Effect of Ventilation on Conveyor Belt Fires

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EFFECT OF VENTILATION ON CONVEYOR BELT FIRES

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1 m/s = 195.5 ft/m

1,5 m/s = 295.3 ft/m
4,1 m/s = 807.1 ft/m

The Bureau of Mines, U.S. Department of the Interior, conducted full-scale fire tests of conveyor belts to determine the effect of airflows of 1,5 m/s and 4,1 m/s on the fire development and propagation. The tests were performed in an aboveground fire gallery approximately 27-m-long. Rubber and polyvinyl chloride (PVC) belt samples 9,1-m-long were placed on the top rollers of a belt conveyor frame and instrumented with thermocouples to measure flame spread rates. Additional sensors monitored air temperatures and major combustion products. The ignition source was a liquid fuel tray fire located just below the upstream edge of the belt sample.

Three different styrene butadiene rubber belts ignited and completely burned at both airflow rates. The flame spread rates, downstream gas temperatures, and CO and CO_2 concentrations for each belt were less at the 4,1-m/s than at the 1,5-m/s airflow. Two PVC belts burned at the lower airflow with rapid flame spread rates, but at the higher airflow the same belts did not propagate flame and damage was limited to the ignition region. A PVC belt and a chloroprene rubber belt did not burn at either airflow. The overall results indicate that for these test conditions, the higher airflow reduced the hazards of propagating conveyor belt fires.

INTRODUCTION

A conveyor belt fire in an underground coal mine is a serious threat to life and property. To minimize the hazard of belt fires, the U.S. Code of Federal Regulations for underground coal mines requires approved fire-resistant belting, automatic fire suppression systems for belt conveyor drive areas, automatic fire sensor and warning device systems along belt haulageways, waterlines installed parallel to the entire length of belt conveyors, and belt slippage and sequence switches[1]. Despite these precautions, the incidence of belt fires in U.S. coal mines is still high. Of the 16 reportable underground coal mine fires in 1985, fires lasting more than half an hour after discovery or causing injury, 6 involved the conveyor belting or the belt structure[2].

Another section of the Code of Federal Regulations addresses air courses and belt haulage entries; it states, in part, that the entries used as intake and return air courses shall be separated from belt haulage entries, and belt entry air shall not be used to ventilate active working places[3]. However, a number of mines have petitioned the Mine Safety and Health Administration (MSHA), U.S. Department of Labor, for modifications to use belt entry air to ventilate working areas. Several such modifications have been granted, on a case-by-case basis, and only if certain conditions are followed. One of the conditions stipulated in all cases is that the velocity of the air current in the belt conveyor entry shall not exceed 1,52 m/s. This limitation resulted from the current MSHA small-scale approval test for fire-resistant conveyor belting[4] that is conducted at a flow of 1,52 m/s, and the uncertainty of the effects of higher ventilation flows on conveyor belt fires. Before permitting higher airflows, MSHA requested the Bureau of Mines to conduct a study on the effect of ventilation, specifically airflows of 1,5 and 4,1 m/s, on conveyor belt fires and to determine if the higher airflow created a greater hazard.

FIRE GALLERY

The fire gallery consists of a 27,4-m-long tunnel constructed of masonry block walls, a metal arched roof, and a concrete floor. The tunnel is coupled to a 1,8-m-diameter, 3500-m^3/min axivane fan via a 6-m-long tapered transition section. The ventilation flow can be varied between 0,5 m/s and 10 m/s by adjusting the pitch of the fan blades and/or by throttling the fan intake with a disk. A schematic of the gallery is shown in figure 1. The cross-sectional area of the tunnel is 7,5 m^2. The interior walls and roof of the tunnel are covered with ceramic blanket insulation. Except where noted, tunnel distances are measured from the junction of the fire tunnel and transition section, designated as the 0-meter mark. A typical conveyor belt frame, 21-m-long and 1,5-m-wide, is centered in the tunnel. The frame consists of a 0,4-m-diameter tail pulley and 12,7-cm-diameter troughed idler assemblies at 1,2-m intervals.

A liquid fuel tray fire is the ignition source for the tests. The tray, 0,6-m-long by 1-m-wide by 0,3-m-deep, is just downstream of the tail pulley at a tunnel distance of 4,5 m and elevated 20 cm above the floor. The tray contains water on which an initial quantity of fuel is floated. Additional fuel can be added remotely during a test from a fuel supply located outside the tunnel. The ignition region is shielded from the ventilation flow by a metal plate and concrete blocks to minimize the effect of airflow on the ignition process. The objective is to ignite the belt sample and monitor the progress of the fire as it interacts with the tunnel airflow.

