RI 9626

REPORT OF INVESTIGATIONS/1996

A 20-Liter Furnace Test Method To Determine the Combustion Gas Toxicity of Conveyor Belts

By Maria I. De Rosa

UNITED STATES DEPARTMENT OF ENERGY

PITTSBURGH RESEARCH CENTER

Report of Investigations 9626

A 20-Liter Furnace Test Method To Determine the Combustion Gas Toxicity of Conveyor Belts

By Maria I. De Rosa

UNITED STATES DEPARTMENT OF ENERGY

PITTSBURGH RESEARCH CENTER

International Standard Serial Number
ISSN 1066-5552

CONTENTS

ILLUSTRATIONS

TABLES

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

em	centimeter
g	gram
gig	gram per gram
gis	gram per second
g/(m^3 x ppm)	gram per cubic meter multiplied by part per million
L	liter
Us	liter per second
rng	milligram
mgig	milligram per gram
m^2	square meter
m^3	cubic meter

m^{3}jg	cubic meter per gram
m^{3}js	cubic meter per second
mm	minute
mL	milliliter
mm	millimeter
mm^2	square millimeter
pct	percent
ppm	part per million
s	second
°C	degree Celsius

A 20-LITER FURNACE TEST METHOD TO DETERMINE THE COMBUSTION GAS TOXICITY OF CONVEYOR BELTS

By Maria I. De Rosa[1]

ABSTRACT

The U.S. Department of Energy Pittsburgh Research Center[2] conducted experiments with mine conveyor belt samples in a 20-L furnace and in a laboratory fire tunnel to measure and compare the major toxic gas concentrations evolved during the combustion of the materials. The toxic gas concentrations, measured simultaneously through a multiport sampling device and treated as yield values, included hydrogen chloride (HO), hydrogen cyanide (HeN), oxides of nitrogen (NO_x treated as NO_2), and carbon monoxide (CO). The data obtained from the two experimental systems were in good agreement. Correlations were developed for the toxic gas yields as a function of the percentage of chlorine (for HO gas), nitrogen (for HCN and NO_Z gases), and carbon (for CO gas) contained in the original materials.

The toxic gas yields were also used to calculate a toxicity index (TI) parameter to assess the potential gas toxicity of belt materials during a fire. Furthermore, the TI and the mass loss burning rate values were used to calculate a toxicity hazard (TH) parameter to estimate the toxic gas hazard produced by a burning belt in a ventilated system.

Results show that polyvinyl chloride (PVC) belts released higher HCl concentrations because of the higher chlorine content; styrene-butadiene rubber (SBR) belts released higher CO, HCN, and NO_Z concentrations because of the higher carbon and nitrogen contents. The TI's, however, were greater for the PVC belts due primarily to the higher levels of HCl produced. The fire tunnel data indicate that the SBR belts can bum with higher mass loss rates than the PVC belts, resulting in a potentially higher toxic hazard (higher TH values) even though their TI values were lower than those of the PVC belts.

---

[1] Industrial hygienist, Pittsburgh Research Center, U.S. Department of Energy, Pittsburgh, PA.

[2] This work originated under the U.S. Bureau of Mines prior to transferring to the U.S. Department of Energy on April 4, 1996.

INTRODUCTION

Underground mine fires pose a serious threat to the lives of miners. Fire deaths are considered to be mainly attributable to the inhalation of toxic combustion products *(1-2)*.[3] The introduction of a variety of new synthetic materials, treated with additives and fire retardants, has made the compositions of the combustion products far more complicated and their toxic hazard more difficult to assess *(3-5)*.

The toxic gases that can occur in fires are CO, HCl, HCN, and NO_2 *(6-7)*. CO is produced by the combustion of carbon-containing materials, hydrogen chloride by the combustion of chlorine-containing materials, and hydrogen cyanide and oxides of nitrogen by the combustion of nitrogen-containing materials *(8)*.

The human consequences of toxic gas poisoning, which depends on concentrations and exposure time *(9)*, may be:

1. Loss of mental concentration, decrease in sense of direction, drowsiness, coma, or death (CO poisoning) *(10)*;
2. Destruction of the mucous membranes of the eyes, nose, and respiratory tract (HCl poisoning) *(11)*;
3. Obstruction of the utilization of oxygen by the body tissue (HCN poisoning) *(12)*;
4. Death from bronchospasm and respiratory failure (NO_2 poisoning) *(13)*.

The National Institute for Occupational Safety and Health (NIOSH) has established toxic gas concentrations that are considered immediately dangerous to life and health (IDLH). The IDLH values represent "the maximum concentration from which, in the event of respirator failure, one could have escaped within 30 min without a respirator and without experiencing any escape-impairing (e.g., severe eye irritation) or irreversible health effects" *(14)*. The recently revised NIOSH definition for an IDLH exposure condition is one that "poses a threat of exposure to airborne contaminants when that exposure is likely to cause death or immediate or delayed permanent adverse health effects or prevent escape from such an environment" *(15)*. The purpose of establishing an IDLH exposure concentration is "to ensure that the worker can escape from a given contaminated environment in the event of failure of the respiratory protection equipment" *(15)*. For the toxic gases investigated in this study, the previous and revised IDLHs, respectively, are: CO, 1,500 and 1,200 ppm *(16-17)*; HCl, 100 and 50 ppm *(18-19)*; HCN, 50 ppm (unchanged) *(20-21)*; and NO_2, 50 and 20 ppm *(22-23)*. For comparison, both the previous and revised IDLH's have been used in this study in the calculations of the toxicity parameters.

In a previous U.S. Bureau of Mines (USBM) study *(8)*, experiments were conducted in a 20-L furnace using chlorine- and nitrogen-containing materials to measure and correlate the gas concentrations of HCl and HCN with the chlorine and nitrogen contents in the original materials, respectively. It was found that the gas concentrations were directly proportional to the chlorine and nitrogen contents in the original materials.

