FIRE PROTECTION FOR MINE CONVEYOR BELT SYSTEMS

by

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ABSTRACT

Conveyor belt fires can present a serious hazard in the confined environment of an underground coal mine; therefore, stringent safety measures are necessary to protect the miner. This Bureau of Mines report briefly summarizes available mine fire statistics and existing fire protection requirements that have been effective in reducing the frequency of coal mine conveyor belt fires. Results of Bureau in-house and contract research are presented to illustrate the limitation of laboratory-scale tests for evaluating the fire-resistance of various conveyor belts and to show the adequacy of the regulations for fire detection and fire suppression systems. In addition, ongoing research designed to help update the Federal Schedule 2G fire-resistance test is described.

INTRODUCTION

Mine fire statistics from 1952 through 1969 reveal that at least 15 pct of the total reported fires (877) in underground coal mines were attributable to conveyor belt ignitions. Also, as shown in table 1, nearly 70 pct (91) of the belt fires were caused by frictional heating, such as that caused by a stuck roller or snarled belt in the belt drive assembly. Since the Federal Coal Mine Health and Safety Act of 1969, the incidence of reported belt fires has reduced drastically, averaging less than two per year from 1970 through 1976. This large reduction in belt fires can be ascribed to the more conservative safety requirements promulgated by the act and specifically defined in the Code of Federal Regulations, 30 CFR 75.1100. These regulations now require that all mine conveyor belts must be fire-resistant, as defined by the Schedule 2G approval test, and that the conveyor must be equipped with a zero speed cutoff switch. Also, rigid requirements are defined for the fire detection and fire extinguishing systems. The development of better fire-resistant belting and better fire-protection hardware has also contributed to the improved safety.

TABLE 1. - Statistics of reported coal mine fires during 1952-69[1]

Location	Total fires	Electrical	Frictional	Spontaneous combustion	Injuries	Fatalities
Face area equipment	351	333	-	-	61	20
Conveyor belts....	134	27	91	-	18	11
Power cables......	112	112	-	-	13	0
Locomotives.......	38	38	-	-	3	5
Trolley wires.....	57	57	-	-	12	18
Gob areas.........	84	-	-	65	3	3
Miscellaneous.....	101	35	-	-	17	4
Total.......	877	602	91	65	127	61

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Bureau of Mines research on conveyor belts in recent years has been directed toward determining the adequacy of existing mining regulations and toward developing the required technology for implementing new or improved regulations. One area of concern is the questionable reliability of the small-scale Schedule 2G test (flame spread) to provide a sufficient margin of safety for all conveyor belting including the polyvinyl chloride type. The European community is also concerned with this problem and many rely upon a small-scale laboratory flame spread test and a drum friction test to evaluate their belts. Another area of concern are the requirements for the fire detection-extinguishing system, although the existing regulations for such systems may account for the large recent reduction in reported belt fires; the fires that are extinguished within 30 min need not be reported. This report briefly summarizes the fire protection requirements for coal mine conveyor belts and the results of Bureau in-house and contract research pertinent to this problem.

Fire-Resistance of Conveyor Belts

Fire-resistance is a relative measure of the ability of a material to resist ignition and the spread of flame and can be expected to vary with such physical variables as material dimensions, space dimensions, ignitor heat flux, air velocity, and burning orientation. The ventilation conditions in conveyor belt haulageways are generally neutral, but actual airflow requirements will depend upon how much methane is being released. In the Federal Schedule 2G test, the fire-resistance of coal mine conveyor belts is determined under laboratory-scale conditions; 1/2- by 6-inch specimens are ignited in a 21-inch cubical chamber with a Bunsen burner flame. The duration of flame or glowing combustion is noted at an air velocity of 300 ft/min. Research is underway to update this test method because the fire-resistance requirements are not sufficiently conservative, as shown later by data from larger scale testing.

Bureau Large-Scale Fire Tests

Fire-resistant-type conveyor belts include those made with neoprene, polyvinyl chloride (PVC), styrene butadiene (SBR), and combinations with natural rubber. The carcasses are generally made of nylon, rayon, cotton, or a combination of these fabrics. The materials used can be the determining flammability factor in the case of used belts.

