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TECHNICAL SERVICE REPORT

POLYVINYL CHLORIDE COMBUSTION TOXICITY: A COMPARATIVE REVIEW

World-wide studies by academia, government and industry have shown that the combustion toxicity and hazard of PVC is not unique or extreme, but is similar to that of many other materials, including wood. In fact, the combustion products of many common materials can cause incapacitation or death in test animals faster or by burning less material than PVC.

Robert K. Hinderer, Ph.D.
Senior Toxicologist

and

M. M. O'Mara, Ph.D.
Vice President of R&D

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BFGoodrich
Chemical Group

The BFGoodrich Company, Chemical Group/6100 Oak Tree Blvd., Cleveland, Ohio 44131

ABSTRACT

For 20 years, considerable research has been conducted to identify and study the effects of combustion products from polyvinyl chloride (PVC). More recently, efforts have been made to compare the combustion toxicity of PVC and other materials. Although universal test methods have not been developed, many investigators have compared the combustion toxicity and hazard of numerous materials. These world-wide studies by industry, academia, and government have shown that the combustion toxicity and hazard of PVC is not unique or extreme but is similar to that of many other commonly used materials. Such research has established that even common building materials such as wood will yield numerous irritating and corrosive substances which can cause pulmonary edema.

INTRODUCTION

Over the past several years, there has been considerable speculation about the toxicity of PVC combustion products relative to those of other materials. We have seen assertions that PVC combustion products are much more dangerous than combustion products from other materials, and PVC combuston products lead to "early knock down", or combustion products from alternative materials are safe or safer than PVC, with little if any factual basis. Reports of real fires, perhaps out of ignorance, sometimes indicate effects common to combustion products of many materials, as "unique" to PVC. While it is often mentioned that the combustion of PVC products produces irritating and corrosive HCl, the fact that other materials such as wood also produce combustion products which are corrosive and can cause pulmonary edema is rarely mentioned (Zikria et al, 1977).

Some people believe that one can predict the relative toxicity of various materials by comparing the type and levels of combustion products given off. This is not correct. There are many variables including the physical properties of the material which affect toxicity. The most meaningful and feasible way to assess the relative toxicity of the materials is to evaluate the combustion toxicity using an animal model.

In 1982, the National Bureau of Standards--through a select committee of academic, government, and industry experts--published a test method to evaluate the combustion toxicity of materials used in buildings and transportation (Levin, NBS, 1982). Although there is still no world-wide concensus, the past 20 years of testing has provided us with a very expansive and extensive body of knowledge relating to the toxicity of combustion products from a host of materials. This document summarizes research comparing the combustion toxicity of many materials including polyvinyl chloride.

RESULTS AND DISCUSSION

Although a considerable amount of combustion research has been conducted in the last 20 years, only a few studies have tried to compare the combustion toxicity of various materials. Furthermore, most of these comparative studies have been conducted within the last six years. These recent studies have been extremely valuable because they have provided the ability to compare materials under identical test conditions.

The data provided in the following discussion are excerpts from these studies. Because of protocol differences, the data in one study may not be directly comparable to another. However, the data in each study does enable a comparison of the combustion toxicities of the materials tested. The following discussion compares the effect of numerous materials on various parameters of toxicity and hazard.

MORTALITY

Studies of the lethality of combustion products of various materials in mice have been conducted by Alarie and Anderson (1979) and by LeMoan and Chaigneau (1977). The results of the studies are presented in Tables 1 and 2. Because the methodologies in these studies differ, only the materials within each study can be compared.

Table 1, the data shows that the combustion products from PVC rank among the least toxic of materials tested[a]. Only Douglas fir and fiberglass were numerically higher (less toxic). Similar results are evident in the French study (Table 2). Again, PVC combustion products rank among the least toxic materials.

More recently, the National Bureau of Standards published the results of interlaboratory evaluations of its new combustion toxicity test method (NBS, 1982). In these evaluations, groups of animals were exposed to the combustion products of PVC and numerous other materials for 30 minutes followed by a 14 day observation period. A 10 minute exposure period was also used to identify rapid acting toxicants. The lethality (LC_{50}) of these materials was compared with that of wood. Any material with an (LC_{50}) value more than one order of magnitude lower than that of wood was considered significantly more toxic than wood. In these studies, the combustion toxicity of PVC was found to be similar to that of wood (Table 3). Furthermore, the combustion products of PVC did not produce rapid intoxication.