This investigation expands on that approach by measuring simultaneously additional toxic gases through a multiport sampling device, comparing the toxic gas yields measured in the 20-L furnace with similar yields measured in the laboratory fire tunnel *(24)*, and correlating the toxic gas yields with the percentage of the chemical contents in the original materials. Additionally, in the course of this study, a toxicity index (TI) and a toxicity hazard (TH) parameters, to assess the potential gas toxicity of mine conveyor belt materials during a fire and estimate the toxic gas hazard produced by burning belts during a fire, were developed.

This work supports the Pittsburgh Research Center's program to develop improved methods and technology for preventing mine fires, thereby improving mine worker safety.

20-LITER FURNACE EXPERIMENTAL SYSTEM

CONFIGURATION

The 20-L furnace system (figure 1A) consists of a furnace (22.5 cm wide by 22.5 cm high by 35 cm long) whose inner panels are embedded with heating elements. A quartz cup (2.5-cm diam) containing the sample is placed on a quartz pedestal (10 cm high) that is inserted in an opening in the center of the furnace floor. The sample and furnace temperatures are measured with thermocouples. The temperature data (logged in 10-s intervals) are transmitted to a laboratory-based real-time data acquisition system and subsequently printed by means of a miniframe computer. During the experiments, an exhaust pump draws ambient air at a constant rate of 0.13 L/s into the furnace through an opening at the center of the furnace door. The combustion gases, drawn by the same pump, are directed through a multipart sampling device into four pairs of impingers containing specific gas-trapping solutions. The device consists of a stainless steel manifold with a single inlet, which is inserted into the upper back of the furnace and four outlets through which the airflow, equally divided by flowmeters (0.03 L/s through each outlet), is directed into four pairs of impingers. Each pair consists of two consecutive impingers, and each impinger contains 15 mL of gas-trapping solution. The combustion gases emerging from the impingers are directed

---

[3] Italic numbers in parentheses refer to items in the list of references at the end of this report.

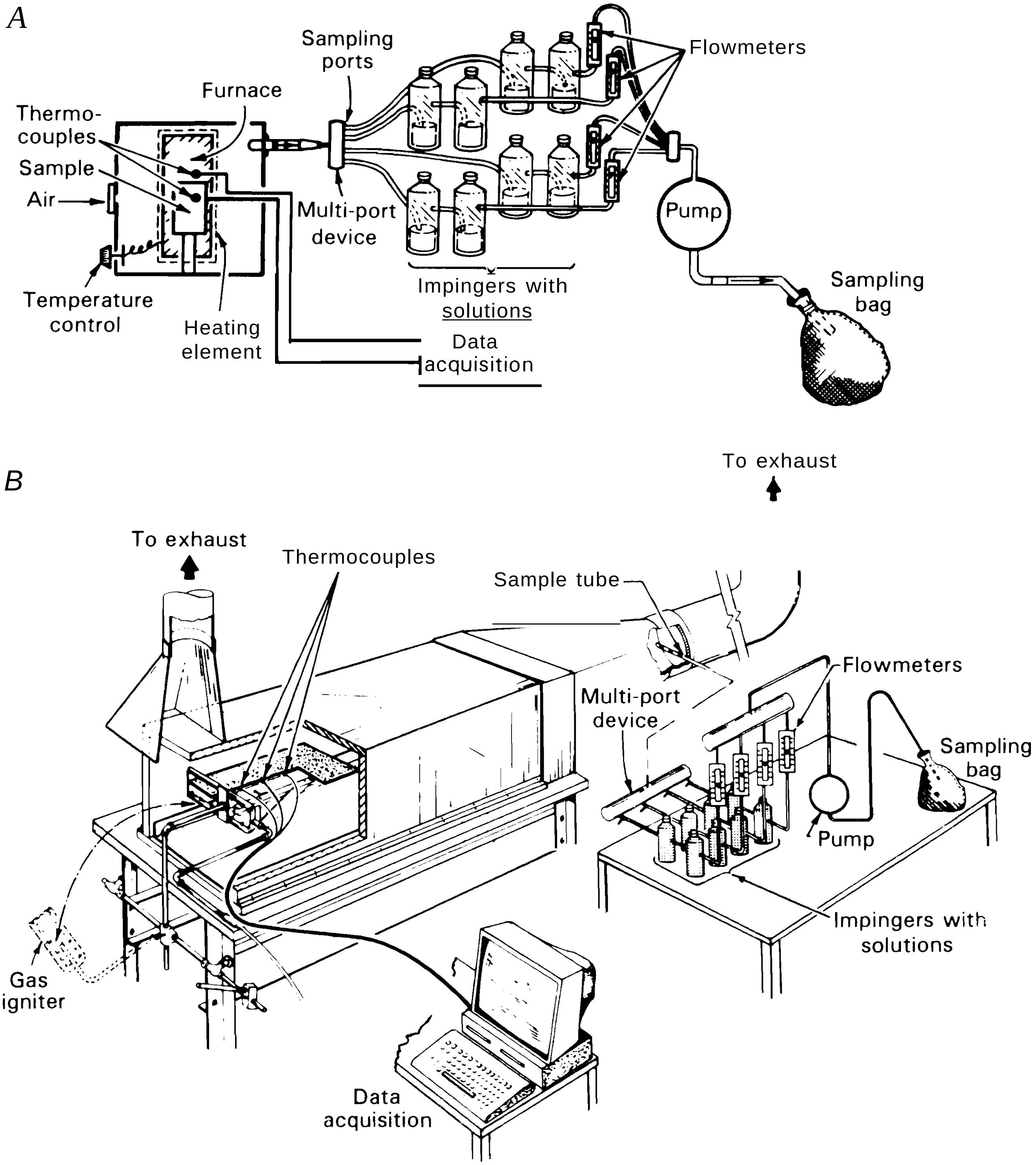


Figure 1.-Experimental systems: *A,* 20-L furnace; *B,* laboratory fire tunnel.

