

Toxicity of the Combustion Products from a Flexible Polyurethane Foam and a Polyester Fabric Evaluated Separately and Together by the NBS Toxicity Test Method

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ABSTRACT

Representative specimens of two materials, a flexible polyurethane foam and a polyester, were thermally decomposed separately and together in order to compare the toxicological effects of the combustion products from the combined materials with those from the single homogeneous materials. Gas concentrations (CO, CO₂, O₂ and HCN), blood carboxyhemoglobin, and LC₅₀ values [the concentration of material necessary to kill 50% of the test animals (Fischer 344 male rats) during a 30 minute exposure and a 14 day post-exposure observation period] were determined for the separate and combined materials under both flaming and non-flaming conditions. The results of the combined experiments indicated that under non-flaming conditions, both materials contributed in an additive manner to the concentration of the combustion products. However, under flaming conditions, the generation of HCN and CO is greater than that predicted from the addition of the maximum amounts produced by the materials separately.

INTRODUCTION

In the industrialized world, the United States is second only to Canada in the number of fire deaths per capita [1]. The fire scenario which produces the most fire deaths in the U.S. begins with an inadvertently dropped cigarette in an upholstered piece of furniture. Since the majority of commercially available upholstered furniture today contains some formulation of flexible polyurethane foam as a filling material and a covering fabric which is either a cellulosic or a thermoplastic such as polyester, these two materials were chosen for this study. Many small-scale laboratory studies have examined the toxicity of the combustion products from flexible polyurethane foams [2] or polyesters [3]. There have also been numerous large-scale room burns of chairs, multiple materials, or composite materials which included these materials. Alarie et al. compared the toxicity of individual materials (determined in small-scale tests) with the toxicity of multiple combined materials (determined in large-scale chair burns) [4]. However, the objective of their study was to compare the toxicity of the major components of the chairs (flexible polyurethane foam, polyester, and

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cotton fiber) with their individual toxicity in small-scale tests. They did not study the toxicity of the combined components in the small-scale tests.

This study was designed to examine and to compare the toxicological effects from the combustion products of a flexible polyurethane foam and a polyester fabric in order to determine the contribution of the combustion products from each material to the overall toxicity of the mixture. Two separate aspects of this problem were considered: (1) Would the toxicity be affected merely because the increased mass of the combined materials increase the concentrations of the pyrolysis or combustion products or does some unexpected toxicological interaction occur? (2) Would the types or yields of toxicants be affected?

MATERIALS AND METHODS

The materials studied, polyester fabric and a flexible polyurethane foam, were generically classified, i.e., the specific chemical formulations were unknown. Both the polyester upholstery fabric (100% polyester, scoured and dyed dark blue) and the flexible polyurethane foam were obtained from the Consumer Product Safety Commission, Washington, DC 20207. The results of a previous toxicological study on this polyurethane foam, designated CPSC #13, have been published [5].

The acute inhalation toxicity of the combustion products from these materials was evaluated according to the NBS Toxicity Test Method [6]. Each material was examined at 25°C above and below its autoignition temperature (Tables 1 & 2). In addition, polyester was tested at the non-flaming temperature of the polyurethane foam (375°C), and the flexible polyurethane foam was examined at the flaming temperature of the polyester (525°C). Combinations of the two materials were thermally decomposed in the cup furnace at a non-flaming temperature of 375°C (which was the highest possible non-flaming temperature, since the polyurethane foam would flame at higher temperatures) and a flaming temperature of 525°C (the temperature at which both the polyurethane and polyester would undergo flaming combustion, if tested separately). In all cases, the amount of material consumed was determined by weighing the residue.

Carbon monoxide (CO) and carbon dioxide (CO₂) were measured continuously by non-dispersive infrared spectroscopy. Oxygen concentrations were measured continuously by a galvanic cell or a paramagnetic analyzer. The HCN generated from the polyurethane foam was sampled with a gas-tight syringe approximately every three minutes and analyzed with a gas chromatograph equipped with a thermionic detector [7].