Results of an early Bureau investigation by Mitchell, Murphy, Smith, and Pollack[2] are indicative of how much the fire-resistance of conveyor belts can vary in small-scale and large-scale fire tests under different ignition conditions. Table 2 summarizes some of the flame propagation data obtained in a 4-foot-diameter gallery with four conveyor belts, three of which were fire-resistant by the Schedule 2G test; belt width was 2-1/2 or 3-1/2 feet in most trials. These moderately large-scale data show that even approved PVC and neoprene belts can ignite and propagate flame when exposed to flame under certain heating and ventilating conditions. Here, flame propagation was attained when the flame ignition source (4,200 Btu/min) was supplemented with a thermal

[2]Mitchell, D. W., E. M. Murphy, A. F. Smith, and S. F. Pollack. Fire Hazard of Conveyor Belts. BuMines RI 7053, 1967, 14 pp.

radiation source (~1,300 Btu/min) and the airflow condition was increased from zero to 200 ft/min, above which the flow effect was small. Neoprene belts were the most difficult to ignite but their propagation rates did not differ greatly from those for PVC belting, ≤3.5 ft/min. The highest rates occurred with the nonfire-resistant rubber, particularly when the carcass was removed. Such variables as belt preheating, belt width, and coal dust-grease accumulations generally increase the fire hazard. The ability of these belt materials to sustain flame propagation was also demonstrated in full-scale fire tests in the Bureau's Experimental Mine.

TABLE 2. - Fire-resistance of conveyor belts in 4-foot diameter gallery under various airflow and ignition conditions[1]

(Belt dimensions, 15 by 3-1/2 feet)

Air velocity, ft/min	Flame propagation rate, ft/min[1]			
	Rubber	Neoprene[a]	Impregnated neoprene[a]	Impregnated PVC[a]
PREHEATING + PROPANE BURNERS (4,200 BTU/MIN) + RADIANT HEATER (~1,300 BTU/MIN)				
~0	NP	NP	NP	NP
200	7.6	2.1	3.5	3.5
500	9.8	1.8	2.1	2.7
PROPANE BURNERS (4,200 BTU/MIN) + RADIANT HEATER (~1,300 BTU/MIN)				
~0	NP	NP	NP	NP
200	4.0	1.1	3.0	3.2
500	5.6	1.2	3.3	2.0
~0, 200, 500	PROPANE BURNERS (4,200 BTU/MIN)			
	NP	NP	NP	NP

NP indicates no propagation.
[1]Bureau of Mines data from reference cited in footnote 2.
[a]Fire-resistant according to Schedule 2G.

Walter Kidde Large-Scale Fire Tests

Results of a recently completed Bureau contract[3] with the Walter Kidde Co. provide further evidence of the inadequacy of laboratory-scale fire tests. In this work, full-scale fire and suppression tests were conducted in a 6- by 15- by 175-foot simulated belt haulageway using a flame source (3,500 Btu/min) and radiation source (~8,500 Btu/min) for igniting the belts; the fire suppression tests are described elsewhere in this report. Figure 1 shows a diagram of the experimental setup used in these tests.

[3]Warner, B. L. Suppression of Fire on Underground Coal Mine Conveyor Belts (Research Contract H0122086 by Walter Kidde & Co., Inc.). BuMines Open File Rept. 27-76, 1974, 105 pp.; PB 250 368/AS; available for consultation at Bureau of Mines facilities in Denver, Colo.; Twin Cities, Minn.; Pittsburgh, Pa.; Spokane, Wash.; Department of Energy, Morgantown Energy Research Center, Morgantown, W. Va.; the National Library of Natural Resources, U.S. Department of the Interior, Washington, D.C.; and National Technical Information Service, Springfield, Va.

