THE IMPACT OF AIRFLOW CHANGES ON THE HAZARDS OF DIRECT FIGHTING OF FIRES INVOLVING CONVEYOR BELTING

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ABSTRACT: The U.S. Bureau of Mines conducted a study to determine the impact of airflow changes on the hazards of direct fighting of underground coal mine fires involving conveyor belting. In the experiments, 15.2-m-lengths of conveyor belting were ignited and allowed to burn until a propagating conveyor belt fire was achieved at an initial air velocity. After the fire reached a steady propagation rate, the airflow over the fire was either increased or decreased and the effects of this change on fire size and growth, propagation rates, gas temperatures and concentrations, flow reversals, and fire intensity were measured. The data were analyzed to determine if the air velocity change increased or decreased the overall severity of the hazards associated with direct fire fighting by personnel upstream and downstream of the fire location. Generally, reducing the airflow increased the overall fire hazard, while significantly increasing the airflow reduced the overall fire hazard under these experimental conditions.

INTRODUCTION

Underground coal mine fires are a serious threat to life and property. From 1980 through 1992, 159 underground coal mine fires were investigated by the Mine Safety and Health Administration (MSHA) (Fidago, 1993). These fires resulted in 29 fatalities, numerous injures, and severe economic losses. MSHA accident reports indicate that ventilation changes were made when fighting the fire in almost all reported major mine fires. In several cases, such as the Wilberg (1984), Marianna (1988), Mathies (1990), and Orchard Valley (1986) mine fires, the fire could not be extinguished and the mines were sealed after ventilation was reduced over the fire. In the Wilberg fire, airflow to the fire area was reduced during initial stages of fire fighting by placing brattice across the intake entry. The fire continued to spread and the mine was sealed. Lack of a continuous water supply, early failure of aluminum overcasts, and a delayed response to the emergency contributed to the unsuccessful attempt to extinguish this fire in which 27 fatalities occurred (Huntley, et. al, 1984). One hour after the fire was discovered at the Marianna Mine airflow was reduced by opening mandoors to the return entry and installing check curtains across the intake and belt entries. The fire continued to spread inby and spread outby when water supplies were interrupted (Strahin, Wolfe, and Pogue, 1988). One of the mine fans were shut off early in the fire fighting efforts at the Orchard Valley Mine. Intake shafts were later sealed and the entire mine was sealed eventually (Denning, 1986). While fighting the Mathies Mine fire, ventilation was increased to remove smoke in the fire area; this change was cited as the possible cause of an explosion (Glusko, Dubovich, and Zilka, 1991). The mine was permanently sealed and over 400 jobs were lost. Effective fire fighting strategies that include optimal ventilation practices for combating mine fires would reduce the possibility of severe mine fires and resultant mine sealings. MSHA has requested that the Bureau of Mines conduct research in this area (Anon, 1989).

The decision to change the air velocity over a fire must be considered carefully. A mining industry consultant states that when fighting a fire directly, never reduce or remove the ventilation without unquestionable reasons (Mitchell, 1990). Several examples are given in this reference as to how, when, and if airflow changes should be made. As stated above, MSHA accident reports indicate that ventilation changes were made when fighting the fire in almost all reported major mine fires. Earlier literature recommends regulating the airflow over a fire and states, "In fighting a fire directly, whether in the preliminary or progressives stages, it is essential to regulate the volume of air flowing over the fire. This should slow down the fire and at the same time keep the distilled vapors of the heated coal from accumulating. This will enable fire fighters to approach the fire close enough to do effective work. In sealing, the air feeding the fire is reduced in order to avoid its fanning and spreading; the entry through which the air that feeds the fire passes is the last to be sealed in conjunction with the return entry or entries. If properly regulated, the tendency of the fire is to travel outward towards the fresh air rather than inward" (Dougherty, 1969). This leads one to believe that a higher air velocity will result in increased fire propagation rates and intensity, which may not always be true. There are advantages and disadvantages to increasing the air velocity, reducing the air velocity, or maintaining the air velocity over a fire and all of these must be considered.

Reducing the airflow over the fire is done to try to limit the oxygen to the fire and slow the growth of the fire. The reduction of airflow to the fire may cause smoke and heat to roll back upstream of the fire and limit fire fighters' access to the seat of the fire. Depending on the size of the fire, the heat and smoke may rollback and contaminate additional areas of the mine. An increase in the temperature can increase fatigue or cause heat exhaustion to personnel fighting the fire. Installation of water lances, cutting conveyor belt to interrupt fuel sources, hanging brattice, or building stoppings would be impossible if high temperatures are present. Increased temperatures can also damage roof support, such as wood cribs, posts, and steel beams, and cause roof falls. The propagation rate of the fire down the entry may also increase as reduced airflow decreases the dilution of heat and unburnt fuel away from the fire. According to Roberts, a reduction of air quantity to a developed fire can, in some circumstances, make matters worse by raising the fuel/air ratio, hence the exit gas temperature, causing an uncontrolled runaway of the fire (Roberts, 1989).

Large-scale fire tests of conveyor belting conducted by the Bureau in the aboveground fire gallery at Lake Lynn Laboratory showed that fire propagation rates were dependent on the air velocity (Lazzara and Perzak, 1987 and Verakis and Dalzell, 1988). Air velocities above and below 1.52 m/s (11.3 m^3/s) resulted in reduced flame spread rates or a nonpropagating fire for rubber and polyvinyl chloride conveyor belting. These results, especially at flows above 1.52 m/s, indicated that the current approach to reduce the airflow over fires to limit the spread of the fire may not be appropriate in all cases. In the Marianna No. 58 Mine fire, the airflow over the fire was reduced within an hour after discovery but the fire continued to spread rapidly (Strahin, Wolfe, and Pogue, 1990).

