FIRE PREVENTION IN THE MINING INDUSTRY

Testing of fire-resistant conveyor belting

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ABSTRACT

The fire resistance of several mine conveyor belts is evaluated using a new belt-flammability apparatus developed by the U.S. Bureau of Mines. The test apparatus, experimental details and a calculated flammability index (FI) are described.

The FI values are useful for ranking the fire resistance of mine conveyor belts. Values are determined using parameters readily measured with thermocouples, high-temperature flow probes and a methane-oxygen torch, all of which are components of the Bureau's new test apparatus. The FI varies directly with the flame-spread rate and the rate of heat release during burning and varies inversely with the critical (minimum) ignitor energy output.

The fire-resistance ranking of nine different belt types using this moderately scaled apparatus is compared with available full-scale data on belt fires. This comparison shows that the ranking based on the FI is consistent with the full-scale data.

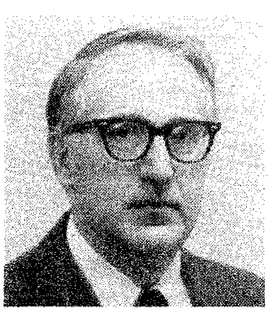
Introduction

Full-scale fire hazard evaluations of mine conveyor belts are not easily related to the properties usually measured in small-scale flammability tests. The inadequacy of small-scale belt fire tests has been demonstrated in works by Mitchell(1), Warner(2) and Reinke(3).

Mitchell and Warner showed that certain neoprene (NP) and polyvinyl chloride (PVC) belts, which had been approved by the Code of Federal Regulations(4) 30 CFR 18.65, were nevertheless capable of propagating flame over their entire length when full-scale fire conditions were simulated. Comparable results were also observed by Reinke at the Tremonia experimental mine in Dortmund, West Germany, where all belts burned in full-scale tests even though they passed the small-scale tests(3). Only by reducing the severity of the full-scale test could these fire-resistant belts be grouped on a pass-fail basis.

The fire resistance test described here was developed to overcome some of the limitations of small-scale tests and to provide quantitative ratings that can be correlated with practical fire situations. It features an approximately one-fifth-scale apparatus to permit measurement of combustibility properties during both the ignition and flame propagation stages.

The conveyor belts examined in this work included several fire-resistant types and one non-fire-resistant type. Table 1 lists the various belts tested. Except for the non-fire-resistant rubber belt, all belts met the fire-resistance requirements specified in 30 CFR 18.65(4).



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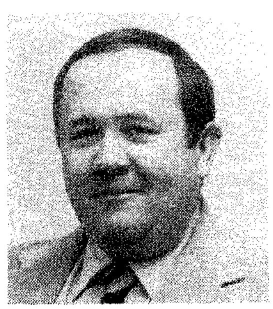

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Keywords: Conveyor belts, Belt conveyors, Fire resistance, Flammability index, Ignitors, Flame spread.