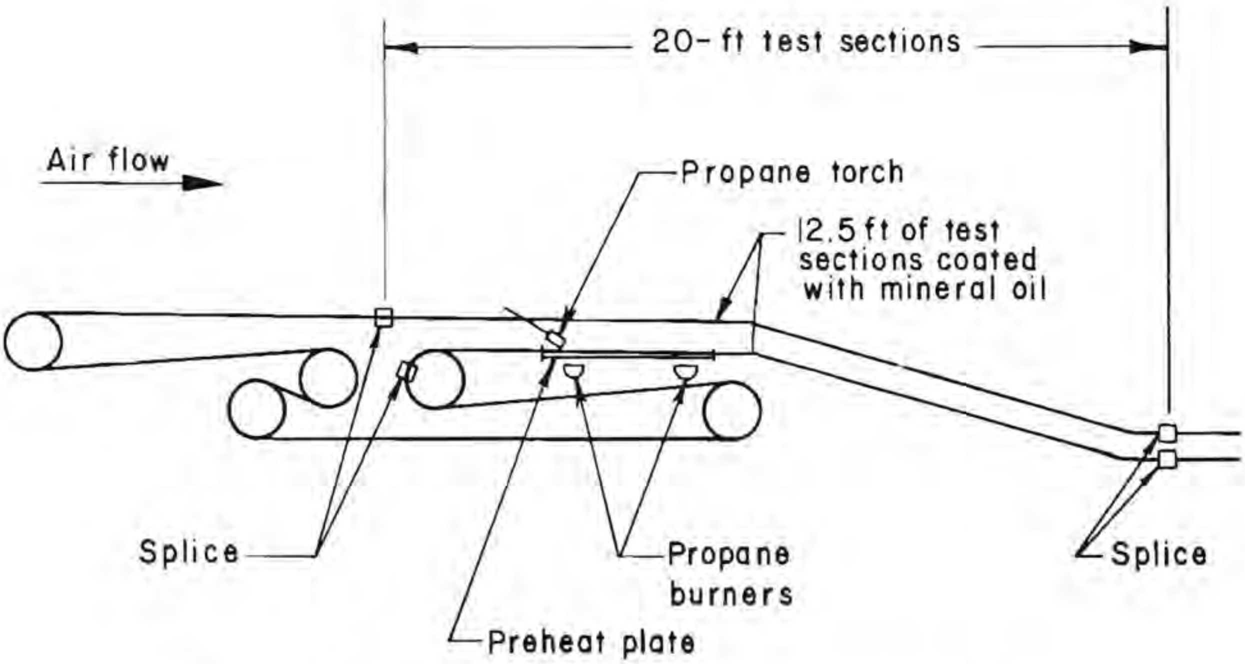

FIGURE 1. - Walter Kidde test gallery setup for conveyor belt fires.

The results of this contract study confirmed many of the trends observed in the Bureau's in-house work, including the greater ease of ignition with belt preheating and great effect of flow conditions. Table 3[4] lists flame propagation rates that were calculated from the reported data of this work for 10 of the conveyor belts evaluated. Again, it is seen that some Schedule 2G approved belts sustained propagation in large-scale fires under moderately high-flow conditions. The new PVC-3 belt gave the highest propagation rates of all the belts tested. This material had propagation rates of 5 and 6.5 ft/min at air velocities of 125 and 350 ft/min compared with only 0.8 ft/min at neutral airflow; these were obtained with a mineral oil coating. As noted in table 2, flame propagation is generally enhanced by belt coatings of mineral oil and/or coal dust; however, coal dust itself tends to have a retarding effect on ignition. Also, new belts appeared to give higher propagation rates than used belts of the same make, but belt thickness was not the same in all such comparisons.

[4]Reference to specific brands or manufacturers is made for identification only and does not imply endorsement by the Bureau of Mines.

TABLE 3. - Fire-resistance of conveyor belts in 6- by 15- by 175-foot gallery at various conditions[1]

(Belt dimensions, 20 by 2-1/2 feet. Total ignitor heat input, 11,500 Btu/min.)

	Flame propagation rate, ft/min		
Air velocity..........................ft/min..	125	200	~350
FIRE-RESISTANT BELTS[2]			
Neoprene 1 (used), B.F. Goodrich, Caricoal....	-	-	NP
Neoprene 2 (used), Acme Hamilton, Pyroprene....	-	NP (0.15)	NP
Rubber (used), Republic Rubber................	-	- (NP)	-
SBR-1 (new), Bridgestone, Nycon...............	-	0.4	-
SBR-2 (new), Goodyear, Glide 220..............	(0.25)	.6	
PVC-1 (new), B.F. Goodrich, Koroseal..........	(1.8), 0.8	.65	-
PVC-2 (used), B.F. Goodrich, Koroseal.........	(.25)	NP (.6)	-
PVC-3 (new), Scandura, Gold Line..............	(5.0)	.9	(6.5)
PVC-4 (used), Scandura, Gold Line.............	(.4)	-	-
NONFIRE-RESISTANT BELT			
Rubber (new), B.F. Goodrich, medium longlife..	(1.4), 1.9	-	-

NP indicates no propagation; values in parentheses obtained with mineral oil and/or coal dust on belts.
[1]Calculated from data of reference cited in footnote 3.
[2]Fire-resistant according to Schedule 2G.

The PVC-3 belt material produced the most intense fires in the gallery full-scale tests. As shown by the temperature profiles in figure 2, the maximum roof temperatures exceeded 1,000° F, and these occurred near the area of ignition where the initial 5 feet of belt was preheated. With a mineral oil coating, the PVC-3 belt fires propagated over the entire belt test section (20 feet) in as little as 3 min after ignition with a 350-ft/min airflow, and within 25 min with the neutral flow condition. Although the fires are spread more rapidly with increasing air velocity, one can expect ignition itself to be increasingly more difficult because of flame instability and convective heat loss.

Schedule 2G results for conveyor belts are less conservative than those from large-scale fire tests because the laboratory-scale method uses marginal heat source conditions for ignition, and the belt dimensions are not optimum for sustaining flame propagation. Furthermore, the specified air ventilation rate (300 ft/min) for the small-scale fires can result in flame blow-out in some cases. Such deficiencies, as well as the lack of quantitative fire-resistance ratings, need to be rectified to make the approval test more reliable and useful.