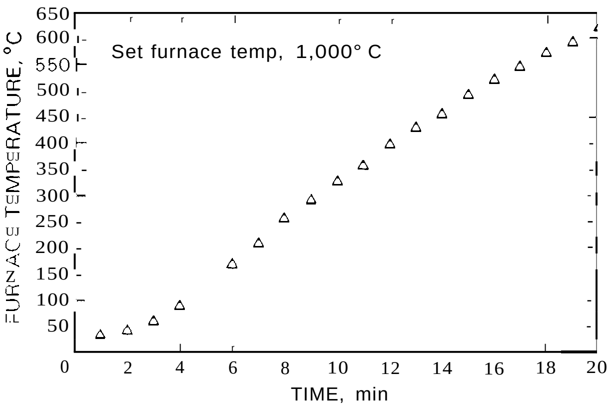
through the pump into a large (170-L) sampling bag. The solutions (0.1 pct) used to recover the combustion gases are sodium hydroxide (to recover the HCl and HeN), triethanolamine (to recover the NOll' treated as NO_2), and alkaline-permanganate (to recover the NO_2, which is used to calculate the nitrogen oxide (NO) yields). Syringe grab samples (20 mL) of combustion gases are taken at 2-min intervals from the sampling port located before the first set of impingers and at the end of each experiment from a sampling bag to measure the CO gas concentrations.

PROCEDURES AND DATA REDUCTION

Two sets of experiments with five different mine conveyor belt samples were performed at a set furnace temperature of 1,000 °C. As shown in figure 2, the furnace temperature rose from ambient at an average rate of 32 °Clmin and reached 640°C at the 20th min. The airflow through the furnace was 0.13 L/s for a 2O-min duration; the 2O-min duration was chosen because during this time all samples burnt completely and only ashlike debris remained. Subsequent exposure of the debris to higher furnace temperatures did not yield any significant gas concentrations.

The combustion gases were directed into four sets of solution-containing impingers beginning at a sample temperature of 150°C, which was reached at about the 8th min. No appreciable gas concentrations were measured at lower temperatures. The mine conveyor belt materials used were 19 samples, of polyvinyl chloride (PVC: P1, P2), styrene-butadiene-neoprene (SBR-neoprene: SN1), and styrene-butadiene rubber (SBR: S1, S2). The description and analyses of the materials are reported in table 1.

The percentage of chlorine, nitrogen, and carbon contents in the original materials was determined by the American Society for Testing and Materials (ASTM) test methods No. 04208, 03179, and 05373, respectively. The impinger solutions were analyzed for gas concentrations by various test methods. The sodium hydroxide solutions were analyzed for HCI by the ASTM test method No. 04327-88 and for HCN by U.S. Environmental Protection Agency (EPA) test method No. 00720. The triethanolamine solution was analyzed for NOll (treated as NO_2) by the American Water Pollution Federation (AWPF) test method No. 418-C, and the alkaline-permanganate solution was analyzed for NO_Z by the EPA test method No. 70. The NO_Z concentrations analyzed by the EPA method were used to calculate the NO concentrations by subtracting the NO_Z yields from the NOll yields and by multiplying the remainder by the ratio of the NO and the NO_Z molecular weights.



Agure 2---furnace temperatures In the 2o-L furnace at a set temperature of 1,000 ·C.

Each gas concentration (mg) was multiplied by a factor of 4 because the total airflow passing through each set of impingers was four times less than the airflow passing through the sampling device. The product: was treated as a yield value, milligrams of toxic gas per gram of original material burnt (mg/g), because it evolved during the complete combustion of the 19 sample.

Syringe grab samples, taken at the sampling port and at the sampling bag, were analyzed by gas chromatography for CO concentrations (ppm). The average CO concentrations measured from the sampling bag were converted to mg and treated as yield values (mg/g). Other variables measured were the sample and furnace temperatures (OC) and the initial and final sample weight (g). The 19 original sample weight was used to calculate the gas yield values because only ashlike debris remained after each experiment.

Table 1.--Descrlption and analyse. of conveyor belt materials

Conveyor belt material and sample	Construction	Thickness, mm	Analyses. pet		
			Chlorine	Nitrogen	Carbon
PVC: Polyvinyl chloride polymer, with fillers:					
P1	Solid woven	13.3	28	0.63	S0
P2	Solid woven	10.6	19.2	0.65	SO.7
SBR-neoprene: Styrene-butadiene-neoprene rubber polymer, with fillers:					
SN1	3-ply	11.9	11.5	0.69	55.5
SBR: Styrene-butadiene rubber polymer, with fillers; treated for fire retardancy:					
S1	3-ply	11.6	7.7	2.3	64
S2	3-ply	11.56	7.4	1.5	63.7

LABORATORY FIRE TUNNEL EXPERIMENTAL SYSTEM

CONFIGURATION

The laboratory fire tunnel (figure *IB),* also known as the belt evaluation laboratory test (BELT) apparatus, consists of a chamber (1.8-m long by 0.46-m^2) constructed of refractory material (2.5-cm thick). The chamber is connected to an exhaust ducting (30.5-cm-diam galvanized steel ducting) via a stainless steel transition section whose inner surface is lined with a ceramic fibet blanket (13-mm thick). The igniter used is a commercial U-shaped natural gas burner with two rows of six nozzles.

The mine conveyor belt sample (23 em wide by 76.2 em long for the tests in this study) is fastened to a steel rack constructed of slotted angle iron and placed in the tunnel at a distance of 20.3 or 12.7 ern from the tunnel roof. The airflow is measured by a vane anemometer (approximately 211.7 Us) placed on the belt surface at about 30 ern from the front of the tunnel. The sample temperatures were monitored by thermocouples that were embedded along the centerline of the belt (half depth of the belt thickness) at distances of 15.2, 30.5, and 45.7 cm. The temperature data were transmitted every 10 s to a data acquisition system and were printed by means of a computer program.