The gallery is instrumented with 40 Type K thermocouples to measure belt and air temperatures. Single thermocouples are located about 10 cm from the roof along the centerline of the tunnel at various distances. An array of 12 thermocouples, connected in parallel and distributed over the cross-sectional area of the tunnel, is located at 24,4 m to measure the average temperature of the stratified gas exit stream.

A gas-sampling probe and a smoke-sampling probe are located at a tunnel distance of 24,4 m, 0,5 m, and 0,6 m from the roof, respectively. Gas and smoke samples are drawn continuously and analyzed for CO, CO_2, and O_2. The Bureau of Mines submicrometer particulate detector[5] is used to measure the smoke particle concentration, size, smoke mass, and optical density.

The outputs of the thermocouples and analyzers are connected to a 48-channel microprocessor that transmits the data to a computer for storage. The data are logged at 15-s intervals and displayed on a computer terminal. After a test, time-temperature traces and gas concentration plots are generated from the disk storage.

Two video cameras are housed in protective enclosures in the tapered transition section of the gallery to observe and record the tests. The video signals are displayed on monitors in a trailer near the tunnel.

TEST PROCEDURE

A 9,1-m-length of conveyor belting was cut from a roll, weighed, and the belt thermocouples installed. The bare thermocouple beads were embedded just below the top surface. The thermocouples were positioned at measured distances from one end of the belt sample along the centerline and near each edge. Typically, 20 belt thermocouples are used to monitor belt temperatures and calculate flame spread rates. The belt sample was then placed on the rollers of the conveyor belt frame, with one end bent downward into the shielded ignition area.

The tunnel airflow was adjusted to either 1,5 m/s or 4,1 m/s. The airflow was measured by a handheld vane anemometer in three places across the width of the belt (at a height of 25 cm above the belt) and at three locations along the sample length, and the values were averaged. The average airflow near the exit of the tunnel was also measured. The airflow fluctuated especially at the higher flow, but was within ±10% of the test value. During a belt burn, the overall ventilation rate did not significantly change.

A fuel mixture of 1,9 L of unleaded gasoline and 5,7 L of kerosene was poured into the ignition tray. Preliminary tests showed that this fuel quantity (7,6 L) would usually ignite the sample or consume the belting in the ignition area. The tray fire with this fuel loading burned for 5 to 6 min, with a peak fire size of about 700 KW. The flames enveloped the top and bottom surfaces of about 1,5 m of belting. The duration of the tray fire could be extended by the addition of kerosene. This was only necessary for some of the belts at the higher (4,1-m/s) airflow.

Belt Samples

Four rubber belts, designated R1 through R4, and three PVC belts (P1 through P3) were tested at both airflows. All the belts except R3 were obtained new from cooperating belt manufacturers. Belt R3 was obtained from a mine; it was worn but in good condition. Table 1 describes the belting.

Belt R1 is considered to be non fire-resistant because it failed the MSHA approval test for fire-resistant belting. All the other belts passed the MSHA test or other approval tests considered more severe such as those of Energy, Mines and Resources (EMR) Canada and the United Kingdom National Coal Board (NCB). Belt R4 was only subjected to the MSHA test, but comparison of the formulation to other belts indicated that it would also pass the NCB tests.

RESULTS AND DISCUSSION

Flame Spread

The R3 belt, obtained from a mine, was tested in the gallery at airflows of 1,5 and 4,1 m/s. The 7,6-L tray fire was sufficient to ignite the belt at both airflows. Belt ignition occurred about 5 min after the start of the tray fire as determined by thermocouple readings and observation via the video cameras. The fire then propagated down the belting in a steady fashion at both airflows and consumed the entire 9,1-m-long sample in about 50 min. As the fire progressed, sections of burning belting hung from the rollers and then fell to the floor. Not more than 1,5 to 2 m of belting was burning on the rollers at any one time. The time-temperature traces obtained from the thermocouples along the centerline of the sample for the test at the 4,1-m/s airflow are shown in figure 2. Zero time is when the tray fire was started; the thermocouple position is the distance from the ignition end of the belt sample. The thermocouple traces clearly show the ignition phase during the first 5 min of the test and the steady wavelike propagation of the fire down the sample. The advancing flame front was considered to have reached a thermocouple position when the thermocouple temperature reached 310° C and continued to rise. The flame spread rate was determined from the time-temperature traces by plotting the flame position versus time and drawing the best straight line through the points. The slope of the line is the flame spread rate in m/min. The flame spread rate for belt R3 at the 4,1-m/s airflow was 0,2 m/min. The time-temperature traces obtained in the test of the R3 belt at 1,5 m/s were nearly identical to those obtained at the higher airflow; the flame spread rate was 0,3 m/min. The data from the other belt thermocouples supported these results. For this belt, there was no significant difference in the way the sample burned as a result of the change in ventilation flow. However, the flame spread rate was slightly less at the higher airflow.