Increasing the air velocity over a developed fire also has serious consequences. For example, if the air velocity is increased over a fire, unburned combustible particles and gases that may have traveled upstream of the fire will be forced back over the fire. If these gases are in the explosive range, they could be ignited by the fire and cause an explosion. Depending on the initial air velocity and the final air velocity, increasing the air velocity may also increase the flame spread rate and heat release rate of the fire. It will definitely decrease the time it takes dangerous combustion products, such as smoke, carbon monoxide, and carbon dioxide, to travel to other parts of the mine. Sometimes, increasing the air velocity is the only way smoke and heat can be removed from the fire area so that fire fighters can approach the fire. Increasing the air velocity will lower the temperature in the immediate fire area, however, it may raise the temperature downstream.

The purpose of this paper is to present available information concerning general instructions and procedures for fighting coal mine fires in regard to ventilation and relate this information to results of experiments conducted in this study. These experiments were performed to determine if an air velocity change increased or reduced the overall severity of conveyor belt fires and the hazards associated with direct fire fighting by personnel upstream and downstream of the fire location.

EXPERIMENTAL PROCEDURES

The large-scale experiments to examine the effect of airflow on fighting conveyor belt fires were conducted in the Bureau's aboveground fire gallery located at Lake Lynn Laboratory. A schematic of the fire gallery is shown in Figure 1. The fire gallery consists of a 27.4-m-long tunnel constructed of masonry block walls, a steel arch roof, and a concrete floor. The interior walls and roof are covered with ceramic blanket insulation. The tunnel ventilation is provided by a 1.8-m-diam, 3,500-m^3/min axivane fan via a 6.1-m-long tapered transition section. The cross sectional area of the tunnel is 7.53 m^2. Tunnel distances are measured from the junction of the fire tunnel and transition section, designated as the 0-m mark. A conveyor frame, approximately 15-m-long by 1.5-m-wide, with a 0.4-m-diameter tail pulley and 0.13-m-diameter troughed idler assemblies spaced at 1.2-m-intervals, is centered in the tunnel for these experiments.

The belt sample was a 15.2-m-length of styrene-butadiene rubber (SBR) belt that passes the Federal acceptance test (30CFR#18.65) for flame-resistant belting. The 1.07-m-wide, 3-ply belt was about 11 mm thick with a weight of 13.97 kg/m^2 or about 14.9 kg per linear meter. As shown in Figure 1, the conveyor belt was placed on top of the idlers of the conveyor frame with the upstream end positioned underneath the tail pulley and above natural gas burners in the ignition area. The gas burners, producing approximately 125 kW, were used to ignite the belts. Cementitious foam blocks were used to shield the ignition area to ensure consistent ignition of the belt, independent of air velocity, in all of the experiments. The gas burners were turned off only after the belt fire was well developed in the ignition area.

Thermocouples were embedded just below the belt surface every 0.6 m along the upper surface and every 1.5 m along the lower surface of the belting. These thermocouples were used to determine the belt flame spread rate, the surface area of burning material, and the time to burn all of the belt in that section.

The airflow over the belt sample was adjusted prior to the start of a test. Measurements were taken at several locations along the length of the belt sample and the exit plane with a hand-held anemometer. A bidirectional flow probe system was also used to measure the airflow in the gallery during the experiments. The system consists of 12 stainless steel differential flow probes, nine at the exit and three at the entrance, connected to a rotary controlled differential valve. The two pressure ports of each flow probe were connected to a differential high accuracy pressure transducer set for +/- 0.13 kPa. The differential pressure data and thermocouple data at each probe were used to calculate the air velocity (McCaffrey and Heskestad, 1976). Airflow changes were made by opening or closing large metal doors located in the transition section and placing or removing wooden discs on the fan inlet.