RESPIRATORY EFFECTS

Alarie and Anderson (1979) studied potential respiratory effects of the combustion products of various materials in mice. The data in Table 1 shows the amount of material required to produce a 50% reduction in respiratory rate and a Stress Index of 100 (200 = maximum stress). For both parameters, PVC is in the middle range of those materials tested.

Asphyxiation, collapse, and incapacitation are terms which describe a general toxic response to short-term (acute) exposures to chemicals--in this case, combustion products. These parameters are important not only because they provide evidence of toxicity, but because they reflect the relative levels of incapacity.

Many studies have determined the amount of material required to cause asphyxiation and collapse, while others have measured the time required to cause incapacitation and/or death. In all cases, these have been used to evaluate and compare the toxicity and hazard of various materials. Studies by Alarie and Anderson (1979) and Kishitani and Yusa (1979) compared the amount of material required to cause asphyxiation and collapse, respectively. The results in Table 1 show that PVC combustion products are among the least asphyxiating of those materials tested. In the latter study, PVC also ranks among those which required the most amount of material to cause collapse (Table 4).

Numerous other investigators have evaluated the hazard of various materials by determining the time required to produce incapacitation or death when samples are combusted at various temperatures ranging from low temperature non-flaming to high temperature flaming (Hilado, Lopez, and Damant, 1977; Hilado and Brauer, 1979; Spurgeon, 1978; Crane, Endecott, Sanders, and Abbott, 1978). Here again they have found that PVC ranks among those which require the greatest time to cause incapacitation and death (Tables 5-8).

OVERALL CLASSIFICATION

Although there is presently no universal test method that enables the classification of materials based on their combustion toxicity, at least one study attempts to classify numerous materials (Alarie and Anderson, 1981). Based on time-response and concentration-response data, the authors placed the materials into one of three categories: Class A--as toxic as wood; Class B--more toxic than wood or Class C--much more toxic than wood. Sixteen of the 23 evaluated fell into the Class B category. These included PVC (92% homopolymer), ABS, urea formaldehyde foam, polyester resin-acrylic modified (commercial), wool, PVC-A (46% homopolymer), modacrylic, polyester resin-styrenated halogen modified, cellulose, flexible polyurethane foam, flexible polyurethane foam with fire retardant, high resilience polyurethane foam, high resilience polyurethane foam with fire retardant, polystyrene expanded, polystyrene expanded with a fire retardant, and phenol formaldehyde-phenol resin, expanded with blowing agent. This shows that PVC combustion toxicity is comparable with that of the majority of materials tested and is less than that of some (Class C).

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CONCLUSION

Although there has been much speculation and misinformation regarding the combustion toxicity of PVC, experimental data generated in world-wide studies by industry, academia, and government do not support the contention that the hazard from PVC combustion products is unique or extreme. The data discussed above and presented in Tables 1-8 clearly show that the combustion toxicity and hazard of PVC is comparable with many other natural and synthetic building materials. Furthermore, studies conducted by Zikria et al (1977) show that wood, not just PVC, contains numerous irritating and corrosive substances which can cause pulmonary edema. When one considers that the combustion toxicity of PVC is similar to that of other materials, that PVC flame spread is low, and that PVC comprises only a small portion of building materials, it is difficult if not impossible to develop a scenario that suggests that PVC presents a unique or unacceptable hazard.

TABLE 1

A COMPARISON OF THE EFFECTS OF THE THERMAL DECOMPOSITION PRODUCTS OF VARIOUS MATERIALS ON SEVERAL TOXICOLOGICAL PARAMETERS WITH MICE

MATERIALS	RD50[a] (mg)	S1100[b] (g)	LC50[c] (g)	Asphyxiation Range (g)
Flexible urethane foam #1	3.7	1.5	13.0	2-15
Flexible urethane foam #2	3.3	2.0	10.4	2-10
Flexible urethane #1	9.2	1.3	8.3	7-10
Flexible urethane #2	8.6	2.0	14.4	2-10
Rigid urethane foam #1	124.0	0.7	10.4	2-8
Rigid urethane foam #2	93.0	0.7	8.2	2-8
Rigid urethane foam #3	92.0	0.9	7.5	2-7
Rigid urethane foam #4	85.0	0.5	8.0	2-6
Isocyanurate #1	106.0	0.5	6.4	2-5
Isocyanurate #2	218.0	0.7	6.1	0.8-2
Polystyrene #1	22.0	4.0	5.8	5.3-10
Polystyrene #2	14.0	13.0	10.0	8-13
Phenol formaldehyde	765.0	4.0	6.3	3-6
Douglas fir	34.0	4.0	63.8	55-95
Urea formaldehyde	20.0	0.3	2.5	0.4-1.25
PTFE	17.0	—[d]	0.64	0.3-1.0
PVC-A[e]	16.0	1.0	15.2	8-20
Fiberglass	—	—	35.7	—
Cellulose	—	—	11.9	—
Wool	—	—	3.0	--