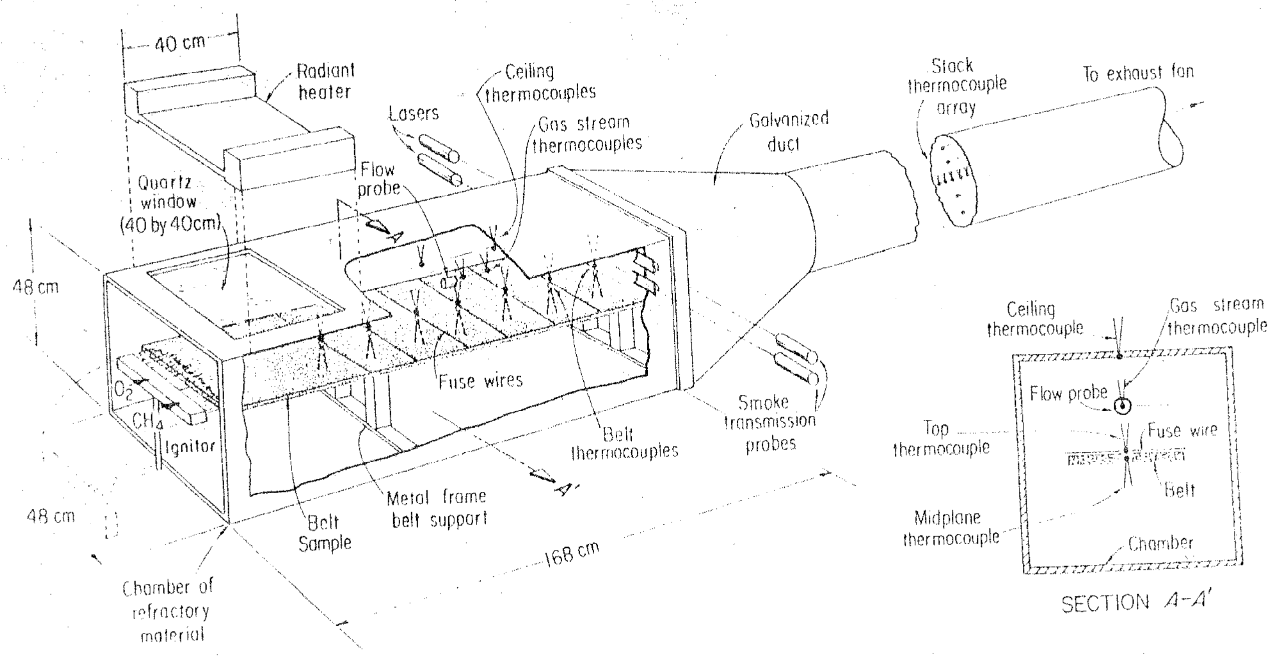

FIGURE 1. Schematic of belt flammability apparatus.

TABLE 1. Description of tested mine conveyor belts

Cover	Ply	Vendor	Trade name/code
Polyvinyl chloride (PVC):			
A-PVC	Cotton-nylon	Fenner America	Fennaplast/S-1942
B-PVC	Polyester	Scandura	Goldline II/Type 3500
C-PVC	Polyester	Georgia Duck	PV 500 A[1]
D-PVC	Polyester-cotton, nylon-rayon	Clouth (West Germany)	Duoply/630-2
Neoprene (NP):			
A-NP	Nylon	Goodyear	Mesa-N/804142
B-NP	Nylon-polyester	Goodyear	Mesa-R/804242
C-NP	Nylon-cotton, nylon-rayon	Clouth (West Germany)	Duoply/E630-2
Styrene butadiene rubber (SBR):			
A-FRR (fire resistant)	Nylon	Goodyear	Glide Mesa SBR/2126
B-NFRR (non-fire resistant)	Nylon	Goodyear	Plylon/315

[1] Formulated to meet Canadian specifications.

Experimental Apparatus and Procedure

Flammability Apparatus

The test apparatus (Fig. 1) was essentially a scaled-down version of a horizontal fire gallery with radiant panels over the ignitor zone. The test chamber was 48 by 48 by 168 cm and was equipped with an adjustable stainless steel rack for mounting the belt samples. Other components of the apparatus included an air ventilation system, a radiant panel for preheating the belt, a methane-oxygen ribbon burner for igniting the sample, and instrumentation for measuring air velocities, air and belt temperatures, flame spread rates, heat release rates and relative smoke densities. The radiant panel was 40 cm square and consisted of three infrared heaters capable of producing heat fluxes of up to 42 kW . m^{-2} over the belt section being ignited. The ribbon burner had a base cross section of approximately 1 by 15 cm and provided a flame that impinged upon the leading edge of the belt and extended approximately 8 cm over the top surface; the burner output was less than 7 kW in these experiments. Full apparatus details are given in reference 5.

Calibration of Ignitor

The methane-oxygen burner was calibrated based on the heat [illegible] the belt, using a total heat flux calorimeter. the belt and decayed exponentially to approximately 0.63 kW · m^{-2} at 20 cm downstream. Data regression gave the following relationship:

$$Q_{ign} = 170 \exp(-0.277x) \qquad (1)$$

where Q_{ign} is the heat flux in kilowatts per metre squared and x is the distance in centimetres from the end of the belt surface. From this relationship, it was calculated that 90 per cent of the total heat received by the top surface of the belt was concentrated over a distance of 8.2 cm from the upstream end. These calculations indicated that a mean heat flux (Q_{ign}) of 67 kW · m^{-2} was received by the belt at an ignitor input of 3.5 kW. This value did not include the small amount of ignitor heat that was delivered to the bottom surface of the belt, which was estimated to be less than 10 per cent of the total input.