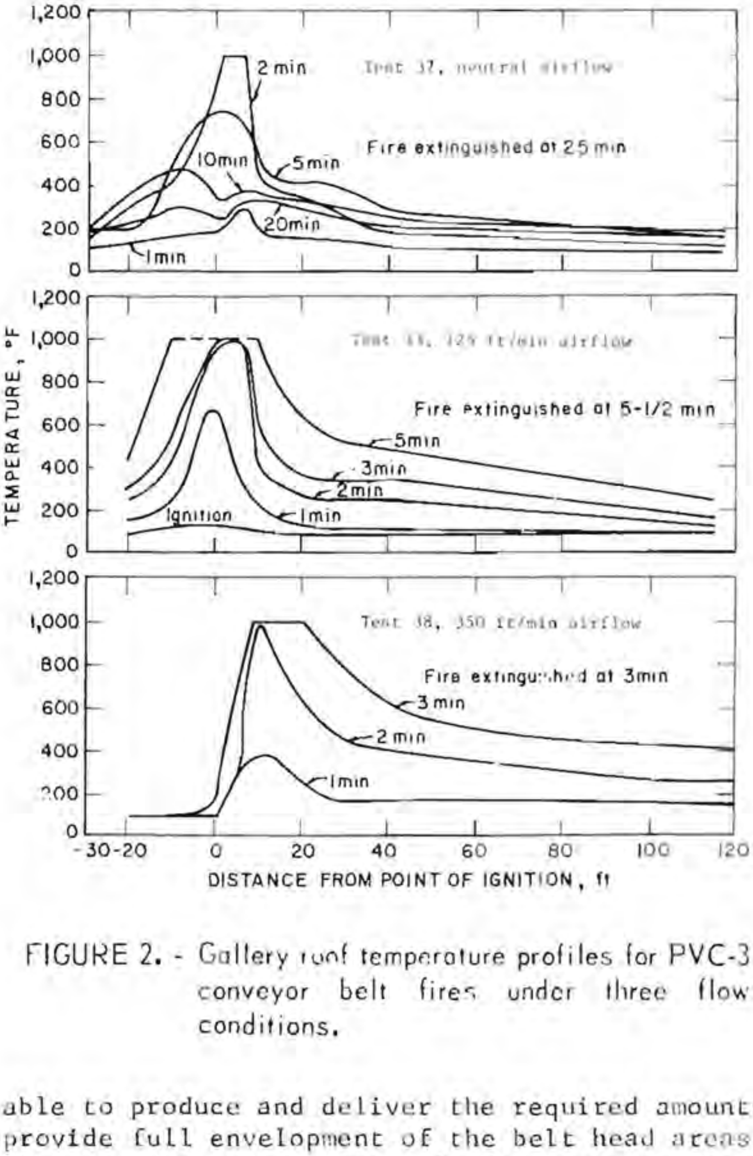

FIGURE 2. - Gallery roof temperature profiles for PVC-3 conveyor belt fires under three flow conditions.

Suppression of Conveyor Belt Fires

Present coal mining regulations (30 CFR 75.1101) require that suitable automatic fire-extinguishing systems be installed at main and secondary belt-conveyor drives and they must provide protection over a belt distance of at least 50 feet. The requirements specified for an automatic water sprinkler- or deluge-type system include an application rate of not less than 0.25 gal/min/ft^2 on the upper surface of the top belt, adequate coverage between top and bottom belts, a maximum spacing of 8 feet for spray nozzles or sprinklers along branch lines, and a sufficient water supply to provide a 10 min flow. Foam and dry powder chemical systems may also be used if they are capable of providing the minimum fire protection requirements defined in the regulations. The foam-generating system must be able to produce and deliver the required amounts of foam within 5 min, it must provide full envelopment of the belt head areas and adjacent belting up to 50 feet, and it must maintain the water or foam flow for at least 25 min. Each dry powder system that is required must contain a minimum of 125 lb of multipurpose dry powder and it must be capable of discharging all the powder within 1 min. Only extinguishing agents that would not create a serious toxic hazard to the miner are acceptable. As a backup system, waterlines are required along the entire length of the conveyor belts with fire hose outlets at 300-foot intervals and with a capability of discharging 50 gallons of water per min at 50 lb/in^2 nozzle pressure. Where applicable, the regulations incorporate National Fire Protection Association recommendations for the installation of fire control components, namely those approved by the Underwriters Laboratories or Factory Mutual Research Corp.