Fischer 344 male rats, weighing 200-300 grams, were obtained from the Harlan Sprague-Dawley Company (Walkersville, Maryland) or Taconic Farms (Germantown, New York) and were allowed to acclimate to our laboratory conditions for 10 days prior to experimentation. Animal care and maintenance were performed in accordance with the procedures outlined in the National Institutes of Health's "Guide for the Care and Use of Laboratory Animals" [8].

Six animals were exposed in the head-only mode in each experiment. Exposures were for 30 minutes, during which blood for carboxyhemoglobin (COHb) analysis was taken at 0 time, approximately 15 minutes and just before the end of the experiment from cannulated animals (one or two animals per exposure were surgically prepared with a femoral arterial cannulae 24 hours before experiments [9]). The number of animals that died at each mass loading of material was plotted to produce a concentration-response curve from which an LC₅₀ value was calculated [10]. The LC₅₀, in this case, is defined as the mass loading of material per

Table 1

Material	AIT (°C)	Mode	Initial Temp. of Expt. (°C)	Type of Expt.	Mass		Average Gas Concentration ¹				Max. CO (ppm)	Highest % COHb (30 min)	No. died		Latest Day of Death	LC ₅₀ 30 min. + 14 days (mg/l)
					Chamber Loaded (mg/l)	Vol. Consumed (mg/l)	CO (ppm)	CO ₂ (ppm)	O ₂ (%)	HCN (ppm)			Within Exp.	Within & Post		
Poly- urethane #13	400	NF	374	A	10.0	9.3	420	470	20.8	8	540	NA	NA	NA	NA	
			375	R	19.8	17.9	620	2370	20.4	ND	800	ND	0/6	1/6	14	
			375	R	30.0	26.6	700	2690	20.4	4	1000	ND	0/6	1/6	11	37.0
			375	R	32.0	27.4	600	2800	20.3	5	1100	26.3	0/6	1/5	7	(29.8-46.0)*
			377	R	35.0	31.1	ND	ND	ND	9	ND	47.0	0/6	4/4	11	
			375	R	40.0	34.3	740	2500	ND	1	1320	ND	0/6	3/5	12	
Poly- urethane #13	400	F	425	A	10.0	9.7	170	8700	19.9	19	210	NA	NA	NA	NA	
			425	R	20.0	19.9	320	21400	18.2	17	370	ND	0/6	0/6	NA	>40
			425	R	30.0	29.8	520	28400	17.4	24	590	ND	0/6	0/6	NA	
			425	R	40.0	39.1	840	33500	16.7	27	940	46.5	0/6	0/4	NA	
			524	A	20.0	19.9	630	10700	19.5	51	720	NA	NA	NA	NA	
			528	A	20.0	19.9	390	19100	18.7	37	430	NA	NA	NA	NA	

Legend:

$$1. \text{ Average gas concentration} = \frac{\text{integrated area under instrument response curve for 30 minutes}}{30 \text{ minutes}} = \frac{\text{ppm-min}}{30 \text{ min}}$$

