the Court of Appeals for the District of Columbia Circuit. The Court granted the mine operator's petition and vacated the requirement on the air velocity cap (MSHA, 2005).

The removal of the air velocity cap from the final rule and the requirement that air velocity be compatible with fire suppression systems led to the need for research on the influence of high air velocity on the performance of fire suppression systems in conveyor belt entries. Test data was needed that illustrated the relationship between fire suppression system performance and air velocity, especially with the increased use of wider belts in underground coal mines. To address this issue, MSHA collaborated with the National Institute for Occupational Safety and Health (NIOSH) on a research project to obtain needed fire suppression performance data. Four different types of fire suppression systems were evaluated in a large-scale fire tunnel to determine their effectiveness in extinguishing conveyor belt fires: a water sprinkler, deluge-type water spray and two different types of dry chemical fire suppression systems. The suppression systems are representative of the types that are used in underground coal mines in the United States. There are few

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Figure 1 — Fire suppression facility.

dry chemical powder systems used in the underground coal mines in the United States. The dry chemical powder systems are primarily used in place of water suppression systems where temperatures are below freezing. The large-scale fire tests were conducted using a fire-resistant rubber belt 183 cm (72 in.) in width that met Title 30, Code of Regulations, Part 18, section 18.65. Each fire suppression system was tested at air velocities of 152.4-167.6 mpm (500-550 fpm) and at 411-457 mpm (1,350-1,500 fpm). A minimum of two tests were conducted at both air velocities for each fire suppression system. Both the water sprinkler and deluge-type water spray systems suppressed the fire to the point where a miner could extinguish it with a fire extinguisher. However, the amount of water needed to suppress the fire to the point where a miner could walk up to extinguish any smoldering belting was greater than current MSHA regulations require. MSHA regulations only require 10 minutes of water supply to the suppression system. In the test setup, neither of these systems would have suppressed the fire had the water been turned off to the system after 10 minutes. Dry chemical suppression system A did not suppress the conveyor belt fire at either air velocity. Dry chemical system B suppressed the fire at the lower air velocity but produced mixed results at the higher air velocity. Details are presented on the large-scale fire test setup, arrangement of the fire suppression systems and conclusions regarding the influence of air velocity on fire suppression system design and performance.

Fire suppression facility

All the experiments were conducted at the NIOSH Fire Suppression Facility (FSF).

The FSF, shown in Fig. 1, is a full-scale, state-of-the-art fire test facility located on the surface at the Lake Lynn Laboratory, approximately 60 miles southeast of Pittsburgh, PA. The fire tunnel is T-shaped to simulate a main entry and crosscut. The main entry is 46.6 m (153 ft) long and the crosscut is 12 m (40 ft) long. Each entry is 5.5 m (18 ft) wide and 2.1 m (7 ft) high. The roof is made of corrugated steel bridge planks, with the interior of the roof coated with 5-cm (2-in.) -thick fire resistant material. The ribs are made of 20-cm (8-in.) -thick solid concrete blocks coated with 2.5-cm (1-in.) fire-resistant material. The floor of the FSF is made of reinforced concrete. A 1.8-m (6-ft) -diameter variable speed axial vane fan is located at one end of the tunnel to provide ventilation. The fan has a pneumatic controller to adjust the fan blades in order to increase or decrease the air velocity. The fan can produce an air velocity over the cross-section of the entry of 457 mpm (1,500 fpm). As a point of reference, distances were measured from the fan to the exit of the tunnel and designated as the 0-m mark, except where noted. The crosscut area and main entry are instrumented with thermocouples. The thermocouples in the main entry protrude from the roof approximately 3 cm (1.2 in.) and are spaced 3 m (10 ft) apart down the center line, starting 3 m (10 ft) from the fan. In addition, a nine-point thermocouple array was set up 45.7 m (150 ft) from the fan across the width and the height of the entry to measure the temperature of the gas as it exited the entry. These array thermocouples were attached to three 1.3-cm- (0.5-in.-) diameter steel pipes spaced evenly across the width and were positioned evenly across the height of the entry and from the roof to the floor.

To measure the gas components produced from a belt burn test, a four-point gas monitoring array was set up at the open end of the tunnel. The array was made of 1.3-cm- (0.5-in.-) diameter black steel pipe positioned at the center of the entry. A total of four 0.3-cm- (1/8-in.-) holes were drilled into the vertical section of the pipe to sample the gases. The sample holes are equally spaced vertically from the roof to the floor. A 1.3-cm- (0.5-in.-)tube was connected to the steel pipe and led back to the control room to a set of infrared gas analyzers. The gas analyzers measure carbon monoxide (CO), carbon dioxide (CO_2) and oxygen (O_2) gas concentrations. The gas concentrations were collected every two seconds and were recorded by a computer-based data acquisition system.

The FSF was equipped with two video cameras to record the test burn. The first camera was mounted on the roof, roughly 23 m (75 ft) from the fan in the center of the roof. The video camera was connected to a video recorder and a monitor inside the control room, which gave a frontal view of the conveyor belt structure during the belt burn test. The second video camera was placed on a stand on the left side of the tunnel, when facing the open end of the tunnel, upstream from the conveyor belt structure. This camera was connected to a separate video recorder and a monitor inside the control room to view the inside of the conveyor belt drive area where the belt was ignited. The FSF has a 18,927 L (5,000 gal) closed water system that was used to supply water to the water sprinkler and deluge-type water spray suppression systems.