The mining regulations for conveyor belt fire-suppression systems are necessarily based upon simulated full scale studies and practical experience. An evaluation of the existing regulations for water sprinkler, high expansion foam, and multipurpose dry powder systems was conducted under the Walter Kidde contract sponsored by the Bureau of Mines. Fire detection systems were also evaluated and are discussed later; water deluge systems were not evaluated because the criteria for water sprinkler systems would also apply to the former. The experiments were conducted in the previously described fire test gallery using the same simulated belt haulageway (fig. 1) and ignitor conditions as in the fire-resistance tests; air velocity was 125 or 350 ft/min in most trials. The test fires were produced by burning the polyvinyl chloride (PVC-3) or nonfire-resistant rubber belting listed in table 3.

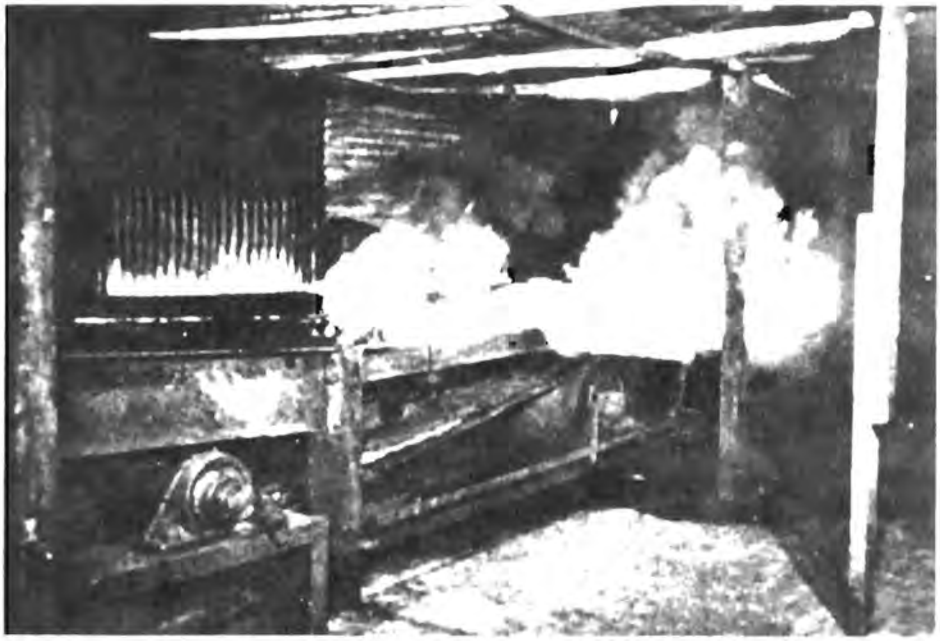

FIGURE 3. - PVC-3 conveyor belt fire prior to actuation of automatic sprinkler system at 350 ft min air velocity.

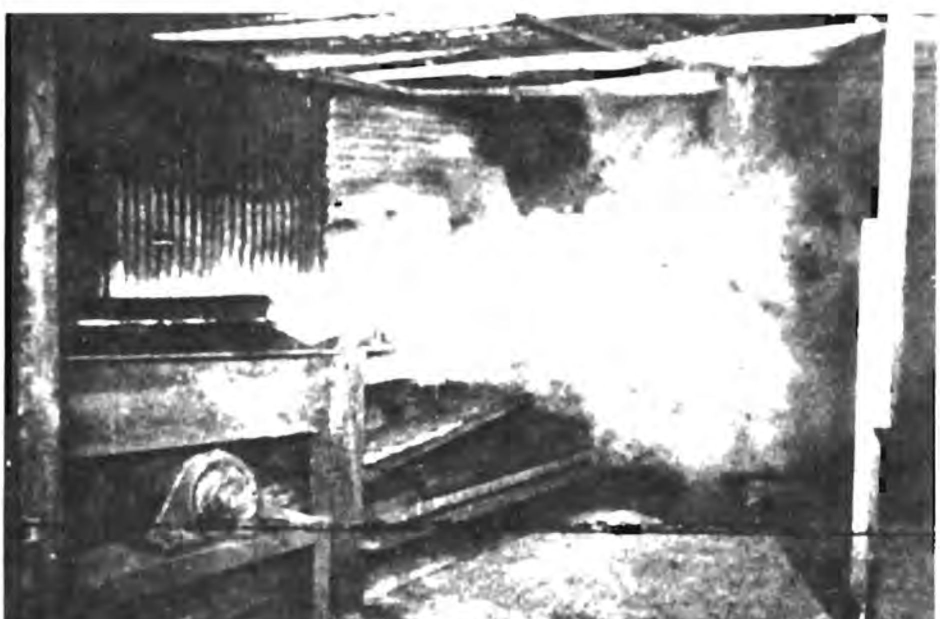

FIGURE 4. - Action of automatic sprinkler system in PVC-3 conveyor belt fire at 350 ft min air velocity.