Test Procedure

To conduct an experiment, the air flow was set at the desired rate, and the infrared preheaters were turned on for 15 min. The burner flame was then applied to the belt, and the radiant panel was usually turned off. At the end of this ignition period, the burner was removed, and the sample was allowed to burn until the belt flame either self-extinguished or burning was indicated at the last thermocouple. If the sample ignited, the ignition process was repeated using shorter times until no [illegible] The critical time thus determined was used

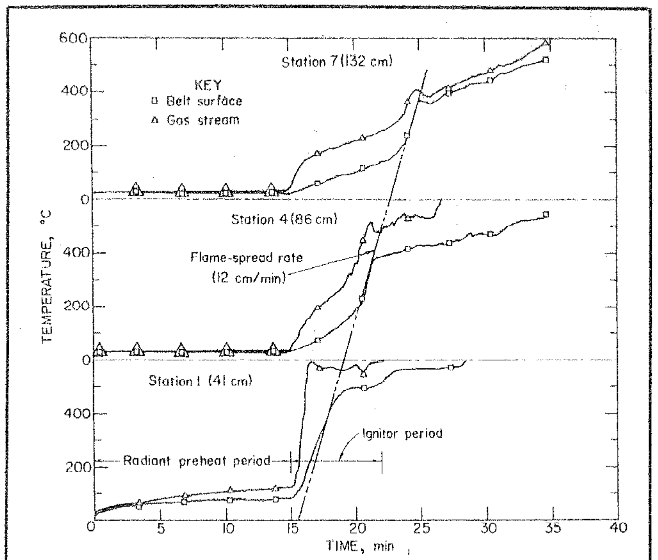

FIGURE 2. Temperature history of A-PVC belt at three stations.

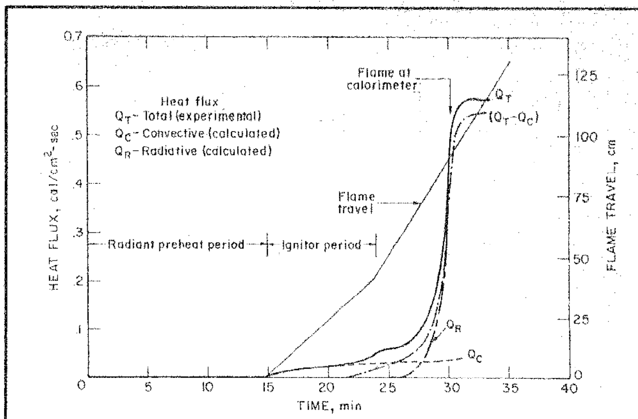

FIGURE 3. Heat flux 90 cm from end of A-NP belt using standard conditions.

to define the minimum ignitor input (I) sufficient to initiate burning. Ignition periods of up to 1 hour were necessary for some samples. Overdriving the ignitor energy input resulted in faster flame spread rates.

Belt and chamber temperature were continuously recorded throughout each test at evenly spread stations along the belt. Typical temperature histories of the belt surface and gas stream are shown in Figure 2 for the PVC belt at an ignitor input of 3.5 kW. These data were obtained at three of the eight equally spaced monitoring stations at 41, 86 and 132 cm from the ignited end of the belt.

The sharp rise in temperature at about 200°C for the belt-surface thermocouples (Fig. 2) can be considered as the piloted ignition point for this belt and is designated T_i in subsequent calculations. The lowest gas or belt-surface temperature at which stable propagation could occur (T_f), about 450°C, was recorded at station 7 (or 4) at about 2 min after the ignitor period.

Smoke transmission measurements were taken continuously, but the values used for calculations were determined when the flame arrived at the last station, which was just before the smoke probe. The temperature and smoke-transmission measurements are used in subsequent calculations.

Effects of Test Variables

The effects of test variables were determined using a moderately fire-resistant belt (A-PVC; as shown in Table 1). The data showed that belt flame spread was not a strong function of the relatively low radiant preheat flux (less than 8 kW · m^{-2}), but was greatly dependent upon the ignitor (burner) heat input, air velocity, and belt width and height. The effects of the latter three variables on flame-spread rates are shown in Tables 2 and 3. The usual or reference test conditions were used (i.e., belt width, 23 cm; height of belt above floor, 34 cm; flow rate, 30 m/min; and ignitor input, 3.5 kW).

Air velocity is one of the most significant parameters that affects flame spread (FS). The flame spread increases directly with the air velocity; however, the A-PVC belt could not be ignited at a flow greater than 60 m/min. The 60-, 90- and 150-m/min values were therefore determined by initiating the flame at 30 m/min and increasing the air flows to the desired rates. The flames blew out at 150 m/min.