A. Analytical experiment

R. Rat experiment

ND. Not determined

NA. Not applicable

F. Flaming

NF. Non-flaming

AIT. Auto-ignition temperature

*. 95% confidence limits

FPU 13. Flexible polyurethane #13

PE. Polyester

Comb. Combined weight of FPU 13 + PE

Table 2

Material	AIT (°C)	Mode	Initial Temp. of Expt. (°C)	Type of Expt.	Mass		Average Gas Concentration ¹				Max. CO (ppm)	Highest % COHb (30 min)	No. died		Latest Day of Death	LC ₅₀ 30 min. + 14 days (mg/l)			
					Chamber Vol. Loaded (mg/l)	Consumed (mg/l)	CO (ppm)	CO ₂ (ppm)	O ₂ (%)	HCN (ppm)			Within Exp.	Within & Post					
Polyester	500	NF	474	A	20.0	16.4	970	1700	20.7	NA	1270	NA	NA	NA	NA				
			474	A	25.0	21.3	1670	2550	20.6	NA	2330	NA	NA	NA	NA				
			473	R	35.0	30.6	2440	4770	20.5	NA	3460	81.6	0/6	0/4	NA				
			473	R	36.5	30.9	2330	4910	20.4	NA	3140	67.8	0/6	0/4	NA				
			476	R	37.1	32.5	2810	5590	20.3	NA	3900	83.7	0/6	0/4	NA	39.0			
			475	R	37.5	32.4	2570	5350	20.4	NA	3590	79.3	1/6	5/5	2	(38.4-39.5)*			
			475	R	38.5	34.3	2910	5920	20.3	NA	4090	82.7	2/6	3/6	12				
			473	R	39.2	33.2	2650	5300	20.4	NA	3730	75.0	2/6	3/5	2				
			475	R	40.0	34.9	2660	4990	20.4	NA	3830	81.0	4/6	5/6	1				
			377	A	20.0	4.3	50	600	20.9	NA	160	NA	NA	NA	NA				
			376	R	40.0	21.9	370	2980	20.5	NA	770	13.5	0/6	0/4	NA	>50			
			375	R	50.0	20.4	410	2710	20.6	NA	840	15.2	0/6	0/5	NA				
			Polyester	500	F	524	R	30.0	28.7	2220	25200	18.4	NA	2990	82.0	0/6	0/4	NA	37.5
						525	R	35.0	33.7	2290	27300	18.2	NA	3400	83.0	1/6	2/5	0	(35.3-39.8)*
523	R	37.5				36.1	2640	28500	18.0	NA	3860	83.2	3/6	3/6	NA				
524	R	40.0				38.8	2990	30500	17.8	NA	4310	84.6	4/6	4/5	NA				

For Legend, see Table 1

unit chamber volume (mg/l) which caused 50% of the animals to die during the 30 minute exposure plus the 14 day post-exposure observation period. (Animals that were still losing weight on day 14 were kept until they died or recovered as indicated by three days of successive weight gain. All deaths were included in the LC₅₀ calculation. Surviving cannulated animals were sacrificed following the test and only counted in the determination of the LC₅₀ if they died during the exposure.) If no deaths occurred at the highest concentration tested, the LC₅₀ is listed as greater than that concentration.

RESULTS AND DISCUSSION

Flexible Polyurethane Foam

The chemical and toxicological data obtained from the flexible polyurethane foam thermally decomposed under non-flaming (375°C) and flaming (425°C and 525°C) conditions are presented in table 1. Similar to other non-fire retarded flexible polyurethane foams tested in this laboratory, no animal deaths occurred during the 30 minute exposures to concentrations up to 40 mg/l regardless of the mode of decomposition [5,6]. Post-exposure deaths only occurred following the non-flaming experiments. The LC₅₀ value for the non-flaming mode was 37.0 mg/l with 95% confidence limits of 29.8-46.0 mg/l, whereas, the LC₅₀ value for the flaming mode was greater than 40 mg/l, i.e., no animal deaths were noted from any of the concentrations tested up to 40 mg/l.

Recent results [11] from this laboratory on the toxicity of CO, CO₂ and HCN alone and in various combinations have shown that the 30 minute LC₅₀ for CO in air was 4600 ppm. No animals died below 4100 ppm or post-exposure. The 30 minute LC₅₀ for CO₂ in air was greater than 18% (1% = 10,000 ppm). However, when CO and CO₂ were combined, the presence of 5% CO₂ increased the toxicity of CO such that animals died from 30 minute exposures to 2500 ppm. Some of these deaths were within 24 hours. The combination of CO and HCN (30 minute HCN LC₅₀ = 160 ppm) showed the following additive effect:

$$\text{If } \frac{[\text{CO}]}{\text{LC}_{50} \text{ CO}} + \frac{[\text{HCN}]}{\text{LC}_{50} \text{ HCN}} \geq 1, \text{ the animals died.}$$

When this formula equalled less than 1, the animals lived. Again deaths were observed up to 24 hours post-exposure.

Comparison of the gas concentrations generated from the polyurethane experiments to the pure gas experiments quoted above showed that lethal amounts were not produced in any of the tests (Table 1). Therefore, the deaths, which occurred as late as 14 days in the non-flaming mode, were due to other toxic combustion products or undetermined factor(s).