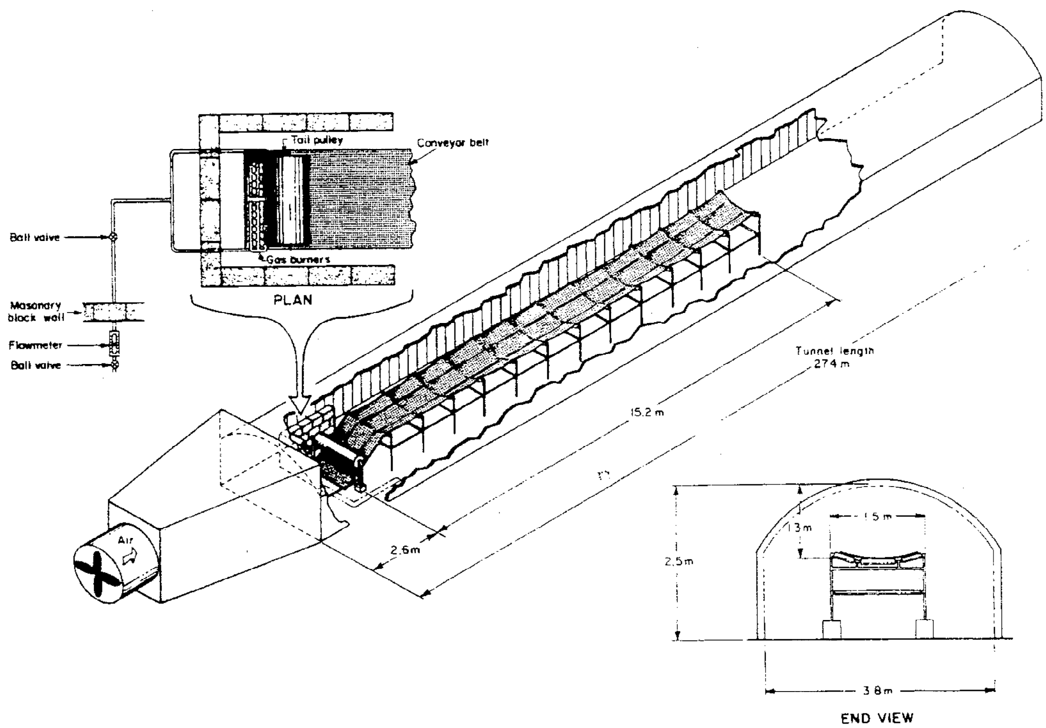

Figure 1. SCHEMATIC OF LAKE LYNN SURFACE FIRE GALLERY

An array of 12 thermocouples was positioned over the tunnel cross-section at 24.4 m to measure the average exit gas temperature. Gas sampling probes, measuring the average gas concentrations over the tunnel cross-section, were placed at 25.9 m and at the beginning of the tunnel, 0 m. The gas samples were analyzed continuously for carbon monoxide (CO), carbon dioxide (CO_2), and oxygen (O_2).

The thermocouple and gas data were collected every 5 seconds and the flow probe data collected every 1.4 min with the outputs connected to three 48-channel microprocessors for transmission to a VAX computer for storage. The experiments were also recorded on videotape and strip chart recordings made of the gas analyzer outputs. Grab samples of the gases were taken at various intervals and analyzed by gas chromatography for comparison with the strip chart and computer outputs.

Experiments were conducted where the airflow was reduced from 4.1 to 1.0 and 4.1 to 0 m/s, 20 min and 21.5 min after ignition of the belt, respectively. Experiments were conducted where the airflow was increased from 0.5 to 2.0 and 0 to 1.0 m/s, 11.17 min, and 22 min after ignition of the belt, respectively. Two experiments were conducted where the airflow was increased from 0.5 to 4.1 m/s at 17.5 min and 18.67 min, to establish reproducibility. Experiments were also conducted at constant airflows of 0.5, 1.0, 2.0, and 4.1 m/s so that the effects of the airflow changes could be better identified and analyzed.

RESULTS AND DISCUSSION

The peak one-minute average entrance and exit CO and temperature data for these experiments are listed in Table 1. The exit temperature was calculated by multiplying the temperature of each of the 12 exit array thermocouples and the percentage of cross-sectional area of the gallery that each thermocouple represented. The 12 weighted values were totaled to determine an exit temperature. The entrance temperature was determined by averaging the three thermocouples of the entrance flow probes.

Table 1 - Temperature and Carbon Monoxide Data

V_o, m/s	T_{exit}^{peak}, °C	T_{entr}^{peak}, °C	CO_{exit}^{peak}, ppm	CO_{entr}^{peak}, ppm
4.1	132	30	480	0
4.1 - 1.0	105 356	11 34	410 1065	0 1135
4.1 - 0.0	91 318	26 193	325 340	0 640
0.0 - 1.0	95 354	75 51	600 1295	720 830
0.5	355	240	335	1640
0.5 - 2.0	169 770	210 55	465 2740	1100 510
0.5 - 4.1	105 206	106 16	371 805	490 0
0.5 - 4.1	105 175	95 12	355 840	510 0
1.0	496	50	1780	1010
2.0	540	26	2185	215

V_o - airflow

T_{exit}^{peak} - peak one-minute average exit temperature

T_{entr}^{peak} - peak one-minute average entrance temperature

CO_{entr}^{peak} - peak one-minute average exit CO concentration

CO_{exit}^{peak} - peak one-minute average entrance CO concentration

The flame spread rate, the average belt burn time over the section of belt burning when flames reach the end of the belt, the one-minute average heat release rate when the flames reached the end of the belt, and the peak one-minute average heat release rate are shown in Table 2. The belt burn time is the average of the time thermocouples embedded in the belt were above 315° C, indicating the presence of flames. When the temperature of the thermocouple fell below 315 °C, it was assumed that all the belt had been consumed at that location of the belt. The flame spread rates are given from 3.05 to 6.1 m and 9.1 to 15.2 m since airflow changes were generally made when the flames reached the 6.1 to 7.6 m position on the belt. The flame spread rates were usually unstable from 6.1 to 9.1 m and a more consistent flame spread rate was measured over the indicated distances.

Table 2 - Flame Spread, Belt Burn Time, and Heat Release Rate.

V_o, m/s	$fs_{6.1}^{3.05-}$, cm/s	$fs_{15.2}^{9.1-}$, cm/s	BBT, min	$\dot{Q}_{end}^{meas}$, MW	$\dot{Q}_{peak}^{meas}$, MW
4.1	0.5	1.0	4.7	2.7	3.8
4.1 - 1.0	1.0	30.5	6.0	2.8	3.3 4.3
4.1 - 0.0	0.6	1.2	6.7	0.7	2.2 1.3
0.0 - 1.0	0.7	21.3	7.5	2.5	0.6 4.8
0.5	0.5	24.4	8.1	0.60	2.1
0.5 - 2.0	0.6	19.3	4.8	3.9	1.9 12.0
0.5 - 4.1	0.5	1.7	4.6	7.2	3.7 8.0
0.5 - 4.1	0.5	1.7	4.3	5.4	1.9 6.1
1.0	1.0	16.2	4.9	2.6	6.2
2.0	0.9	20.3	5.4	5.1	11.5

V_o - airflow

$fs_{6.1}^{3.05-}$ - flame spread rate from 3.05 m to 6.1 m of belt

$fs_{15.2}^{9.1-}$ - flame spread rate from 9.1 m to 15.2 m of belt

BBT - belt burn time

$\dot{Q}_{end}^{meas}$ - measured one-minute average heat release rate when flames reached the end of the belt