The conveyor belt structure is located 26 m (85 ft) from the fan and is slightly off center of the entry to allow for heavy equipment to pass on one side of the place the belting is attached. The conveyor belt structure is 15.2 m (50 ft) long and 2.2 m (7.25 ft) wide. Two-hundred-and-eight-L (55-gal) steel drums are used to simulate the head roller, drive rollers, idler roller and take-up rollers. The diameter of each drum is 0.6 m (2 ft) and each drum is 1.7 m (5.6 ft) long. On each end of the drum a steel plate is welded, with a 12.7-cm (5-in) hole cut out of the center of the drum to allow for a 10-cm (4-in.) diameter steel pipe to be inserted through the center of the drum. The 10-cm (4-in.) diameter pipe is then attached to the structure, as shown in Fig. 2. The trough idlers are 12.7 cm (5 in.) in diameter and are placed at 1.5-m (5-ft) intervals.

To ignite the belt, four sets of natural gas impingement burners connected in series were placed approximately 15 cm (6 in.) below the belt along the width of the belt next to the drive roller closest to the fan, as shown in Fig. 3. Each burner was equipped with 60 stainless steel jets and had a rated output of 44-114 kW. The ignition region was confined by metal shields on three sides, with the fourth side unshielded toward the open end of the fire tunnel to reduce the effect the ventilation may have had on the ignition process.

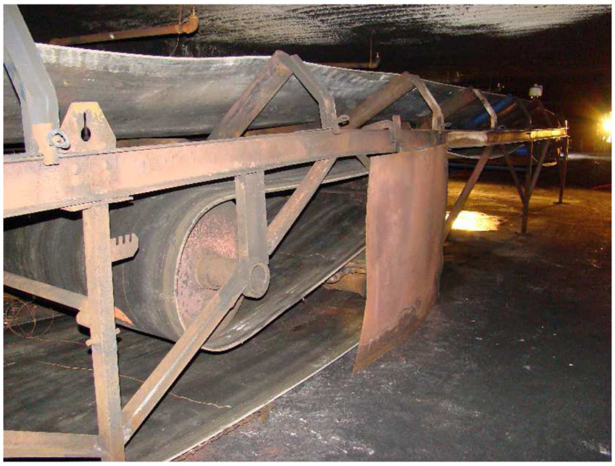


Figure 2 — 208-L (55-gal) drum as drive roller.

Figure 3 — Natural gas burners to ignite belt.

Test procedure

A 1.8-m (6-ft)-wide fire-resistant rubber belt that meets 30 CFR Part 18.65 was installed on the conveyor belt structure shown in Fig. 4. Typically, the length of the belt ranged from 42.7 to 50.1 m (140 to 165 ft). Thermocouples were installed on the belt starting from the head roller in the center and on each edge of the belt in 3-m (10-ft) intervals. Each thermocouple was placed just below the surface of the belt to measure the belt temperature. Depending on which fire suppression system was tested, additional thermocouples were placed on the sensors used to detect the fire. For example, the dry chemical fire suppression system A used three-point-type heat sensors to detect the fire, so thermocouples were placed on the end of each point-type heat sensor to determine which sensor activated the suppression system and at what temperature. In the case of the water sprinkler fire suppression system, thermocouples were placed on the sprinkler heads in the area where the fire would most likely activate the sprinkler.

To determine the air velocity for the test, a handheld vane anemometer was positioned over the top belt above the drive area in the center of the belt and approximately 0.3 m (1 ft) from the roof. Two measurements were taken and averaged together. Each measurement had to be within 10% of each other before recording the average as the air velocity. As mentioned previously, a nine-point thermocouple array was set up 46 m (150 ft) from the fan across the cross section area of the entry to measure the temperature of the air as it exited the entry. The air velocity was measured at each of the nine points where the thermocouples were located. The exit air velocities at each point were averaged together and recorded as the exit

