FLAME PROPAGATION ON CONVEYOR BELTS

by

Donald W. Mitchell,[1] Allan F. Smith,[2] Samuel P. Polack,[3] and Edwin M. Murphy[4]

SUMMARY

Factors affecting ignition and flame propagation on conveyor belts are being investigated at the Federal Bureau of Mines Experimental Coal Mine. The parameters studied are ignition source, air velocity, belt cover, and belt carcass. Each parameter was evaluated at three or more levels.

Neoprene, polyvinyl chloride, and rubber belts ignited when a high temperature gas flame source impinged on the belt surface. The total heat input required for ignition was as low as 700 Btu. After a belt ignited, ventilating conditions had a critical effect on flame propagation; flame did not propagate in a neutral condition when air movement was caused only by the heat from the ignition source and the burning belt. At air velocities greater than 100 feet per minute (fpm), flame propagated along the three types of belts; the rate was highest for the rubber belt. Limited data indicate that the rate of flame propagation was affected by the cross-sectional area of the gallery, to a minor extent by belt carcass, but not by belt width.

---

[1]Asst. Chief, Branch of Dust Explosions, Health and Safety Research and Testing Center, Bureau of Mines, U.S. Department of the Interior, Pittsburgh, Pa.

[2]Chemist, Health and Safety District B, Bureau of Mines, U.S. Department of the Interior, Pittsburgh, Pa.

[3]Mining Health and Safety Engineer, Health and Safety District B, U.S. Department of the Interior, Pittsburgh, Pa.

[4]Chemical Research Engineer, Branch of Dust Explosions, Health and Safety Research and Testing Center, Bureau of Mines, U.S. Department of the Interior, Pittsburgh, Pa.

INTRODUCTION

Following serious fires in the Whitfield and Creswell Collieries in England in 1948 and 1950,[5] intensive studies on conveyor belt flammability were conducted by the British and other safety-in-mine-research establishments. As a result, most conveyor belts presently purchased for use in mines conform with materials passing approval tests. These tests generally determine the potential resistance of conveyor belt samples to flame and friction. In most countries, tests are also conducted to evaluate belt resistance to wear, impact damage, slippage, transversal flexibility, aging and electrostatic charge build-up; some establishments are conducting research to improve greases, pulleys, and idlers, and on other measures for preventing heat evolution on a conveyor.

In the years 1962 to 1965 more than six relatively serious fires involving conveyor belts occurred in the United States. Analysis of these and other belt fires indicates that most are started when the conveyor is not operating. Generally the fire was not discovered for several hours and flame had propagated through hundreds of feet of belt entry. Research is being conducted by our Bureau to determine factors affecting flame propagation and to develop methods for alleviating this hazard. This report summarizes initial findings.

TEST PROCEDURES

Test Zone.--Conveyor belt ignition and flame propagation tests are conducted in two galleries, the smaller of which is illustrated in figure 1. This gallery, 60-ft long with a 20-ft high air shaft, is made of 4-ft diameter, 12-gage corrugated steel. Ventilating air is provided by a 2-speed fan mounted on the top of the air shaft; air velocity in the gallery is adjusted by louvers controlling secondary air into the vertical air shaft. The other gallery is a 150-ft long rectangular chamber, 10-ft wide, 5-ft high, made of corrugated steel. Both single and double (parallel) belts were studied. In the single belt tests, a 15-ft-long specimen is laid on a 5-ft-long, 1/4-in steel plate heater; the rest of its length is supported by steel rods spaced 1 ft apart. In the double belt tests, a second belt, supported on rods, is parallel with and 9 in above the lower belt.

Temperatures in the air 1/8 in above the belt, in the interior of the belt, and between the belt and steel-plate heater are measured by Chromel-Alumel thermocouples connected to a 12-point recorder (fig. 2).

[5] Jones, S. Fires on Belt Conveyors. Sheffield Univ. Min. Mag., v. 45, 1952.