During the experiments, a small amount of the combustion gases (0.13 Us) is drawn by an exhaust pump via a multiport sampling device. The device consists of a stainless steel manifold with a 1-cm-diam, 30-em-long perforated inlet tube (three equidistant perforations along the tube) inserted horizontally into the tunnel transition section. The combustion gases are then directed equally by flowmeters through four manifold outlets into four sets of solution-containing impingers as described in the "20-Liter Furnace Experimental System" section earlier in this report. The gases emerging from the impingers flow through the pump into a large (170-L) sampling bag. Syringe grab samples are taken at a sampling port at 4-min intervals and from the sampling bag at the end of each experiment.

PROCEDURES AND DATA REDUCTION

Experiments with the same mine conveyor belt materials described in table 1 were performed in the laboratory fire tunnel. The sample weights were: PI = 2,926 g; P2 = 2,335 g; SNI = 2,812 g; Sl = 2,495 g; and S2 = 2,445 g. The experiment with sample S1 was repeated to verify the gas concentrations.

During the experiments, a belt sample was fastened to a steel rack with 1.4-mm-diam cotter pins and thin washers to prevent the belt from shrinking away from the burner. The fastened belt was placed in the fire tunnel at a distance of 20.3 em (S1 and S2 samples) or 12.7 em (PI, P2, and SN1 samples) from the fire tunnel roof. The shorter distance from the roof facilitated the combustion of these samples which, otherwise, would not have completely burnt. The flames from the gas burner impinged equally upon the upper and lower surfaces of the sample for a duration of 5 min (S1, S2, SN1, and P2 samples) or 8 min (P1 sample). The longer flame impingement time for sample P1 was required to maintain the combustion process, which otherwise would have not been sustained.

Because only ashlike debris remained after each experiment, the initial sample weight was used to calculate the toxic gas yields. The gas solutions and the syringe grab samples were analyzed in the same manner as described for the 20-L furnace. Each toxic gas concentration value (mg) was first multiplied by a factor of 4 for the reasons given earlier in the "20-Liter Furnace Experimental System" section, and then normalized to a yield value (mg/g). The normalization was accomplished by multiplying the toxic gas concentration value (mg) by the ratio of the total volumetric airflow in the tunnel and the total volumetric airflow in the sampling device during the test duration; the product was then divided by the initial sample weight.

DISCUSSION AND TREATMENT OF EXPERIMENTAL RESULTS

The gas yields (mg/g) ofHCI, HCN, $N0_2$, and CO measured in the 2O-L furnace and in the laboratory fire tunnel are shown in table 2. The calculated NO yields for both systems also are shown in table 2. The CO gas yields measured in the fire tunnel were higher (average for all belt materials, 43 pct) than those measured in the 20-L furnace; the HCI and HCN gas yields were slightly higher (average for all belt materials, 16 and 20 pet, respectively), and the $N0_2$ and NO gas yields were slightly lower (average for all belt materials, 11 and 20 pct, respectively). The difference between the gas yields measured in the fire tunnel and those measured in the 20-L furnace is due perhaps to the use of a horizontal sampling inlet only. The use of vertical and diagonal inlets, intersecting the horizontal one, may yield better results by drawing representative samples of the combustion air in the fire tunnel ventilation system. Considering the significant differences in the experimental systems, however, the toxic gas yields measured in both systems may be considered in good agreement.

For all samples, the HCl and CO yields were much higher than the HCN, NO_2, and NO yields. As expected, samples P1 and P2, followed by sample SN1, released the highest HCl yields because of the high percentage of chlorine content in the original materials; they released the lowest HCN, NO_2, and CO yields because of the low percentage of nitrogen and carbon contents in the original materials. On the other hand, samples S1 and S2 produced the lowest HCl yields because of the low percentage of chlorine content of the materials and the highest HCN, NO_2, and CO yields because of the high percentage of

Table 2.-ToxIc gas yields measured In the 2o-L furnace and laboratory fire tunnel experimental systems (mg/g)

Conveyor belt material and sample[1]	2O-L furnace					Laboratory fire tunnel				
	Hcr	HCN	NO?z		CO	HCI	HCN	NO_2[2]	NO[3]	CO
pvc:										
PI	73	0.11	0.25	0.16	69	94	0.12	0.22	0.09	90
P1[4]	90	0.11	0.30	0.16	70					
P2	53	0.14	0.30	0.11	71	69	0.16	0.27	0.11	96
P2[4]	50	0.09	0.44	0.12	71					
5BR-neoprene:										
5NI	46	0.07	0.36	0.09	61	59	0.17	0.26	0.09	68
5N1[4]	48	0.11	0.38	0.11	54					
5BR:										
51	33	0.28	0.67	0.29	99	30	0.26	0.66	0.21	164
51[4]	30	0.18	0.73	0.31	114	25	0.34	0.59	0.26	145
52	23	0.25	0.39	0.26	98	24	0.23	0.60	0.20	172
52[4]	26	0.21	0.64	0.19	103					

[1] 2O_L furnace: all samples = 1 g. Laboratory fire tunnel (normalized to 1g sample): PI = 2,926 g, P2 = 2,335 g, 5NI =2,812 g, 51 =2,495 g, 52 =2,445 g.

zNO. treated as NO_Z.

[3] Calculated values.

[4] Second set of experiments.

nitrogen and carbon contents of the materials. It is important to note that the HCl yields measured in this study are at least 50 pet higher than similar yields measured in a previous U5BM study (8) using materials with comparable chlorine contents. The increase in HCl recovery is due to the longer contact time of the combustion gases with the gas-trapping solutions. However, even the present HCl yield values are at least 50 pct below the theoretical HCI values based on the percentage of chlorine in the original material (25-27). The difference between the theoretical HCl yields and the measured ones may be the result of HCl decay by deposition on the furnace walls and floor and on sampling lines (28-29).