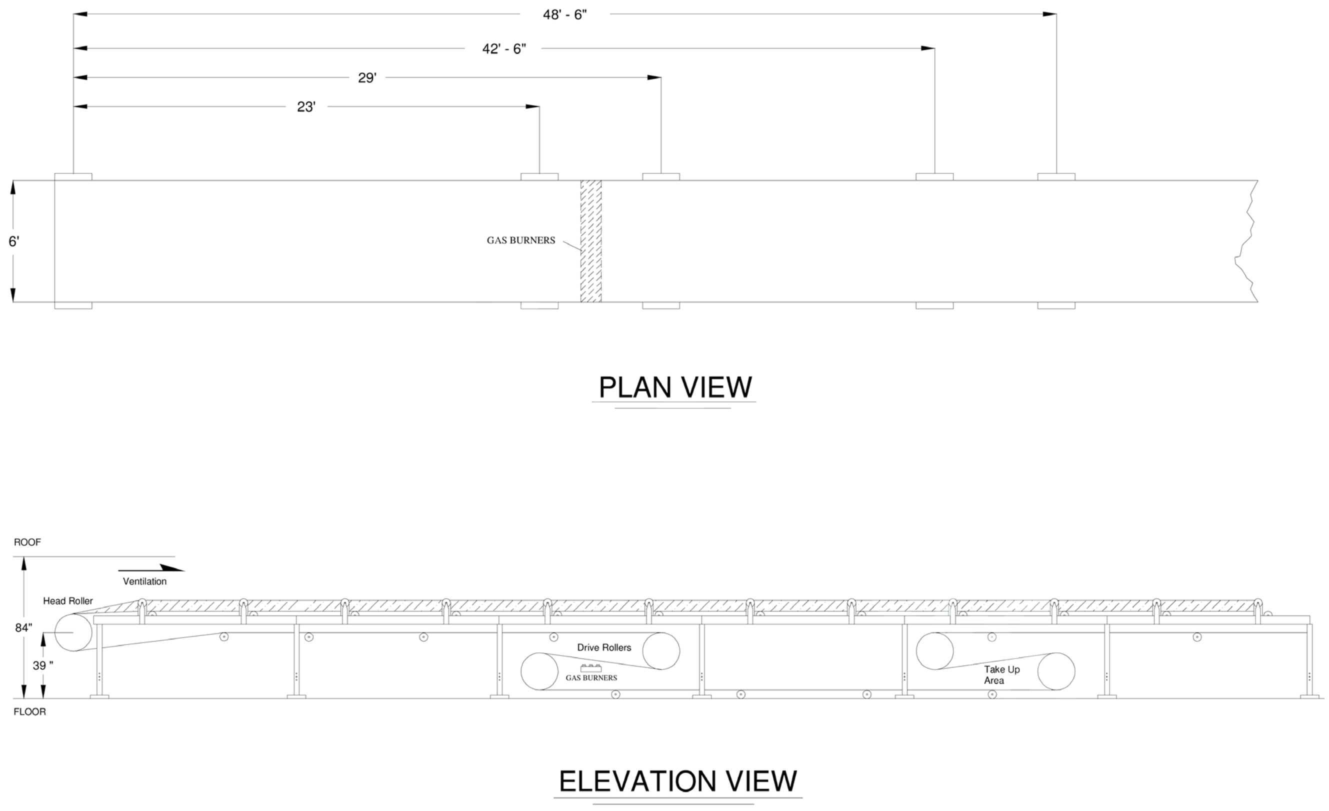


Figure 4 — Test setup.

Sprinkler Location[1]			
Nozzle	x-Coordinate	y-Coordinate	z-Coordinate[2]
1	2'-4"	72"	36"
2	2'-4"	40"	15"
3	10'-4"	72"	36"
4	10'-4"	40"	15"
5	18'-4"	72"	36"
6	18'-4'	40"	15"
7	26'-4"	72"	36"
8	26'-4"	40"	15"
9	34'-4"	72"	36"
10	34'-4"	40"	15"
11	42'-4'	72"	36"
12	42'-4"	40"	15"
13	50'-4'	72"	36"
14	50'-4"	40"	15"
15	58'-4'	72"	36"
16	58'-4"	40"	15"

[1] Measurements taken from center line of head roller and floor

[2] All odd numbered sprinklers are located along centerline of conveyor belt

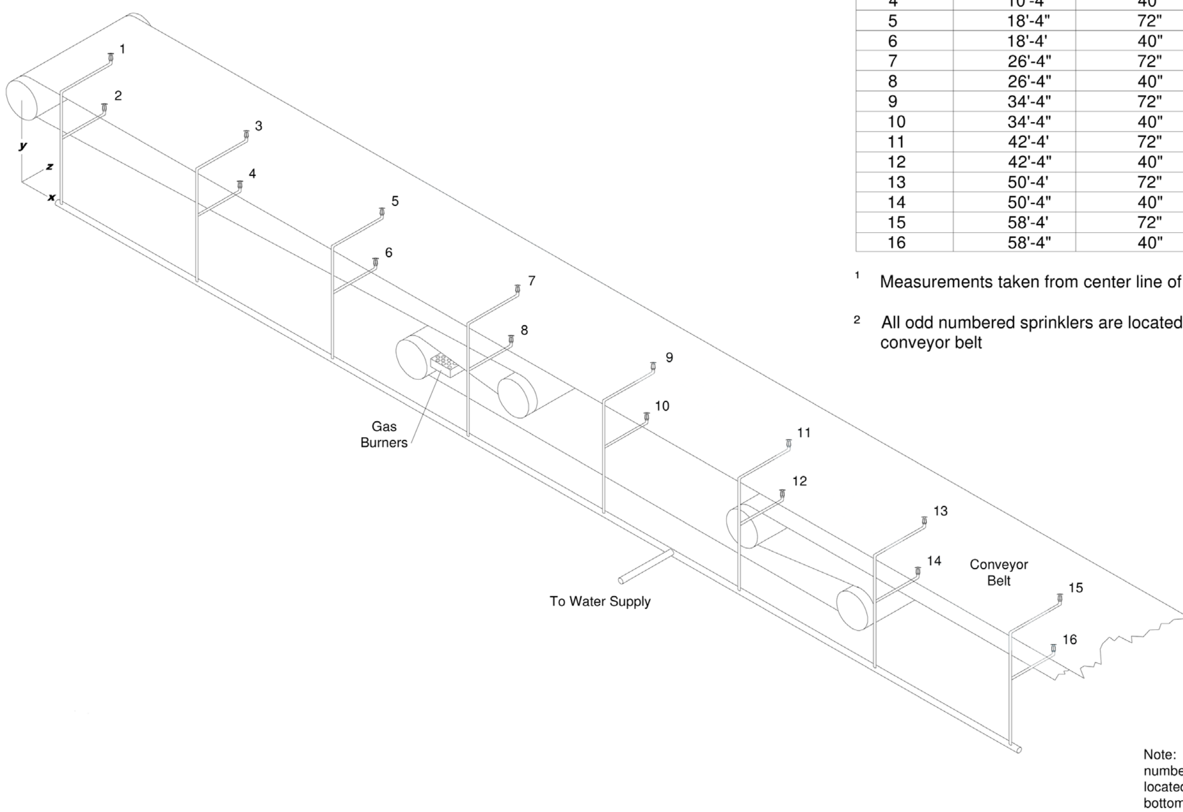


Figure 5 — Water sprinkler system.

velocity. It is important to mention that once the air velocity was determined for the test, at no time was the fan turned off or adjusted until the test was completed.