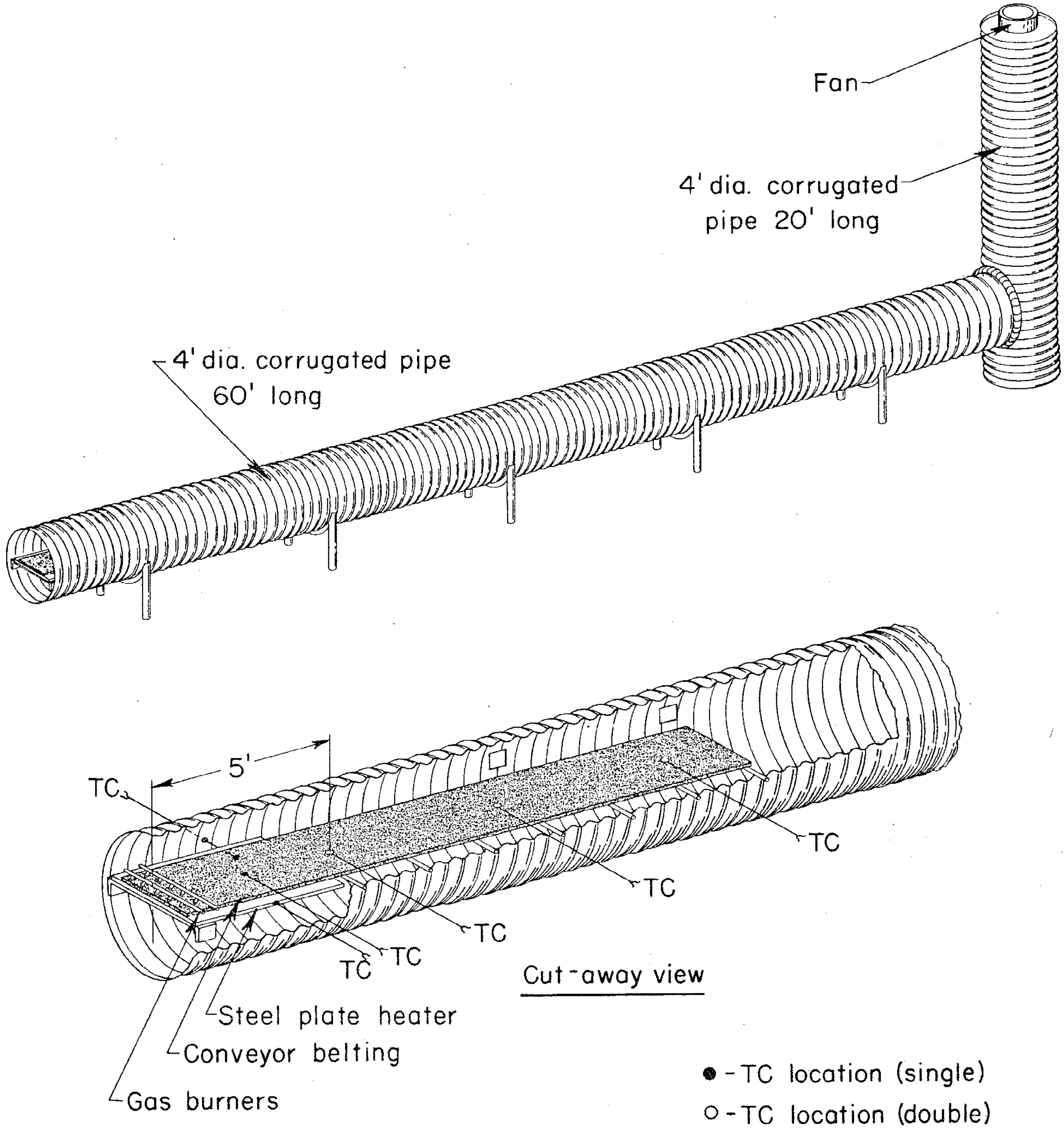

FIGURE 1. - Gallery for Study of Flame Propagation on Conveyor Belts.