$\dot{Q}_{peak}^{meas}$ - measured peak one-minute average heat release rate

Reducing the Ventilation

In the experiment where the ventilation was reduced from 4.1 to 1.0 m/s, the flame spread rate increased dramatically from the 1 cm/s measured prior to the airflow change. Sustained flames flashed to the end of the belt immediately after the airflow was reduced with a resulting flame spread rate of 30.5 cm/s. As shown in Table 2, this is the highest flame spread rate obtained in all of the experiments. It is not known how far flames would have spread downstream if more belt were available. If the flame spread continued at this rate until the belt burned completely at the 3.05 m position of the belt, 110 m of belt would be actively involved in flames. The rapid spread of flames experienced in this experiment can be described as "flashdown" and is characterized by rapid flame spread rates of 7 cm/s or more. Flames may rapidly travel down the belt and then completely involve the belt with sustained burning, or they may dwindle and diminish. When the airflow was reduced from 4.1 to 0 m/s, the flames were at the 6.7 m position on the belt when they flashed to the end of the belt shortly after the airflow was changed. These flames were not sustained and the flame front receded to the 6.7 m position on the belt. When the sustained flame spread resumed, the rate increased from 0.6 cm/s prior to the airflow change to 1.2 cm/s over the last 6.1 m of belt. However, the flames and fire were still pulsing somewhat. Under these experimental conditions, reducing the airflow from 4.1 to 1.0 m/s caused a large increase in the flame spread rate. Whereas, reducing the airflow from 4.1 to 0 m/s only slightly increased the flame spread rate. This would make it imperative to have water lances or curtains installed downstream to limit spread of the fire before the airflow is reduced.

Reducing the airflow also caused changes in the gas temperatures upstream and downstream of the fire. Figure 2 shows the one-minute average exit gas temperatures determined from the thermocouple array for the experiments where the airflow was reduced. When the airflow was reduced from 4.1 to 1.0 m/s at 20 min, the peak exit temperature increased from 105 °C to 356 °C in ten minutes, which is near the pilot ignition temperature of wood, and was much more than the 132 °C peak exit temperature observed in the experiment at a constant airflow of 4.1 m/s. Temperatures at the roof level at the end of the belt also increased to above 1,100 °C, which is capable of damaging steel or igniting wood roof support and roof coal. This is compared to roof temperatures of 380 °C at the end of the belt at a constant airflow of 4.1 m/s. Additionally, since the flames were travelling faster down the belt than the belt was burned completely at the upstream end of the burning zone, it cannot be determined how high the temperature would have increased if more belting were available. Also, the peak average entrance temperature increased from 11 to 34 °C when the airflow was reduced to 1.0 m/s. This may hinder the direct fire fighting efforts of unprotected personnel from upstream of the fire. Downstream fire fighting efforts may be limited due to high temperatures and possible roof damage.

In the experiment when the airflow was reduced from 4.1 m/s to 0 m/s at 21.5 min, the exit gas temperature increased and peaked at 318 °C at approximately 35 min when sustained flames travelled to the end of the belt. The entrance temperature increased to almost 200 °C when the airflow was reduced to 0 m/s. Reducing the airflow to 0 m/s would increase temperatures both upstream and downstream of the fire. This would severely limit direct fire fighting due to high temperatures even if turnout gear and other personal protective equipment were available.

Changing the airflow can affect the production and dilution of toxic products and also the speed that they travel to other areas of the mine. When the airflow was reduced from 4.1 to 1.0 m/s, the average peak exit CO concentration was more than doubled from 410 to 1,065 ppm and may have continued to rise, since the flame spread rate was still increasing when flames reached the end of the belt. These values are approaching levels which could be dangerous if exposure time is significant and activity is strenuous. Entrance CO concentrations also increased from zero to approximately 640 ppm. The smoke rolled back and completely obstructed upstream visibility 15 s after the airflow was changed and did not clear until all of the belt had completely burned. As calculated assuming all combustion products left the exit of the tunnel. In fact, the average air velocity exiting the tunnel did remain slightly positive after the airflow was reduced. Second, the heat release rate was calculated using the temperature difference determined at both the exit and the entrance to approximate the total heat release rate of the fire. The two methods were very similar, however, data at the entrance was limited to only three flow probes. In all probability, most of the heat and combustion gases were recirculated at the entrance and eventually travelled out the exit of the tunnel.

Figure 3 shows the heat release rates of experiments where the airflow was reduced. In the experiment at a constant airflow of 4.1 m/s, the heat release rate was somewhat constant throughout the entire experiment and reached a peak of 3.8 MW. In the experiment when the airflow was reduced from 4.1 to 1.0 m/s, the heat release rate initially decreased, then increased to 4.3 MW, a value slightly higher than the heat release rate obtained at a constant 4.1 m/s airflow, but lower than the value of 6.2 MW obtained in the experiment at a constant 1.0 m/s airflow. When the airflow was reduced the flames quickly travelled to the end of the belt and would have continued further downstream if more belting were available. This would have involved more belting in the fire which would also increase the heat release rate. In addition, the heat release rate when the flames reached the end of the belt, as shown in Table 2, is less than the peak heat release. As shown in Figure 3, the heat release continues to increase, indicating a higher mass