Polyester

All the chemical and toxicological data collected from the thermal degradation of polyester are shown in table 2. In the non-flaming mode at 475°C, the LC₅₀ value of the polyester was 39.0 mg/l with 95% confidence limits of 38.4 - 39.5 mg/l. Animal deaths were noted both during and following the 30 minute exposures. At 375°C, however, no animal deaths were observed up to concentrations of 50 mg/l. However, it is important to note that at the lower temperature (375°C), only 22-55% of the original sample was consumed; whereas, at 475°C, approximately 85% of the sample was consumed. Based upon a comparison of the toxicological effects at the actual masses consumed at 475°C, deaths would not be expected at the masses consumed at the lower temperature.

Examination and comparison of the gas concentrations that were generated during these non-flaming experiments with our pure and combined gas toxicity experiments discussed above indicate that the average CO levels are 37-80% lower than that necessary to cause death by CO alone. In many experiments, the CO levels did not plateau but continued to rise throughout the exposures reaching a maximum at 30 minutes. This maximum value, however, was still lower than the 30 minute LC₅₀ value for CO in air (4600 ppm) (Table 2). The average CO₂ present is about 10% of that necessary to increase the susceptibility of the rats to lower levels of CO. However, the maximum COHb levels at the end of these 30 minute lethal exposures are relatively high, 75-83%. These results indicate that CO, although low, is contributing to the within-exposure deaths, but other toxic or irritant gas(es) are also acting in conjunction with or to potentiate the effects of the CO. The cause of the late post-exposure deaths are unexplained.

In the flaming mode, the LC₅₀ value for the polyester was 37.5 mg/l with 95% confidence levels of 35.3 - 39.8 mg/l (Table 2). In the lethal experiments, the COHb levels ranged from 83-85% and the rats died within exposure or shortly thereafter. These factors would implicate CO as the main toxicant. However, the average CO is approximately 50-65% of the lethal concentration determined for CO alone. Even considering the effect of CO₂ on CO, the average values of CO and CO₂ from flaming polyester are still too low to account for the deaths that occurred during these 30 minute exposures. Only if one considers the maximum CO levels along with the CO₂ concentrations would the deaths be predictable.

Combined Flexible Polyurethane Foam and Polyester

Non-flaming experiments. The thermal decomposition of both flexible polyurethane foam and polyester in the non-flaming mode was studied at 375°C which was 25°C below the autoignition temperatures of the polyurethane. In these experiments, the polyester fabric was folded and dropped into the cup furnace immediately preceding the polyurethane foam. Upon heating, the samples collapsed in less than one minute and formed a black ball in approximately two minutes.

Since the polyester, by itself, was not toxic at 375°C² even at the highest loading tested (50 mg/l), a sublethal amount of polyester (20 mg/l) was chosen to test whether this addition would increase the toxicity (lethality) of the polyurethane foam in the combination experiments. If the polyester component has no effect at this temperatures, then the addition of 20 mg/l of polyester to the LC₅₀ value of the polyurethane would increase the LC₅₀ value of the mixture by 20 mg/l; that is, the LC₅₀ value of the polyurethane, 37 mg/l, would increase to approximately 57 mg/l. The results, however, showed that the LC₅₀ value of the combined materials only increased to 47.5 mg/l; an indication that the polyester was not inert but contributed to the toxicity by about 10 mg/l (Table 3). The total amount of polyurethane in the combined LC₅₀ is only 27.5 mg/l, which is outside the 95% confidence limits of the LC₅₀ for polyurethane alone.

Since a significant proportion of the polyester is not decomposed at 375°C, these data were also analyzed on the basis of mass consumed/chamber volume. The experiments on the polyester alone at 375°C showed that when 3.88 grams (20 mg/l) were loaded into the cup furnace, 78% remained as residue and only 4.3 mg/l

²This lower toxicity is probably due to the large fraction (more than 45% of the initial mass loading) of the polyester which is not consumed at the lower temperature.