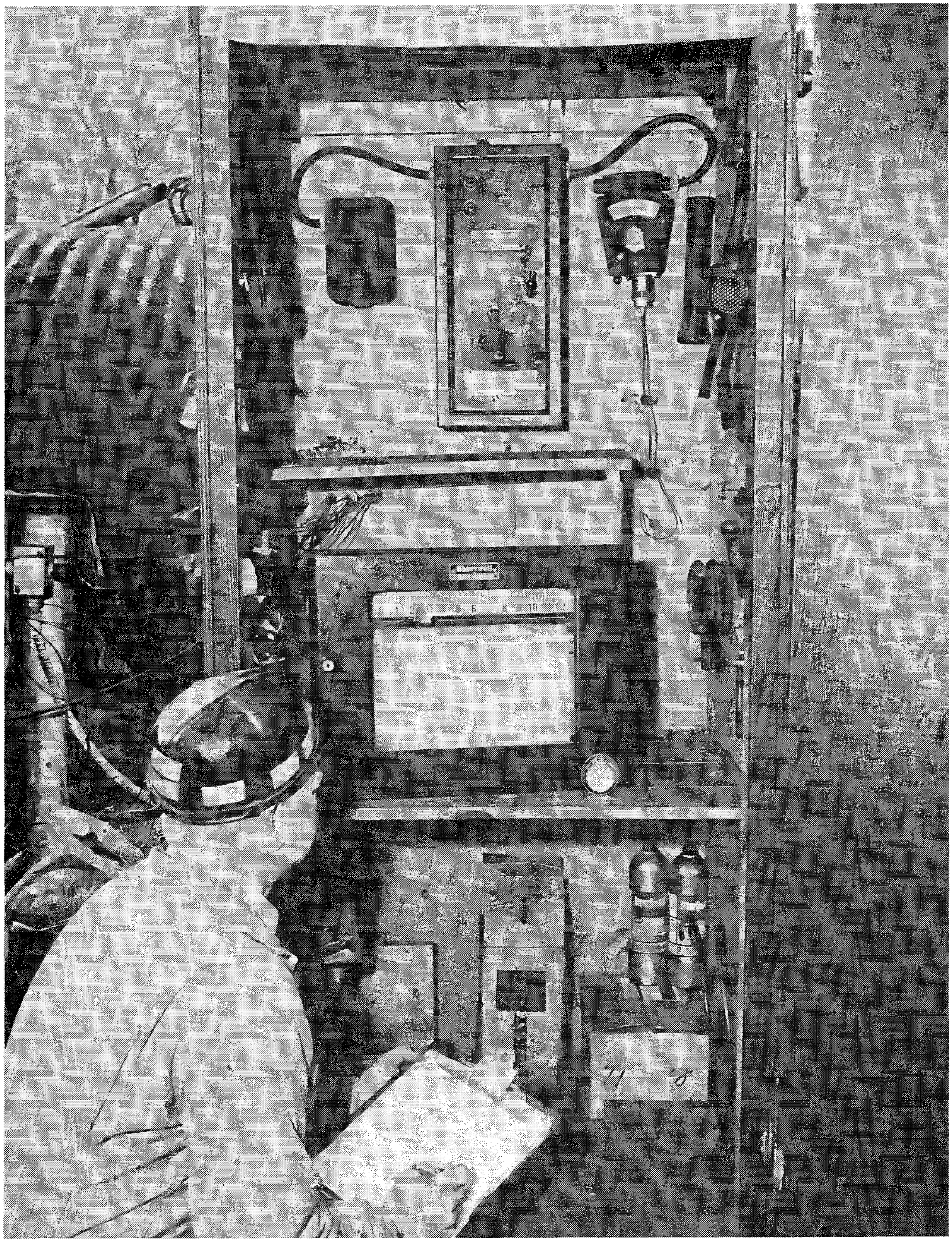

FIGURE 2. - Temperature Recorder and Heater Controls for Study of Flame Propagation on Conveyor Belts.

The belt thermocouples were attached at the top surface and in the interior at 1, 2-1/2, 5, 10, and 14 ft from the front (fig. 3). The steel plate under the belt is heated by eighteen 1,500-watt strip heaters attached to the underside. A thermostat set at 450° F was connected in the heater circuit.