To ignite the belt, four natural gas burners connected in series were mounted about 15 cm (6 in.) underneath the belt drive roller across the width of the belt. The gas burners were ignited with a propane torch. The natural gas was left on for 10 minutes before it was turned off. Visual observation looking at the monitor in the control room or through the side window portal on the tunnel was used to determine if the belt remained ignited after the gas was turned off. If it appeared that the conveyor belt fire was not self-sustaining, the gas was turned back on to the burners until the belt was on fire and the fire was able to sustain itself. In a few cases, the fire suppression system detected the fire and activated before the end of the 10-minute ignition period. In this case, once the fire suppression system alarm sounded, the gas supply to the burners was immediately shut off.

Each fire suppression system was installed according to the manufacturer's instructions or recommendations and, as applicable, was armed before the conveyor belt was ignited. Once the fire suppression system detected the fire and was activated, the fire was monitored from inside the control room to determine if or when the fire was extinguished or under control. For the water sprinkler and deluge-type spray tests, the water was left on until it was visually determined that the fire was extinguished. Subsequent to the fire suppression test, handheld 19-L (5-gal) water extinguishers were used to extinguish the remaining fire.

Fire suppression system set installation

Four different types of fire suppression systems were evaluated in the study: a water sprinkler suppression system (Fig. 5), a deluge-type water spray suppression system (Fig. 6) and two different dry chemical powder systems (Figs. 7 and 8). The setup for the water sprinkler fire suppression system for the conveyor structure required 16 sprinklers to cover 15.2 m (50 ft) of structure. The spacing for the sprinkler was set up in intervals of 2.4 m (8 ft), in accordance with 30 CFR 75 1101-8. The reference point was the center of the head roller. The first sprinkler, which is denoted as Sprinkler 1 in Fig. 5, was located 0.70 m (2.3 ft) from the center head roller, 157 cm (62 in.) vertically from the floor and 122 cm (48 in.) over the center of the belt. The activation temperature of each sprinkler was 141° C (286° F). A thermocouple was placed on each sprinkler head to determine which sprinkler activated and the time of activation during the test.

The setup for the deluge-type water spray fire suppression system required a total of 28 nozzles to protect 15.2 m (50 ft) of belt structure. Unlike the sprinkler fire suppression system, where the sprinklers were placed over the center of the belt, the deluge-type water spray system requires 14 nozzles along one side of the structure and 14 on the opposite side of the structure. The deluge-type water spray system was set up in accordance with 30 CFR 75 1101-1. Detection and actuation of the system was achieved by five-point-type heat sensors that are strategi-

Heat Detection Sensor Location			
Sensor	x-Coordinate	y-Coordinate	z-Coordinate
A	5'-2"	48"	0
B	19'-10"	72"	7"
C	24'-5"	30"	27"
D	38'-1"	72"	7"
E	47'-9"	72"	8"

Water Spray Location*		
Nozzle	x-Coordinate	y-Coordinate
1	7'-8"	73"
2	7'-8"	53"
3	14'-8"	73"
4	14'-8"	53"
5	21'-8"	73"
6	21'-8"	53"
7	28'-8"	73"
8	28'-8"	53"
9	35'-8"	73"
10	35'-8"	53"
11	42'-8"	73"
12	42'-8"	53"
13	49'-8"	73"
14	49'-8"	53"