Automatic Water Sprinklers

The sprinkler system in the gallery consisted of a 2-inch main at the roof with 1/2-inch branches that were fitted with sprinkler heads and spaced at intervals of 8, 10, 12, and 15 feet over the conveyor belt. Each sprinkler head was equipped with a fusible link that was actuated at 165°, 212°, or 280° F. Figures 3-4 show a typical conveyor belt fire before and after actuation of the sprinkler system with 10-foot spacing of the sprinkler heads; here the air velocity was 350 ft/min and extinguishment occurred within approximately 15 min. Sprinkler spacing appears to be one of the most critical variables in determining the system effectiveness.

Test results indicated that a single overhead branch line with 1/2-inch orifice sprinklers located on 10-foot centers and with actuation temperatures between 200° and 300° F can be adequate for suppressing conveyor belt fires in most situations; also, the residual water pressure may be as low as 10 lb/in^2. An exception to these results is that observed at high air velocities (for example, 350 ft/min) which tend to delay sprinkler actuation because of the cooling effect. To cover such situations, the actuation temperature should be no higher than 225° F, or the sprinkler spacing should be no greater than 8 feet, the maximum distance specified in the present regulations. The lowest practical actuation temperature should be used because it is more difficult to extinguish fully developed fires.

In these experiments, the fires were controlled with a spray application rate of 0.72 $gal/min/ft^2$ on the top surface of a 30-inch-wide belt. This rate would correspond to 0.36 $gal/min/ft^2$ for a 60-inch-wide belt that meets the minimum spray requirement ($\sim$0.25 $gal/min/ft^2$) in the mining regulations for the upper surface of a top belt. Although only overhead sprinkler heads appeared to be necessary in these tests, early Bureau work[5] demonstrated the need for sprinklers between belts, which are also required in existing regulations.

Automatic sprinkler systems are advantageous because of economy, reliability, good suppression capability, moderate water requirements, and minimum maintenance requirements. Also, they are not dependent upon a separate detection system, and the independent actuation of each sprinkler head provides a safeguard against the failure of a given sprinkler. Their primary disadvantage is that they are not practical at freezing temperatures.

High Expansion Foam

A foam generator with a rated capacity of 5,000 ft^3/min was used to produce high expansion foam (~1,000:1) for the fire suppression tests (fig. 5). The unit was located on the air intake side, and it was capable of filling approximately 50 feet of the simulated haulageway (6 by 15 feet) within 1 min. Actuation time for the foam system was generally set for 2 min after ignition.

High expansion foam is effective for extinguishing belt-head fires, as evidenced by its performance in the present tests where the fires were rapidly quenched after they became enveloped by the foam. A foam generation rate of 10 ft/min in a belt haulageway was sufficient for extinguishment of such fires. Although the effect of preburn time was not evaluated, adequate protection seems to be possible with as little as 50 to 100 gallons of water. Since higher rates than 10 ft/min are readily achieved, the regulation requirement

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[5] Reference cited in footnote 2.

FIGURE 5. - High expansion foam overflowing from test gallery.

of enveloping 50 feet of conveyor belting within 5 min is not unreasonable. Also, if the 25-min operation requirement is satisfied, this provides increased belt coverage and greater assurance of extinguishment.

The main advantages of the foam system are rapid fire suppression and low water requirements. The disadvantages include slow delivery rate, increased maintenance requirements, and potential development of gaps at the roof of the haulageway because of ventilation effects particularly at high air velocities (for example, 350 ft/min).

Multipurpose Dry Powder

The dry powder system utilized an ABC multipurpose powder (monoammonium phosphate) that was contained in a 150-lb extinguisher pressurized to 350 lb/in^2. The system provided coverage for 50 feet and consisted of branches on either side of the belt drive and takeup sections (see fig. 1), and along one side of adjacent belting beyond the takeup assembly. Nozzles were arranged to provide a powder discharge onto the top surface of the top belt and between the top and bottom belt layers. To simulate worst case conditions, the belt