Conveyor Belts.--Conveyor belts constructed of various polymers and carcass compositions were obtained from three commercial sources in the United States and one in Great Britain. According to the suppliers, the materials in these belts are comparable to those in most belts sold to mining companies. Belt covers, friction, and skim coats were basically neoprene, designated by the symbol "N"; polyvinyl chloride, designated by the symbol "P"; and, rubber, designated by the symbol "R".

The basic tests were conducted on belts having no carcass; these belts, designated "NC", consist of the 1/8-in thick cover. Two types of the belt carcass were studied. One was a cotton-rayon carcass, designated "CR", consisting of a breaker ply of open-weave nylon fabric integrally contained in the 1/8-in thick top cover, 4 plies of fabric having cotton cords as longitudinal members and transverse rayon cords and a 1/16-in thick bottom cover. This belt was 3/8-in thick. The other carcass, designated "IMP", is prestretched open-weave nylon fabric impregnated with the same polymer used for the cover; the cover was 1/16-in thick on both sides, and the "IMP" belt was 1/4-in thick. Most of the belts were 30-in wide and 15-ft long. Preliminary trials were made with 10-in, 30-in, and 40-in wide belts having a length of 20 ft. The suppliers stated that belts containing neoprene and polyvinyl chloride were fire resistant in accordance with Schedule 28[6] of the Federal Bureau of Mines.

Ignition Source.--Three ignition sources were used: Electrical preheating of the first 12-1/2 sq ft of belt before applying flame (source S_1); simultaneous application of electrical heat and flame (source S_2); and, flame only (source S_3).

For source S_1, the steel-plate heater is brought to a temperature of 450° F; this takes approximately 30 minutes. The plate temperature (450° F) is maintained for 1/4 hour before a gas flame is applied and air flow is established. The air flow, gas flame, and plate temperature are maintained for 1 hour or until flame propagation occurs, whichever is first. In tests with source S_2, a gas flame is applied, the heater-plate electrical circuit is energized, and the air flow is established simultaneously; these conditions are maintained for 3 hours or until flame propagation occurs, whichever is first. With source S_3 the air

[6] Schedule 28, Title 30--Mineral Resources, Chapter 1, Part 34--Fire-Resistant Conveyor Belts. BuMines, Amended Dec. 9, 1957, 5 pp.

velocity is established, and the gas flame is applied for 3 hours or until flame propagation occurs, whichever is first.

Propane gas flame (fig. 4) is used for ignition. The flaming gas develops a temperature as high as 2,300° F and liberates about 4,200 Btu per minute. The gas is fed to 12 bunsen burners placed in two rows 6 in apart and 5 in above the belt. The burners are 6 in apart in each row and angled into the air flow so the flame impinges vertically on the surface; the front burners are about 10 inches from the edge of the belt. For the S_1 and S_2 sources, the entire area of the steel plate under the test specimen is heated uniformly. The rate of heat application from the plate to a 30-in wide belt averages 1,300 Btu per minute. When the propane gas is lit, heat application to a belt averages 5,500 Btu per minute for the S_1 and S_2 sources and 4,200 Btu per minute for the S_3 source.

Ventilating Conditions.--The air velocity in the test zone was measured by anemometer readings taken on the belt at its front, midpoint, and end. The three measurements were nearly the same. Three ventilating conditions were studied:--A neutral condition, V_n, which was the uncontrolled air movement in the gallery caused by heat effects from the ignition source and burning belt; and, V_2 and V_5 air velocities through the gallery averaging 200 and 500 fpm, respectively.

PRELIMINARY TRIALS

Prior to the principal investigation, parameters that might affect flame propagation on conveyor belts were examined. Some trials were conducted in the gallery shown in figure 1 using the S_1 source and ventilating air velocities of 100, 400, and 800 fpm. Polyvinyl chloride (P-IMP) specimens 20-ft long and 10-, 30-, and 42-in wide were tried as single and parallel belt configurations. Other trials were made in the larger gallery using the S_3 igniting source and single pieces of N-NC, P-NC and R-NC belt, 30-in wide and 15-ft long. An important difference between test conditions in the large and small galleries is related to air flow, convection, and radiation patterns.