Table 3 shows the CO concentrations and sample temperatures versus time measured in both experimental systems. For the 2O-L furnace system, all samples released high CO concentrations at sample temperatures above 300 °C. However, sample 51 released the highest CO concentration at the lowest sample temperature. Furthermore, this sample, together with samples 52 and 5N1, continued to release high CO concentrations for the longest duration. For the fire tunnel system, samples 51 and 52 burnt within shorter periods of time than the other samples, releasing high CO concentrations. Of further importance is that samples 51 and 52 reached high temperatures (above 400 0c) simultaneously along their entire lengths. These belts burnt completely within a very short time, thus releasing the toxic gases earlier and at faster rates.

Figure 3 shows the toxic gas yields (mglg) of HCI, HCN, NO_2, and CO measured for each material in each experimental system plotted as a function of the percentage of the chlorine, nitrogen, and carbon contents in the original materials. Using the average values of each gas yield (mglg converted to gig) measured in both systems for each belt material, least square regression analyses were made. The regression analyses results, valid for the range of chlorine, nitrogen, and carbon percentage encountered in this study, are reported in equations 1 through 4 below and are also shown in figure 3 as solid lines.

$$\text{YHO (gig)} = (0.00275) \times (\text{CI,pct}) + (0.0088); \qquad (1)$$

the correlation coefficient $(r^2) = 0.93$.

$$\text{YHCN (gig)} = (0.000093) \times (\text{N,pct}) + (0.000055); \qquad (2)$$

the correlation coefficient $(r^2) = 0.87$.

$$\text{YN0}_2 \text{ (gig)} = (0.000226) \times (\text{N,pct}) + (0.000177); \qquad (3)$$

the correlation coefficient $(r^2) = 0.89$.

$$\text{YCO (gig)} = (0.00405) \times (\text{C,pct}) + (-0.136); \qquad (4)$$

the correlation coefficient $(r^2) = 0.85$.

The results shown in figure 3 indicate that good and direct correlations exist between the yield values of HO, HCN, NO_2, and CO and the percentage of chlorine, nitrogen, and carbon contents of the original belt materials; the higher the chemical contents, the higher the toxic gas yield values.

Table **3.—CO** concentration, sample temperature, and total airflow measured In the 2G-L furnace and laboratory fire tunnel experimental systems for first set of experiments

Conveyor belt material and sample[1]	2O-L furnace				Laboratory fire tunnel					
	Time, min	CO, ppm	Sample temp, °C	Total airflow, L	Time, min	CO,[2] ppm	Sample temp, °C, at thermocouple distance of— 15.2 cm	3O.5 cm	45.7 cm	Total airflow,[3] L(10^3)
PVC:										
P1	8	44	183	96	3	1,000	450	205	205	508
	10	58	262		7	1,380	375	235	205	
	12	1,036	356		11	950	275	250	215	
	14	1,263	450		15	780	225	265	235	
	16	441	533		19	500	195	315	245	
	18	508	615		23	300	175	450	325	
	20	300	668		27	200	150	570	400	
					31	180	135	600	425	
					35	150	125	620	475	
					39	100	115	620	560	
P2	8	41	167	96	3	1,030	425	260	250	254
	10	57	241		7	1,050	400	260	300	
	12	1,040	302		11	389	225	275	275	
	14	1,300	397		15	197	165	450	375	
	16	530	495		19	144	165	625	550	
	18	509	585							
	20	301	640							
SBR-neoprene:										
SN1										
	8	90	170	96	3	1,500	502	193	146	254
	10	180	257		7	1,200	463	306	233	
	12	913	378		11	540	290	565	500	
	14	1,220	460		15	276	239	560	620	
	16	1,440	542		19	277	192	620	560	
	18	695	604							
	20	368	654							
SBR:										
S1	8	80	165	96	3	800	306	142	129	190.5
	10	104	250		7	4,504	341	285	244	
	12	1,428	319		11	3,994	666	752	454	
	14	1,290	455		15	1,050	341	467	822	
	16	1,388	545							
	18	541	575							
	20	468	660							
S2	8	75	162	96	3	1,215	350	201	135	127
	10	98	245		7	3,824	590	420	300	
	12	1,390	370		9	1,500	530	709	503	
	14	1,300	460		11	850	340	500	850	
	16	1,206	540							
	18	490	609							
	20	450	658							

[1] 2O-L furnace: all samples = 1 g. Laboratory fire tunnel: P1 = 2,926 g, P2 = 2,335 g, SN1 = 2,812 g, S1 = 2,495 g, S2 = 2,445 g.

[2] The CO concentration measured in the fire tunnel at the 3rd min has been reduced by 50 ppm, which is the CO concentration measured during the standardization of the gas burner.

[3] The total airflow for the fire tunnel experiments was calculated by multiplying the experimental airflow by the time taken by each belt to burn (P1 = 40 min, P2 = 20 min, SN1 = 20 min, S1 = 15 min, S2 = 11 min).