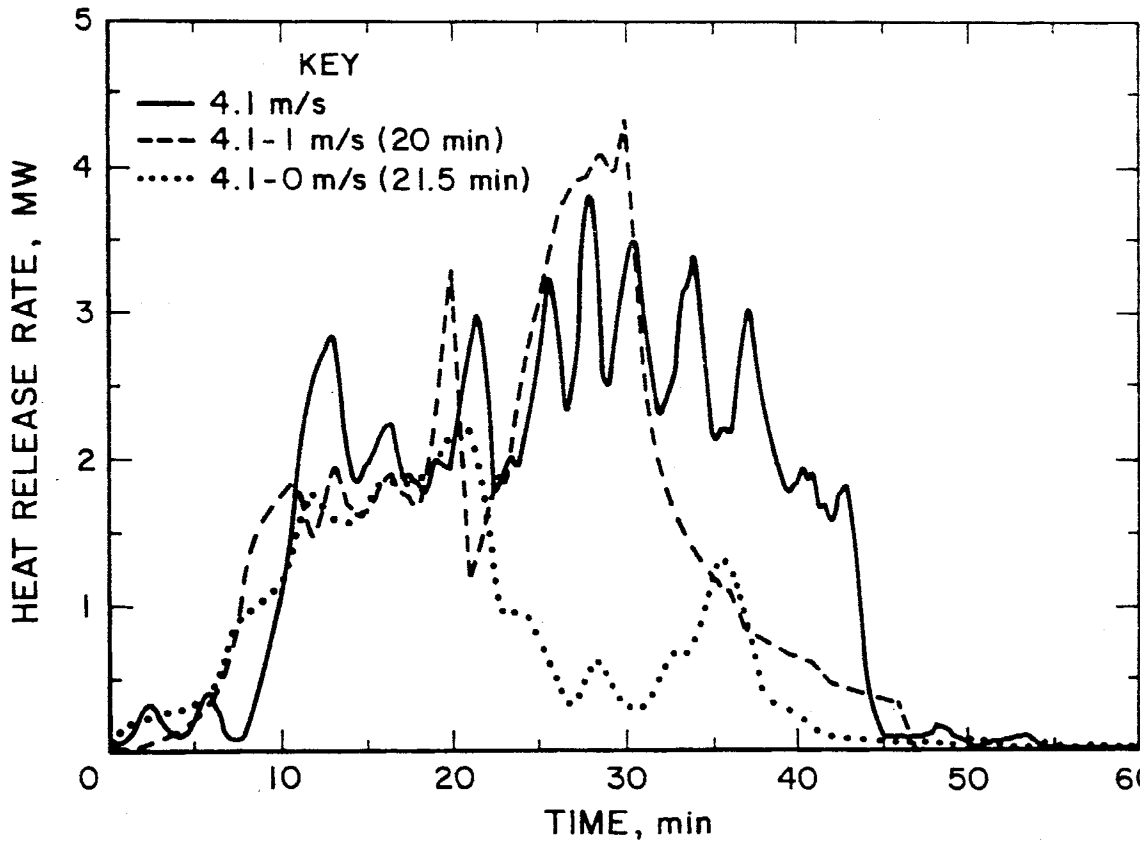

Figure 3. ONE-MINUTE AVERAGE HEAT RELEASE RATE OF EXPERIMENTS WHERE THE AIRFLOW WAS REDUCED, ( ) INDICATE WHEN AIRFLOW WAS CHANGED

large fuel loading, such as a conveyor belt in an underground coal mine. Due to the limited length of belt and the likelihood that outside air can enter the tunnel at low airflows, it is improbable that a fuel-rich condition could occur under the experimental conditions used in this study.

Increasing the Ventilation

Increasing the airflow to remove smoke and heat also caused changes in the fire characteristics. In the experiment where the airflow was increased from 0 to 1.0 m/s, initial flame spread rates of approximately 0.7 to 1.0 cm/s were obtained. When the airflow was increased, the flames flashed to the end of the belt with a flame spread rate of 21.3 cm/s. Based on a burn-out time of 7.5 min, 96 m of belt would be involved in active flames before the belt burned out at the upstream end of the belt. In the experiments where the initial airflow was 0.5 m/s, flame spread rates over the interval of 3.0 to 6.1 m on the belt were fairly slow. However, when the airflow was increased from 0.5 to 2.0 m/s, the flame spread rate reached 19.3 cm/s over the last 6.1 m of belt. Interestingly, the flame spread rate increased slightly when the airflow was increased to 4.1 m/s and was much lower than the flame spread rate obtained at a constant airflow of 0.5 m/s over the last 6.1 m of belt. Based on these results, if the airflow is increased to aid in direct fire fighting, it should be significantly increased or not at all.

Changing the airflow over the fire caused changes in the temperatures upstream and downstream of the fire. When the airflow was increased from 0 to 1.0 m/s, the peak average exit gas temperature was almost four times higher than at the airflow of 0 m/s. Entrance temperatures were reduced by approximately 33% when the airflow was increased. Increasing the airflow from 0 to 1.0 m/s will increase downstream temperatures significantly, making downstream fire fighting and rescue efforts difficult. Increasing the airflow to 1.0 m/s reduced roof temperatures at the upstream end of the belt below the ignition temperatures of coal and wood. Figure 4 shows the one-minute average exit gas temperatures for the experiments where the airflow was increased from 0.5 m/s and the time at which the airflow change was made. Similar to the experiment where the airflow was increased from 0 to 1.0 m/s, increasing the airflow from 0.5 to 2.0 m/s produced increased temperatures downstream of the fire. The peak exit temperature increased from 169 °C to 770 °C when the airflow was increased and reached its peak almost ten minutes earlier, as compared to when the airflow was a constant 0.5 m/s. It is also interesting to note that when the airflow was increased from 0.5 to 2.0 m/s the exit temperature was 230° C higher than when the airflow was a constant 2.0 m/s. This could be due to the belt being preheated at the 0.5 m/s airflow before the airflow was increased. Roof temperatures at the end of belt were above 1,200 °C in both experiments. Entrance temperatures at a constant 0.5 m/s airflow reached 240 °C, while entrance temperatures fell from 210 to 55 °C when the airflow was increased from 0.5 to 2.0 m/s. In contrast to when the airflow was increased from 0.5 to 2.0 m/s, downstream and upstream temperatures decreased when the airflow was increased from 0.5 to 4.1 m/s. Although peak exit temperatures increased from 105 to 206 and 175° C in the two experiments when the airflow was increased from 0.5 to 4.1 m/s, these values are less than the 355 °C peak exit temperature obtained in the experiment at a constant airflow of 0.5 m/s. Increasing the airflow from 0.5 m/s would aid in approaching the fire from upstream. However, downstream temperatures were raised dramatically when the airflow was raised to 2.0 m/s, which would counteract any direct fire fighting advantage gained upstream of the fire.