In these preliminary trials, flame propagated the entire length of all belts. No marked differences in quantity of heat for ignition, time to ignition, or rate of flame propagation were observed between single and parallel belts. The rate of flame propagation was influenced by the air velocity and the cross-sectional area of gallery. In the small gallery, flame spread at rates approximating 2 fpm for a 100-fpm air velocity and 5 fpm for an 800-fpm air velocity. In the large gallery, the rate of flame spread was less than 1 fpm for a 400-fpm air velocity. Belt width appeared to have no effect other than on the quantity of toxic gases evolved. Although samples of the atmosphere taken in the

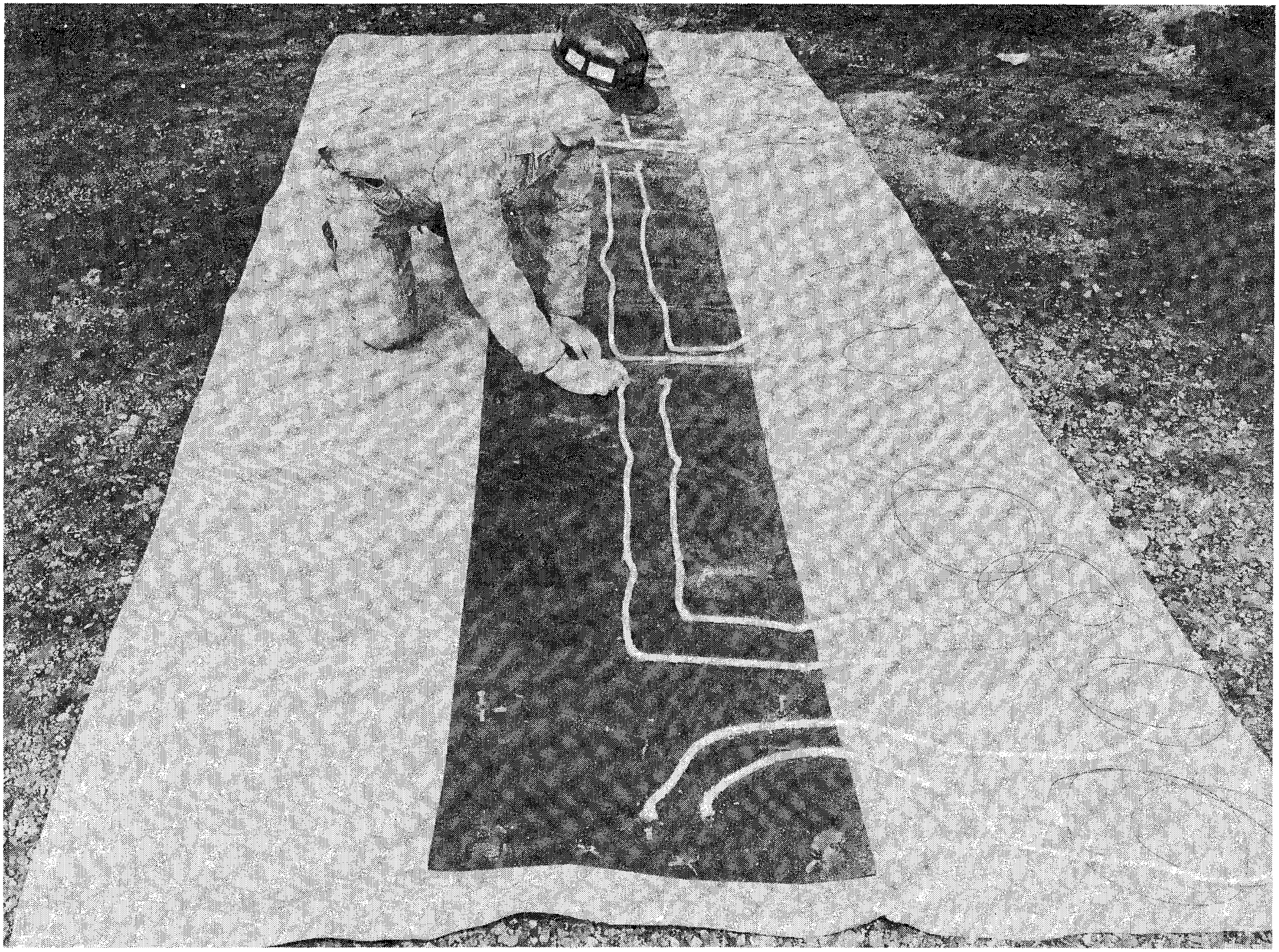

FIGURE 3. - Installing Thermocouples in and on Conveyor Belt.