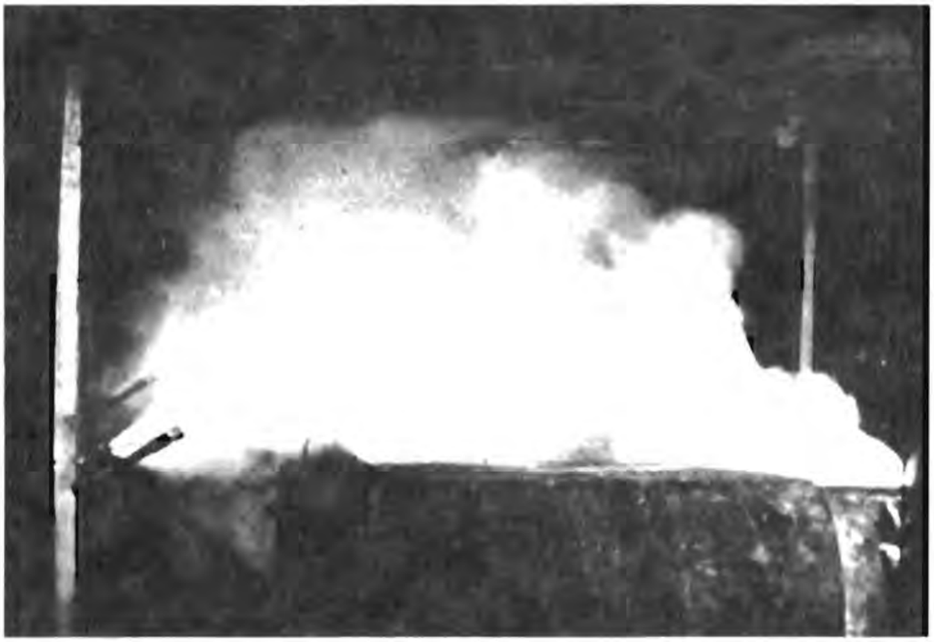

FIGURE 6. - PVC-3 conveyor belt fire prior to actuation of multi-purpose dry powder (ABC) extinguishing system at 350 ft/min air velocity.

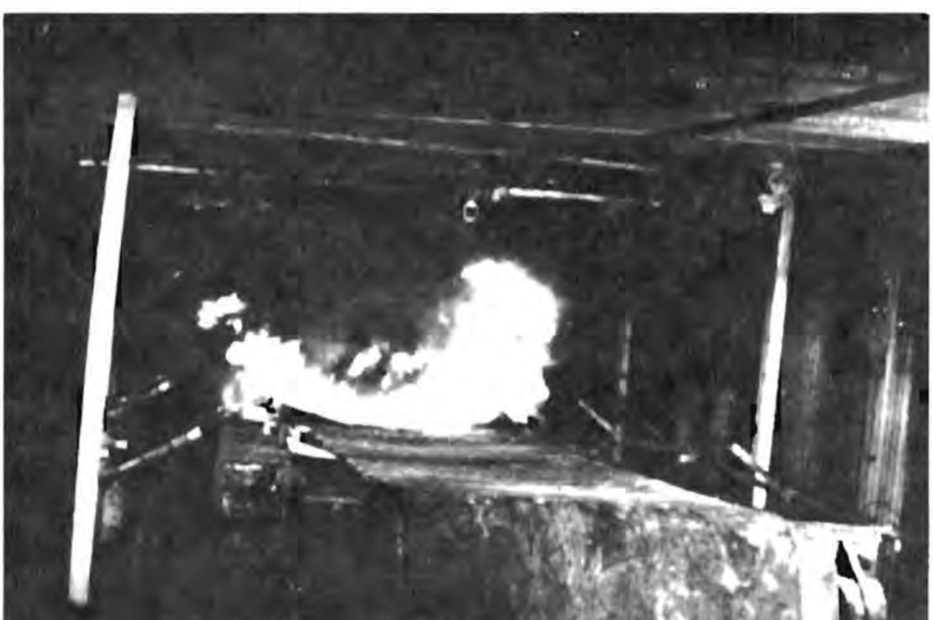

FIGURE 7. - Action of dry powder (ABC) extinguishing system in PVC-3 conveyor belt fire at 350 ft/min air velocity.

fire was allowed to progress until a belt layer had burned through and separated. Figures 6-7 show a belt test fire before and after actuation of the extinguishing system with 50 lb of powder and an air velocity of 350 ft/min.

As with high expansion foam, extinguishment with the dry powder system is rapid. Generally, extinguishment occurred within the discharge time, which was less than 1 min as required by regulation. The most important design consideration is powder distribution to insure adequate belt surface coverage. All belt fires, except those involving decking on the conveyors, were extinguished with 75 lb of powder or less, indicating the currently specified requirements in the regulations are satisfactory. Each dry powder system should be individually designed to provide the proper dispersion and distribution of agent along the conveyor belt system and to overcome any limitations due to shielding by decking, conveyor structure members, or other obstacles.

The advantages of the dry powder system are primarily its suppression effectiveness and capability for low temperature applications. Its disadvantages include powder distribution problems, increased maintenance requirements, and potential reignitions because of little cooling capability.

Fire Warning Systems

Regulations (30 CFR 75.1103) require that a fire sensor system be installed on each coal mine belt conveyor to stop the belt drive and provide an automatic warning, both audible and visual, when a belt fire occurs. Point temperature rise sensors are one recommended type. The sensors must be installed at the beginning and end of each belt flight, at the belt drive, and in maximum increments of 125 feet along each belt flight (50 feet where the ventilation rate is >100 ft/min). Sensors responding to radiation (ultraviolet, infrared), smoke, combustion product gases, or other indications of fire may also be used if they are spaced at proper intervals and if they provide protection equivalent to the thermal point-type sensors. Where applicable, appropriate measures must be taken to protect against loss of effectiveness caused by dust, dirt, or moisture.