The time-temperature traces obtained from the R2 belt thermocouples in the test at an airflow of 1,5 m/s are shown in figure 3. The tray fire ignited the belt, and a rapid flame spread (5,8 m/min,) occurred over most of the top surface of the sample about 6 min after the start of the test. This initial flame, however, was not sustained but was followed by a steadily propagating flame front, with a rate of 0,9 m/min over the last 5 m of the sample, that destroyed the belting. The 9,1-m-long sample was totally consumed in about 25 min. At the 4,1-m/s airflow, the belt also ignited and burned; however, there was no evidence of an initial rapid flame spread, and the belt was consumed by a slower advancing flame front (0,4 m/min). The belt fire lasted about 40 min. Maximum belt temperatures were approximately 900° C at both airflows. For belt R2, the steady flame spread rate was two times slower at the 4,1-m/s airflow than at the 1,5-m/s flow.

Belt R4 did not propagate flame at either the 1,5-m/s or 4,1-m/s airflows. At the 1,5-m/s flow, the tray fire destroyed 1,5 m of the belting in the ignition area and charred the next 0,3 m. The remainder of the 9,1-m-long sample was undamaged. At the 4,1-m/s airflow, an additional 7,6 L of kerosene was added to the tray fire during the ignition phase to extend the duration of the igniter. The first 1,2 m of the belt sample was destroyed, and the next 0,3 m charred; the remaining 7,6 m was not damaged. The fire performance of belt R4, a chloroprene formulation, was obviously superior to that of the styrene butadiene rubber belts R2 and R3.

To see how a non fire-resistant rubber belt would behave, belt R1 was also tested. At the 1,5-m/s flow, flames flashed over the top surface of the 9,1-m belt sample about 1 min after ignition of the tray fire. The rapid flame spread rate was about 7,6 m/min. The entire sample then burned in an intense fire that consumed the belting in about 15 min. At the 4,1-m/s flow, the belt sample ignited and was consumed by a steadily advancing flame front with a flame spread rate of 0,7 m/min. The belt fire lasted about 30 min after the start of the tray fire. The flame spread rate for belt R1 was about 10 times greater at the lower airflow of 1,5 m/s than at the higher airflow of 4,1 m/s. The flame spread rate of R1 at the 1,5-m/s flow was also much greater than those of belts R2 and R3, which are fire-resistant styrene butadiene rubber belting.

The time-temperature traces obtained for belt P1 at a tunnel airflow of 1,5 m/s are shown in figure 4. About 2,5 min after the ignition of the tray fire, flames flashed over the entire length of the 9,1-m belt at a flame spread rate of about 6,7 m/min. The entire sample then burned in an intense fire that destroyed the belting in about 10 min. This result was not apparent from the time-temperature traces due to belt thermocouples that were damaged or had pulled away from the belt during the rapid flame spread. Similar results were obtained when a 15-m-length of belt P1 was tested at the 1,5-m/s airflow. In the test of P1 at 4,1 m/s, an additional 3,8 L of kerosene was added to the tray fire during the ignition phase. The first 2 m of belting in the ignition area was destroyed, and the top surface of the following 2 m was badly charred along one edge. Flames did not propagate, and the remaining 5 m of belting was undamaged. In this test, the belt temperature at the 8,2-m location never exceeded 80° C. For belt P1, the entire sample was destroyed at the 1,5-m/s airflow in a rapidly spreading fire, but at the 4,1-m/s airflow flames did not propagate.

Belt P2 behaved in a manner similar to that of belt P1 except that the sample was not completely destroyed at the 1,5-m/s airflow. Flames spread rapidly over the entire top surface of the sample at a rate of 6,6 m/min about 3 min after ignition of the tray fire. A 12-min fire ensued that deeply charred the entire top surface and then went out. The belting remained on the rollers; the bottom surface, beyond the 2 m of sample destroyed in the ignition area, was undamaged. At the 4,1-m/s airflow, an additional 7,6 L of kerosene was added to extend the tray fire, but flames did not propagate down the belt sample. The first 1,2 m was burned away, the next 1 m was charred, and the remaining 7 m was undamaged.

Belt P3 did not propagate flame at either the 1,5-m/s or 4,1-m/s airflow. At 1,5 m/s, the tray fire consumed 0,5 m of the belting in the ignition area, and the top surface of the next 2 m was charred. At the 4,1-m/s flow, an additional 7,6 L of kerosene was added during the ignition phase: 1 m of belting was destroyed and the next 1,5 m was charred. The results were similar to those obtained for belt R4.

The flame spread rates for all the belts are listed in table 2. At the 1,5-m/s airflow, rapid flame spread occurred for belts R1, P1, and P2, and a slower flame spread for belts R2 and R3. At the 4,1-m/s airflow, only belts R1, R2, and R3 propagated flame: the flame spread rates for R2 and R3 were slower than that for non fire-resistant belt R1. Belts R4 and P3 did not burn at either airflow.