*Measurements taken from center line of head roller and floor

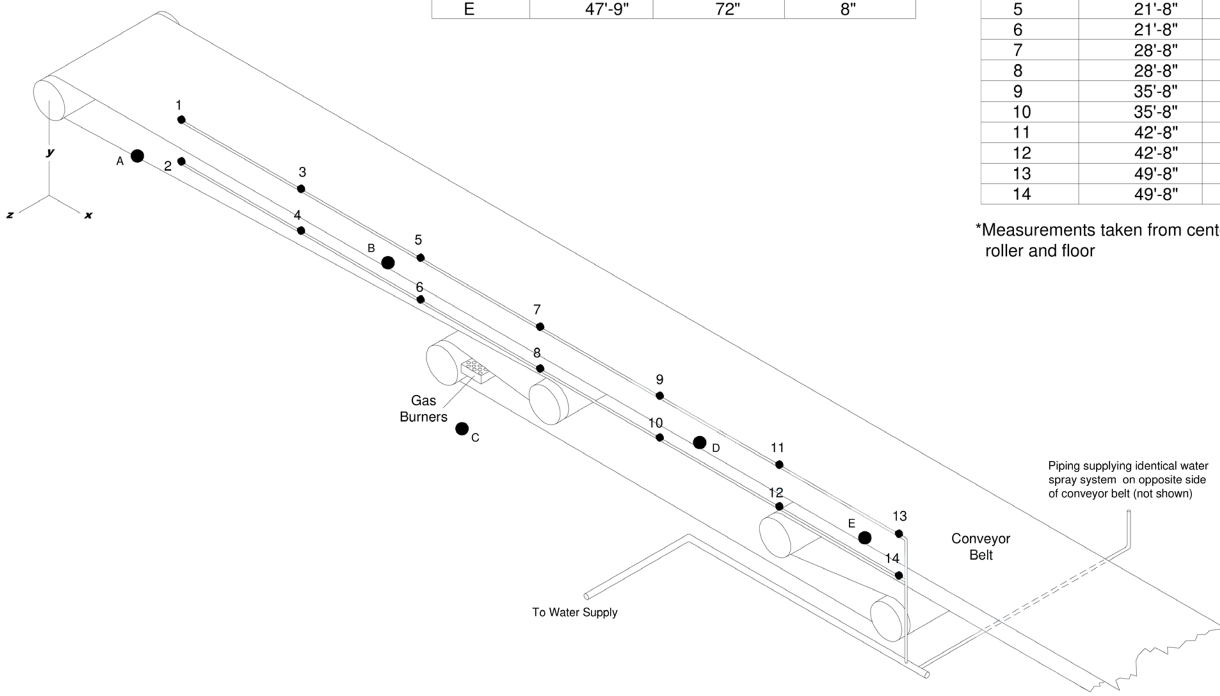


Figure 6 — Deluge water spray system.

cally placed on the structure. A thermocouple was placed on each sensor to determine which sensor activated the system. The activation temperature for the point-type sensor was 74° C (165° F). Once the activation temperature was reached by any one of the five sensors, the deluge-type valve was manually opened and water flowed to all 28 nozzles. The location and spacing of the nozzles and sensors are shown in Fig. 6.

For the dry chemical powder fire suppression system A, the manufacturer determined that a total of 40 nozzles were needed to protect 15.2 m (50 ft) of structure. Just like the deluge-type water spray suppression system, half (20) of the nozzles were arranged to protect one side of the structure and the other half (20) were arranged to protect the opposite side of the structure. The dry chemical powder used was ABC powder extinguishment agent. This system has a nominal weight of 136 kg (300 lb) of ABC powder. To activate the system, three-point-type heat sensors were strategically located on the structure. The activation temperature for each point-type sensor was 286° F. A thermocouple was attached to each point-type sensor to determine which one activated the system. Once the fire was detected and the system activated, ABC powder was simultaneously dispersed through all 40 nozzles. The location and spacing of the nozzles and point-type heat sensors are shown in Fig. 7. One important point to mention is that these systems must be designed for each particular installation. For these tests, a representative from each company designed the nozzle installation location based on this configuration setup.

For the second dry chemical fire suppression system, B, the manufacturer determined that a total of 64 nozzles were needed to protect the 15.2 m (50 ft) of structure. Just like dry chemical system A, half of the nozzles protected one side of the structure and the other half protected the opposite side of the structure. This system also used an ABC powder extinguishment agent. This system required a nominal weight of 227 kg (500 lb) of ABC powder to protect 15.2 m (50 ft) of structure in this setup. To detect that a fire was present, system B did not use point-type heat sensors, but instead used a linear heat detection wire. The wire was mounted along the outside of the structure, 183 cm (72 in.) above the ground. The activation temperature for the linear heat detection wire was 180° C (356° F). Once the fire was detected and the system was activated, ABC powder was simultaneously dispersed through all 64 nozzles. A representative from Company B designed and installed the suppression system on the conveyor belt structure. The location and spacing of the nozzles are shown in Fig. 8.

Results and discussion

The results for all tests at 152.4-167.6 mpm (500-550 fpm) are shown in Table 1, while the results from tests at 411-457 mpm (1,350-1,500 fpm) are shown in Table 2. The results of the water sprinkler suppression tests showed that for this setup, the system stopped the flames from spreading out of the drive area and suppressed the fire at both 154.2 and 167.7 mpm (500 and 1,500 fpm) air velocities. At 167.6 mpm (500 fpm), only the number 8 sprinkler, located between the belts near the ignition area, activated. At the 457 mpm (1,500 fpm) air velocity, sprinkler number 10 activated first, followed by sprinkler 8. The number 10 sprinkler most likely activated first because the higher air flow pushed the heat downstream from the ignition area, where sprinkler 8 was located. The heat release rate at the time of activation was significantly higher at the high air velocity than the lower air velocity, because more belting was involved in the fire before sprinkler 10 activated. The heat release rate is computed by the following equation:

Heat Detection Sensor Location			
Sensor	x-Coordinate	y-Coordinate	z-Coordinate
A	15'-9"	54"	3"
B	24'-6"	28"	18"
C	32'-9"	54"	3"

Dry Chemical Nozzle Location*		
Nozzle	x-Coordinate	y-Coordinate
1	1'-8"	61"
2	1'-10"	33"
3	6'-4"	61"
4	6'-6"	39"
5	11'-3"	61"
6	12'-5"	42"
7	17'-3"	61"
8	16'-7"	40"
9	22'-1"	61"
10	21'-7"	32"
11	27'-9"	61"
12	27'-2"	28"
13	32'-7"	61"
14	32'-2"	33"
15	38'-6"	61"
16	39'-1"	38"
17	44'-2"	61"
18	43'-10"	39"
19	49'-6"	61"
20	50'	34"