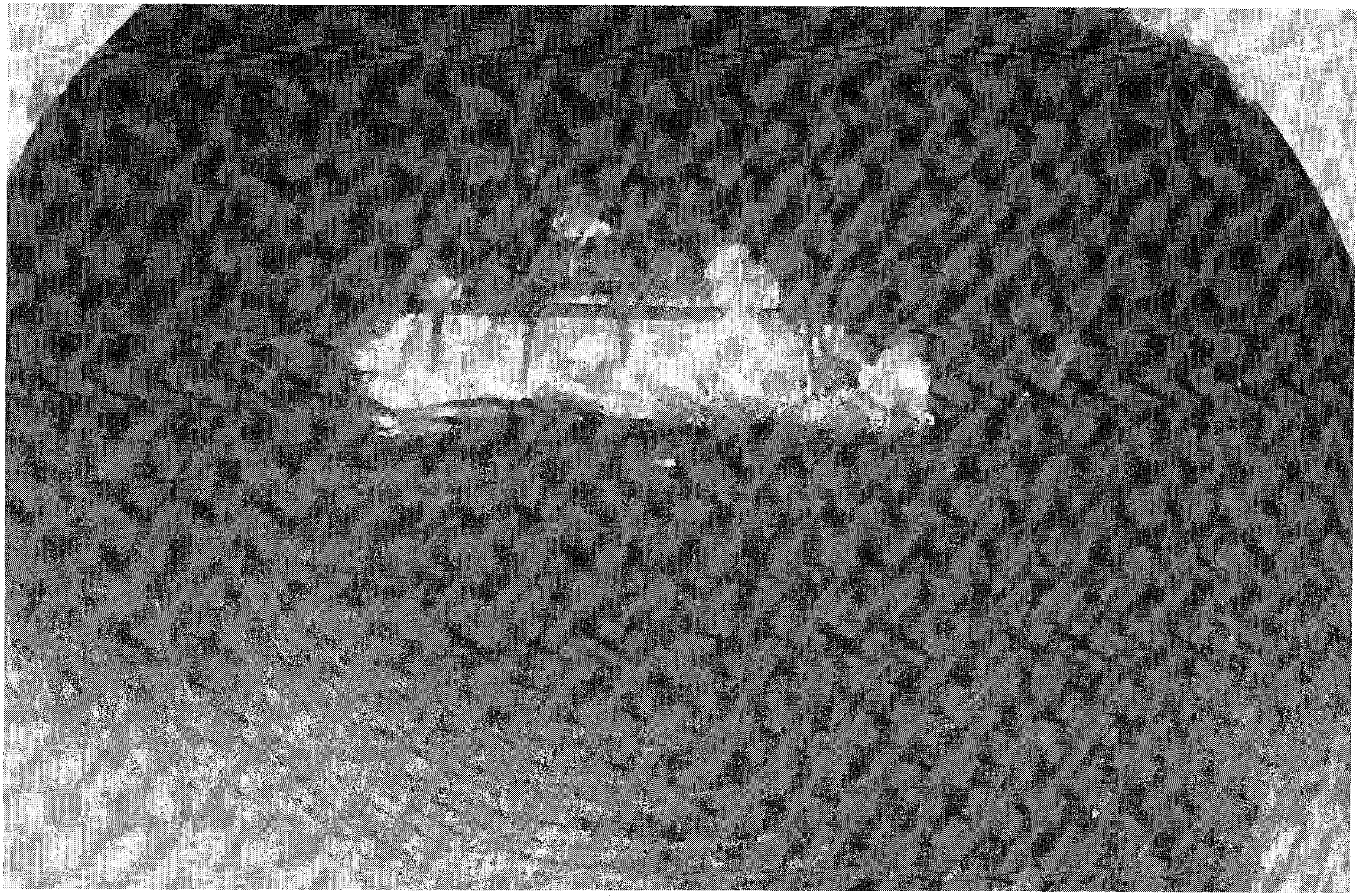

FIGURE 4. - Propane Gas Igniting Source for Flame Propagation Tests of Conveyor Belts.

gallery during these tests were inconclusive, indications are that wide belts produce more carbon dioxide, carbon monoxide, and hydrocarbons in the atmosphere than narrow belts. No tests were made for chlorine in the decomposition products.

TEST RESULTS

Method of Analysis.--A test program was developed to permit examination of the effects of the individual parameters and the interaction of the parameters. The analysis is based on a hypothesis that assumes no difference exists between the various levels of a parameter or between parameters. This hypothesis is tested by comparing the ratio of the mean square of the variance of a parameter and the mean square of the variance of the interaction between parameters to a critical "F" value in standard tables. If this ratio is equal or less than the critical "F" value, it may be concluded that the hypothesis is correct; that is, variations in the parameter have no real effect. However, if the calculated ratio exceeds the "F" value, then it is concluded that the parameter has an effect at a specified confidence level. In the following discussions the term "highly significant" means a 99 percent probability exists that the parameter has a real effect; the term "significant" refers to a 95 percent probability.

Belt Ignition.--All belts used in the research were ignited by the gas flame at the point of impingement as was evidenced by a marked increase in the volume of flame at the burner site. The time for ignition was less than 1 minute in all instances. As shown by tests with the S_3 source, heat from the gas flame was all that was necessary to cause ignition.