Table 3

Material	AIT Mode (°C)	Initial Temp. of Expt. (°C)	Type of Expt.	Mass					Average Gas Concentration ¹				Max. CO (ppm)	Highest % COHb (30 min)	No. died		Latest Day of Death	LC ₅₀ + 14 days (mg/l)		
				Chamber Volume							CO (ppm)	CO ₂ (ppm)			O ₂ (%)	HCN (ppm)			Within Exp.	Within & Post
				Loaded (mg/l)	Consumed (mg/l)		FPU 13	PE	Comb.											
Polyester plus poly-urethane #13	500 NF	373	R	20.0	20.0	40.0	21.0	690	2600	20.5	ND	890	31.9	0/6	0/4	NA				
	400	375	R	27.5	20.0	47.5	26.2	670	3120	20.5	ND	960	26.4	0/6	2/4	8				
		373	R	30.0	20.0	50.0	31.2	850	3400	20.5	5	1270	35.2	0/6	3/4	7	47.5			
		373	R	32.5	20.0	52.5	33.4	1130	3920	20.3	ND	1420	43.9	0/6	3/4	2	(43.0-			
		374	R	35.0	20.0	55.0	35.4	1300	3810	20.4	ND	1710	35.4	0/6	4/4	16	52.5)*			
		376	R	37.5	20.0	57.5	37.3	1390	3850	20.4	ND	1860	54.9	0/6	4/4	2				
		375	R	40.0	20.0	60.0	43.1	1160	4090	20.4	ND	1550	40.9	0/6	4/4	2				
Polyester plus poly-urethane #13	500 F	527	R	20.0	15.0	35.0	34.0	1870	30200	17.5	62	2370	76.2	1/6	1/5	NA				
		523	R	20.0	20.0	40.0	38.9	2270	33600	17.1	63	3120	80.2	3/6	3/5	NA	39.0			
	400	525	R	20.0	22.5	42.5	41.8	2410	31100	17.4	50	3420	78.7	5/6	5/6	NA	(36.0-			
		524	R	20.0	25.0	45.0	44.0	2780	34400	16.8	48	3930	ND	6/6	6/6	NA	42.2)*			
		524	R	20.0	30.0	50.0	49.0	3070	34700	17.1	59	4500	ND	6/6	6/6	NA				
		425	R	20.0	30.0	50.0	43.7	1750	31500	17.4	13	1950	69.1	1/6	1/5	NA				

For legend, see Table 1

were actually consumed. Using the same null hypothesis as before, that is, the polyester at this temperature has no effect on the combined toxicity, then one would expect the LC_{50} of the polyurethane (31.9 mg/l, consumed weight) should increase by 4.3 mg/l producing a combined LC_{50} of 36.2 mg/l. However, the LC_{50} of the combination is only 26.2 mg/l, consumed weight, indicating that the polyester increases the toxicity by about 10 mg/l; this is the same value calculated when the mass loaded, rather than mass consumed, was considered.

In these non-flaming experiments in which 20 mg/l of polyester were added to different loadings of flexible polyurethane foam, all deaths occurred during the post-exposure period. These results are more characteristic of the polyurethane experiments, decomposed by itself, and different from those seen with the polyester alone. The concentrations of measured gases (CO, CO₂, HCN) were not responsible for the post-exposure deaths that occurred.

The average concentration of the primary gases (CO, CO₂, HCN) generated from the thermal decomposition of the mixture of the materials appear to be approximately equal to the sum of the average concentrations generated from the individual materials under non-flaming conditions (Table 4 and Figure 1). Therefore, if the concentrations of the primary gases from the thermal decomposition of the individual components are known, then a reasonable prediction of the gas concentrations from the mixture decomposed under the same conditions can be made.

