Effect of ventilation air velocity on the detection of conveyer belt fires

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In underground mines conveyor belt entries may often extend for thousands of feet with only periodic inspections, often at long intervals corresponding to the beginning/ending of shift changes. Fires within conveyor belt entries typically develop in three stages. First, loose coal from the conveyor belt deposits along a conveyor idler or trailing cable and if the idler begins to overheat due to friction or if there is an electrical short in a trailing cable, the heat generated is dissipated within the loose coal producing low temperature smoldering combustion. If the coal temperature increases, then at some point, fuel vapors from the smoldering coal ignite producing the second stage of visible flame from the loose coal that will begin to spread across the surfaces of the coal. When the flames from the coal fire can impinge upon the surfaces of the conveyor belt for a sufficient period of time, then the surface of the conveyor belt ignites and the flames begin to spread along the conveyor belt surfaces. This is the third stage of fire development. When the heat release rate from the burning conveyor belt is of sufficient intensity, then rapid flame spread along the surface of the conveyor belt can occur, producing disastrous consequences. Because the toxic combustion products and smoke from a fire travel with the ventilation, the possibility for rapid and significant contamination of a working section greatly increases, thus placing a greater burden on the fire detection and warning system. The ventilation air velocity not only impacts the detection process via the transport of combustion products, but also through dilution of the products being generated, the degree of combustion product stratification that may exist downstream of the fire, the rates at which the combustion products are produced, and the rates of increase of the fire intensity. In order to understand and quantify these effects, a series of large-scale experiments were conducted in an above ground fire gallery used to simulate an underground coal mine conveyor belt haulageway.

A total of twelve experiments were conducted at four different air velocities (1.02 m/s, 2.03 m/s, 4.06 m/s and 6.86 m/s) using three different conveyer belt materials, namely styrene butadiene rubber (SBR), polyvinyl chloride (PVC) and neoprene (NP). In the experiments, six electrical strip heaters were embedded within a pile of coal rubble approximately 5 cm from the top surface to simulate common heat sources such as a frictionally overheating by a frozen conveyor idler or an electrical cable short. In the twelve experiments conducted, the average time (measured from the moment power was supplied to the electrical heaters) to observe smoke from the smoldering coal was 8 minutes. From the time the heaters were energized, the average time for the coal to burst into flame was 24 minutes, or 16 minutes after smoldering began. Subsequently, the flaming coal eventually ignited the edges and bottom surface of a conveyer belt situated 5-10 cm above the coal pile, with an average time to reach belt ignition of 16.4 min measured from the time of flaming ignition of the coal. All of these times are comparable to those measured from previous experiments (1)

During each test, carbon monoxide (CO) and smoke levels were monitored to determine their generation rates as the fire progressed through the various stages at the different air velocities. In addition, downstream air temperatures, carbon dioxide (CO_2), and oxygen (O_2) were continuously measured in order to determine the fire heat release rate. Commercially available smoke sensors were mounted near the gallery roof downstream of the fire and their times to alarm measured for each experiment. A video smoke and fire detection system was also used to monitor the visible smoke levels and the progress of the developing fires. Both smoke mass concentration and smoke obscuration (at a wavelength of 635 nm) were measured near the roof downstream of the fire.

Underground conveyor belt fires can produce tremendous heat along with potentially lethal levels of CO and smoke (2). Because these effects are generally produced only after the conveyor belt is ignited and the fire grows to an intensity sufficient to support flame spread along the conveyor belt surfaces, a reasonable, if not necessary criterion, for the detection of the fire is that detection must be achieved within a time frame no later than the time required for the small coal fire to ignite the conveyor belt. The average time to detect a developing fire is calculated from the bulk average alarm concentration appearance time of either CO or smoke plus the time for these products to travel with the ventilation air velocity a distance equal to one-half the distance between sensors (150 m) plus one minute for an average sensor response time. In addition, both CO and smoke sensor alarm levels depend upon the air velocity via the process of dilution and the velocity dependent CO/smoke production rates and fire growth rates.

Table 1 displays the estimated average time of alarm for CO sensors at the specified alarm thresholds for sensors spaced at 300 m. Overall, the average CO detection time was earlier than the belt ignition time. While there are some discrepancies in the data and there are some detection times greater than the time to belt ignition, the average was 28.2 s (0.47 min) before belt ignition.