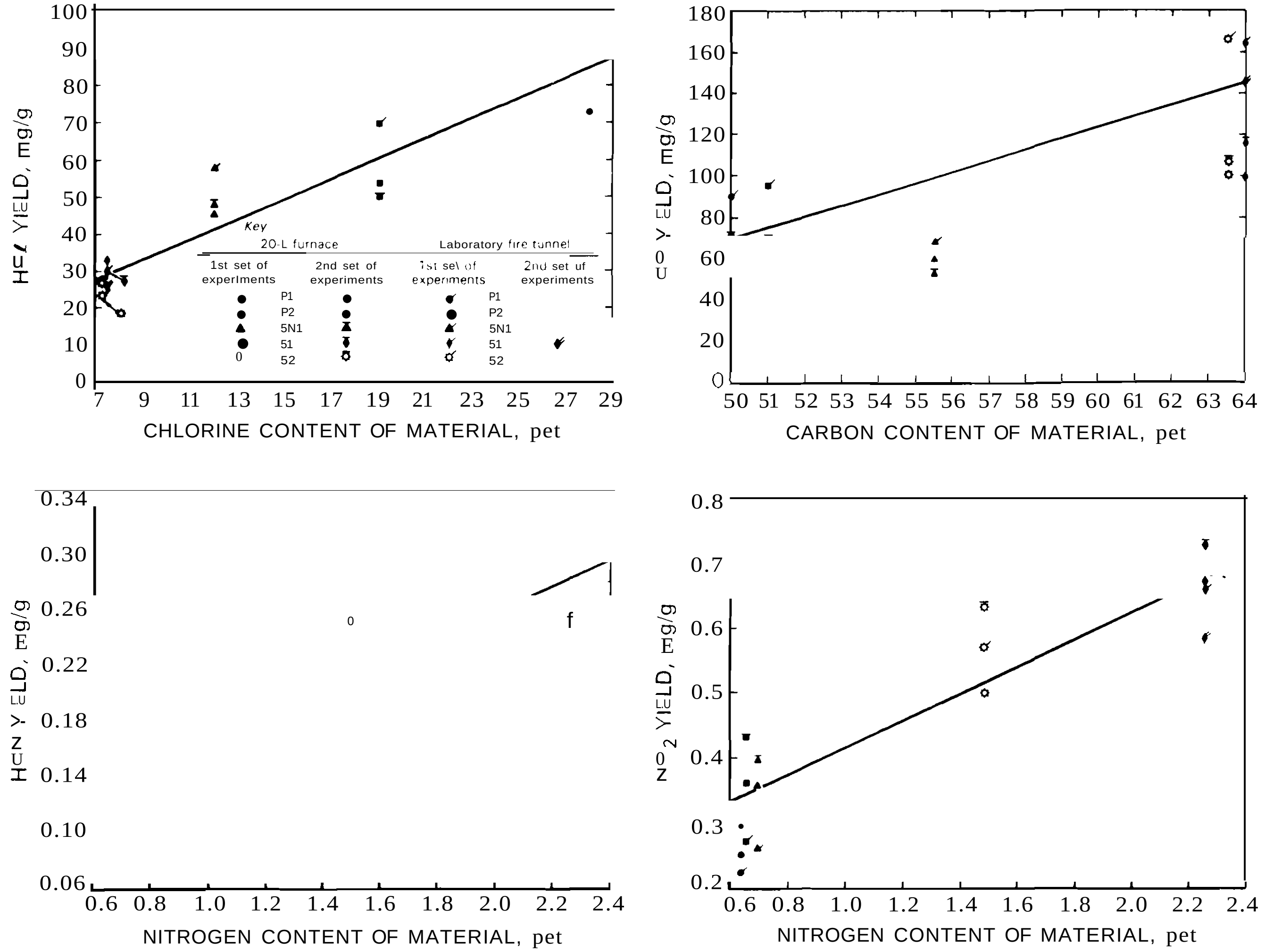


Figure 3.---Correlations between the HC1, HCN, NO_2, and CO gas yields and the percentage of chlorine, nitrogen, and carbon contents In the original materials.

TOXICITY INDEX PARAMETER

The toxicity index (TI) parameter is a measure of the potential gas toxicity hazard of a belt material during a fire. The TI is considered to be the sum of all the IDLHs contained in each toxic gas yield for that material, assuming the gas toxicities are additive *(30-31)*. The TI can be calculated according to equation 5:

$$TI = \sum(Yx\, 1(IDLHx)\; Cx), \qquad (5)$$

where TI = toxicity index parameter (m^3/g),

Yx = yield of toxic gas (grams of gas produced per gram of original material consumed during the combustion process, gig),

and Cx = constant to convert the toxic gas yield from gig to ppm, as given by *(10-6/0.022414)* x (molecular weight gas, x), gI(m^3 x ppm).

For CO (molecular weight = 28.01 g), the Cx value =(28.01/0.022414) x (10-6) =0.00125 gI(m^3 x ppm).

Considering the toxic gas yields measured in this study, equation 5 can be written as equation 6:

$$TI\ (m^3/g) = (YHCI)/(IDLH_{Hc1} \times C_{HCl}) + (YHCN)/(IDLH_{HCN} \times C_{HCN}) + (YNO_2)/(IDLH_{NO_2} \times C_{NO_2}) + (YCO)/(IDLH_{CO} \times Cco). \qquad (6)$$

Good agreement exists between the TI's calculated for the 2O-Lfurnace and those calculated for the fire tunnel, as shown in figure 4. As expected, the TI's calculated with the revised IDLH's (revised TI's) are about twice as high as the TI's calculated with the previous IDLHs (previous TI's) for all of the belt materials in both experimental systems. The higher the TI, the greater the potential toxicity of a conveyor belt during a mine fire.

The TI's were the highest for sample PI, followed by samples P2 and SN1, and the lowest for samples S1 and S2 in both experimental systems. For sample P1, the revised TI's were 1.06 and 1.22 m^3/g (20-L furnace and fire tunnel, respectively), and the previous TI's were 0.54 and 0.64 m^3/g (20-L furnace and fire tunnel, respectively). For sample S2, the revised TI's were 0.39 and 0.43 m^3/g (20-L furnace and fire tunnel, respectively), and the previous TI's were 0.21 and 0.23 m^3/g (20-L furnace and fire tunnel, respectively).