Of the various types of fire detectors examined in the Walter Kidde program, the thermal point- and thermal continuous-types were found to be suitable for the mine conveyor belt application. Most are adequately sensitive for early fire detection and sufficiently durable to withstand the mine environment; also, they are relatively economical and simple to use. For belt fires with temperature histories as shown in figure 2, detection by the thermal point-type sensors can be expected to occur within 2 to 4 min; the models in the 135° to 160° F range appeared to be adequate for detector spacings up to 60 feet. In comparison, the thermal continuous-type sensors are somewhat more sensitive and can be suitable at higher temperature ratings for signaling an alarm.

Products of combustion-type detectors are less practical than the thermal-type because of their vulnerability to dust. Both ionization- and photoelectric-types displayed high sensitivity to early fire products but did not perform reliably in dust-laden air such as that possible from rock dusting operations. Smoke or combustion products from areas other than the belt haulageways could also lead to false actuations of the extinguishing system with these detectors; the same limitation applies to carbon monoxide detectors. Spacing requirements for such detectors would necessarily depend upon the ventilation rate and the time within which the detector should operate.

Optical-type detectors also have rapid response capability, but their effective range appears to be too limited for the conveyor belt application. The normal settings of most UV and IR detectors would limit their use to about 20 feet, and this assumes no gross dust obscuration or shielding by any obstacles. Furthermore, the detectors must be insensitive to extraneous light sources and the costs may be prohibitive.

Current Fire Research on Conveyor Belts

Because of the inadequacies of the Schedule 2G fire-resistance test, the Bureau recently initiated research to assist MESA in updating this approval test for conveyor belts. As part of this effort, full-scale fire tests are being conducted with various conveyor belts in a fire test gallery that was constructed for the Bureau by the Factory Mutual Research Corp. Results from this test program are intended to provide necessary design data for developing a reliable, laboratory-scale, fire-resistance test.

Figure 8 shows the fire test gallery, which is T-shaped, with each section measuring 8 by 8 by 150 feet, and with part of one section having a 12-1/2° slope. The test belts are mounted on a conveyor belt-type frame and ignited to simulate various mine fire conditions by varying the belt width, air velocity, burning angle, preheating time, ignitor heat flux, and coal dust-grease or oil accumulation. Both fire-resistant and nonfire-resistant belts are being investigated. Their fire-resistance is determined from measurements of flame spread rates, propagation distances, gallery temperatures, and the heat flux at various stations. Based upon the full-scale fire

FIGURE 8. - New fire test gallery at Factory Mutual Research Corp. test site.

data, a laboratory-scale, flame spread-type apparatus will be designed to provide fire-resistance ratings for conveyor belts that can be correlated with mine fire situations. The test method is being designed to provide quantitative ratings and to discriminate between low, moderate, and high fire-resistant materials. The Bureau is conducting the laboratory-scale study under an in-house project of its Fires and Explosions Group at Bruceton, Pa.

The toxic products formed by conveyor belts are also to be determined in the full-scale fire tests. These will include such gaseous products as HCl, NO_x, CO, and CO_2. These data will be compared with those obtained in laboratory-scale studies under an ongoing contract with Ultrasystems, Inc.[5]

Results to date from the full-scale fire tests indicate that the most important variables are the air ventilation rate, ignitor heat flux, and the distance between the belt and the roof of the simulated mine entry. An air velocity of approximately 200 ft/min and an ignitor heat flux of at least 6,000 Btu/min (8 ft^2 belt surface) appear to be required for any noticeable flame spread of fire-resistant conveyor belts. Furthermore, the spread of flame is much greater when the belt is mounted nearer to the roof than to the floor of the entry. This information is being used to design the initial prototype of a laboratory-scale fire-resistance test for conveyor belts. Final design of the prototype test apparatus will necessarily depend upon the determination of a realistic mine fire situation.

[5] Paciorek, K. L., R. H. Kratzer, J. Kaufman, and J. H. Nakahara. Coal Mine Combustion Products Identification and Analysis (Research Contract H0133004 by Ultrasystems, Inc.). BuMines Open File Rept. 8-74, 1973, 158 pp., PB 226 944/AS; BuMines Open File Rept. 32-76, 1975, 158 pp., PB 250 527/AS; available for consultation at Bureau of Mines facilities in Denver, Colo.; Twin Cities, Minn.; Pittsburgh, Pa.; Spokane, Wash.; the National Library of Natural Resources, U.S. Department of the Interior, Washington, D.C.; and National Technical Information Service, Springfield, Va.

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