There are cases, such as the Mathies Mine fire, where the airflow is increased to remove smoke and toxic products such as CO from the fire area to allow direct access for fire fighting. In the experiment where the airflow was increased from an initial airflow of 0 m/s to an airflow of 1.0 m/s, entrance CO concentrations increased slightly from 720 to 830 ppm, while exit CO concentrations more than doubled. Smoke rollback completely reduced visibility to zero even after the airflow was increased.

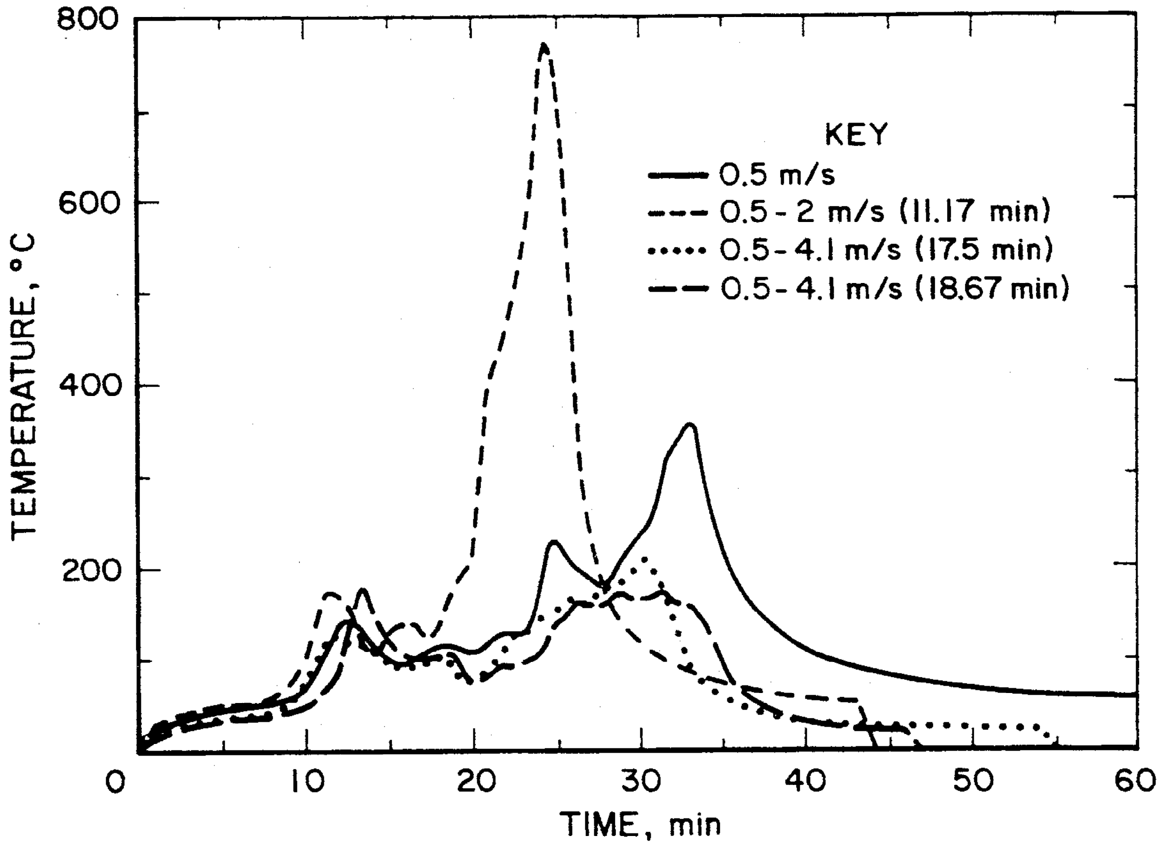

Figure 4. ONE-MINUTE AVERAGE EXIT TEMPERATURES OF EXPERIMENTS WHERE THE AIRFLOW WAS INCREASED, ( ) INDICATE WHEN AIRFLOW WAS CHANGED

In experiments where the initial airflow was 0.5 m/s, increasing the airflow increased the exit CO concentration in all cases. When the airflow was increased from 0.5 to 2.0 m/s, entrance CO levels were reduced from 1,100 ppm to approximately 500 ppm. They were not reduced to zero until the belt fire had completely burned out at 25 min. Exit concentrations increased from 465 ppm to over 2,700 ppm after the airflow was increased, and could have reached higher values if more belting were available. Entrance CO concentration levels at a constant airflow of 0.5 m/s reached peak values of 1,640 ppm. These values are dangerous and can cause symptoms such as dizziness, headaches, impairment of vision, etc., in a relatively short time. Upstream visibility was improved as soon as the airflow was increased. However, smoke continued to rollback at the ceiling until flames had burned out at the end of the belt. Increasing the airflow to intermediate levels did not significantly reduce the CO hazard upstream of the fire and could produce dangerous results downstream.