Test	**Air Velocity, m/s**	**t_{BI}, mins**	**CO alarm level, ppm**	**CO alarm time, mins**	**Smoke Alarm, OD (m^{-1})**	**Smoke alarm time, mins**
SBR	1.0	3.8	9	8.8	0.044	7.5
	2.0	15.0	5	18.3	0.044	18.4
	4.1	7.8	3	8.8	0.022	6.3
	6.9	35.4	1	35.4	0.022	49.8
PVC	1.0	61.8	9	69.5	0.044	25.2
	2.0	9.2	5	7.4	0.044	7.8
	4.1	14.7	3	14.6	0.022	8.8
	6.9	22.9	1	-0.4	0.022	5.4
Neoprene	1.0	9.8	9	16.8	0.044	15.2
	2.0	20.7	5	27.1	0.044	27.4
	4.1	11.2	3	10.3	0.022	9.5
	6.9	15.7	1	5.8	0.022	14.9

Table 1**.** CO detection times, smoke alarm times and the measured times to belt ignition.

Previous data indicates that when CO or smoke sensors are positioned near the roof of an entry, the higher CO and smoke concentrations in the buoyancy – induced stratification of combustion products result in earlier detection of developing fires (3). The data indicate that the degree of stratification is greatest at the lower are velocities (1.02 m/s and 2.03 m/s) than at the higher air velocities (4.06 m/s and 6.86 m/s) and that the degree of stratification increases as the fire intensity increases.

Table 2 below shows the alarm times obtained for the smoke sensors, roof CO alarm (at alarm levels from Table 1) and the video smoke/flame detection system. All alarm times are measured from the moment of flaming ignition of the coal (t = 0.0) so that negative times represent minutes before flaming ignition of the coal. On average the video smoke detection system was the first to observe the smoke (average alarm 9.80 minutes before flaming coal ignition) followed by smoke sensor alarms(average of 4.32 minutes before flaming coal ignition) followed by the CO alarms (9.9 minutes after flaming coal ignition but still 10.2 minutes before ignition of the conveyor belt). It is also worth noting that smoke sensor alarms were slightly earlier at the higher air velocities (4.06 m/s and 6.85 m/s) than at the lower air velocities (1.02 m/s and 2.03 m/s) (4.44 minutes and 4.20 minutes, respectively, before flaming coal ignition).

Test	Velocity, m/s	Roof smoke alarm, mins	Roof CO alarm, mins	Video alarm, mins
SBR	1.0	-16.8	1.7	-15.7
	2.0	-23.8	16	-26.5
	4.1	-12.3	4.3	-16.0
	6.9	NA	38.9	NA
PVC	1.0	NA	17.3	-9.3
	2.0	5.8	-1.3	-20.6
	4.1	-7.7	-1.7	5.3
	6.9	-1.3	-7.6	-3.9
Neoprene	1.0	17.2	14	-8.5
	2.0	-3.3	NA	-18.1
	4.1	2.3	NA	-4.2
	6.9	-3.3	17.1	9.7

Table 2. Roof smoke sensor, roof CO and video alarm times relative to flaming ignition of the coal.

The heat release rates of the flaming coal fires were calculated using the combustion gases of CO_2 and CO and represented in table 3. The coal fire intensity (heat release rate, Q_F) divided by the ventilation air velocity (V_0), at the time of flaming ignition of the conveyor belt was found to have an average value of 24.26 kJ/m ± 8.75, indicating that the fire was still relatively small when the belt ignited and that Q_F increased with air velocity.

Test	Air velocity, m/s	Q_F at belt ignition, kW	Q_F/V_0 at belt ignition
SBR	1.0	16.3	16.0
	2.0	38.5	18.9
	4.1	72.2	17.8
	6.9	100.0	14.6
PVC	1.0	NA	NA
	2.0	35.7	17.6
	4.1	45.4	11.2
	6.9	NA	NA
Neoprene	1.0	19.8	19.5
	2.0	47.1	23.2
	4.1	64.8	15.9
	6.9	61.9	9.0

Table 3: Heat release rate at the time of coal ignition, belt ignition and estimated CO detection time, compared to the air velocity.

References

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