The ratio of the width of the belt (W) to its distance from the ceiling (H) also has a strong effect on whether a belt flame can propagate or not. In the Bureau's test apparatus, conveyor belt W/H ratios ranging from about 1.3 to 4.5 allowed a steady flame spread. The flame spread decrease at the W/H

TABLE 2. Effect of air velocity (V) on flame spread (FS) for A-PVC belt

V(m/min)	0	15	30	60[1]	90[1]	150[1]
FS(cm/min)	8.2	8.5	12.2	80	120	0

[1] Air velocity after ignition was achieved at 30 m/min.

TABLE 3. Effect of ratio of belt width (W) divided by belt distance to ceiling (H) on flame spread (FS) for A-PVC belt

Ratio (W/H)	1.0	1.5	2.0	2.5	4.5
FS (cm/min)	None	About 0	12.0	14.3	1.4

ratio of 4.5 was attributed to lower oxygen concentrations resulting from restricted air circulation close to the ceiling.

Buckley[6] reported that full-scale belt fires using the A-PVC belt could not be initiated when the W/H ratio was less than 0.7, but were readily propagated at a ratio of 1.3. In the German full-scale tests by Reinke[3], when the W/H ratio was about 1.4 (full belt width, with H = 0.7 m), all the belts tested burned; but when they were tested near the floor, with the W/H ratio ranging between about 0.5 and 1, some of the belt samples would not burn and the different belts could then be differentiated. A similar W/H effect occured in an actual conveyor belt fire mine accident in which 100 m of belt burned except for a 6-m section directly under a roof fall where the ceiling was higher.

This W/H effect can be explained by treating the belt flame spread solely as a radiation transfer problem. The relatively greater effect of the radiative component of heat transfer with respect to convective transfer is illustrated in Figure 3. In this illustration, the calculated radiative (Q_R) and convective (Q_C) components are compared to the measured total heat flux (Q_T) at the belt surface, 90 cm from the ignited end. Q_C was calculated from measurements of belt-surface (T_b) and gas stream (T_g) temperatures between stations, and Q_R was determined by the difference (Q_T-Q_C) and by an independent calculation according to Hottel[7]:

$$Q_T = Q_C + Q_R \qquad (2)$$

$$Q_C = h\,(T_g - T_b) \qquad (3)$$

$$Q_R = \sigma F_{12} T_f^4 \qquad (4)$$

where T_f is the gas temperature (K), h is the heat transfer coefficient (11.1 W · m^{-2} K^{-1}), σ is the Stefan Boltzman constant (5.65 · 10^{-8} W · m^{-2} K^{-4}) and F_{12} is a radiation view factor. As shown in Figure 3, convective heat transfer largely accounts for the total thermal flux transmitted downstream during the ignition period, but radiative heat transfer comprises about 90 per cent of the total measured flux when the flame reaches the calorimeter.

The greater stability of a large belt flame in a large test

TABLE 4. Summary of flammability index data for red oak and various conveyor belts at reference test conditions in new belt flammability apparatus; ignitor input of 3.5 kW (67 kW . m-2) and air velocity of 30 m/min.

Belt type	Flame spread rate, FS (cm/min)	Heat release rate, Q_f (kW · m-2)	Critical ignitor input, I (MJ · m-2)	Flammability index, FI[1]	Normalized flammability index, FI*[2]
Red oak standard	20.8	160	6.1	546	100
Goodyear (B-NFRR)	10.9	149	6.1	266	49
Goodyear (A-NP)	10.6	115	10	122	22
F. America (A-PVC)	12.2	85	14	74	14
Goodyear (A-FRR)	5.8	42	14	17	3.2
Goodyear (B-NP)	7.2	53	34	11	2.1
Scandura (B-PVC)	7.3	52	54	7.0	1.3
Georgia Duck (C-PVC)[3]	0 (4.0)	NI (45)	> 60 (<56)	0 (3.2)	0, (0.6)
Clouth (D-PVC)[4]	0, 4.6	NI, 50	>100, 36	0, 6.4	0, 1.2
Clouth (C-NP)	0	NI	>100	0	0

NI No ignition

[1] $FI = \frac{FS \times Q_f}{I}$, cm/sec²

[2] Normalized with respect to red oak.

[3] Ignitor input was 7 kW for values in parentheses.