*Measurements taken from center line of head roller and floor

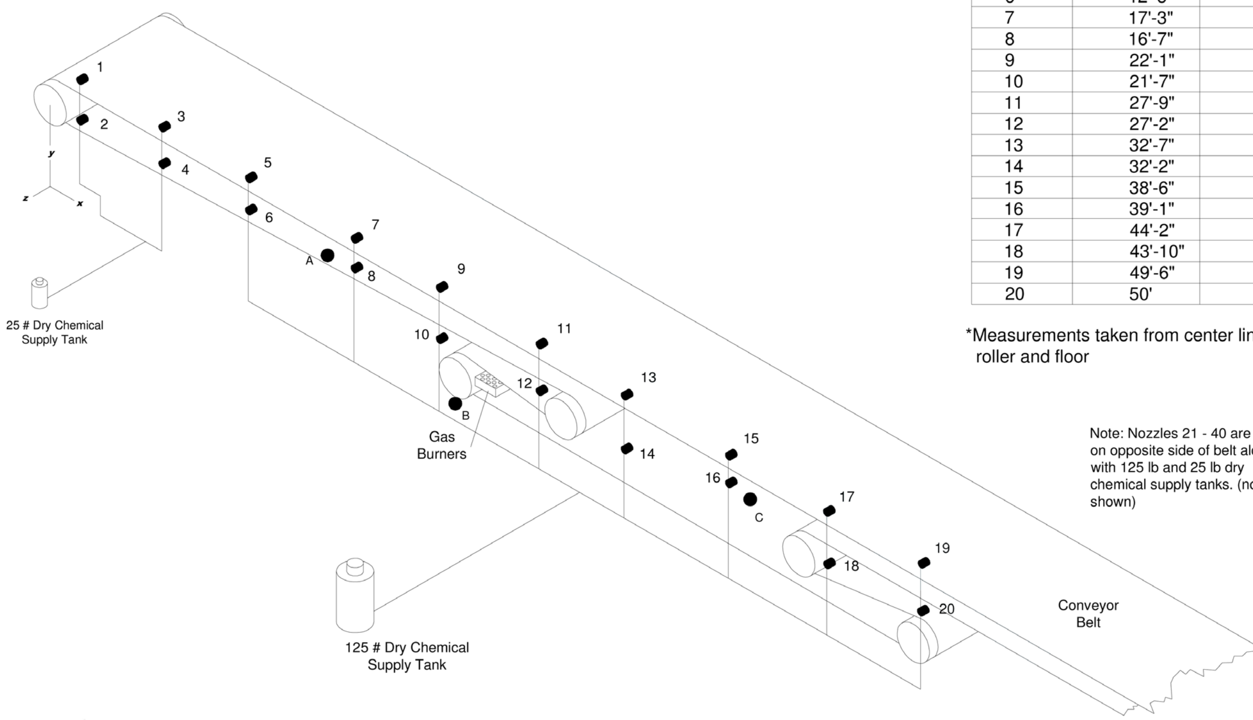


Figure 7 — Dry chemical fire suppression system "A."

$$Q_{\text{total}} = C_p \times \varrho_o \times V_e \times A_o \times \Delta T$$

where:

C_p = heat capacity of air, 1.088×10^{-3} kJ/g °C
ϱ_o = density of air, 1,200 g/m^3
V_e = air velocity, m/s
A_o = entry cross section area, m^2
ΔT = exit temperature – initial temperature, °C

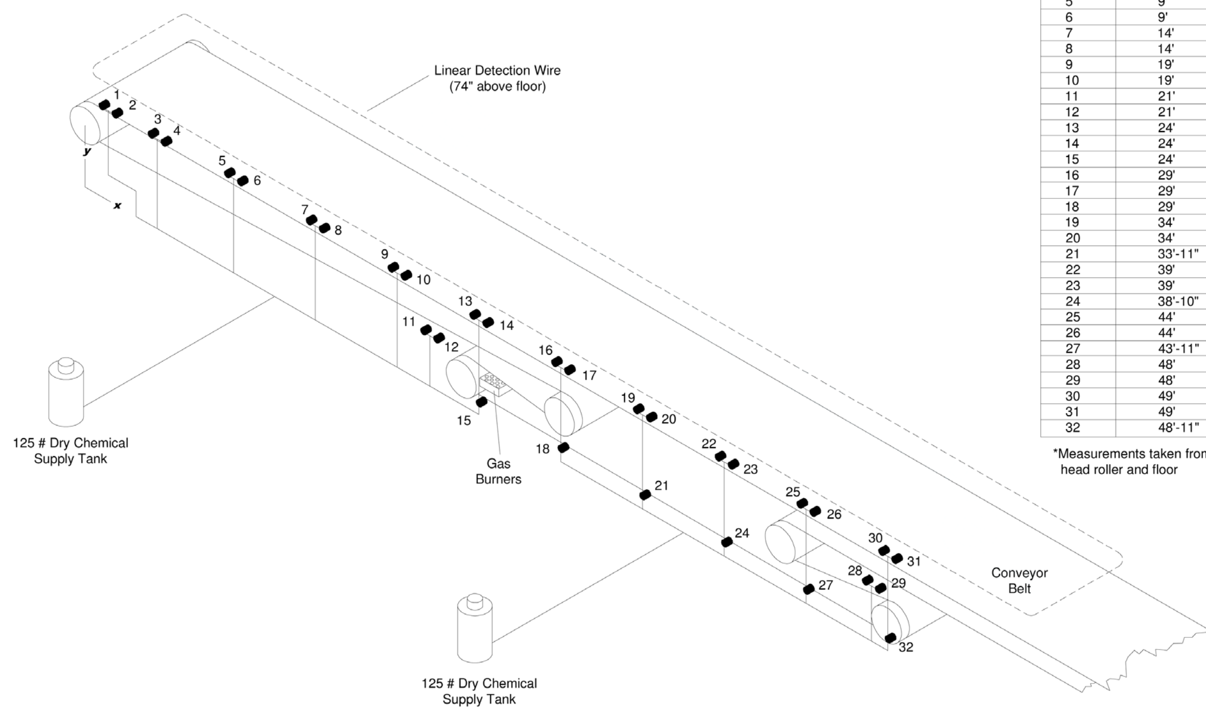
The heat release rate was calculated based on exit-gas temperatures, rather than gas concentrations, because the gas concentrations were not available for the entire test suite.