Flaming experiments. The experiments in which the flexible polyurethane foam and polyester were combined and tested in the flaming mode were conducted at 525°C (25°C above the autoignition temperature of the polyester) to ensure that both materials would flame. In these experiments, the mass concentration of polyurethane was kept constant at 20 mg/l and only that of the polyester was varied (Table 3). The reason for this approach was to see if a non-lethal amount of the less toxic material (in this case, the polyurethane foam) would increase the toxicity of the polyester whose LC_{50} could be measured. The polyurethane foam when tested by itself in the flaming mode at 425°C had produced no deaths either during or post-exposure at concentrations up to 40 mg/l, whereas, the polyester fabric when decomposed by itself in the flaming mode at 525°C had produced both within and post-exposure deaths. The LC_{50} value for the flaming polyester fabric by itself was 37.5 mg/l. Therefore, if the polyurethane was toxicologically inert, the addition of 20 mg/l of polyurethane should have raised the LC_{50} value to 57.5 mg/l. In actuality, the 30 minute and 14 day LC_{50} value calculated for the combined exposures was 39.0 mg/l with 95% confidence limits of 36.0 - 42.2 mg/l. These results, showing that the LC_{50} value for the combined materials was lower than expected by almost the exact amount of polyurethane added to the system, are an indication that the polyurethane and the polyester are both contributing in an additive manner to the toxicity. In other words, the combination of 19 mg/l of polyester and 20 mg/l of polyurethane produced the LC_{50} ; whereas, 20 mg/l of the polyurethane foam decomposed by itself in the flaming mode produced no deaths (Table 1) and the polyester decomposed by itself did not produce any deaths below a concentration of 35 mg/l (Table 2). Thus individual sublethal concentrations of this polyurethane foam and polyester fabric are adding up to a concentration which is lethal.

Examination of the average gas concentrations of CO, CO₂, and HCN which were generated during these exposures and comparison of these gas values with our pure gas toxicological studies shows that the concentrations of these gases were sufficient to account for the deaths that occurred. Table 3 also shows HCN levels higher than those seen in the flaming exposures of polyurethane alone at 525°C which, in turn, were greater than at 425°C (Table 1). Figure 2 shows the

generation of HCN from 20 mg/l of the flexible polyurethane when decomposed alone or combined with the polyester under various flaming conditions. Polyurethane decomposed alone at 425°C produced an average HCN concentration of 19 ppm; whereas, at 525°C, it produced an average of 37 ppm in one experiment and 51 ppm in another. The flaming decomposition of various amounts of polyester with 20 mg/l of polyurethane at 525°C produced greater concentrations of HCN than in any of the experiments on the polyurethane alone (Tables 1,3 and Fig. 2). This result was unexpected since polyester contains no nitrogen and should not contribute to the HCN generation. Figure 2 also shows that the HCN generation over time from 20 mg/l of flaming polyurethane foam alone tends to plateau during the 30 minute test, whereas, in the combination studies of this polyurethane (20 mg/l) and polyester, the HCN continues to increase throughout the experiments. The reason for this increased level of HCN is unexplained at this time.

Table 4

Gas Concentrations from the Thermal decomposition of Polyurethane Foam and Polyester Alone and in Combination

Mode	Temp. (°C)	Material	Mass Loaded Chamber Volume (mg/l)	Average Gas Concentration ¹		
				CO (ppm)	CO ₂ (ppm)	HCN (ppm)
Flaming	525	Polyurethane	20 ²	510 (+ 120)	14900 (+ 4200)	44 (+ 7)
		Polyester	30	2220	25200	--
		Total		2730	40100	44
		Polyurethane + Polyester	20 + 30	3070	34700	59
Non-Flaming	375	Polyurethane	30	700	2690	4
		Polyester	20 ³	50	600	--
		Total		750	3290	4
		Polyurethane + Polyester	20 + 30	850	3400	5

¹ Average gas concentration:

$$\frac{\text{integrated area under instrument response curve for 30 minutes}}{30 \text{ minutes}} = \frac{\text{ppm-min}}{30 \text{ min}}$$

² Results are average ± range of two analytical experiments

³ Analytical experiment (no animals)

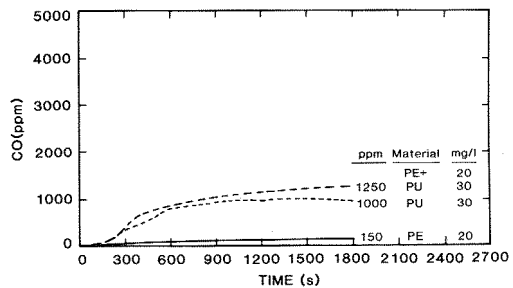


Figure 1. CO Generation from Flexible Polyurethane Foam and Polyester Decomposed Alone and Together. Non-Flaming 375°C.