The maximum increase of the gas temperature near the roof at the 27-m tunnel mark for all the tests is also given in table 2. The length of the tunnel is not sufficient for complete mixing of the combustion gases, so the temperature near the roof should represent the highest temperature in the exit gas stream. In tests where flames did not propagate down the sample, the maximum values occurred during the tray fire and burning of the belting in the ignition area. A comparison of the values for the same belt shows a lower temperature for the higher airflow for all cases. This lower temperature is consistent with the slower flame spread rate and the increased ventilation flow that results in more mixing and cooling of the combustion gases.

Fire Size

The size of the conveyor belt fire was estimated from the temperature increase of the thermocouple array at the 24,4-m tunnel location. This increase is assumed to be the temperature rise of the intake air as it passes over the fire. The assumptions of constant heat capacity and gas composition (air) were also made to facilitate the calculation. These assumptions introduce about a 10% error in the belt fire size. The fire size, q, in watts, was calculated from the expression

$$q = C_p A V \rho \Delta T,$$

where C_p is the heat capacity of air, 1,01 J/g-°K; A is the cross sectional area of tunnel, 7,5 m^2; V is the ventilation flow, m/s; ρ is the density of air, 1,3 kg/m^3; and ΔT is the temperature increase of the thermocouple array, °K.

Figure 5 shows the fire size, in megawatts, versus the time after ignition of the tray fire for belt P1 at the 1,5-m/s airflow and for belt R2 at the 1,5-m/s and 4,1-m/s airflows. For the P1 belt, the fire size increased rapidly to the peak value of 3,1 MW when the flame was rapidly spreading over the top surface of the belt sample. The fire size then decreased as the belt sample was consumed. For belt R2 at the 1,5-m/s airflow, the fire size increased as the flame front steadily progressed down the belting; the peak value of 4,2 MW occurred near the end of the test. This increase is due to greater amounts of belting burning on the rollers and floor as the fire progressed. The peak fire size for the R2 belt at 4,1 m/s was 2,7 MW near the end of the test which is in agreement with the slower burning of the belt at the higher airflow. The total energy output for belt R2 was similar for both tests, as indicated by the area under each curve. In general, the fire size was in good agreement for a given belt with the type of burning that occurred during the test. Table 2 gives the peak fire size, averaged over 1 min, for all the tests. In the tests in which flame did not propagate, the peak fire size occurred during the tray fire and burning of the belt in the ignition area. As noted earlier, additional fuel was added to the tray fire in some of the tests at the 4,1-m/s airflow. The greatest fire size was 5,7 MW for the non fire-resistant R1 belting at the 1,5-m/s airflow. For the belts that burned at both airflows (R1, R2, and R3), the peak fire size was greater at the lower airflow, or about the same in the case of R3. This is consistent with the burning behavior of the belts. In the tests of belts P1 and P2 at the 1,5-m/s airflow, flames spread rapidly over the entire belt surface, and the peak fire sizes were 3,0 and 2,3 MW, respectively.

Products of Combustion

Large quantities of smoke were generated by the burning belts, and vision was severely limited at both airflows except for a narrow region near the gallery floor. Smoke samples were obtained via the smoke probe at the 24,4-m tunnel location and analyzed by the submicrometer particulate detector. The smoke characteristics, including concentration, particle diameter, and optical density are presented in reference 8 and will not be discussed here. In general, the smoke data indicated that smoke properties of the burning belts can vary significantly depending on the type of belting and ventilation rate.

Gas samples were obtained via the gas probe at the 24,4-m tunnel location and analyzed for CO, CO_2, and O_2. Since the exit gas stream is not well mixed, the concentrations represent the gas composition only at the sampling probe location and not the average gas concentration in the exit flow. The maximum CO and CO_2 concentrations and minimum O_2 concentrations for all the tests are given in table 2. For tests in which no flame spread occurred, the values were obtained during the tray fire and burning of the belt in the ignition region. For a given belt, the CO and CO_2 concentrations and O_2 depletion were always greater at the lower airflow. Belts that burned at the 1,5-m/s airflow with rapid flame propagation (R1, P1, and P2) produced high concentrations of CO and CO_2 and significantly depleted the O_2 concentration.

In tests at 4,1 m/s in which additional fuel was added to the initial tray fire during the ignition phase, the total fuel quantity is listed in the comments column of table 2. The table also contains the data for the fuel-mixture tray fire at both airflows when no belting was present.