Based on previous research conducted by the Bureau of Mines, the temperature-based heat release rate calculation is typically about 50% less than the average value calculated using carbon monoxide and carbon dioxide produced from the combustion process and the oxygen consumed in the combustion process (Litton et al., 1987). This is due to heat loss to structure and the surrounding environment.

It should be noted that in this test series, the water supplying the suppression system was not turned off for 40 to 50 minutes to make sure the fire was suppressed to the point that any small residual pieces of belting that were smoldering could be extinguished with a water extinguisher. However, based on MSHA regulations, the supply of water had to be adequate to provide a constant flow of 0.95 L (0.25 gal) per minute of water for 10 minutes, with all sprinklers functioning based on 30 CFR 75 1101-8. If the water flow had been turned off after 10 minutes, the water sprinkler suppression system would not have suppressed the fire, based on visual observations.

The results of the deluge-type water spray suppression tests showed that for this configuration, the suppression system stopped the flames from spreading out of the drive area and suppressed the fire. In the lower air flow tests, point-type heat sensor D activated the system, while in the high air flow tests there were mixed results. In the first test, sensor D activated the system, while in the second test, sensor C activated the system. The heat release rates were slightly higher at the lower air velocity versus the higher air velocity. The water supply to the deluge-type water spray suppression system was not turned off for about 30 to 50 minutes. The MSHA regulations for deluge-type water spray systems require that the water supply shall be adequate to provide flow for 10 minutes, with the exception that pressure tanks may be used as a source of water supply, and shall be of 3,785-L (1,000-gal) capacity for a fire-resistant belt. Also, 11,356 L (3,000 gal) for a non-fire-resistant belt may be provided (U.S. Code of Federal Regulations 30 CFR 75 1101-3). If the water to the system had been turned off after 10 minutes, the fire would not have been suppressed.

The dry chemical fire suppression system A did not suppress the fire at either air velocity. There were two major issues with this suppression system: the time it took to detect the fire and the durability of the hoses. The delay in detection of the fire resulted in a number of the supply hoses being damaged by the fire. If the fire was detected sooner, the fire would have been smaller and, therefore, would have imposed less damage on the hoses. In both of the tests, several of the nozzles didn't disperse any dry chemical agent onto the belt because they



Dry Chemical Nozzle Location*

Nozzle	x-Coordinate	y-Coordinate
1	1'-5"	55"
2	1'-5"	55"
3	4'-5"	63"
4	4'-5"	63"
5	9'	68"
6	9'	68"
7	14'	68"
8	14'	68"
9	19'	68"
10	19'	68"
11	21'	32"
12	21'	32"
13	24'	68"
14	24'	68"
15	24'	7"
16	29'	68"
17	29'	68"
18	29'	8"
19	34'	68"
20	34'	68"
21	33'-11"	8"
22	39'	68"
23	39'	68"
24	38'-10"	8"
25	44'	68"
26	44'	68"
27	43'-11"	8"
28	48'	35"
29	48'	35"
30	49'	68"
31	49'	68"
32	48'-11"	7"

*Measurements taken from center line of head roller and floor

Figure 8 — Dry chemical fire suppression system "B."

were damaged by fire. In the lower air flow test, the nozzles that were affected were 5, 6, 7, 8, 16, 18, 19, 20, 24, 31, 33, 34, 35 and 36. As seen in Fig. 7, all of these nozzles were controlled by the two 56.7-kg (125-lb) tanks. The two 11.3-kg (25-lb) tanks functioned properly, because the entire dry chemical agent was dispersed onto the belt. In the high air flow test, there were fewer nozzles that didn't disperse compared to the low air velocity test. The nozzles affected were 22, 24, 28, 34 and 35. The main hose from the 56.7-kg (125-lb) tank on the opposite side of the structure was damaged, so that none of the dry chemical agent from that tank was discharged onto the belt. The three remaining tanks functioned properly, dispersing the dry chemical agent onto the belt. In one test at the lower air velocity, sensor B activated the suppression system, while in the other test, sensor C activated the system. At the higher air velocity, the same result was repeated, with sensor B activating the suppression system in one test, while sensor C did for the other test.

The dry chemical fire suppression system B produced mixed results. In the lower air velocity tests, the fire suppression system completely extinguished the fire. In the higher air velocity tests, the fire was completely extinguished in one of the tests, but was not extinguished in the second test. Although the fire size for the second test was much larger than the other tests, this may have been due to the wear factor of the belting (note the belting used in this study was not new and for each subsequent test the belt was replaced and not reused). Also, ambient conditions, such as air temperature and humidity, may have contributed to the differences. In the test where the fire was not extinguished, one of the tanks did not function properly, resulting in nozzles 16 through 32 not discharging any dry chemical onto the belt. It should be noted that the location of these nozzles show that this powder would not have contributed to extinguishing the fire, because the nozzles are downstream of the fire in the test setup. Unlike the dry chemical suppression system A, the hoses for the dry chemical fire suppression B were not damaged during the test. The malfunction occurred in the tank activation mechanism. The system used a linear heat detection system to activate the system. It was not possible to determine the specific location on the linear detection wire that activated the system in any of the tests.