Increasing the airflow to 4.1 m/s resulted in peak CO exit concentrations being raised from approximately 371 and 355 ppm to 805 and 840 ppm, respectively. However, entrance CO concentrations were almost immediately reduced to zero from about 500 ppm. Upstream visibility was also immediately improved so that the base of the fire was visible after the airflow was increased. Downstream visibility was limited at all airflows. Based on results from these experimental conditions, protection from CO and smoke would be needed for fire fighters both upstream and downstream of the fire, unless the airflow was raised to at least 4.1 m/s.

When the airflow was increased there was also an increase in the heat release rate. In the experiment when the airflow was increased from 0 to 1.0 m/s, the heat release rate seemed to be pulsing somewhat when the airflow was 0 m/s. When the airflow was increased to 1.0 m/s, the heat release rate increased with the flame spread rate. The peak values were similar to values obtained at a constant airflow of 1.0 m/s of approximately 6 MW. Also, since the flames quickly travelled to the end of the belt, the heat release rate could have been higher if more belting were available.

Figure 5 shows the heat release rate of the experiments where the airflow was increased from 0.5 m/s. The heat release rate at a constant airflow of 0.5 m/s peaked at approximately 2 MW. When the airflow was increased from 0.5 to 2.0 m/s, the heat release rate increased dramatically from 1.9 MW to 12 MW. This value is close to the value obtained at a constant airflow of 2.0 m/s. Since the flames flashed to the end of the belt, more belting would have been involved and the heat release could have been much higher. When the airflow was increased to 4.1 m/s, there was an increase in the heat release rate to 8.0 and 6.1 MW which are much higher than the value obtained at a constant airflow of 4.1 m/s. Due to the limited length of belt, it cannot be determined if this heat release rate would continue, increase, or return to levels similar to those obtained at a constant airflow of 4.1 m/s. Heat release rates of 7.2 and 5.4 MW when the flames reached the end of the belt indicate that peak values may have been reached.

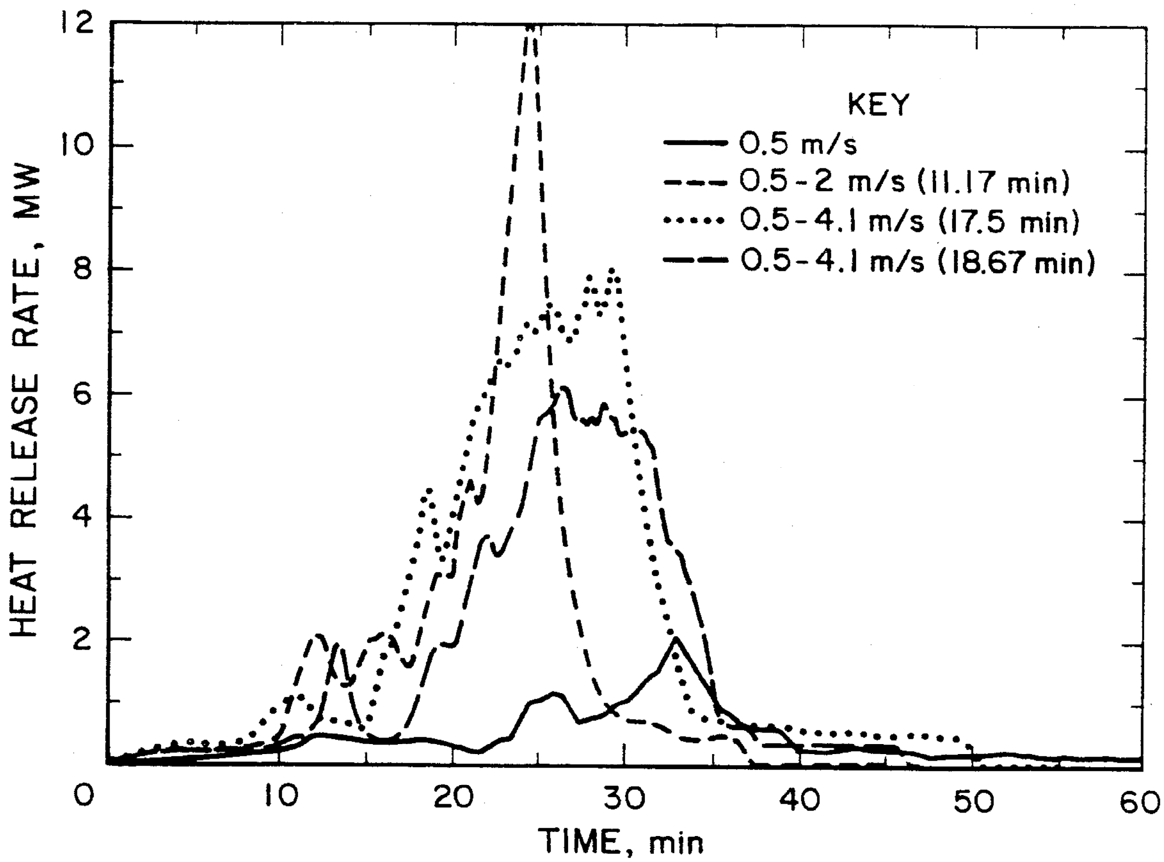

Figure 5. ONE-MINUTE AVERAGE HEAT RELEASE RATE OF EXPERIMENTS WHERE THE AIRFLOW WAS INCREASED, ( ) INDICATE WHEN AIRFLOW WAS CHANGED

SUMMARY

The results of these experiments indicate that significantly increasing the airflow over a conveyor belt fire from a low initial airflow will lessen the overall fire hazard in regard to direct fire fighting under these experimental conditions. Significantly increasing the airflow will reduce the upstream temperatures and smoke concentrations and the downstream temperatures. In these experiments, the heat release rate was initially increased when the airflow was increased; however, it is not certain if these levels would continue. The significant increase in airflow would decrease the time it would take heat and CO to travel downstream; however, the lower temperatures achieved would lessen the severity of the fire hazard. Increasing the airflow to an intermediate value reduced upstream temperatures; however, downstream exit temperatures and heat release rates increased dramatically.