[a] Sample weight associated with a 50% decrease in respiratory rate.
[b] Stress index; 200 is maximum value.
[c] Amount of material required to produce mortality in 50% of the animals.
[d] Not calculated
[e] (46% homopolymer; incorrectly reported as 92% homopolymer).
(Alarie and Anderson, 1979)

TABLE 2

COMPARISON OF THE AMOUNT OF MATERIAL REQUIRED
TO PRODUCE A 50% MORTALITY RATE IN MICE
WHEN THE SAMPLE IS COMBUSTED AT 1472°F (800°C)

MATERIAL	AMOUNT OF SAMPLE REQUIRED FOR 50% MORTALITY (Grams)
Polyacrylonitrile	0.160
PVC	0.14
Polystyrene	0.12
Polyethylene	0.052
Polyurethane	0.038
Polypropylene	0.030
Nylon	0.023
ABS	0.005

(LeMoan and Chaigneau, 1977)

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TABLE 3

COMPARISON OF THE AMOUNT OF VARIOUS MATERIALS REQUIRED TO PRODUCE A 50% MORTALITY RATE IN RATS

MATERIAL	LC_{50} (95% CONFIDENCE INTERVAL) IN mg/l FLAMING	NON-FLAMING	440°C
Wool	28.2 (23.0-34.5)	25.1 (22.3-28.3)	32.1 (30.2-34.1)
Douglas fir	36.0 (21.1-50.8)	22.8 (13.4-32.2)	--
PVC	17.3 (14.8-20.2)	20.0 (14.7-27.2)	25.0 (20.2-31.0)
ABS	19.3 (16.7-22.3)	30.9 (21.2-45.0)	--
Rigid polyurethane	13.3 (12.2-14.5)	39.6	--
Modacrylic	4.4 (3.9-5.0)	5.3 (4.0-7.1)	7.3 (6.3-8.5)
Polytetrafluorethylene	0.045 (0.39-0.054)	0.045 (0.017-0.120)	--

(Levin, NBS, 1982)

TABLE 4

COMPARISON OF THE AMOUNT OF MATERIAL REQUIRED TO PRODUCE COLLAPSE IN MICE IN 2.5 to 6.0 MINUTES WHEN COMBUSTED AT SELECTED TEMPERATURES

MATERIALS	AMOUNT OF SAMPLE REQUIRED FOR COLLAPSE (Grams)	
	1022°F (550°C)	1562°F (850°C)
Japanese cedar	5.50-8.32[a]	3.72-5.83[a]
Lauan	6.13-9.11[a]	3.47-5.21[a]
Hardboard	---	3.09-4.46[a]
Untreated plywood	4.35-6.98[b]	1.31-2.19[a]
Fire retardant-treated plywood	3.42-4.91[a]	2.20-3.55[a]
Melamine resin-impregnated sheet #1	---	0.60-1.00[a]
Melamine resin-impregnated sheet #2	2.47-3.72[a]	0.64-0.97[a]
Polyacrylonitrile	0.61-0.88[a]	0.24-0.33[a]
Polyamide	0.38-0.55[a]	0.17-0.25[a]
Wool	---	0.41-0.60[a]
Urea resin foam	0.25-0.39[a]	0.24-0.33[a]
Polystyrene foam	10.7-15.20[b]	17.7-24.60[c]
Polyurethane foam	---	0.58-0.87[a]
Polyvinyl chloride foam	3.45-5.45[a]	2.61-4.02[a]
Polyvinyl chloride A	---	34.5-48.60[c]

[a]Collapse time = 2.5-3.5 minutes

[b]Collapse time = 3.5-4.5 minutes

[c]Collapse time = 4.5-6.0 minutes

(Kishitani and Yusa, 1979)