The observed differences in the flammability behavior of a belt sample at the two airflows are attributed to greater cooling and dilution of the combustion gases at the higher flow. This lowers belt surface temperatures just downstream of the flame front, resulting in reduced flame spread rates or nonpropagating fires. In full-scale tests conducted in the French gallery at CERCHAR, propagating chloroprene belt fires were extinguished at airflows above 0,85 m/s[9]. In these tests, the ignition source was a 300 kg wood pile, and the 15-m-long belt sample was located 0,5 m from the gallery floor, 3 m from the center of the arched roof. The belt temperature necessary to propagate a belt fire will vary with the composition of the belt and the generation rate of combustible decomposition products.

SUMMARY AND CONCLUSIONS

Full-scale fire tests of 9,1-m lengths of several conveyor belts were conducted in a surface gallery at airflows of 1,5 m/s and 4,1 m/s to evaluate the effect of these ventilation rates on the belt fires. Four types of burning occurred: (1) rapid flame spread, ≥6 m/min, followed by the entire sample burning, (2) rapid flame spread that deeply charred the entire top surface of the belting, but left the bottom surface undamaged, (3) a steadily progressing flame, with spread rates

.66 ft/m 3 ft/m

ranging from 0,2 to 0,9 m/min, that completely consumed the belting, and (4) a nonpropagating fire with belt damage limited to the ignition region.

Three styrene butadiene rubber belts burned completely at both airflows (1,5 and 4,1 m/s), but the flame spread rates, downstream temperatures, and CO and CO_2 concentrations were less at the 4,1-m/s airflow. The fire sizes were also less, or in the case of one belt, about the same, at the higher airflow. Flames propagated rapidly over the entire surface of two PVC belts at the 1,5-m/s flow, but flame spread did not occur for the same belts at the 4,1-m/s flow. A chloroprene rubber belt and a PVC belt with superior fire-resistant characteristics did not burn at either flow. The largest fire occurred with the non fire-resistant belt at the 1,5-m/s airflow. The overall results indicate that at these full-scale test conditions, the hazards of propagating conveyor belt fires are reduced at the 4,1-m/s airflow compared with the 1,5-m/s flow. These findings may result in an increase in the mine ventilation limitation of 1,52 m/s now imposed by MSHA for mines granted modifications to use belt entry air to ventilate working areas.

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TABLE 1
Conveyor belting description

Belt	Construction	Width, m	Thick-ness, mm	Weight, kg/linear-m	Fire-resistant quality	Heating value[1], MJ/kg
R1...	4-plies SBR[2] 7 mm top cover 2 mm bottom cover	1,07	15	17,8	NFR[3]	36,8
R2...	4-plies SBR 5 mm top cover 2 mm bottom cover	1,07	12,5	16,9	MSHA[4]	29,1
R3...	4-plies SBR 6 mm top cover 3 mm bottom cover	1,02	14	18,6	MSHA	29,2
R4...	chloroprene solid woven 3 mm top cover 2 mm bottom cover	1,07	9	14,3	MSHA	18,7
P1...	solid woven PVC[5]	1,07	11	14,2	MSHA	23,4
P2...	solid woven PVC	1,07	11	13,8	EMR[6]	24,1
P3...	solid woven PVC	1,05	9	11,4	NCB[7]	24,3

[1] Determined by American Society for Testing and Materials D 2015, Gross Calorific Value of Solid Fuel by Adiabatic Bomb Calorimeter.
[2] SBR - styrene butadiene rubber.
[3] NFR - non fire-resistant. Failed U.S. Mine Safety and Health Adminstration approval test[4].
[4] Passed U.S. Mine Safety and Health Administration approval test[4].
[5] PVC - polyvinyl chloride.
[6] Passed Canadian Energy, Mines and Resources approval tests[6].
[7] Passed U.K. National Coal Board approval tests[7].

TABLE 2
Conveyor belt fire test results

Belt	Air-flow, m/s	Flame spread rate, m/min	Max. gas temp[1], °C	Peak fire size, MW	Max. CO, ppm	Max. CO_2, vol%	Min. O_2, vol%	Comments
R1....	1,5	7,6	428	5,7	4000	9,9	7,5	Rapid flame spread followed by entire belt burning.
	4,1	0,7	227	4,6	840	1,6	17,5	Belt consumed by a propagating flame.
R2....	1,5	0,9 (5,8[2])	330	3,9	800	1,7	18,5	Rapid flame spread followed by a propagating flame.
	4,1	0,4	102	2,7	670	0,6	19,8	Belt consumed by a propagating flame
R3....	1,5	0,3	315	0,6	870	0,4	19,6	Do.
	4,1	0,2	68	0,7	440	0,3	20,2	Do.
R4....	1,5	0	132	0,7	910	0,6	19,0	1,5 m consumed in ignition zone.
	4,1	0	47	0,8	120	0,3	20,4	15,2 L fuel; 1,2 m consumed in ignition zone.
P1....	1,5	6,7	394	3,0	5600	7,2	10,8	Rapid flame spread followed by entire belt burning.
	4,1	0	88	ND[3]	560	0,4	20,2	11,4 L fuel; 2 m consumed in ignition zone.
P2....	1,5	6,6	275	2,3	4700	3,3	14,8	Rapid flame spread; top surface deeply charred, bottom surface undamaged.
	4,1	0	63	1,2	600	0,5	20,4	15,2 L fuel; 1,2 m consumed in ignition zone.
P3....	1,5	0	164	0,7	2370	1,8	18,4	0,5 m consumed in ignition zone.
	4,1	0	78	1,5	400	0,5	20,2	15,2 L fuel; 1 m consumed in ignition zone.
Tray fire	1,5	NAp[4]	135	0,8	330	1,4	18,8	No belt; 7.6 L fuel.
	4,1	NAp	40	0,6	100	0,2	20,6	Do.