TOXICITY HAZARD PARAMETER

The toxicity hazard (TH) parameter estimates the level of toxic gas hazard produced by a burning belt material in a ventilated system. The TH is the product of the TI and a ratio of mass loss to ventilation airflow rates; it corresponds to the number of IDLH's contained in an airflow during the burning of a belt; the higher the TH value, the greater the toxic gas hazard. The TH parameter is given by equation 7:

$$TH = TI\ (Ms/Q), \tag{7}$$

where TH = toxicity hazard parameter (dimensionless),

Ms = mass loss rate of a burning sample (gls),

and Q = volumetric airflow rate (>0) into which the toxic gas concentration is mixed (m^3/s).

In calculating the TH parameter, consideration must be given to the mass loss rate of a burning belt, because different belts may burn at different rates. For example, the fire tunnel data indicated that the average mass loss rate for belt S2 (3.7 gls) was about three times greater than that for belt P1 (1.2 g/s) at an airflow of 0.212 m^3/s. These values were derived from the original sample weight and the time of burning given in table 3. Previous data from USBM large-scale fire gallery tests of conveyor belts (24) also indicated that the burning rates can differ for various types of belts. Then, using the 2O-Lfurnace revised TI values for belts S2 (0.39 m^3/g) and P1 (1.06 m^3/g) and the fire tunnel airflow (0.212 m^3/s), the calculated TH values for the fire tunnel system are 6.8 for belt S2 and 6.1 for belt PI. The TH value for belt S2 would be even higher if the belt had been tested under the more severe experimental conditions (8-min flame impingement, 12.5-cm distance from the tunnel roof) of belt P1 because these conditions would have resulted in larger mass loss rates for belt S2. This example illustrates that, although the TI is important in assessing the potential toxic gas hazard of belt materials, the mass loss burning rates could be equally or more significant in determining the actual toxic gas hazard of a burning belt in a ventilated system.

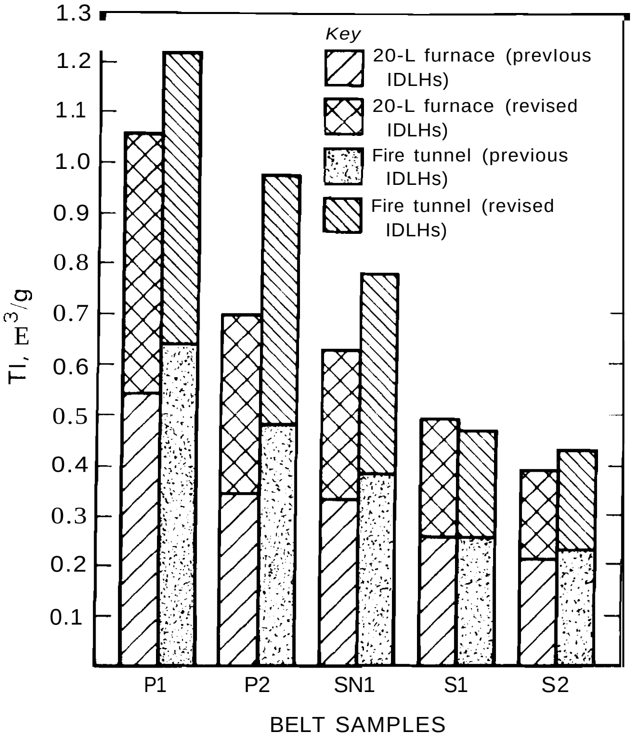


Figure 4.-ToxJcity **Index parameter for the 20-L furnace and laboratory fire tunnel experimental systemL**

CONCLUSIONS

The toxic gas yields of Ha, HCN, NO_2, and CO measured in the 2O-L furnace system are in good agreement with similar yields measured in the laboratory fire tunnel system. Thus, either system could be used to obtain the gas yield data for mine conveyor belts. However, the 20-L furnace system is preferred due to the smaller sample size and less time required to set up and run an experiment.

Good and direct correlations were found between the percentage of chlorine, nitrogen, and carbon contained in the original materials and the HCl, HCN, NO_2, and CO gas yields. Both experimental systems produced essentially the same results. The greater the percentage of chemical contents, the higher the corresponding toxic gas yield values. As expected, the PVC belt samples with the highest percentage of chlorine released the highest HO. The SBR belt samples with the highest percentage of nitrogen and carbon released the highest HCN, NO_2, and CO.

Using the toxic gas yield data, a toxicity index (TI) and a toxicity hazard (TH) parameters were calculated for each belt material. The TI is a measure of the potential gas toxicity that a belt can produce during a fire; the higher the TI value, the greater the potential toxicity. As expected, the TI was the highest for the PVC belts and the lowest for the SBR belts. The TH parameter is the product of the TI and a ratio of mass loss burning rates to ventilation airflow rate. It can be used to estimate the level of toxic gas hazard produced by a burning mine conveyor belt in a ventilated system. In some cases, the mass loss rates may be sufficiently great that a belt with a low TI actually produces a more severe toxic gas hazard than one with a much higher TI. For example, for the fire tunnel system, the TIl value calculated for belt S2, whose TI is 60 pet lower than that for belt PI, was higher than the TH value calculated for belt PI because of the higher mass loss burning rate of belt S2.

ACKNOWLEDGMENTS

The author wishes to thank Nick Harris (deceased), Mine Safety and Health Administration, for conducting the combustion experiments in the laboratory fire tunnel; Frank J. Perzak, U.S. Department of Energy Pittsburgh Research Center, for measuring the conveyor belt sample temperatures during the experiments in the laboratory fire tunnel; and C. D. Litton, also with the U.S. Department of Energy Pittsburgh Research Center, for his technical assistance in developing the equations in this report.

REFERENCES

1. Chu, C. S., M. Chan, B. Y. Ouygan, and Q. Y. Zhang. Chemical Pulmonary Bum Injury and Chemical Intoxication. Human Medical College, Beijing, China, v. 9, No.2, 1982, pp. 111-114.

2. Hirscbler, M M Fire Hazard and Toxic Potency of the Smoke From Burning Materials. J. Fire Sciences, v. 5, 1987, pp. 289-307.