TABLE 5

COMPARISON OF TIMES TO DEATH IN MICE EXPOSED TO THERMAL DECOMPOSITION PRODUCTS OF MATERIALS (1.0g) COMBUSTED AT TEMPERATURES RANGING FROM 392°F (200°C) TO 1472°F (800°C)

MATERIAL	Td[a] (MINUTES)
Wool fabric	7.6
Cotton	10.3
Red oak	11.5
Polypropylene	13.0
Nylon 6	13.5
Douglas fir	13.6
Polyethylene	14.0
PVC-nylon	15.3
PVC #2	16.4
PVC #1	16.8
Polychloroprene #1	17.4
Nylon fabric	19.1
ABS	19.3
Polystyrene	20.0
CPVC #1	21.8
CPVC #2	22.7
Polychlorprene #2	27.5

[a]Time to death

(Hilado et al 1977)

TABLE 6

COMPARISON OF TIMES TO DEATH IN MICE EXPOSED TO THERMAL DECOMPOSITION PRODUCTS OF MATERIALS (1.0g) COMBUSTED AT TEMPERATURES RANGING FROM 392°F (200°C) TO 1472°F (800°C)

MATERIAL	Td[a] (MINUTES)
Polyethlene #2	11.5
Polypropylene	10.4
Polystyrene	22.1
Polyoxymethylene	2.6
ABS #19	7.1
Nylon 6 (#21)	6.8
Polychloroprene #12	12.2
Polyurethane #6	8.7
Polystyrene #2	15.4
PVC #11	14.5
Polyamide #9	2.7
Polychloroprene #15	16.3
Red Oak	6.1
Douglas fir	7.0

[a]Time to death

(Hilado et al 1979)

TABLE 7

COMPARISON OF TIMES TO INCAPACITATION AND DEATH
IN MICE EXPOSED TO THERMAL DECOMPOSITION PRODUCTS
OF MATERIALS (0.750g) COMBUSTED AT 1112°F (600°C)

FOAMS	Ti[a] (MINUTES)	Td[b] (MINUTES)
FR polyurethane	4.3	6.6
FR PET polyurethane	4.8	7.3
FR polyurethane	5.0	8.1
FR PE polyurethane	5.1	7.8
FR polyethylene	5.3	8.1
PVC	5.5	n.r.
FR PE urethane	5.6	8.6
FR urethane	7.6	12.4
FR PE urethane	9.6	n.r.
FABRICS		
Modacrylic	1.1	2.3
FR wool	2.0	4.2
Polyamide	2.1	4.2
FR wool-nylon	2.2	4.7
Polyamide	2.2	6.1
FR cotton/rayon	2.9	4.2
FR cotton	3.1	4.6
FR wool/PVC	3.5	6.1
FR rayon	4.2	5.1
Wool/PVC	4.6	10.2
PVC	7.6	14.4

[a]Time to incapacitation

[b]Time to death

N.r. = not reported
(Spurgeon, 1978)

TABLE 8

COMPARISON OF TIMES TO INCAPACITATION AND DEATH IN RATS EXPOSED TO THERMAL DECOMPOSITION PRODUCTS OF MATERIALS (1.0g) COMBUSTED AT TEMPERATURES RANGING FROM 887°F (475°C) TO 1562°F (850°F)

ELECTRICAL INSULATION MATERIAL	TIME TO INCAPACITATION (MINUTES)		
	LTNF[a]	LTF[b]	HTF[c]
Silicone rubber, glass braid, Mylar	21.9	-	-
Silicone rubber, x-polyethylene	19.3	-	17.7
Polyethylene, aluminum, PVC	8.2	12.1	7.3
PVC	21.2	12.0	7.3
Polyethylene	6.8	10.6	7.3
EPR-neoprene	9.2	9.4	7.4
Cross linked polyethlene	13.2	15.7	7.2
Exane (cross-linked polyolefin)	13.8	9.7	7.0
Teflon	6.7	11.2	8.2
EPR/Hypalon	13.5	13.2	6.3
Proprietary compound/neoprene	10.8	9.0	5.9
Halar	5.8	7.9	4.7
Tefzel	10.8	10.4	4.5
Kapton	7.0	7.7	4.5

[a]Low temperature nonflaming

[b]Low temperature flaming

[c]High temperature flaming

(Crane et al, 1978)

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