[1]Temperature increase near roof at 27 m.
[2]Nonsustained rapid flame spread.
[3]ND, not determined.
[4]NAp, not applicable.

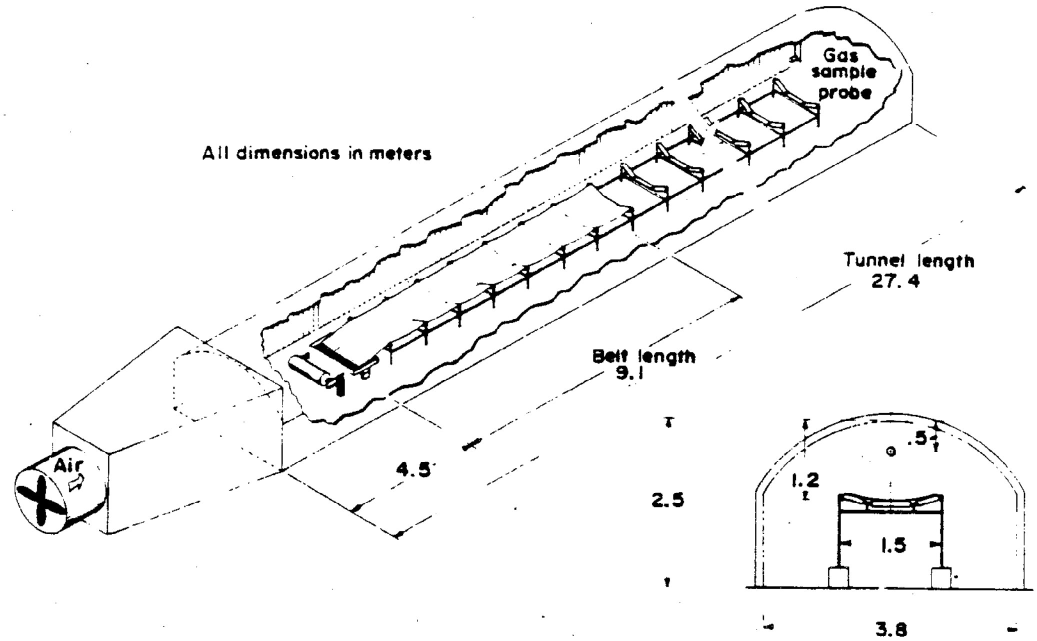

FIGURE 1 - Schematic of surface fire gallery.

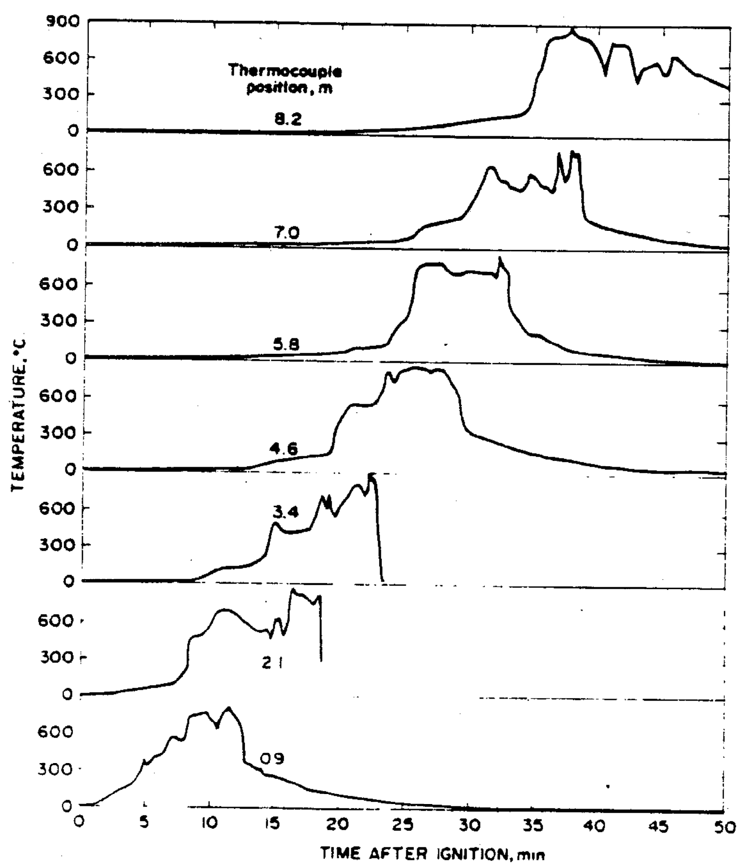

FIGURE 2 - Time-temperature traces of belt thermocouples for test of belt R3 at 4,1 m/s airflow. The tray fire was ignited at zero time.