[4] Only one ignition in four trials.

gallery versus the scaled-down small flame in a small test gallery can be estimated by considering the radiation exchange across the area formed between a parallelopiped volume of hot gas to one of its surfaces (the belt). Rough estimates sufficient for this purpose indicate that for a given belt width, doubling the distance from the ceiling reduces the energy exchange between the flame volume and the belt surface by about 25 per cent (ref. 7, p. 264). Doubling the belt width increases the energy exchange by about 10 per cent. In a tunnel with cold walls, the radiation energy would presumably be more easily lost from fires involving smaller belts and those farther from the ceiling. For most fire-resistant belts, even small energy losses appear to have strong effects on flame stability. Smaller fires, with their higher radiation losses, will therefore require more severe test conditions to produce stable flames than larger fires.

Flame Spread Correlation with Belt Flammability Parameters

A correlation of horizontal belt flame spread rates with belt flame properties measured in gallery tests is given here for the first time. An empirical equation[8] derived from a flame spread model for wood-lined tunnels has been useful for correlating theoretical data to experimental data from conveyor belt gallery fires. The calculated belt flame spread, $(FS)_{calc}$, can be written

$$(FS)_{calc} = 1.19 \times 10^{-8} K_a (R-7) V (T_f - T_i)^{2.5} \quad (5)$$

where K_a is the smoke index, cm-1
(R-7) is the duct cross-section area factor, cm
V is the average duct velocity, cm/min
T_f is the lowest gas flame temperature for stable propagation, °C
T_i is the piloted ignition temperature of the belt, °C
and R is the cylindrical tunnel radius in centimetres assuming a circular cross-section area, πR^2.

The (R-7) factor for cylindrical tunnels was modified to $([WH/\pi]^{0.5} - 7)$ for calculating an effective rectangular flame area (W x H) above the belt, where W is the belt width and H is the distance from the belt surface to the ceiling. Applying the experimental values and measurements developed above to the A-PVC belt data (Fig. 2), equation 5 becomes

$$(FS) = (1.19 \times 10^{-8}) \underset{K_a}{(.152)} \underset{R}{([23 \times 11.7/\pi]^{0.5} - 7)} \underset{V}{(3000\ cm/min)} \ldots \underset{T_f - T_i}{(450-200)^{2.5}} = 12.1\ cm/min.$$

In over 50 tests, this calculation predicted the measured flame spreads within 10 per cent and always within a factor of 2 for both the one-fifth-scale and the full-scale galleries.

Fire-Resistance Ratings For Conveyor Belts

Three factors were considered in defining a fire resistance rating:
1. Critical heat input for sustained ignition (I).
2. Measured flame spread rate at critical ignitor heat input (FS).
3. Heat release rate at critical ignitor heat input (Q_f).

Q_f is calculated using the temperature increase of the exhaust air during the burning period. Because ignition was a function of the magnitude and duration of the ignitor heat flux, a time-integrated flux (Q_{ign} x t) was used to define the ignition factor I (p. 9, ref. 5); the exposure time (t) was varied and Q_{ign} was fixed at 67 kW · m-2 unless otherwise noted. To obtain a combined fire-resistance rating that reflects the contribution of all three factors, the following empirical flammability index (FI) is proposed:

$$FI = \frac{FS \times Q_f}{I} \quad (6)$$

Table 4 summarizes the data obtained for various conveyor belts together with data for red oak, which was used as a reference material. It is apparent that fire-resistance ratings can be misleading unless both ignition and flame-propagation stages are considered. For example, the A-PVC and A-FRR belts have the same I value, but noticeably different FS and Q_f values. Also, the B-NFRR and A-NP belts have approximately the same FS values, but different I and Q_f values.

By the proposed rating scheme, the normalized flammability index (FI*) was 100 for the red oak standard, 49 for a non-fire-resistant belt and near 0 for the most fire-resistant belts. The latter belts were very difficult to ignite and generally required an ignitor flux greater than 67 kW · m-2, which is an unusually severe ignition condition. Ratings for belts which give intermediate FI* values must be considered suspect, depending on the belts' FS, Q_f and I values. For such belts, it would be prudent to define their flammability index under at least two air velocity conditions to determine how sensitive their FS and Q_f values are to the ventilation flow. The order of the fire-resistance ratings shown in Table 4 was consistent with those indicated by full-scale tests using the same belt materials[5,6].

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