Flame Propagation.--Although the belts ignited without difficulty, flame propagation did not always occur. In the small gallery tests, flame stopped within 2-1/2 ft from the burners or propagated and consumed the full specimen. In tests with complete flame propagation, it was necessary to apply the igniting source until the flame traveled the 2-1/2 ft. The ventilating condition had a highly significant effect on flame propagation. Propagation was not obtained in any test with the V_n condition; and in general, the higher the air velocity the greater the heat input required to induce propagation. Propagation occurred more frequently and readily in tests with the S_1 and S_2 sources and was most difficult with the S_3 source. The probability of obtaining flame propagation on "N" and "P" belts is increased by the application of heat under the belt. In our tests the temperature under the belt for propagation on "N" and "P" belts ranged from 20° to 80° F above ambient. Belt cover composition had the least effect on conditions required to induce propagation. Typical data from individual tests on heat input are given in table 1.

Statistical analyses of data similar to those in table 2 show that after propagation was induced the rate of flame travel for the rubber belt was significantly greater than for belts with polymer covers. No significant difference was observed between rates on "N" and "P" belts. Belt carcass has a significant effect on rate of flame propagation; however, ventilating condition and ignition source were more important. Rates of flame propagation increased with increase in velocity of the ventilating air current. The highest rates were measured in tests with ignition by source S_1; the lowest were measured in tests with ignition by source S_3.

Air and belt temperatures 30 seconds before flame arrival were from 40° to 120° above ambient (table 3). These temperatures are considerably below those required to cause decomposition of conveyor belting (table 4). Therefore, it may be assumed that little or no decomposition of the belt occurs ahead of the flame.