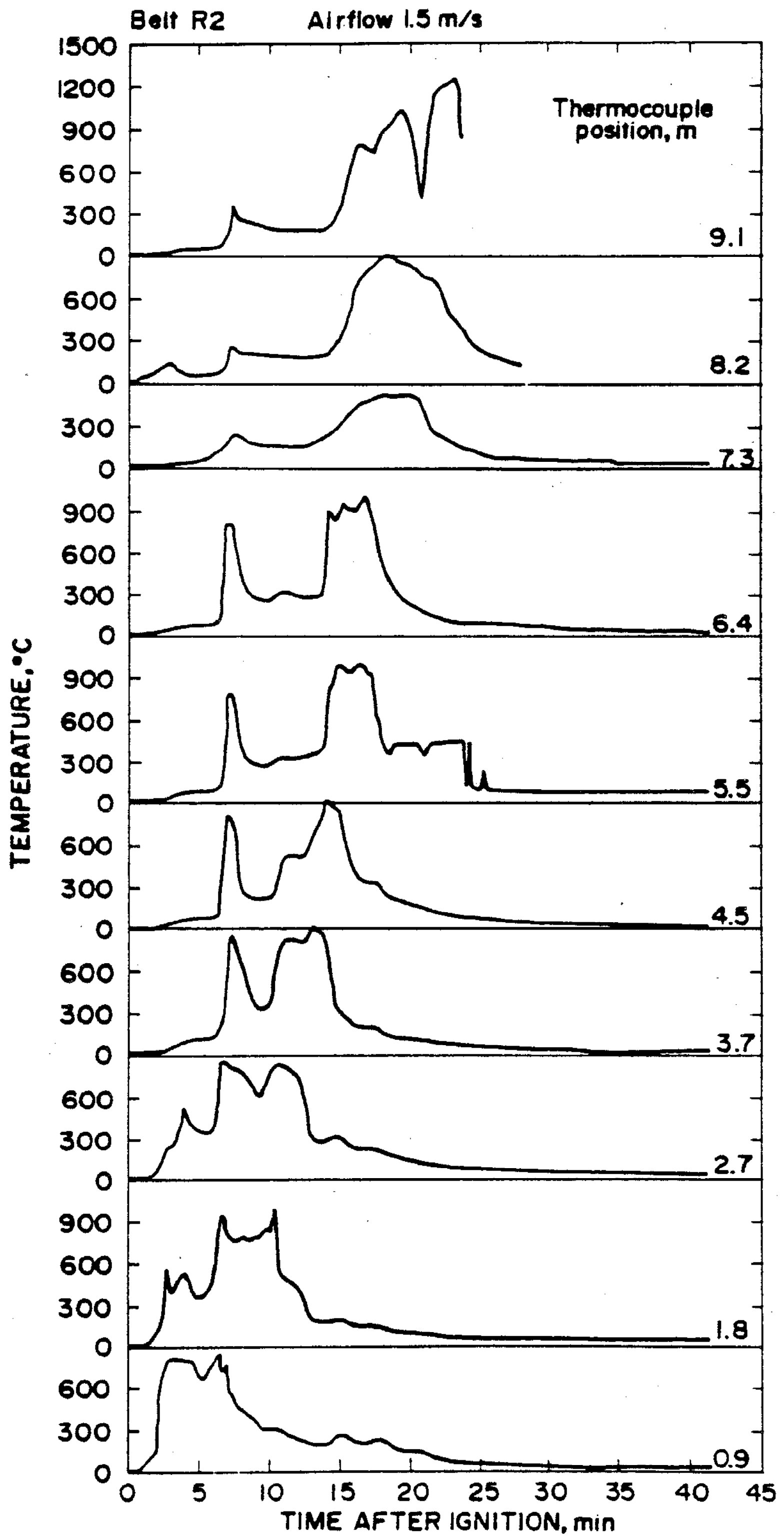

FIGURE 3 - Time-temperature traces of belt thermocouples for test of belt R2 at 1,5 m/s airflow.