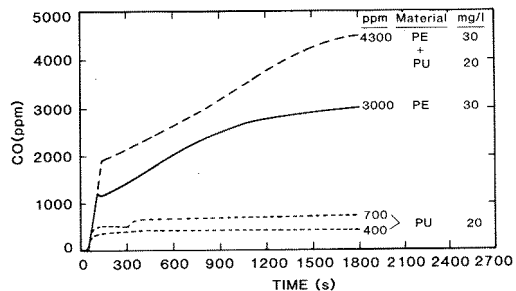


Figure 3. CO Generation from Flexible Polyurethane Foam and Polyester Decomposed Alone and Together. Flaming 525°C.

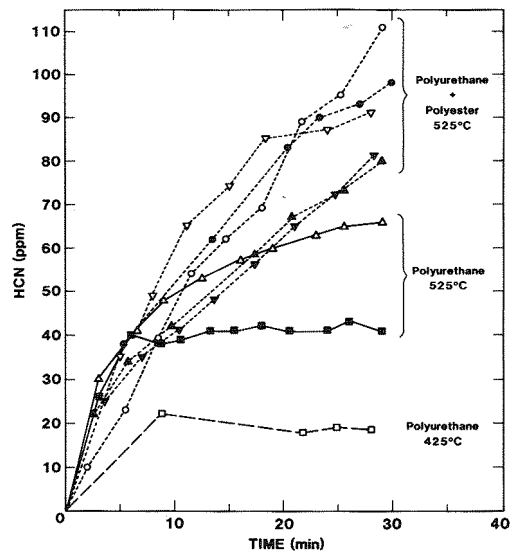


Figure 2. Generation of HCN from 20 mg/l of Polyurethane Decomposed Alone and with Different Amounts of Polyester Under Flaming Conditions.

In the flaming mode, the concentrations of CO from combined materials was also greater than the sum of the CO concentrations from the individual materials (Figure 3). This was more apparent from the graphic representation of the actual generation of CO than from the tabular depiction of the average concentrations (Table 4).

CONCLUSIONS

Individual Materials

- The decomposition products of the flexible polyurethane foam produced no deaths during exposure and only caused post-exposure deaths in the non-flaming mode.
- The polyester when decomposed 25°C above or below its autoignition temperature caused deaths both during and following exposures.
- Comparison of the CO, CO₂, and HCN concentrations generated from the individual materials with pure gas toxicity experiments (performed with single and multiple gases) indicated:
 1. the deaths from flexible polyurethane could not be explained by the concentrations of these gases,
 2. non-flaming polyester produced relatively high COHb (75-83%) levels, but lower than lethal average or maximum CO concentrations. Even when CO was considered with CO₂ (which potentiates the toxicity of CO), the combination was not sufficient to account for the deaths, and
 3. the deaths from exposures to flaming polyester products were probably due to CO since COHb values were 83-85%. In this case, the maximum (not the average) concentrations of CO plus CO₂ were sufficient to predict the deaths.

Combined Materials

- Depending on the amount thermally decomposed, both materials contributed to the combined toxicity. In the flaming mode, the contribution was additive.
- Similar to the polyurethane results, the non-flaming combined experiments only produced post-exposure deaths which were not attributable to the generated CO, CO₂, and HCN concentrations.
- The deaths observed from the flaming combined experiments were explainable based on the concentrations of CO, CO₂, and HCN.
- Comparison of the gas concentrations from the combined materials to those from the individual materials indicated:
 1. The non-flaming generation of CO, CO₂, and HCN appear to be approximately equal to the sum of the concentrations from the single materials.

2. The flaming generations of CO and HCN were greater than the sum of those from the single materials.

ACKNOWLEDGEMENTS

This work was supported in part by the Consumer Product Safety Commission, Washington, DC, Dr. Rita Orzel, Project Officer. The conclusions are those of the authors and not the Consumer Product Safety Commission.

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