Reducing the airflow increased the upstream and downstream temperatures, carbon monoxide levels, and the flame spread rate. Upstream visibility was reduced and the heat release rate initially was reduced; however, it was increasing when the flames flashed to the end of the belt. Overall, reducing the airflow increased the severity of the fire in regard to direct fire fighting under these experimental conditions.

This study has shown some of the effects of airflow changes on the hazards of direct fighting of fires involving conveyor belting. The fuel supply was limited in this study due to the length of the tunnel and the use of a single strand of conveyor belting. Additional data may be required with greater fuel loadings, such as rib and roof coal, to determine if reducing or increasing airflow over large, well developed fires near the fuel-rich condition causes runaway of the fire or ignition of unburnt combustibles. Experiments are currently being conducted using double strands of conveyor belting to increase the fuel loading. As stated earlier, airflow changes during fires in underground coal mines should be made over well developed fires only after careful consideration and with extreme caution. Fire fighting personnel with turnout gear and equipment, such as fire hose, water lances and curtains, brattice and other stopping building materials, etc., should be in place both upstream and downstream and evacuation of all personnel inby the fire should be complete before airflow changes are made. This requires an established fire detection and notification system, trained and equipped fire brigades, and an extensive fire fighting plan.

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REFERENCES

Anon, Mine Safety and Health Administration, 1989, "Belt Entry Ventilation Review: Report of Findings and Recommendations," p. 34.

Denning, W., 1988, "Report of Investigation, Non-Injury Underground Coal Mine Fire, Orchard Valley Mine (ID No. 05 02898) June 1, 1986," Mine Safety and Health Administration, 10 pp.

Dougherty, J. J., 1969, Control of Mine Fires, West Virginia University, Morgantown, WV, 89 pp.

Fidago, C. J., 1993, "Summary of Underground Coal Mine Fires 1980 through 1992," Report No. 02-098-93, Mine Safety and Health Administration, Industrial Safety Division, 16 pp.

Glusko, T., S. Dubovich, and R. Zilka, 1991, "Report of Investigation, Non-Injury Underground Coal Mine Fire, Mathies Mine (ID No. 36 00963) October 17, 1990," Mine Safety and Health Administration, 120 pp.

Huntley, D., R. Painter, J. Oakes, D. Cavanaugh, and W. Denning, W., 1987, "Report of Investigation, Underground Coal Mine Fire, Wilberg Mine (ID No. 42 00080) December 19, 1984," Mine Safety and Health Administration, 93 pp.

Lazzara, C. P., and F. J. Perzak, 1987, "Effect of Ventilation on Conveyor Belt Fires," Proceedings, Symposium on Safety in Coal Mining, Pretoria, Republic of South Africa, 15 pp.

McCaffrey, B. J., and G. Heskestad, 1976, "A Robust Bidirectional Low-Velocity Probe for Flame and Fire Application," Combustion and Flame, Vol. 26, pp. 125-127.

Mitchell, D. W., 1990, Mine Fires, Maclean Hunter, Chicago, IL, 167 pp.

Roberts, A. F., 1989, "Review Paper: Mine Fires," Proceedings, 23rd International Conference of Safety in Mines Research Institutes, pp. 3-19.

Strahin, R. A., D. N. Wolfe, and C. W. Pogue, 1990, "Report of Investigation, Non-Injury Underground Coal Mine Fire, Marianna Mine No. 58, March 7, 1988," Mine Safety and Health Administration, 76 pp.

Tewarson, A., 1980, "Heat Release Rate in Fires," Fires and Materials, Vol. 4, No. 4, 1980, pp. 185-191.

Verakis, H. C., and R. W. Dalzell, 1988, "Impact of Entry Air Velocity on the Fire Hazard of Conveyor Belts," Proceedings, Fourth International Mine Ventilation Congress, pp. 375-381.

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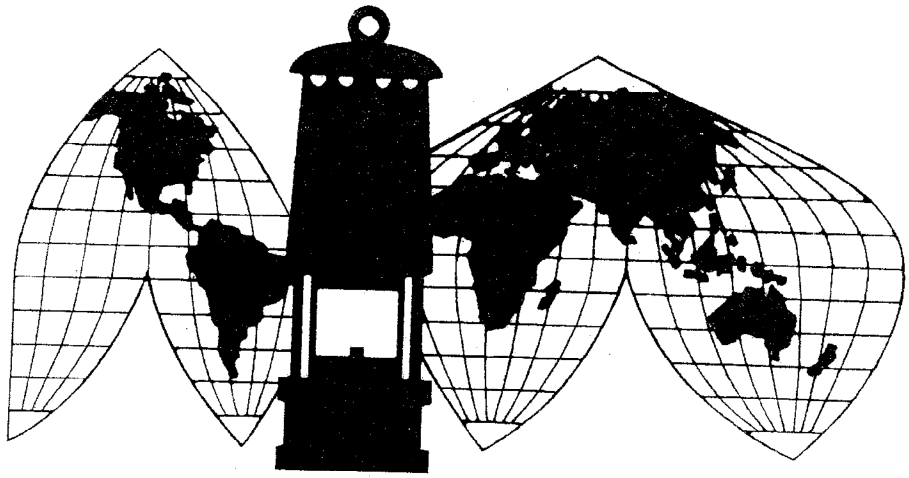

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