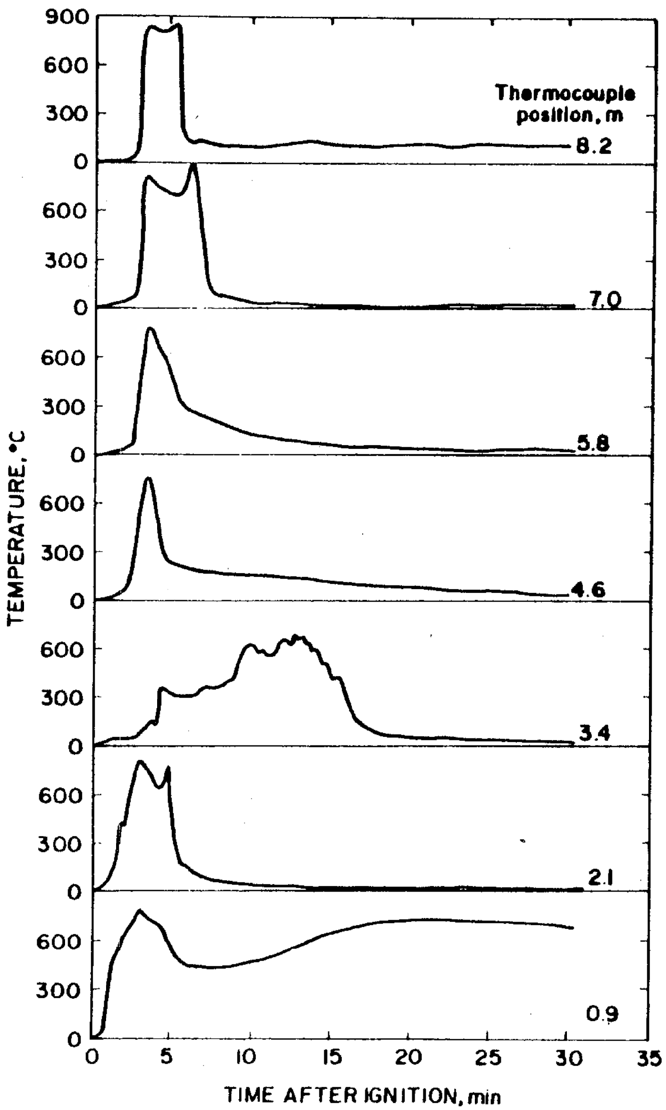

FIGURE 4 - Time-temperature traces for test of belt P1 at 1,5 m/s airflow.

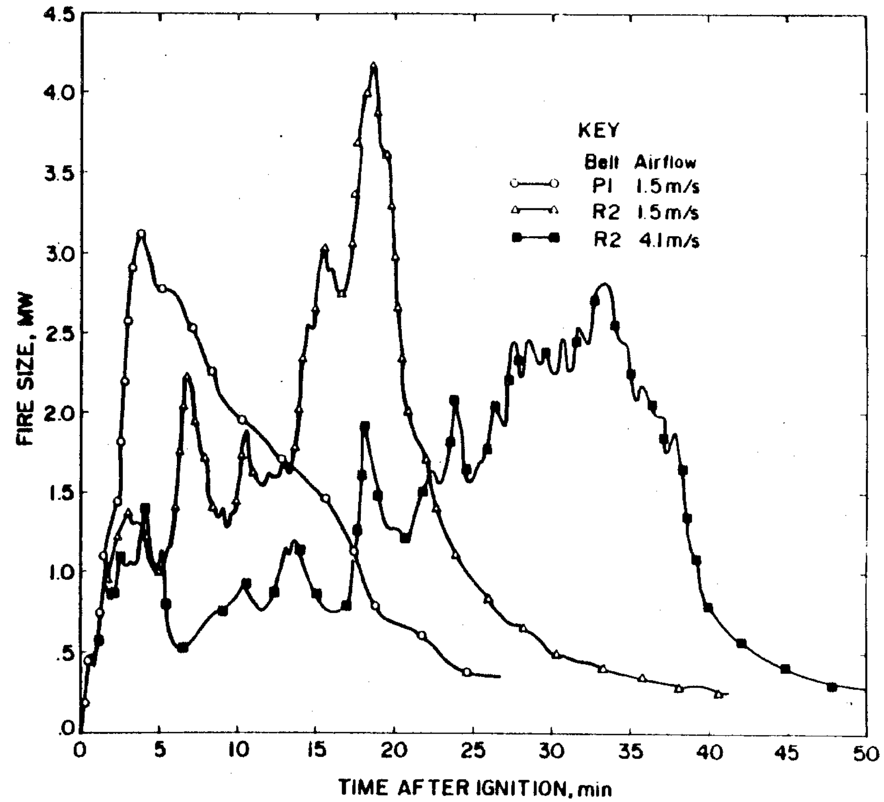

FIGURE 5 - Fire size versus time after ignition of the tray fire for belts P1 and R2.