3. Kaplan, H L, A F. Grand, and G. E. Hartzell. Toxicity of the Smoke Problem. J. Fire Safety, v. 7,1984, pp. 11-23.

4. Caldwell, D. J., and Y. C. Alarie. A Method To Determine the Potential Toxicity of Smoke From Burning Polymers. J. Fire Sciences, v. 9, 1991, Tecbnomic Publ. Co., Lancaster, PA, pp. 470-518.

5. Babrauskas, V., R. H Harris, R. G. Gann, B. C. Levin, B. T. Lee, R. D. Peacock, M. Paabo, W. Twilley, M. F. Yoklavich, and H. M. Clark. Fire Hazard Comparison of Fire-Retarded and Non-Fire Retarded Products. Natl. Bureau of Standards Spec. Publ. No. 749, 1988, pp. 1-86; NTIS PB 88-249966.

6. Snell, T. E., B. C. Levin, and A J. Fowell. Workshop on Combustion Product Toxicity. Natl. Bureau of Standards (Washington, IX, Sept. 10, 1982), NBSIR 82-2634,1982, pp. 1-65.

7. Woolley, W. D. Toxic Products From Plastic Materials in Fires. J. Plastics and Polymers, 1973, pp. 280-286.

8. De Rosa, M. I. Correlations of Hydrogen Chloride and Hydrogen Cyanide Concentrations Evolved During the Combustion of Chlorine- and Nitrogen-Containing Materials. USBM RI 9521, 1994, 14 pp.

9. Caldwell, D. J., and Y. C. Alarie. A Method To Determine the Potential Toxicity of Smoke From Burning Polymers. J. Fire Sciences, v. 8, 1990, Tecbnomic Publ. Co., Lancaster, PA, pp. 275-309.

10. Stewart, R. The Effect of Carbon Monoxide on Man. J. Fire Flamm. Comb. Toxic., v. 1,1974, pp. 167-170.

11. Birky, M M Toxicity and Incapacitation Due to Hydrogen Chloride. J. Fire and Mater., v. 10, 1986, pp. 125-132.

12. Esposito, F. M., and Y. C. Alarie. Inhalation Toxicity of Carbon Monoxide and Hydrogen Cyanide Gases Released During the Thermal Decomposition of Polymers. J. Fire Sciences, v. 6,1988, pp. 195-242.

13. Ben-Jebria, A, R. Marthan, and J. P. Savineau. Effect of In Vitro Nitrogen Dioxide Exposure on Human Bronchial Smooth Muscle. J. Amer. Rev. Resp. Disease, v. 146, No.2, 1992, pp. 378-382.

14. NIOSH Pocket Guide to Chemical Hazards, June 1990, Washington, IX, p. 5.

15. NIOSH Respirator Decision Logic Publ. No. 87-108. NTIS publ.-151183 as reported in NIOSH Pocket Guide to Chemical Hazards, June 1994, p. xii.

16. NIOSH Pocket Guide to Chemical Hazards, June 1990, p. 60.

17. NIOSH Pocket Guide to Chemical Hazards, June 1994, p. 55.

18. NIOSH Pocket Guide to Chemical Hazards, June 1990, p. 126.

19. NIOSH Pocket Guide to Chemical Hazards, June 1994, p. 167.

20. NIOSH Pocket Guide to Chemical Hazards, June 1990, p. 126.

21. NIOSH Pocket Guide to Chemical Hazards, June 1994, p. 168.

22. NIOSH Pocket Guide to Chemical Hazards, June 1990, p. 164.

23. NIOSH Pocket Guide to Chemical Hazards, June 1994, p. 228.

24. Lazzara, C. P., and F. J. Perzak. Conveyor Belt Flammability Tests: Comparison of Large-Scale Gallery and Laboratory-Scale Tunnel Results. Paper in Proceedings of the 23rd International Conference of Safety in Mines Research Institutes, Washington, DC, Sept. 11-15, 1989, compo by E. T. Wallace and T. H. Koslosky. USBM OFR 27-89,1989, pp. 138-148; NTIS PB 89-225262/AS.

25. Chatterjee, M., S. &su, S. K. Palit, and M. M. Maiti. A Reexamination of the Degradation of Polyvinyl Chloride by Thermal Analysis. J. Polym. Sci., v. 32, No.7, 1994, pp. 1225-1236.

26. Troitskii, B. B., and L S. Troitskaya. Mathematical Models of the Initial Stage of the Thermal Degradation of Polyvinyl Chloride. J. Polym. Sci., v. 31, No.1, 1993, pp. 75-81.

27. Rogestedt, M, and T. Hjertberg. Structure and Degradation of Commercial Polyvinyl Chloride Obtained at Different Temperatures. J. Macromolecules, v. 26, No.1, 1993, pp. 60-64.

28. Beitel, J. J., and C. A Bertelo. Hydrogen Chloride Transportation and Decay in a Large Apparatus: Variables Affecting Hydrogen Chloride Decay. J. Fire Sciences, v. 5,1987, Tecbnomic Publ. Co., Lancaster, PA, pp. 105-145.

29. Jones, W. W. A Model for the Transport of Fire, Smoke and Toxic Gases (FAS1). Natl. Bureau of Standards, NBSIR 84-2934,1984, pp. 1-60.

30. Levin, B. C., M. Paabo, J. L Gunnan, and S. E. Harris. Effect of Exposure to Single or Multiple Combinations of the Predominant Toxic Gases and Low Oxygen Atmospheres Produced in Fires. J. Fundam. and Appl. Toxicol., v. 9, 1987, pp. 236-250.

31. Yamamoto, K. Acute Combined Effects of HCN and CO, With Special Reference to a Theoretical Consideration of Acute Combined Effects on tbeBasisofthe Blood Cyanide and CHb Analyses. J. Comb. Toxic., v. 4, 1977, pp. 69-78

☆ U.S. GOVERNMENT PRINTING OFFICE: 1996-709-439