Conclusion

Four different types of fire suppression systems were tested under two air-velocity conditions, 152.4 - 167.6 mpm (500-550 fpm) and 411 - 457 mpm (1,350-1,500 fpm). Two water-based suppression systems, a water sprinkler and a deluge-type water spray, were able to suppress the fire under the test conditions in this setup. However, the amount of water needed to suppress the fire to the point where a miner could walk up to and extinguish any smoldering belt was greater than the current MSHA regulations require. MSHA regulations only require 10 minutes of water supply to the suppression system. In the test setup, neither of these systems would have suppressed the fire had the water been turned off to the system after 10 minutes.

The two dry chemical suppression systems provided mixed results. The dry chemical fire suppression system A did not extinguish the fire in either air-velocity condition. This system

Table 1 — Suppression test results at air velocity 152-168 mpm (500-550 fpm).

	Air velocity	Total duration time of gas flow to burners	Time system activated	Fire size at activation	Results
	fpm	minutes: seconds	minutes: seconds	megawatts	
Sprinkler test 1 (1)	532	14:00	37:50	0.7	Positive
Sprinkler test 2 (2)	513	14:00	36:06	0.7	Positive
Deluge water test 1 (3)	522	15:00	33:03	1.5	Positive
Deluge water test 2	503	15:00	23:14	1.2	Positive
Dry chemical test system A Test 1	540	15:00	18:08	4.9	Negative
Dry chemical test system A Test 2	530	13:56	13:56	6.0	Negative
Dry chemical test system B Test 1	540	07:07	07:07	0.2	Positive
Dry chemical test system B Test 2	524	13:28	13:28	0.2	Positive

Positive - suppressed fire under these test conditions
Negative - did not suppress fire under these test conditions
(1) Burners turned off after 10 minutes then turned back on at the 23 minute mark for 4 additional minutes
(2) Burners turned off after 10 minutes then turned back on at the 19.5 minute mark for 4 additional minutes
(3) Burners turned off after 10 minutes then turned back on at the 18.5 minute mark for 5 additional minutes

Table 2 — Suppression test results at air velocity 411-457 mpm (1,350-1,500 fpm).

	Air velocity	Total duration time of gas flow to burners	Time system activated	Fire size at activation	Results
	fpm	minutes: seconds	minutes: seconds	megawatts	
Sprinkler test 1	1488	10:00	13:42	5.5	Positive
Sprinkler test 2 (4)	1499	13:00	34:04	2.3	Positive
Deluge water test 1	1427	12:00	20:38	2.6	Positive
Deluge water test 2	1411	15:00	20:12	1.7	Positive
Dry chemical test system A Test 1	1478	14:31	14:24	1.1	Negative
Dry chemical test system A Test 2	1494	13:01	13:01	4.4	Negative
Dry chemical test system B Test 1	1367	13:31	13:31	4.6	Positive
Dry chemical test system B Test 2	1397	15:00	19:13	10.8	Negative

(4) Burners turned off after 10 minutes then turned back on at the 18.5 minute mark for five additional minutes

uses a nominal weight of 136 kg (300 lb) of dry chemical agent and 40 nozzles to protect 15.2 m (50 ft) of fire resistant conveyor belt. The primary failure mechanism was damage to the hoses from the fire prior to system activation. Several of the nozzles in system A did not discharge any dry chemical agent, because the hoses leading to the nozzles were severely damaged by the fire. The dry chemical fire suppression system B performed well at the lower air velocity; however, at the higher air velocity, mixed results were obtained. Dry chemical fire suppression system B required a nominal weight of 227 kg (500 lb) of dry chemical agent and 64 nozzles to protect 15.2 m (50 ft) of fire resistant conveyor belt. One of the higher air velocity tests resulted in the fire not being extinguished. In addition, there was a malfunction with one of the four dry chemical supply tanks, resulting in one tank not discharging any dry chemical to the connected nozzles. This malfunction, however, would not have affected the extinguishing of the fire, because the nozzles were located outby (downwind) of the fire area.

The large-scale testing indicated that air velocity does in fact have significant effect on the detection, activation and suppression capabilities of the fire suppression system. The water-based fire suppression systems each performed well under both sets of air velocity conditions, but required more time than the 10-minute requirement in 30 CFR. The dry chemical systems, however, did not perform as well, and resulted in failure to extinguish the test fires in some experiments. Several factors may have contributed to the dry chemical system not performing well under these large-scale test conditions. The ventilation rate not only affects the discharge pattern of the dry chemical agent, but also contributed greatly to the detection and actuation of the system. The increased air velocity condition had a cooling effect on the detection systems, which would have allowed the fire to grow and propagate further before the system detected and actuated the dry chemical. The importance of early detection is imperative for any fire condition. The higher air velocity tests may have actually been larger fires by the time the system discharged, resulting in a more challenging suppression. A combination of the bigger fire conditions under high air velocity, caused by detection cooling, detection location, the transference of dry chemical by the ventilation and the overall fire suppression system design, may have impacted and affected the performance of each system. NIOSH will conduct research to improve fire suppression systems by evaluating new technologies and new designs, such as new nozzle designs, spacing of nozzles, smoke and CO sensors and system activation temperature.

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