TABLE 1. - Typical data on heat input between belt ignition and end of test

Belt	Heat input, Btu x 10^4								
	S_1[1]			S_2[1]			S_3[1]		
	V_n[2]	V_2[2]	V_5[2]	V_n[2]	V_2[2]	V_5[2]	V_n[2]	V_2[2]	V_5[2]
N-NC...	[3]14.1	0.70	0.57	[3]99.0	0.41	0.56	[3]76.0	[3]76.0	1.07
P-NC...	[3]14.1	.29	.15	[3]99.0	1.11	2.24	[3]76.0	[3]76.0	.57
R-NC...	[3]14.1	.47	.54	[3]99.0	.97	1.89	[3]76.0	1.11	.82
N-CR...	[3]14.1	[3]14.1	.26	[3]99.0	8.10	10.39	[3]76.0	[3]76.0	[3]76.0
R-CR...	-	-	.33	-	-	1.96	-	-	-
N-IMP..	-	-	2.95	-	-	[3]99.0	-	-	-
P-IMP..	[3]14.1	.42	.47	[3]99.0	3.49	4.58	[3]76.0	[3]76.0	[3]76.0

[1]Ignition source.
[2]Ventilating condition.
[3]Propagation not obtained.

TABLE 2. - Typical data on rate of flame propagation in small gallery tests

Belt	Rate of flame propagation, fpm								
	S_1[1]			S_2[1]			S_3[1]		
	V_n[2]	V_2[2]	V_5[2]	V_n[2]	V_2[2]	V_5[2]	V_n[2]	V_2[2]	V_5[2]
N-NC..........	0	8.0	8.1	0	4.0	3.5	0	0	1.9
P-NC..........	0	5.0	5.1	0	3.2	2.3	0	0	3.0
R-NC..........	0	48.0	50.0	0	7.3	31.0	0	6.4	16.0
N-CR..........	0	0	1.8	0	1.1	1.2	0	0	0
R-CR..........	-	-	9.8	-	-	5.6	0	-	-
N-IMP.........	-	-	2.1	-	3.5	3.5	-	0	-
P-IMP.........	0	3.5	2.7	0	3.2	2.0	0	0	0

[1] Ignition source.
[2] Ventilating condition.

TABLE 3. - Air and belt temperatures immediately ahead of flame in tests with S_2 igniting source

(Ambient = 50-65° F)

Air velocity, fpm	Type of belt	Average temperature, ° F, 30 seconds before flame arrival		Flame velocity, fpm
		Air	Belt	
V_4	P-NC	150	135	2.3
V_2	P-NC	175	175	3.2
V_2	P-IMP	140	95	3.2
V_2	N-NC	150	150	4.0
V_2	N-CR	140	100	1.1

TABLE 4. - Gaseous products of decomposition of a conveyor belt burning in an air stream[1]

Gas	Temperature, ° F	Average volume of gas per gram of belt sample, ml at 60° F and 30-in of Hg		
		R-CR	N-CR	P-IMP
CO_2	390	4.3	2.8	6.0
	480	26.8	26.2	28.3
	570	118.8	66.4	60.2
CO	390	1.0	.4	.4
	480	13.1	10.0	13.6
	570	61.0	25.8	28.4
HCℓ	390	-	0	.2
	480	-	12.0	60.4
	570	-	29.3	78.7

[1]Work cited in footnote 6.

DISCUSSION

The results of the preliminary tests in this investigation show that rubber, neoprene, and polyvinyl chloride belts ignite readily when subjected to an impinging flame. Although preheating of the belt is not necessary for ignition, preheating does increase the probability of development of a self-sustaining flame. Flame propagation along the belt was obtained only when air flowed over the belt surface at a velocity of 100 fpm or higher; flame did not propagate along any belt when forced ventilation was not used. In practice, consideration might be given to limiting air flow in belt installations. Also, further tests and research might disclose the need for more stringent approval requirements.

Our tests were made on new belts; investigations conducted at the Centraal Proefstation of Staatsmijnen, The Netherlands,[7] indicate a greater hazard exists with an old belt and that the hazard is reduced by increasing the thickness of belt cover, minimizing the velocity of the ventilating air, and using minimum tension on the belt.

[7]Maas, W. Fire Hazards Due to Slipping Rubber Belt Conveyors. Geologie en Mijnbouw (The Netherlands), 11e Jaargang No. 11, Nov. 1949, pp. 309-312.